C-Roads Working Group 3 – Evaluation and Assessment

Final Report

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C-ROADS

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Publication History

Version	Date	Description, updates and changes	Status
1.0	24/11/2021	First release of the WG3 Final Report, collecting and presenting the final or preliminary results made available by Countries at the 16th of December 2021	Final
1.1	31/12/2021	Update of contributions by Italy and France and Addition of contribution by Austria	Draft

Preface

This document represents the C-Roads WG3 Evaluation and Assessment Final Report.
It is intended to organize, summarize and present the outcomes of the Evaluation and Assessment activities developed within C-Roads, based on the current available contributions (as of the December 2021) provided by the Countries that are part of the C-Roads Platform.
A summary of the status of contributions from Countries is presented in Table 1.

Table 1 - Status of contributions by Countries

Country	Status of the contribution
Austria	Final
Belgium	Final
Czech Republic	Final
France	Final
Germany	Final
Hungary	Final
Italy	Final
NordicWay 2	Final
Portugal	Pending
Slovenia	Final
Spain	Final
The Netherlands	Final
United Kingdom	Final

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2. Executive summary

Hereafter the main results emerged from the first Phase of the C-Roads Project (2016 – 2021) subdivided by impact area and then by service are presented.

2.1. Safety

Below are a set of summary statements per Service. For more detail, please refer to the full Safety results from each C-Roads Pilot.

Roadworks Warning (RWW)

The main results regarding the impact area Safety related to the Service RWW are referred to the analysis of speed, accelerations/decelerations, start and end of the maneuver and its length.

As general conclusion, changes in speed were recorded by the different pilots. However, these changes varied widely.

In Spain the analysis of changes in speed considered different KPIs:

- Change in speed adaptation: the vehicles reduced their average speed with respect to the limit after the implementation of the RWW-Road Closure (RC) (Benefit: 10%). On the other hand, the vehicles increased their average speed with respect to the limit after the implementation of the RWW-Lane Closure (LC).
- Change in instantaneous decelerations: the number of times that the vehicles brake harshly is reduced in the service RWW-RC for Madrid pilot and also detected in the service RWW deployed in DGT3.0 pilot (Benefit: -49% in the best case).

The changes in speed were less meaningful for pilots in United Kingdom and the Netherlands, both considering RWW-LC. In United Kingdom the analysis of contextual factors indicated the actual change in speed was most likely due to other contextual factors (queue) or was at best inconclusive. In the Netherlands, the mean speed did not change significantly before and after the reception of the C-ITS message.

The same Use Case was also tested in Czech Republic, with meaningful results especially for the Sub-pilot DT3, with recorded decreased minimum (122.02 Km/h vs 117.05 Km/h), maximum (108.10 Km/h vs 94.14 Km/h) and the mean average speed differs by approximately 10 km/h after RWW message notification. Acceleration comparison shows similar mean values around 0, but greater variance of acceleration values after receiving the RWW message, more centered on negative values, i.e., on the deceleration.

The Italian pilot reported a high number of Field Test KPIs highlighting significant benefit of the Use Case RWW-LC in terms of anticipated reaction and maneuvering and smoothness of the lane change. Both for light and heavy vehicles.

The lane change started before (-93m for heavy vehicles and -181m for light vehicles), finished in advance (-102m/-128m), the maneuver is shorter in time (-11%/-20%) and more smooth (steering angle is -91% for HV and -37% for LV).

The slowdown started (-585m for HV, -181m for LV) and ended before (-114m/-128m). It is carried out much more gradually in terms of space (+496m for HV, +53m for LV) and time (+27s/+4,5s), arriving at a speed of full compliance with the speed limits at the entrance of the restricted area of the carriageway. In the C-ITS OFF scenario the reduction in speed is not sufficient to fully respect the speed limits at the entrance to the site.

For light vehicles the slowdown in terms of speed reduction is relevant (-32km/h and +10% more reduction for C-ITS ON).

In Austria, the lane change maneuver, performed by the drivers, started during the test drives between 800m and 500m in advance with respect to the event.

KPIs concerning safety not linked to speed and accelerations were considered in Spain:

- A decrease in the maximum steering angle of the vehicles has been observed after the implementation of the RWW-RC service (Benefit: -20), suggesting smoother and less sudden maneuvers by drivers.
- A reduction in the number of lane changes is appreciated in the evaluated services RWW-RC (Benefit: -38%) and RWW-LC (Benefit: -15%), witnessing a more cautious driving behavior.

In United Kingdom, feedbacks were collected through interviews to the users: 29% of the participants reported having reduced their speed after seeing RWW, which may suggest that the technology has the potential to be effective in encouraging speed management if it provided more accurate information.
Moreover, half the participants agreed that RWW service can contribute to improving driver alertness in road works situations, evidenced by 47% of drivers saying they felt more alert to the presence of roadworks with the information appearing in-vehicle. In addition, 53% felt it was more effective in bringing attention to the driver in the vehicle than signs on the roadside.
Finally, Italy estimated that the Use Case RWW-LC could reduce, in Italy, in one year with 100% C-ITS market penetration the number of injured people by 306 (- 0,13%) and the fatalities by 12 (- 0,38%).

In Italy the assessment of socio-economic impacts of RWW-LC related to safety were estimated around 32,81 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 2 - Safety - Qualitative Socio-Economic Impact for RWW

Impact area	**Indicator**	**Effect**	**Socio-economic impact**
Safety	Average speed	average speed is not comparable between services or sub-pilot	?
	Instantaneous accelerations	No impact for RC Increase for LC	0 -
	Instantaneous decelerations	Reduction for LC Reduction for RC	+ +
	Speed adaptation	Reduction for RC Inconsistent for LC (in Italy it was observed a more gradual speed adaptation)	+ ?

In Vehicle Signage (IVS)

The main results regarding the impact area Safety related to the Service IVS are referred to the analysis of speed. For this service, particular care was often oriented to study the compliance of the drivers to the communicated speed limits that are featuring the different use cases considered.
In Spain the analysis of changes in speed considered different KPIs:

- Change in speed adaptation: the vehicles reduced their average speed with respect to the limit after the implementation of the IVS (Benefit: 143,4% for Dynamic Speed Limit Information (DSLI) and 42% for Embedded VMS “Free Text” (EVFT).
- Change in speed standard deviation: the service IVS-DSLI helps to reduce the amount of time vehicles exceed the speed limit (Benefit: -25,1%).
- A reduction was recorded in the average speed during the implementation in DSLI (Benefit. -4,8%)
- Change in instantaneous accelerations and decelerations: reductions were recorded in the use cases DSLI and EVFT. The first one features a more significant reduction around -60%.

The Italian DSLI pilot reported a high number of Field Test KPIs highlighting significant benefit of the C-ITS message in terms of anticipated reaction, shorter space and time of the deceleration maneuver and higher compliance with the speed limits. Both for Heavy Vehicles (HV) and Light Vehicles (LV).
In the C-ITS ON scenario the slowdown starts (-260m for HV and -465m for LV) and ends (-550m/-298m) considerably earlier than in the C-ITS OFF scenario, it is carried out faster (-14s/-58% for HV) and in shorter space (-290m/-64% for HV), reaching a speed compliant with the speed limit even before entering the section with the reduced speed limit (section -100m/0m). On the contrary, in the C-ITS OFF scenario the vehicles do not reach full speed limit compliance even after the end of the slowdown.
In the Netherlands, analyses were specifically oriented to study the behavior of users towards speed limits, dealing with the Use Case IVS-DSLI. Differences were observed considering lower speed limits (50 and 70 km/h) and higher speed limits (90 or 100 km/h). For the first group the users were exceeding the speed limits. For the 90 and 100 km/h the Controlled and Naturalistic drivers were adhering to the speed limits. It could also be possible that the users were relying on the information outside the car because the existing roadside gantries with VMS matrix signs were also active during the test periods.
Similarly, in Austria the motorway stretches where the field test took place were equipped with a high number of VMS dispatching the same message as the C-ITS. According to the test, the average speed did not change significantly, neither in the area before or after the message, nor throughout the rest of the evaluated stretch of motorway.
Consequently, on such a perfectly VMS-equipped motorway stretch, no major advantages of C-ITS messages versus those received from VMS could be proven.
Interviews were deployed in United Kingdom. Main outcomes of this approach are referred to IVS- Dynamic Lane Management (DLM), considered able to improve safety for the 75% of users, and to IVS-EVFT, considered useful for safety purpose especially for HGV drivers with information about road width and height restrictions.
Finally, Italy estimated that the Use Case IVS-DLSI could reduce, in Italy, in one year with 100% C-ITS market penetration the number of injured people by 382 (- 0,22%) and the fatalities by 21 (- 0,66%).

In Italy the assessment of socio-economic impacts of IVS-DSLI related to safety were estimated around 67,26 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 3 - Safety - Qualitative Socio-Economic Impact for IVS

Impact area	Indicator	Effect	Socio-economic impact
Safety	Average speed	Decrease for DSLI (in Italy also for heavy vehicles) Inconsistent for EVFT	+ ?
	Speed standard deviation	Decrease for DSLI Slight increase for heavy vehicles Inconsistent for EVFT	+ - ?
	Instantaneous accelerations	Decrease for DSLI Decrease for EVTF	+ +
	Instantaneous decelerations	Decrease for DSLI Decrease for EVTF	+ +
	Speed adaptation	Decrease for DSLI Decrease for EVFT	+ +

Hazardous Location Notification (HLN)

The main results regarding the impact area Safety related to the Service HLN are referred to the analysis of speed and accelerations/decelerations, elements considered by all the Countries.
In Spain the analysis of changes in speed considered different KPIs:

- A reduction in the average speed is recorded during the implementation of the use case Weather Condition Warning (WCW). The services Accident Zone (AZ), Traffic Jam Ahead (TJA), Stationary Vehicle (SV) and EBL show different results in the sub-pilots, so any common conclusion can be provided.
- Change in speed adaptation: the results obtained for the TJA use case are not similar over the different sub-pilots.
- Change in speed standard deviation: the service HLN-WCW helps to reduce the amount of time vehicles exceed the speed limit (Benefit -100% best case).
- Change in instantaneous accelerations: the number of times that the vehicles accelerate harshly is reduced in the service HLN-TJA (Benefit: -20% best case).
- Change in instantaneous decelerations: the number of times that the vehicles brake harshly is reduced in the services TJA (-60% best case), WCW (-78% best case), EBL (-100% best case), Animal or Person on the Road - APR (-47% best case) and Emergency Vehicle Approaching - EVA (-23% best case). There is an increase in the service Stationary Vehicle (SV).

Spain also considered the KPI number of lane changes, recording a reduction in all the subservices where this KPI is evaluated (Benefit: -50% best case). This element could witness a more cautious driving behavior.
Speed was also considered in Czech Republic, analyzing use cases involving Public Transport systems. Concerning HLN - Railway Level Crossing (RLX), drivers drove faster on average with C-ITS message “Attention, railway crossing!” (36.71 Km/h vs 37.8 Km/h)., with higher accelerations (0.25 m/s^2 vs 0.49 m/s^2). In the “Passing Train!” warning drivers drove slower (29.53 Km/h vs 28.41 Km/h), with less decelerations (-1 m/s^2 vs -0.95 m/s^2). For HLN - Public Transport Vehicle Crossing (PTVC), a reduction in the mean (16.71 Km/h to 13.76 Km/h), maximal and minimal speed with C-ITS was recorded. The speed comparison of Public Transport Vehicle at a Stop (PTVS) use-case evaluation before and after the display of the message showed slightly lower mean speed (59.22 Km/h vs 55.21 Km/h), but greater speed range (27.16 Km/h vs 36.89 Km/h) and standard deviation.
In Slovenia, evaluation results developed using driving simulations show a positive influence on speed adaptation. Drivers adjusted their driving styles ahead of the HLN traffic event zone and not while driving inside the HLN traffic event zone.
Other analyses were developed through driving simulator, leading to these observations:

- No measurable differences in safety distance adaptation or adaptation of instantaneous acceleration and deceleration were recorded.
- A reduction in the erratic movement of the steering wheel and a measurable decrease in the number of hard braking events was detected.

The Accident Zone (AZ) use cases was the most important HLN event use case for reporting traffic events and for receiving traffic events notifications. For this use case:

- A 66% decrease in erratic movement of the steering and a 44% reduction in hard braking was recorded when the DARS Traffic Plus application was used.
- A reduction in the number of hard braking events subsequently raised the driving speed. When drivers were using the DARS Traffic Plus application, there was a 15% less chance that they were driving too slowly. We must note that this does not mean that they were over-speeding. Drivers were driving according to the speed limit.

The Italian pilot reported a high number of Field Test KPIs highlighting significant benefit of the C-ITS message in terms of anticipated reaction and maneuvering far before the danger point and smoother decelerations. For all Use Cases considered.
Use Case HLN-SV - Heavy Vehicles (HV) and Light Vehicles (LV)

- Lane change: In the C-ITS ON scenario the maneuver is started (-67m for HV, -274m for LV) and finished (-98m/-283m) clearly in advance compared to the C-ITS OFF scenario. For LV the maneuver is performed in less time (-0,7s/-21%) and space (-8m/-9%) and it is also carried out more smoothly for HV (the steering angle is -18%) but more rapidly by HV (the max steering angle is +23%).
- Slowdown: for LV, in the C-ITS ON scenario, the slowdown begins (-235m) and ends (-253m) further upstream than in the C-ITS OFF scenario. In the C-ITS scenario the maneuver is shorter in term of space (-52m/-39% for HV and -18m/-5% for LV) and of time (-3s/-43% for HV and -2,8s/-22% for LV). In addition, the slowdown maneuver with C-ITS ON for HV is smoother (deceleration standard deviation is -66%) and has lower instantaneous deceleration peaks (-51%) while for LV the magnitude of the slowdown is much higher (+79%) and the instantaneous deceleration peak is also higher (+125%).

Use Case HLN-TJA - Heavy Vehicles
The slowdown starts far in advance (-328m) and ends before (-52m) the event and the speed reduction is evident (-12%). A relevant part of the slowing down is deployed before the event point and the reduced speed is maintained throughout the entire section where the hazard event is potentially present.

Use Case HLN-WCW - Heavy Vehicles
The slowdown starts far in advance (-416m) and ends slightly after the event (+73m) and the speed reduction is evident (-18%). A relevant part of the slowing down is deployed before the event point and the reduced speed is maintained throughout the entire section where the hazard event is potentially present.

Finally, Italy estimated that the Use Cases HLN could reduce, in Italy, in one year with 100% C-ITS market penetration the number of injured people by 117 (- 0,05%) and the fatalities by 3 (- 0,09%).
In Italy the assessment of socio-economic impacts of HLN-SV related to safety were estimated around 44,15 M€ and for HLN-WCW up to 10,06M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 4 - Safety - Qualitative Socio-Economic Impact for HLN

Impact area	Indicator	Effect	Socio-economic impact
Safety	Change in nr of accidents	Decrease for WCW	+
	Change in nr of accidents with injuries	Decrease for TJA and WCW	+
	Change in speed adaptation	Inconsistent	?
	Change in speed standard deviation	Increase for TJA Decrease for WCM	- +
	Change in average speed	Decrease for TJA and WCM	?
	Instantaneous accelerations	Inconsistent for SV Decrease for TJA Slight increase for AZ	? + 0
	Instantaneous decelerations	Inconsistent for AZ Decrease for TJA Increase for SV Decrease for WCM, EBL, APR, EVA (controlled tests)	? + - +
	Nr of lane changes	Decrease for TJA, SV, WCW	+
	Amount of time vehicles exceed speed limit	Decrease for WCW, SV	+

Signalized Intersections (SI)

Main outcomes are connected to the analysis of speed and accelerations/decelerations, elements considered by all the Countries.

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Spain considered different KPIs:

- A reduction in the average speed during the implementation in Signal Phase and Timing Information - SPTI (benefit: -21% in the best case) and Imminent Signal Violation Warning - ISVW (Benefit: -32% best case) was recorded. On the other hand, there is an increase for the service Emergency Vehicle Priority - EVP (+11%).
- Change in instantaneous accelerations: The number of times that the vehicles accelerate harshly is reduced in the service SI-SPTI (Benefit: -65% best case) and SI-ISVW (Benefit -98% best case). There is an increase in EVP use case.
- Change in instantaneous decelerations: the number of times that the vehicles brake harshly is reduced in the services EVP (Benefit: -52%) and SPTI (benefit: -23% best case). There is an increase in the service ISVW as expected (Benefit: 21% best case).

In United Kingdom the objective impact assessment of GLOSA was carried out, analyzing objective data from individual drivers. Key results for GLOSA showed examples of drivers slowing, following advice on Time to Red and also maintaining speed based on the speed advice given.

In Czech Republic the evaluation of the ISVW in terms of speed reduction was not found to be the expected result. The average and maximum speeds were higher after receiving and displaying the ISVW message, while the minimum speed remained the same.

In United Kingdom feedbacks with interviews to the users indicated a change in driving behavior due to the information provided on the HMI. Although this is not statistically significant, several drivers in their interviews indicated a change in their behavior (speed adaptation) either by following the speed advice or slowing earlier than they usually would.

Table 5 - Safety - Qualitative Socio-Economic Impact for SI

Impact area	**Indicator**	**Effect**	**Socio-economic impact**
Safety	Average speed	Reduction for SPTI and ISVW Increase for EVP and ISV	+ -
	Instantaneous accelerations	Reduction for SPTI and ISVW Increase for EVP	+ -
	Instantaneous accelerations	Reduction for EVP and SPTI Increase for ISVW	- +
	Adoption of speed in line with advice	Yes for GLOSA	+
	Instantaneous speed	No impact for ISV	0

C-ITS as a Bundle

In NordicWay 2 the safety impacts were calculated for all networks studied for 2030 for the low and high effectiveness scenarios in percentages for the Nordic countries. Road safety was assessed to be improved with fatal accidents dropping by 1.2–4.8% in the low and 1.7–6.3% in the high scenario. The corresponding changes for less severe accidents were assessed to be 0.9–2.0% and 1.5–3.5%, respectively. These effects are shown in terms of reduced numbers of accidents in the following tables. The effects were assessed lowest in Finland, where a large part of the networks consists of rural main roads with low levels of service and event coverage.

Low effectiveness scenario	Denmark		Finland		Norway		Sweden	
Fatal accidents (number/year)	-1.86	-3.3%	-1.02	-1.2%	-3.46	-4.8%	-2.48	-3.9%
Non-fatal injury accidents (number/year)	-7.6	-1.6%	-11.6	-0.9%	-47.2	-2.0%	-46.0	-1.7%
Property damage only accidents (number/year)	-26.6	-1.6%	-51.3	-1.0%	-236.2	-2.0%	-334.7	-1.7%
High effectiveness scenario	**Denmark**		**Finland**		**Norway**		**Sweden**	
Fatal accidents (number/year)	-2.48	-4.5%	-1.40	-1.7%	-4.55	-6.3%	-3.29	-5.2%
Non-fatal injury accidents (number/year)	-13.03	-2.7%	-19.26	-1.5%	-82.21	-3.5%	-80.60	-2.9%
Property damage-only accidents (number/year)	-45.94	-2.7%	-84.92	-1.6%	-411.06	-3.5%	-586.19	-2.9%

2.2. Traffic Efficiency

Below are a set of summary statements per Service. For more detail, please refer to the full Traffic Efficiency results from each C-Roads Pilot.

Roadworks Warning (RWW)

With regard to **traffic efficiency**, the RWW use cases are mainly considered by countries with the perspective of the impact on the **Average Travel Time** (Speed) and on the **Congestion Level** (congestion length and duration). Some secondary Key Performance Indicators are also under consideration depending on the country and the use case: the **traffic heterogeneity** through the analysis of the change in acceleration or in speed and the impact on **road capacity** through the evolution of the traffic throughput.

Since RWW messages are not dedicated to efficiently enhancing road management, the results of KPIs related to the **Average Travel Time** are really different across use cases and sometimes across countries since it depends on the implementation and evaluation process (Field Operational Test, Simulation, etc.). In the Spanish report, RoadWorks Mobile (RM) have a negative impact on Travel Time, which is probably observed due to the difficulty to collect a large amount of comparable data. The Road Closure (RC) has almost a neutral impact (+0,69% on Travel Time) on the Spanish Field Tests, while the Lane Closure (LC) provides some positive trends at a low market penetration rate (MPR): Spain and Italy suggest a reduction of travel time at low market penetration rate within the range [-4%; -11%]. With a higher market penetration rate (>40%), the results are based on simulations and some differences appear: Spain observes a slight increase in Travel Time (+2%), while Italy report an improvement encompassed within the range [-5%; -7%] depending on the Market Penetration Rate (MPR). Some individual behaviors might explain such differences in the results since 29% of the participants in the United Kingdom study claimed having reduced their speed in the vicinity of the roadworks.

In terms of **Congestion Level**, most of the findings (Spain and Italy) are converging to say that no significant impact can be observed at a low penetration rate for RoadWorks Warning use cases. Italy has highlighted an improvement of the queuing duration reaching -50% in the best configurations (Market Penetration Rate higher than 80%). The analysis was drawn in the case of a Lane-Closure and within a simulated environment of a motorway. Such improvements with a high MPR might be expected for these use cases since it should facilitate the organization of the vehicle when approaching the roadworks and improve the road capacity. The field tests conducted in Austria also revealed smoother manoeuvres in slowdown and lane-change by the C-ITS equipped vehicles which can lead to a reduction in congestion by removing disturbances in the traffic flow. The simulation-based study drawn in Italy and Spain highlighted an improvement (+2,4% in Spain, MPR=100%) in the **traffic throughput** for high Market Penetration Rate. However, some instabilities in the traffic throughput with consequences on the congestion level (queue duration) are noted by Italy on the closing lane when MPR is lower than 20%. This singularity is reflecting a specific traffic dynamic that occurs due to mixed traffic conditions. One explaining factor might be that Connected Vehicles are shifting lane sooner, which reduced the gap (headway) between vehicles and prevent other vehicles to merge later on. Such **traffic heterogeneity** is further explored by Italy and Spain. While Italy emphasizes some differences in behavior between lanes when MPR is varying, Spain focuses on the changes in instantaneous acceleration and reported varied findings according to the use case: A growth (+14%) in acceleration variations is reported for Lane Closure use case, while a reduction by 25% is observed considering Road Closure.

Despite some heterogeneities in implementation and use case, it might be noticed that RoadWorks Warning use cases are designed for safety purposes, but do not involve strong deteriorations with regard to congestion level. Therefore, some indirect impacts are highlighted by Italian report by considering the avoidance of accidents. Based on such considerations and assuming the occurrence of 600 accidents per year, a total of 121,614 hours could be saved. Nevertheless, the situation of mixed traffic (intermediate/low market penetration rate) deserves some further investigation, since it might generate instabilities in global traffic stream, mainly due to the discrepancies of behavior between connected and non-connected drivers.

In Italy the assessment of socio-economic impacts of RWW-LC related to traffic efficiency were estimated around 25,74 M€ in one year with 100% C-ITS Market Penetration Rate. Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 6 - Traffic Efficiency - Qualitative Socio-Economic Impact for RWW

Impact area	Indicator	Effect	Socio-economic impact
Efficiency	Total travel time	Reduction for LC Almost no impact for RC	+ 0
	Number and duration of stops and queues	Almost no impact for RC	0
	Change in instantaneous accelerations/decelerations	Reduction for RC Reduction for LC	+ +
	Difference between the average speed of the vehicle and the speed limit	Average speed is not comparable between services or sub-pilot Reduction for LC (about 1/3 users in United Kingdom)	? +
	Traffic flow	Slight increase for LC, not significant result Indirect positive impacts for Italy (services could save up to 1,165 k hours/year)	-

In Vehicle Signage (IVS)

With regard to Traffic Efficiency, the IVS use cases are mainly considered by the C-ROADS partners according to 2 Key Performance Indicators: the Average Travel Time and the Traffic Heterogeneity, featured by the changes in Instantaneous Acceleration for instance.

A combination of field tests and simulation-based evaluations have been carried out by several countries on different C-ITS use cases related to IVS, that include DSLI (Dynamic Speed Limit), EVFT (Embedded VMS Free Text), SWD (ShockWave Damping) and DLM (Dynamic Lane Management).

The major impacts on traffic efficiency include improved **speed** and **travel time** performances with increased penetrations of connected vehicles with the DSLI use-case, and the results from the French simulation-based experiments, suggest that if the *market penetrations exceed 30%*, then an enhanced performance can be achieved in terms of average vehicle speeds and travel time, with no additional costs of installing and maintaining variable message signs. However, the field tests conducted in Spain show a reduction in the average speed in the range [5%; 8%], which shows that it may be ineffective or counter-effective in terms of speed performance for the connected vehicles at *a very low market penetrations rate*.

On the other hand, the **traffic homogeneity** is significantly improved, with *almost 60%* and *10% reductions* in the change in instantaneous accelerations/ decelerations for DSLI and EVFT use cases respectively. The field tests conducted in Austria revealed smoother slowdown manoeuvres and good compliance to speed limit for the DSLI use case.

Implementation of the SWD use case, using traffic simulation in Spain, indicates a substantial reduction of *about 39%* in the **number of stops,** and a reduction of *more than 17%* in the **stop duration,** in a fully connected environment.

User acceptance studies conducted in the United Kingdom, revealed that DSLI improved **driver preparedness** when entering a different speed limit zone. Moreover, DLM use case displayed a potential to improve traffic efficiency, by giving the driver more time to select the correct lane, thus reducing late stopping and blocking of lanes.

The IVS use cases are designed with safety and traffic efficiency considerations. While some improvements on the Travel Time are not systematically observed, the impact on Traffic Homogeneity and the Congestion Level is usually positive. It means that with sufficient market penetration rate, the IVS use cases trend to improve the homogeneity of the flow stream and the balance between drivers (since the congestion can be reduced, but not systematically the Average Travel Time). It is to notice, that it is difficult in some use cases, to distinguish the benefits related to the implementation of a Road Management Strategy, from the one resulting from the Technology / Connectivity. The DSLI use case can be implemented on the Field with Variable Message Signs, (refer to French report) as well as Roadside Units or Cellular Network.
Furthermore, some indirect impacts are highlighted by the Italian report by considering the avoidance of accidents. Based on such considerations and assuming the occurrence of 382 accidents per year, a total of 1.723.958 hours could be saved.

In Italy the assessment of socio-economic impacts of IVS-DSLI related to traffic efficiency were estimated around 34,48 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 7 - Traffic Efficiency - Qualitative Socio-Economic Impact for IVS

Impact area	Indicator	Effect	Socio-economic impact
Efficiency	Number and duration of stops and queues	Decrease for SWD Smooth speed change and speed profile with DSLI	+ +
	Total travel time	Significant improvements DSLI and EVTF	+
	Traffic flow	Avg speed decreased in DSLI Avg speed increased in SWD Indirect impact of 1723 k hours /year saved	+ -

Hazard Location Notification (HLN)

With regard to Traffic Efficiency, the HLN use cases are mainly addressed by the countries with consideration of three types of Key Performance Indicators: (i) the **Average Travel Time** or Speed, to feature the road performance, (ii) the **Congestion Level**, featured by the queue duration and the volume of involved vehicles and (iii) the **Traffic Heterogeneity**, usually featured by the changes in acceleration.
The studies have been led on Field Operational Test (Spain), micro-simulation (Spain) and driving simulators (Slovenia).
While the Hazard Location Notification use cases are mainly designed for safety purposes, the impact in terms of traffic efficiency is really heterogeneous and strongly depends on the use cases under consideration.
About the **Average Travel Time**, the use case Weather Condition Warning (WCW) shows a consequent growth (+17,4% in Spain) in Travel Time on Spanish motorways as well as Slovenian simulations. Such a result is expected since bad weather conditions are affecting in a homogeneous way the traffic conditions, whatever is the initial position of the driver in the traffic flow. On the contrary, Traffic Jam Ahead (TJA) and Stationary Vehicle

(SV) are highlighting some opposite findings probably depending on the context of implementation and the location of the pilot site. A hypothetical explanation relies on the heterogeneities between road configurations, and the context experimented by the connected drivers (traffic in the surroundings, etc.).
The Spanish pilot reported for both use cases (TJA, SV) some variations on Travel Time between -35% and +45%. In some cases, it seems that connected vehicles are strongly reducing their speed before passing the obstacles, while in some other cases the awareness of the danger enables to improve the flow organization. These results are observed for a low market penetration rate only in Spain, but the driving simulations performed in Slovenia confirmed a trend to reduce the speed in the vicinity of the hazardous location. The same findings are observed concerning the **Traffic Heterogeneity**: except for WCW use case, where an improvement is observed with a reduction of the changes in acceleration in the range [0%; -22%], the conclusions are various for other use cases. It is to notice that Spain reports some improvements for the Traffic Jam Ahead (TJA) with a reduction reaching -20% in some configurations, while a deterioration by +20% of the acceleration variations is observed for the Stationary Vehicles (SV). Such differences might be explained by the disparities of situations encountered by the Connected Vehicles.
In terms of **Congestion Level**, most of the use cases have a neutral or a slightly negative (+3% in Spain) impact while the Market Penetration Rate is low. Some improvements on the number of stops (-61,7%) and the stop duration (-88%) are observed in simulation by Spain for a flow composed of 100% of Connected Vehicles. Some further investigations are required to confirm these first observations.
The main highlight concerning HLN with regard to Traffic Efficiency relies on the fact that these use cases are not designed to optimize traffic, but safety. Some improvements in safety (e.g. speed reduction) are identified as negative in terms of traffic efficiency. Currently, the studies provide some trends about the consequences of these use cases on traffic efficiency, but in most of the cases, the findings are still unclear because of the large number of factors affecting the observations, while Field observations remain limited. Despite, some strong trends are highlighted for Hazardous Events without punctual impact, but large ones (e.g. bad weather conditions): for adverse weather conditions, the HLN messages enable to reduce the speed and the variations of acceleration with a neutral impact on Congestion Level.
Furthermore, some indirect impacts are highlighted by the Italian report. By considering the avoidance of accidents, an average of 4,509 hours per accident could be saved.

In Italy the assessment of socio-economic impacts of HLN-SV related to traffic efficiency were estimated around 13,19 M€ and for HLN-WCW up to 5,03M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

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Table 8 - Traffic Efficiency - Qualitative Socio-Economic Impact for HLN

Impact area	Indicator	Effect	Socio-economic impact
Efficiency	Change event time	Decrease for EVA, EBL (controlled tests) Slight increase for AZ Increase for APR	+ - -
	Travel time	Increase for WCW Inconsistent for TJA, SV Decrease for EBL	- ? +
	Number of stops and duration	Inconsistent	?
	Traffic flow	Slight decrease for SV	+
	Speed	Positive for TJA Inconsistent for WCW	+ ?

Signalized Intersection (SI)

With regard to traffic efficiency, the SI use cases are addressed by C-ROADS pilots through various approaches (simulation and/or Field Operational Tests). The GLOSA (Green Light Optimal Speed Advisory) is the most studied use case across the countries and multiple findings are consistent between countries. For Signalized Intersections, the Key Performance Indicators are mainly focusing on the Congestion Level usually depicted by the number of stops at the intersection and/or the average/total queuing duration. Italy and Hungary drew further analysis on travel time or delays with diverse outputs.

The Spanish pilots related to EVP use-case caused an increase of about 9% in the **event time** while with the SPTI use-case a reduction in the range of [6%; 8%] was observed.

The ISVW use-case has a detrimental impact on traffic efficiency causing an increase in the range of [41%; 99%] and [54%; 109%] in **event time** and **number of stops** respectively. However, this is not a matter of concern as the primary objective for this particular use case is to improve safety by reducing risky crossing behavior at intersections.

With the implementation of the GLOSA use case, Hungary reported a significant reduction in the **number of stops** (more than 20%) and **total stopped delay** (more than 10%). An increase of about 13% was observed in the **average delay for stopped vehicles** which is an indication of the fact that a vehicle using GLOSA services only stops when it is unavoidable i.e., at the beginning of the red interval. By reducing the number of stops, the average delay for stopped vehicles becomes misleading, while the total stopped delay shows some improvements. A similar finding is also reflected in the French report. The simulation-based experiments conducted in Italy and in France further display a positive combined effect of GLOSA and SPTI in the reduction of **queue length** and total delay and the benefits were observed to improve with an increase in the market penetration rate of equipped vehicles.

Some other factors are at stake such as the *number of lanes*, the *activation distance* and the *cycle length* as illustrated by French and Italian simulations. For instance, with a cycle of 90s and an MPR=30%, an activation distance of 300m will provide only 3% of improvement, while it reaches 60% for 500m. Alternatively, a reduction in the cycle length to 60s will provide an improvement of about 40% even with an activation distance of 300m. The GLOSA performs better when no-overtaking option is possible, especially at low market penetration levels.

Furthermore, the tests conducted in the United Kingdom reveal that the drivers equipped with GLOSA are more prepared for the signal to turn green which can, therefore, potentially improve traffic flow and junction capacity. Hungary also shows evidence of smoother traffic flow for GLOSA equipped vehicles.

No significant impact was observed in terms of **travel time** and **speed** with the GLOSA use case.

The SI use cases are settled into urban areas. As a consequence, the main challenge with regard to traffic relies on the optimization of the global flow and the limitation of the number of stops and the stop duration. While the red-light violation (ISVW) use case involved, as expected, an increase in the number of stops ([+54%; +109%] in Spain), the GLOSA and SPTI use cases are dedicated to eco-driving strategies compliant with traffic efficiency purposes. As a consequence, most of the studies show an improvement in some traffic conditions and road configuration, but the Operational Design Domain still require some refinements. For instance, the implementation of GLOSA use cases on the Field requires to find a trade-off between an appropriate response rate of the drivers with activation distance in the range [100m; 300m], an appropriate cycle duration and a stronger impact on the number of stops.

Table 9 - Traffic Efficiency - Qualitative Socio-Economic Impact for SI

Impact area	Indicator	Effect	Socio-economic impact
Efficiency	Number of stops	Reduction for GLOSA Increase for ISVW	+ -
	Stopped delay	Reduction for total delay with GLOSA and SPTI Increase for stopped vehicles with GLOSA	+ -
	Queue length	Reduction for GLOSA and SPTI	+
	Total delay	Reduction for GLOSA	+
	Total travel time	No impact for GLOSA Reduction in travel time for SPTI Increase for transition from green to red with EVP, ISVW and SPTI	0 + -
	Traffic flow	Improvement for GLOSA	+
	Junction capacity	Increase for GLOSA	+

C-ITS as a Bundle

In NordicWay 2, regarding the long-term impact on traffic efficiency, the findings result from projections fed by the trends observed on each use case under study. The Nordic countries took the practical exercise to perform prediction of Travel Time and Congestion Level evolution with the horizon of 2030. The Key Performance Indicators under consideration consists in the **Global Travel Time** and the **Global Level of Congestion**. Such indicators are expressed by the volume of traffic multiplied by the time spent on the road (Travel Time) or in congestion (Congestion Level). The implementation of C-ITS services highlights, on average and according to current predictions, some benefits by reducing Global Travel Time by values encompassed between 0,01% and 0,1% and Congestion by 0% - 1,8%.

The French report is taking into consideration the evolution due to the deployment of C-ITS services and various telecommunication infrastructures configurations over the year. The impacts are converted into a generalized cost. It highlights that some steady benefits can be expected from 2025, when LTE-V2X and 4G technologies are at stake on the road network.

2.3. Environment

Below are a set of summary statements per Service. For more detail, please refer to the full Environment results from each C-Roads Pilot.

Roadworks Warning (RWW)

The evaluation of road works warning use-cases by all countries has, in general, focused on speed or rate of change of speed, i.e. acceleration and deceleration. Generally, speed and change in speed were monitored during pilot deployment for evaluation purposes; however, the results are rather widespread.
The largest number of KPIs were considered for evaluation by the Spanish pilot, taking into account results from Lane Closure, Road Closure and Road Works Mobile. The most important results concerning the lane closure use-case consider different KPIs:

- Change on fuel consumption and CO_2 emissions
- Change in pollutant emissions NO_x
- Change in pollutant emissions PM2.5

Generally speaking, a decrease of up to approximately -20% for all these KPIs can be seen. All pilots show, as an average, decreasing emissions, except the "Andalusian – Mediterranean"-pilot.
There are positive effects on the environment of lower emissions which were directly measured as a result of the evaluation process, such as those from the Spanish pilots. Others, like the UK pilot, also showed that improvement in environmental factors was most likely due to contextual factors, such as, earlier speed and lane change maneuvers, which avoided heavy deceleration and acceleration due to smoother traffic flow, leading to reduced fuel consumption and noise reduction.
Similar to this, the Italian pilot also considered contextual factors, such as avoided congestions as a consequence of impacts on traffic efficiency, that lead to positive factors both in lower fuel consumption and emissions.
Also, the Austrian pilot proved the potential of positive environmental impacts from earlier speed and lane change manoeuvres, avoiding congestions due to better traffic flow and therefore leads to lower fuel consumption. Additionally, it was shown that a low range of speed-changes (which can be reached with the help of C-ITS-tools) keeps CO_2 (and other)-emissions constantly low.

In Italy the assessment of socio-economic impacts of RWW-LC related to environment were estimated around 0,39 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 10 - Environment - Qualitative Socio-Economic Impact for RWW

Impact area	Indicator	Effect	Socio-economic impact
Environment	Fuel consumption	Reduction for RWW-LC	+
	CO_2 emissions	Reduction RWW-LC (1 pilot case with increases)	+
	NO_X emissions	Increase RWW-LC in 1 pilot case, reduction in 2 pilots	?

In Vehicle Signage (IVS)

Similar to road works warning, the evaluation of In Vehicle Signage use-cases, in general related to either speed or speed-change. Generally, the reaction of the driver to the transmitted speed and change in speed as well as the lane-change behavior was taken into consideration for the evaluation.

The IVS use cases that were investigated by different countries included Dynamic Speed Limit Information (Spain, UK), Embedded VMS “Free Text (Spain, UK) and IVS Dynamic Lane Change Information (UK) as well as the French output of the PHEMlite emission model (integrated with SUMO).
Although there were no directly measured Environmental KPIs in the UK pilot, analysis of the tested IVS use cases indicated that implied environmental benefits could be realized as a result of driver behavioral change. Depending on the message displayed, there could be a secondary traffic efficiency benefit from warning drivers early of an event downstream, such as debris, animal or persons. Consequently, this reduces sudden braking/lane changes and also warns upstream traffic of hazards that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue.
The Spanish pilot evaluated a large number of KPIs. Taking into account the summary results of Spain, the following main conclusions at the Spanish level were obtained:

- Change in fuel consumption and CO_2 emissions: the result of this KPI indicated a reduction for IVS-DSLI use case in all the pilots where this KPI was evaluated. In the case of EVFT, Catalan sub-pilot detected a reduction, while the result in the Andalusian sub-pilot was neutral.
- Change in pollutant emissions NO_x: There was a reduction in the pollutant emissions in the DSLI use case. In the case of EVFT for Catalan sub-pilot, there was also a reduction but for this same use case in Andalusian sub-pilot, the result was an increase of 1,4%.
- Change in pollutant emissions PM2.5: A reduction was detected in the service EVFT for Andalusian sub-pilot, but it was a result of 1,5% in Catalan sub-pilot. For the service IVS-DSLI, the result was positive (3,9% and 4,7%).

In France, significant results were derived from the simulation of the “Dynamic Speed Limit Information” use-case. The key impacts on environment in terms of different KPIs are highlighted as follows:

- Impact on CO_2 emissions: there was a decrease in emissions as the market penetrations of connected vehicles increased, primarily due to the speed oscillations of the unequipped vehicles.
- Impact on NO_x emissions: there was a significant decrease in emissions with rising market penetration. Again, this was mainly due to the speed oscillations of the unequipped vehicles.

Though these trends were similar for both CO_2 and NO_x emissions, the gains were higher for NO_x emissions at high market penetrations of Connected Vehicles, while CO_2 emission gains were higher at low Market Penetration.
With all these statements, it’s worth noting that, even with a market penetration as low as 10% of connected vehicles in the traffic stream, there was a substantial improvement in emission performance when compared to the case where no dynamic speed limits were implemented.
In Italy, Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency. Consumption and emission factors are adopted accordingly, assuming that 382 events of traffic congestion due to road accident were avoided thanks to the Use Case. According to this approach, there is a saving of more than 1liter of gasoline (and more than 1.4 liter of Diesel) per avoided accident, which leads to emission savings of 6.19 CO_2 tons per accident and of 2.368 CO_2 tons in total.
In Austria, the evaluation results on this KPI showed that the main cause for an increase of emission is rather not a certain (eventually too high) speed, but more the result of

frequent speed-changes. Proving that use of C-ITS tools lead to speed-changes within a very low range, low CO_2 (and other)-emissions are a consequence from this. This is equally true for noise emissions.

In Italy the assessment of socio-economic impacts of IVS-DSLI related to environment were estimated around 0,24 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 11 - Environment - Qualitative Socio-Economic Impact for IVS

Impact area	Indicator	Effect	Socio-economic impact
Environment	Fuel consumption and CO_2 emissions	Decrease for DSLI Decrease for EVTF	+ +
	NO_X emissions	Decrease for DSLI Decrease for EVTF	+ +
	Pollutant emissions PM2.5	Increase for DSLI Decrease for EVTF	- +

Hazardous Location Notification (HLN)

The following hazardous location notification use-cases were evaluated:

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-WCW: Hazardous Location Notification - Weather Condition Warnings
- HLN-APR: Hazardous Location Notification - Animal or Person on the Road
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- HLN-EVA: Hazardous Location Notification - Emergency Vehicle Approaching

The following main conclusions at the Spanish level were obtained:

- Change in fuel consumption and CO_2 emissions: the result of this KPI indicated a reduction for HLN-SV use case in the Catalan and DGT3.0 sub-pilots, but Andalusian sub-pilot showed an increase of 8,6%. In the case of TJA, Andalusian sub-pilot detected an increase of 3,3%.
- Change in pollutant emissions NO_x: There was a reduction in the pollutant emissions in WCW use case. In the case of the Madrid sub-pilot, the evaluation was based on a simulated environment. The TJA use case showed an increase of 8,3% in the Madrid sub-pilot. For the SV use case it was not possible to conclude common results.
- Change in pollutant emissions PM2.5: A reduction was detected in the TJA use-case. For the WCW use case, the pollutant emissions were highly reduced in the Andalusian sub-pilot and neutral in Catalan sub-pilot.

The Italian pilot assessed environmental impacts by considering the avoided congestion, so that these saving are then a consequence of impacts on traffic efficiency. Avoiding congestions lead to significant lower consumption factors, especially for heavy vehicles, potential emission saving is up to 2,61 kg CO_2 per liter. The total average emissions savings are then as high as 906 tons of CO_2 for the HLN-SV use case and 346 tons of CO_2 for the HLN-WCW use case.

In Italy the assessment of socio-economic impacts of HLN-SV related to environment were estimated around 0,09 M€ and for HLN-WCW up to 0,03 M€ in one year with 100% C-ITS Market Penetration Rate.
Moreover, a qualitative socio-economic impact evaluation is reported in the following table.

Table 12 - Environment - Qualitative Socio-Economic Impact for HLN

Impact area	Indicator	Effect	Socio-economic impact
Environment	Fuel consumption and CO_2 emissions	Inconsistent Decrease for SV / WCM (indirect estimated impact based on hours saved)	?
	NO_X emissions	Decrease for WCM Increase for TJA Inconsistent for SV	+ - ?
	Pollutant emissions PM2.5	Reduction for TJA Significant reduction for WCW	+ +

Signalized Intersections (SI)

Several use cases with reference to Signalized Intersection were investigated by different countries, that included Signal Phase and Timing Information (Spain, Italy), Imminent Signal Violation Warning (Spain), Emergency Vehicle Priority (Spain), and Green Light Optimal Speed Advisory (Italy, UK, France).
The most important outcomes related to the analysis of speed and accelerations/decelerations, these elements were considered by all Countries.
The impacts on environment in terms of different KPIs are summarized below:

Signal Phase and Timing Information
Overall, the Spanish evaluation showed a significant decrease in vehicle emissions:
-52% in the DGT3.0 area, and of -16%, resp. -77% in the SISCOGA area.

Green Light Optimal Speed Advisory
Italy obtained two main types of results:

- The first type of results consists of a set of attributes that characterized the approaches to traffic light intersections, such as the vehicular flow, the distance of reception of the messages, the duration of the traffic light cycle and the market penetration
- The second type reported the results in relation to the GLOSA/SPTI implementations planned in selected cities, providing an impact assessment of the equipped intersections.

Summarizing these results, the total fuel saving was between -0.9% (in case of a penetration rate of 5%) and -8.7% (with MP = 100%).
The UK also reported that GLOSA had observed Environmental benefits due to drivers slowing earlier and smoother driving on the approach to a red or passing on a green signal more easily due to the HMI GLOSA advice given.
Additionally, drivers felt this service would be particularly beneficial for HGV drivers, who would be keen to reduce gear changes, and the consequent smoother driving is known to reduce congestion, which could then provide improved junction throughput and finally reduce harmful emissions.
Finally, drivers were reporting being less stressed - which often contributes to less aggressive driving, which also results in less emissions due to smoother driving.
The Spanish pilots also showed a positive change on fuel consumption and CO_2 emissions. The result indicated a reduction for all the use cases where GLOSA was evaluated (EVP, SPTI and ISVW). It was highly reduced in the naturalistic study of “SISCOGA Extended” with a value of -77% for SI-SPTI (red-green case).
France evaluated the emission output using the PHEMlite emission model (integrated with SUMO).

It can be stated that significant benefits in terms of environmental efficiency for the entire traffic stream were observed only when the market penetration rate exceeded 30%. A benefit of 3-5% was calculated, with even higher values of up to 15% with a MPR of 100%. Moreover, there is a stronger effect with increase in MPR for single lane roads. Although the general trend is similar for CO_2 and NO_x emissions, there was an even higher improvement of up to 15% in NO_x emission gain with a MPR of 30%.

Table 13 - Environment - Qualitative Socio-Economic Impact for SI

Impact area	Indicator	Effect	Socio-economic impact
Environment	Fuel consumption	Reduction for EVP, SPTI and ISVW	+
	CO_2 emissions	Reduction for EVP, SPTI, ISVW and GLOSA	+
	Start of slowing down before intersection	Earlier for GLOSA	+
	Smooth driving	Result depends on penetration rate and cycle length for GLOSA	?
	NO_X emissions	Reduction for GLOSA	+

C-ITS as a Bundle

In NordicWay 2 the environmental impact assessment focused on CO_2 emissions, which are closely linked to the fuel consumption of the vehicles, as well as changes in speed level and congestion.
The assessment also took the fuel efficiency and its relation to CO_2 emissions into account, which is likely to improve due to ongoing electrification of vehicle fleets
The table shows the environmental impacts for the high and low effectiveness scenarios in percentages for the Nordic countries in 2030:

Low effectiveness scenario	Denmark	Finland	Norway	Sweden
CO_2 emissions (million tons/year)	-0.05%	-0.01%	-0.07%	-0.02%
High effectiveness scenario	**Denmark**	**Finland**	**Norway**	**Sweden**
CO_2 emissions (million tons/year)	-0.07%	-0.07%	-0.10%	-0.03%

The changes in CO_2 emissions range from -0,01% to -0,07% in the low and from -0,03% to -0,10% in the high scenario.
The table shows the Impacts in terms of vehicle hours driven and vehicle hours spent in congestion in 2030 in terms of million tons of CO_2:

Low effectiveness scenario	Denmark	Finland	Norway	Sweden
CO_2 emissions (million tons/year)	-0.0024	-0.0005	-0.0032	-0.0018
High effectiveness scenario	**Denmark**	**Finland**	**Norway**	**Sweden**
CO_2 emissions	-0.135	-0.049	-0.662	-0.102

The changes in CO_2 emissions range from -500 to -3.200 kg in the low and from -49.000 to -662.000 in the high scenario.
Lowest values can be seen in Finland and highest in Norway.

2.4. User Acceptance

User Acceptance Background Context:

This executive summary on User Acceptance includes a wider commentary and key observations across each main service area, for all Pilots conducted in Phase 1, and also considers C-ITS services when evaluated as a bundle. Each evaluation used the following common assessment criteria, using where feasible both quantitative based (surveys) and qualitative based (interviews) as an evaluation method. The other aspect that was considered is how users changed their acceptance towards services pre and post-test (acceptability vs acceptance).

User Acceptance overall assessment criteria:

- Perceived Efficiency taking into consideration a general perspective, environment, safety, and traffic efficiency, can include 'subjective impact' if evidenced
- Perceived usability – ease of use etc.
- Workload – included how distracting it might be
- Perceived usefulness and satisfaction – included the effectiveness of the service from a user's point of view
- Equity - Willingness to adopt/use the new service/technology in the future
- Willingness to pay for the service (or services)
- What improvements would you introduce in the service? (asked in some interviews)

Below are a set of summary statements per Service. For more detail, please refer to the full User Acceptance results from each C-Roads Pilot.

Road Works Warning (RWW)

The majority of participants said it was useful and increased awareness and helped them to be alert and prepare for the roadworks, for example in Flanders 83% of drivers felt more alert. In some countries drivers reported that RWW was more effective than roadside signage. Drivers also stated that getting advanced information would help them to plan their journey better. In Austria there was a clear tendency towards an agreement of the implementation of HLN-services in a car, especially concerning RWW-related services.
In general, the perceived efficiency and effectiveness of the service was also high with around two thirds of Spain's users agreeing and just over two thirds of Belgian drivers reported reducing speed and increasing the gap to the car in front. 29% of United Kingdom drivers surveyed said they would do the same.
A large number of participants thought that it would improve safety and would like the service to be available permanently and made them feel more at ease whilst driving. Although willingness to pay for the service was quite low, in the range 10-30%, the majority of participants were unconcerned about data sharing, with 79% of Belgian users agreeing to data sharing. This measure in Austria differed if asked about sharing data with road operators versus car manufacturers, with the latter receiving a lower score.

In Vehicle Signage (IVS)

The IVS service was widely used across all pilots, shown by two examples, where the United Kingdom recorded that 72% of drivers and 70% of drivers for the Netherlands said they used the IVS speed assistant.
62% of United Kingdom drivers and the majority of Netherlands participants thought it was more effective than existing roadside signage. United Kingdom Drivers also felt more at ease and less stressed as the messages appeared on screen for longer. Most users in

the Netherlands indicated they would recommend the service to others. The majority of the users wanted the service to be available permanently, although it is worth noting that there were considerably fewer Spanish participants wanting the service permanently post-testing.

Across the countries that tested IVS most drivers felt the service was not distracting and as many as 91% of United Kingdom users said they were not distracted. However, drivers in the Netherlands and Spain indicated that they were more distracted than they thought they would be before testing.

The perception of the trustworthiness of the information presented on the HMI in the Netherlands slightly increased after the test, as did those that thought the service was useful with 69% of drivers saying they used the information. Significantly in Spain, three regions recorded that over 63% were influenced by the information. In contrast, in the Netherlands, the feeling of being at ease or more secure, the feeling of alertness and perception of road safety reduced after testing. Furthermore, the majority of users appeared to feel that they were more distracted than they initially indicated.

In contrast in the United Kingdom, IVS Dynamic Lane Management saw an increase from 63% to 75% of respondents agreeing it would improve safety after testing. 62% thought it was more effective than roadside signage, 21% further stated that they adapted their speed immediately. United Kingdom Participants stated that they were more likely to pay attention to the in-car speed signage which in turn made them more aware of the current speed limit. In Austria pre and post test results remained relatively consistent.

There was a general unwillingness to pay for IVS information. This trend was seen across all services but particularly low with IVS. However, most drivers across all pilots who implemented IVS indicated general acceptance of the idea of sharing their positional data. In Austria, the response differed if asked about sharing data with road operators versus car manufacturers, with the latter receiving a lower score.

Hazardous Location Notification (HLN)

The HLN service was used by most drivers and in some areas of Spain around two thirds of participants found it to be useful. Slovenia stated that the DARS Traffic Plus application offered a good user experience. High scale values indicated that the application was easy to get familiar with to use the application.

Opinions of users from Spain across all regions varied somewhat before and after testing, but in general there was a good acceptance, thus in some areas a majority felt the service improved trip quality and that it didn't distract them.

In Czech Republic results showed that driving with the DARS Traffic Plus smart phone application provided a better user experience than without the service. The results of questions regarding usefulness, satisfaction and safety were very positive and users strongly agreed that the information about SSV was useful. It increased their overview when approaching a slow vehicle or rail crossing and helped them feel safer. Half of Spain's participants said that HLN improved their trip quality.

One region of Spain reported that half of the users would like to have the service permanently in their vehicle. In Slovenia it was concluded that DARS Traffic Plus application offered motivation for future use of the application.

Most drivers across Spain were also generally unconcerned about the idea of sharing positional data, although 20% of drivers in two regions were not in favor. Drivers still showed a lack of interest in paying for the service.

Signalized Intersection (SI)

The SI service suffered from some technical and presentation difficulties but despite these problems, it was well used by most participants (over 55% in Spain).

Nearly two thirds of Spain's users said they felt at ease because of the service, which was a common theme across all C-Roads pilots where services operated reliably. United Kingdom drivers stated that they felt more at ease driving; 61% of United Kingdom participants reduced their speed to avoid stopping, while 30% increased their speed for the same reason. The fact drivers knew when lights would change appeared to have a positive effect on their feeling when approaching traffic signals. It was also found when waiting at red lights that GLOSA had a positive effect on a driver's preparedness and awareness.
Czech Republic users said the information was useful, satisfactory, and clear and most drivers marked the service for usefulness as neutral to strongly agree. Unfortunately, due to widespread use of adaptive-traffic light controllers in the Netherlands drivers felt that the information was less valuable, although results were more positive for fixed time signals.
While 19% of Spain's users post-test said that the service could distract, in general, participants considered that the SI information did not distract them. 60% of United Kingdom users felt it wasn't distracting at all.
Most of Spain's participants stated that the service was effective with the general score of 77%. Over 80% of Spain's participants would like to have the service permanently. 61% of United Kingdom drivers and over half of Spain's users stated that SI influenced their driving.
Both Spain and Czech Republic saw an increase in users willing to pay after experiencing the service but the numbers prepared to pay are still quite low with 20% and 11% respectively.
Confusion could arise from the presentation of too much information, for instance presenting speed advice and a countdown timer together. Care must be taken in how the information is presented as two sets of numbers may lead to the wrong decision. These aspects are discussed in more detailed under the Functional Evaluation area of this report.

C-ITS as a Bundle

NordicWay 2 user acceptance results clearly showed that C-ITS services were considered relevant and the acceptance was high. 84% of respondents stated that they would use C-ITS services as part of their travel. Respondents considered the information content important for most strategic roads, as well as urban environments. They also perceived the services to have safety, fluency and comfort benefits and did not expect the services to distract them. Most drivers indicated that they were unwilling to pay for services and only 15% indicated that they would pay.
The results from the NordicWay2 user acceptance evaluation were echoed by the online survey carried out by Hungarian Public Roads in which the general awareness and the potential acceptance of C-ITS services were also examined. Based on the perceived benefits, there was a general positive attitude toward C-ITS services. 80-90% of the respondents think that receiving C-ITS messages comes with advantages. 90% answered that they would use C-ITS services in the future and 62% of the respondents find it very important to be able to use the same platform and receive the same messages and warnings across the country.
77% of people who mostly drive within a city found safety related services important to some extent as opposed to the 92% of extra-urban drivers. In this survey, 25% of respondents said that they would be willing to pay for the services.
In France, the C-ITS services were well accepted by most users with 81% continuing to use them during the pilot, either standalone or alongside other existing nav apps. Most users felt the app required too much information when reporting events suggesting that training in reporting the events was needed especially. Usability is therefore key.

User Acceptance Overall Conclusions

Although it was found most C-ITS services evaluated were considered relevant and the acceptance was high. It must be borne in mind though, that in a lot of the pilots most of the drivers had never heard of C-ITS services, and sometimes a much lower proportion had used them, so this is more a measure of acceptability than acceptance.

Thus, even if there is acceptance for those who know or are informed about these services, the overall awareness within the populous is still relatively low. The lack of willingness to pay may become a barrier to full scale deployment of the services. However during interviews in some pilots it was clear users would like C-ITS services to be integrated into existing consumer applications e.g. Google Maps, Waze, HERE etc., which could help mitigate this.

In some pilots offering a bundle of C-ITS services, only a small number of drivers had personal experience of the services when completing surveys (acceptability), and as such the results should be considered indicative. Although post-test (acceptance) survey results from other pilots showed users maintaining and sometimes increasing their positive views of the services and their perceived influence on their behavior. So, the indicators from wider national surveys are backed up by users actually testing the services.

However, it is worth noting that the positive but arguably indicative acceptance results in this report are in line with the recently published evaluation results from the Talking Traffic service in the Netherlands. (Talking Traffic is a large scale connected services deployment evaluated since 2018 with 2 million users). This project has demonstrated tangible and statistically significant benefits of deploying IVS and SI services when applied to a large number of users.

In the future when the services become more widely known and used, issues such as the HMI, integration into existing Navigation applications etc. may become more relevant for acceptance and willingness to use. This aspect is discussed in more detailed under Functional Evaluation, as are suggested improvements to the services captured during the evaluation.

2.5. Functional Evaluation

The main goal of C-Roads is to create a set of specifications for sending C-ITS messages from the back office i.e., the Digital Network Infrastructure (DNI), down to Roadside Units (RSUs) and on to On Board Units (OBUs) located within vehicles. There are detailed technical specifications covering these requirements and as a result, technical evaluations were carried out in each pilot.

It should be noted however that the C-Roads evaluation scope as agreed within WG3 did not cover these detailed technical evaluation aspects, including message parameters such as information / relevance zones, or assessing the quality of the HMI etc. It was instead down to the individual pilots (road administrator, OEMs) to independently evaluate these technical aspects. The technical evaluation within C-Roads was focused on interoperability tests that were specified under WG2, TF5 and have been reported on separately by this Task Force.

Against this context it was not possible to evaluate these aspects as a whole across the C-Roads project. Further, as there aren't explicit specifications for quality of service and quality of HMI, it was only possible to pick up lessons learned and to look for the added value of the C-ITS services.

It is worthy of note that results of User Acceptance and expected impact of the services mainly depended on the quality of the functional aspects of the service so were highly relevant to forming a successful evaluation overall.

The main results of the Functional Evaluation covered three main topics:

- Warning Zone and Relevance Zone: these 2 parameters are part of the messages. In the lessons learned we analyzed terms that noted the timings of messages as 'well in advance", 'distance to reach the event', 'early warning', 'information when event is passed'.

It was noted that there are currently no explicit requirements in the service specifications about the warning time or warning distance for the start of road works, or warning about an object in the road for example. For RWW it was also not clear if a message about road works should remain active for the whole section of the road works (perhaps with just the speed advice and not the warning).

One conclusion under Functional Evaluation is that there is a need to harmonize these parameters for the different C-ITS services.

- Mapping and GPS-location: some C-ITS services need a highly accurate GPS location (e.g., warning for traffic light violation, advice for lane changing etc.). In some situations, due to the dense urban environment, trees etc., achieving these levels of GPS accuracy especially if the OBU doesn't have GNSS and tracking correction algorithms provisioned, can still be a problem due to obscuration in such environments.

Some services also need high-definition maps so this could also be a problem if they are not specified and implemented before rolling out the service.

- HMI: there are many remarks and suggestions about the HMIs used in the various pilots (voice, audible beeps, integration with existing car systems, SAT NAV software etc.). It is therefore worthwhile to read the full report in Chapters 3.5 to 7.5 on Functional Evaluation results to ascertain the detailed commentaries for each Pilot.

There was also useful advice captured under Lessons Learned about setting up pilots, e.g.:

- Do not evaluate C-ITS services when other existing ITS services (e.g., RDS-TMC, VMS) are in operation as establishing a counterfactual will be compromised (as drivers with no C-ITS warning were still seeing the matrix signs / VMS so these influenced their driver behavior)
- Keep in mind that the quality of the information available in the back office being used by the C-ITS services and ultimately relayed into vehicles has a major impact on the user acceptance
- To be aware that to implement C-ITS services you will require additional technical equipment, communication lines, low latency data platforms etc., but will also need to specify detailed requirements for data storage, tagging and retrieval/analysis for the successful evaluation of C-ITS services

2.6. Socio-economic impacts

The socio-economic impact assessment comprises the monetized impacts on road safety, mobility and the environments. The results show and reconfirm the road safety-improving nature of the C-ITS services. Safety improvements are the main driver of the total benefits. The aggregated socio-economic impact on reducing injury accidents is larger than the one stemming from fatal accidents reduction because injury accidents occur more frequently. The benefits of reduced congestion and reduced environmental pollution add to the total benefits. Overall, the socio-economic benefits are evident and relevant in most of the cases.

NordicWay 2 project (Denmark, Finland, Norway and Sweden) assessed the impacts of C-ITS as a bundle of use cases. In their work, the safety, efficiency and environmental benefits were calculated for all networks studied for 2030 for the low and high effectiveness scenario concerning the impacts. Table below shows the quantitative benefits of the C-ITS services in 2030 on the networks of the NordicWay countries for the low and high effectiveness scenario. The range is between 142,5 M€ and 253 M€.

Table 14 - Benefits or user-cost changes due to the deployment of C-ITS services in 2030 in the low and high effectiveness scenario (Innamaa et al. 2020)

Benefits for Denmark, Finland, Norway and Sweden	
Low effectiveness scenario 2030	142.543.577 €
High effectiveness scenario 2030	253.165.990 €

According to NordicWay 2, the comparison of costs and benefits shows that from the road operator perspective, the benefits even in the low effectiveness scenario in 2030 exceed the sum of the annual operating and maintenance costs that year and the investment costs up to that year in all countries. In the high effectiveness scenario, the benefits would also cover the operation and maintenance costs of the in-vehicle units in other countries than Finland.

France performed socio-economic assessment of C-ITS services as a bundle, too, addressing period 2022-2052. In the scenarios considered, differences were essentially contained in the year of deployment and the interconnection with the cellular network.
During this period, scenarios are presenting positive benefit values ranges between 360 M€ and 5.464 M€.

Table 15 - Benefits and costs for C-ITS service provision in France during 2022-2052

Scenario	1	2	3	4	5	6
Connected vehicles	Only cellular	ITS-G5 only	ITS-G5 and 4G	LTE-V2X	LTE-V2X and 4G	5G long and short range
Total	- 4 419 M€	360 M€	5 464 M€	-132 M€	3 660 M€	2 925 M€

In Italy the potential benefits of the Use Cases tested were estimated based on the impacts generated (directly or indirectly) by C-ITS on road safety, traffic efficiency and environment. The calculation was made on a 1-year basis considering a 100% C-ITS market penetration and referring to the Italian highway network. The results are reported in Table below.

Table 16 - Estimated socioeconomic benefits of the Use Cases tested in Italy

Use Case	Economic Impact [M€ saved]
Roadworks Warning - Closure of a Lane (RWW-LC)	58,95
In-Vehicle Signage - Dynamic Speed Limit Information (IVS-DSLI)	101,98
Hazardous Location Notification - Stationary Vehicle (HLN-SV)	57,44
Hazardous Location Notification - Weather Condition Warning (HLN-WCW)	15,12

2.7. Final Remarks

As final remarks these statements could summarize the main results emerging from the study of the impacts of C-ITS within C-Roads:

- The users DO react to C-ITS messages. They change their driving behavior; the change is rarely neutral.
- The impact on Road Safety is very relevant: speed, acceleration and deceleration and lane change differ significantly after the reception of the C-ITS messages.
- Impact on Traffic Efficiency: when it is the main aim of the C-ITS message, the change in driving behavior is relevant. If the key objective of the Use Case is the improvement of road safety, Traffic Efficiency effects can be negative or neutral.
- Impact on Environment: it is not always the primary objective of the Use Cases. Relevant positive changes were recorded especially for Use Cases linked to intersections but these effects should be further investigated.
- User Acceptance: C-ITS are generally, in all the aspects very well accepted; only the willingness to pay is often low.
- Functional Evaluation: this chapter provides useful recommendations for the next C-Roads phase in order to improve the effectiveness of the C-ITS services.
- Socio-Economic impacts: Overall, the socio-economic benefits are evident and relevant in most of the cases.

3. Introduction

3.1. C-Roads platform for harmonization of C-ITS deployment

The C-Roads Platform is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonization and interoperability. Through the C-Roads Platform, authorities and road operators join together to harmonize the deployment activities of cooperative intelligent transport systems (C-ITS) across Europe. The goal is to achieve the deployment of interoperable cross-border C-ITS services for road users.

C-ITS enables vehicles to interact directly with each other and the surrounding road infrastructure. In road transport, C-ITS typically involves vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. To enable an efficient and undisturbed exchange of information within these services as well as a cross-border implementation, harmonized C-ITS specifications are indispensable. The approach starts from a functional perspective, then requirements applicable to all implementations and then towards technology specifications of currently validated implementations (ITS-G5 for short range communication, IP based for long range cellular). In order to meet these challenges, the C-ROADS platform is divided into five Working Groups. Working Group one is concerned with organizational tasks, Working Group 2 with Technical Aspects and Working Group with Evaluation and Assessment. Working Group four is about Urban C-ITS Harmonization and Working Group 5 is about Digital Transport Infrastructure (DTI).

The C-Roads Platform is steered by the C-Roads Steering Committee which is composed by Member State representatives. With the support of the Supporting Secretariat, decisions for achieving the goal of the implementation of interoperable end-user services are taken. In this respect specifications, plans and reports, which are proposed and recommended by specific Working Groups, are approved.

The Working Groups provide analysis and an evidence base to support the Steering Committee to make robust decisions on key issues such as interoperable deployments. Individual experts participating in the national pilots work together in these Working Groups to prepare proposals and recommendations. Also, members of the national pilot activities as well as of the C-Roads-Working Groups actively contribute to the work of the EU-C-ITS-Platform.

The C-Roads WG3 Final Report is intended to provide an overview of the Evaluation and Assessment activities developed by the different Countries within their national Pilots.

3.2. Scope of the document

The document is intended to organize, summarize and present the outcomes of the evaluation and assessment activities developed within C-Roads, based on the current available final or preliminary contributions (as of 16th December 2021) provided by the Countries that are part of the C-Roads Platform.

Section 4 of this report provides a brief overview of the evaluation and assessment activities carried out by each Country.

This report is then structured to present results per Service category, meaning a clustering of use cases based on a common denominator, for example, an objective, such as awareness or a context. The Service categories considered are:

- Road Works Warning (RWW) – see section 5
- In Vehicle Signage (IVS) - see section 6
- Hazardous Location Notification (HLN) see section 0
- Signalized Intersections (SI) – see section 8

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It is worth noting that the NordicWay2 project adopted a different approach to their analysis and assessed C-ITS services deployed as a bundle rather than individually. A separate section has therefore been provided (see section 9.

For each Service category, a dedicated sub-section is developed. These sub-sections are then structured according to the Impact Areas detailed within the C-Roads WG3 Evaluation and Assessment Plan [RD.1]:

- Safety
- Traffic Efficiency
- Environment
- User Acceptance
- Functional Evaluation
- Socio-economic impacts

Countries provided results, outcomes, impact assessments and estimations, under these headings, describing the Use Cases tested, the evaluation method, the data collected and results.
A summary is provided for each impact area, consolidating contributions from each Country.
Further details about the contents presented can be investigated by accessing the national reports of each Country.
The Executive Summary (Section 1) provides overall conclusions.

3.3. Use Cases description

The following Table 17 provides a brief description of the Use Cases, based on [RD.2].

Table 17 - Concise description of Use Cases

Acronyms	Use case	Description
HLN-APR	Hazardous Location Notification – Animal or Person on the Road	A road operator knows that one or several animal(s) is(are) present on the road network and broadcasts the information to road users. A driver detects one or several animals on the road and signals that information via his HMI, broadcasting a message to road users, or both situations or warnings are combined.
HLN-AWWD	Hazardous Location Notification – Alert Wrong Way Driving	This Use case is to warn a driver that he could encounter a vehicle that is driving in the wrong way. It is not the primary aim of this use case to alert the wrong-way driver that he is on the wrong way. This V2V use case could be added in the future to the warning sequence if detection quality and confirmed status of information is improved.
HLN-AZ	Hazardous Location Notification – Accident Zone	The road operator detects that an accident has happened on the network and broadcasts the information to road users who can benefit from this information
HLN-EVA	Hazardous Location Notification – Emergency Vehicle Approaching	The emergency vehicle is equipped with the necessary technology for a vehicle-to-vehicle (V2V) communication to send appropriate messages and alert the road users in advance.
HLN-EVI	Hazardous Location Notification – Emergency Vehicle in Intervention	The task of the Emergency Vehicle in Intervention (EVI) is to warn drivers about the location (e.g. a traffic accident, rescue and recovery work) of an emergency vehicle in intervention so the drivers will be able to adjust their speed or lane position on the road. The equipped emergency vehicle is sending a warning message when the vehicle is stationary with an activated light bar and being stationary for more than the defined time period. Only

Acronyms	Use case	Description
		the emergency vehicle equipped with the certified C-ITS unit is allowed to send the message.
HLN-OR	Hazardous Location Notification – Obstacle on the Road	A road operator knows that there is one or several obstacles on one or several lanes of his network and broadcasts the information to road users. However, traffic can still pass the obstacles (not a blockage).
HLN-PTVC	Hazardous Location Notification – Public Transport Vehicle Crossing	Vehicle is approaching a location of a high risk of collision with PT vehicles. The driver is informed about this situation via in-car information and warning.
HLN-PTVS	Hazardous Location Notification – Public Transport Vehicle at a Stop	Providing in-car information and warning about public transport vehicle at a stop.
HLN-RLX	Hazardous Location Notification – Railway Level Crossing	The railway infrastructure manager or a service provider informs the driver about the presence of a railway level crossing and its type/parameters/status. This use case covers both protected level crossings along with unprotected ones. The messaging to drivers and the information provided is addressed, too.
HLN-SV	Hazardous Location Notification – Stationary Vehicle	Stationary Vehicle(s) service warn approaching drivers about stationary/broken down vehicles ahead, which may represent obstacles in the road. It is a preventive safety service, as drivers will have advanced notice and more time to prepare for the hazard.
HLN-TJA	Hazardous Location Notification – Traffic Jam Ahead	A road operator detects a traffic jam and sends the information to the road user (mentioning the position, the length of the traffic jam and the section/ lanes concerned if the information is available).
HLN-TSR	Hazardous Location Notification – Temporary Slippery Road	A road operator knows that a section of a road (or a single lane or point) is temporarily slippery and sends thus information to the road user, or/and a vehicle detects that it is slipping and broadcasts an alert message to other vehicles. The combination of these two information sources within a C-ITS system makes it possible to generate much better information quality and accuracy compared to both single sources used up to now.
HLN-UBR	Hazardous Location Notification – Unsecured Blockage of a Road	An operator in the TCC gets the information that there is a blockage of a road. Till the time that operating agents arrive to the site to protect and manage it, the operator sends a warning message to road users. A blockage means that there is no traffic going through the road segment and passing it by on a single or several lanes., The complete road is blocked (not an obstacle on one or more lanes).
HLN-WCW	Hazardous Location Notification – Weather Condition Warning	Weather Conditions Warning (WCW) use case shows both static and dynamic information of weather conditions and road status in-vehicle.
IVS-DLM	In-Vehicle Signage – Dynamic Lane Management	The use case is to inform road users of the status of the lanes (open/closed, normal, high occupancy vehicle (HOV) lane, bus lane or rush hour) of a road.
IVS-DSLI	In-Vehicle Signage – Dynamic Speed Limit Information	The road users receive in-vehicle speed limit notifications as they drive. The message subject is the dynamic speed limit given by the road operator.
IVS-EVFT	In-Vehicle Signage – Embedded VMS "Free Text"	The goal of this use case is to display to the road user in-vehicle information of type "free text". The information will either reproduce what is displayed at a physical VMS (e.g. variable text panel) or display a completely new message that does not mirror a physical VMS (a virtual VMS).
IVS-OSI	In-Vehicle Signage – Other Signage Information	The aim of this use case is to display signage information to road users other than the speed limit and free text information presented in previous use cases, e.g. bans on overtaking. The information will either reproduce what is displayed at a physical VMS (e.g. variable text panel) or display a completely new message that does not mirror a physical VMS (a virtual VMS).

Acronyms	Use case	Description
IVS-SWD	In-Vehicle Signage – Shock Wave Damping	Providing I2V in-car information to avoid emerging or ideally even accomplish the elimination of shockwave situation in highway traffic.
RWW-LC	Road Works Warning – Lane Closure (and other restrictions)	The road user receives information about the closure of part of a lane, whole lane or several lanes (including hard shoulder), but without the road closure. The closure is due to a static road works site. In this use case, alternate mode and road closure are excluded.
RWW-RC	Road Works Warning – Road Closure	The road user receives information about a road closure due to a set of static road works. The closure is temporary.
RWW-RM	Road Works Warning – Road Works Mobile	The road user receives information about a zone on the road that contains, at some point, the neutralization of part of a lane or a lane closure (but without road closure) due to a planned mobile work site.
RWW-ROVA	Road Works Warning – Road Operator Vehicle Approaching	A road operating agent in his intervention vehicle needs to access urgently an incident area to protect it. The agent requests to road users that they facilitate the agent’s way on the road, broadcasting a message.
RWW-ROVI	Road Works Warning – Road Operator Vehicle in Intervention	An operating agent in his vehicle stops in front of an accident/incident to protect the obstacles or is currently setting the equipment (lane delineation) to protect a site (in case of road works for example).
RWW-WM	Road Works Warning – Winter Maintenance	The winter maintenance vehicle, equipped with the necessary technology for a road operator vehicle-to-vehicle (Vro2V) communication, sends a message signaling their activity (salting and/or snow/ice removal). The alerted road user can adapt its driving behavior accordingly.
SI-EVP	Signalized Intersections –Emergency Vehicle Priority	This use case will actively contribute to the phase control of an equipped intersection to aid the passage of emergency vehicles (EV). It will also provide the prioritization status to other users approaching and passing traffic light controlled intersections.
SI-GLOSA	Signalized Intersections – Green Light Optimal Speed Advisory	This service will provide speed advice information to road users for a safe and efficient approach and crossing of a signalized intersection(s)
SI-ISVW	Signalized Intersections – Imminent Signal Violation Warning	This service will provide imminent signal violation warnings to road users approaching traffic light controlled intersections.
SI-SPTI	Signalized Intersections – Signal Phase and Timing Information	This service will provide information to road users approaching and passing traffic light controlled intersections, on the current phase as well as upcoming phase(s) and the moment these are expected to start and end.
SI-TLP	Signalized Intersections – Traffic Light Prioritization	This service will give priority to designated vehicles (e.g. public transport, heavy goods vehicles, etc.) over individual vehicles at signalized intersections for assuring on time transportation schedule (e.g. bus, tram) and/or minimize emissions.

4. Evaluation activity by Country/Project

4.1. Spain

C-Roads Spain consists of five test sites along the TEN-T core network in several Spanish areas (regions of Galicia, Madrid, and Cantabrian and Mediterranean coasts and the whole Spanish core TEN-T network), including parts of the Mediterranean and Atlantic TEN-T corridors and urban nodes.

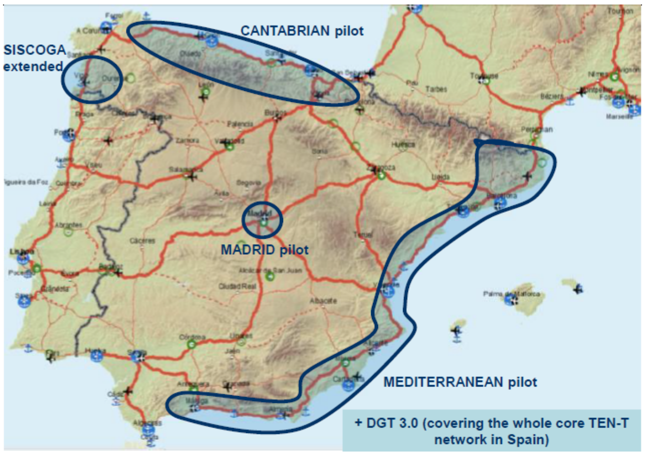

Figure 1 - Spanish Pilots Location

Each of the five Pilots of C-Roads Spain has different characteristics and were executed by a combination of multidisciplinary partners. All partners were oriented to achieve the goals of the project.

SISCOGA Extended sub-pilot: The infrastructure consists of 10 km of urban road covering mainly Vigo City center and 120 km of interurban roads including the main motorways that connect Vigo with the surroundings: AP9, A55, A52 and VG20.

Madrid sub-pilot: The C-ITS systems were deployed along the M30 motorway in Madrid, an urban highway with a length of 32 km that surrounds the central districts of Madrid, which has a high traffic intensity and the longest urban motorway tunnels in Europe, in equivalent length.

The **Cantabrian sub-pilot** was deployed approximately on 75 kms along the several road sections located in Galicia, Asturias and Basque Country.

The **Mediterranean sub-pilot** was deployed and executed along the Mediterranean Corridor (along approximately 125 km of road sections located in Catalonia and Andalusia), in several sections of the AP-7 Motorway, which runs along the Spanish Mediterranean Coast.

DGT3.0 sub-pilot deployed and evaluated the following:

DGT3.0 SISCOGA extension: Based on the collaboration with DGT 3.0, a fleet of 20 vehicles for the pilot was deployed in the region of Galicia in order to try and to evaluate six services selected from the DGT 3.0 catalogue.

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Figure 2 - DGT 3.0 pilot location. SISCOGA Extension

DGT3.0 SATELISE: The purpose of DGT3.0 pilot was to deploy a test pilot with the users of the SATELISE service. SATELISE is a smartphone application for GNSS-based pay-per-use of toll roads developed for both iOS and Android operating systems.
The pilot participants used the information received from DGT3.0 platform in Catalunya in Autema, the toll road running from Terrasa to Manresa along 48,3km.
The SATELISE platform not only is connected to DGT3.0 platform, but also connected to the SCT (Servei Català de Trànsit), traffic information from Catalunya.

Figure 3 - DGT 3.0 pilot location. SATELISE

The services of DGT3.0 platform were also deployed in the M30 motorway in Madrid. They were evaluated together with Madrid sub-pilot.
The Spanish pilot was implemented with ITS-G5, Cellular and hybrid communications, but not all the sub-pilots use the three types.

Evaluation area

Table 18 summarizes the Day 1, Day 1.5 and hybrid services implemented with the respective use cases in the Spanish pilot.

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The impact areas considered by the different Pilot Tests are the following:

- User Acceptance
- Functional Evaluation
- Safety
- Traffic Efficiency
- Environmental
- Technical

The evaluation from Spain is the result of contributions from all different C-Roads Spain sub-pilots, based on the final results obtained during its deployment and evaluation and impact assessment tasks in relation to C-ITS services. This section includes an exhaustive summary of the final report provided by Spain.

Refer to the final report of Spain [RD.3] to read the evaluation report in depth, as well as more evaluation results not considered in this document. (e.g.: Day 1.5 services evaluation or hybrid services.)

The COVID-19 pandemic affected pilot operations due to mobility restrictions. The pandemic had other effects; from March 2020 there was a large decrease in traffic due to the strict lockdown. The number of accidents also decreased due to the fall in traffic.

This situation caused negative effects to the pilots: less drivers participating in the pilot due to the teleworking, planned final test, done in real traffic environment, have been disrupted by mobility restrictions.

It is possible that negative impacts in the results obtained, could be derived from the lockdown due to Covid.

Table 18 - Day1, Day1.5 and hybrid Services Use Cases in Spain.

				Implemented	Safety	Traffic efficiency	Environment	User Acceptance	Functional Evaluation
IVS In Vehicle Signage	IVS	DSLI	Dynamic Speed Limit Information	X	X	X	X	X	X
		EVFT	Embedded VMS "Free Text"	X	X	X	X	X	X
		DLM	Dynamic Line Management						
		OSI	Other Signage Information						
		SWD	Schock Wave Damping	X	X	X			
HLN Hazardous Locations Notification	HLN	AZ	Accident Zone	X	X	X	X		
		TJA	Traffic Jam Ahead	X	X	X	X	X	X
		SV	Stationary Vehicle	X	X	X	X	X	X
		WCW	Weather Condition Warning	X	X	X	X	X	X
		TSR	Temporarily Slippery Road						
		APR	Animal or Person on the Road	X	X	X		X	
		OR	Obstacle on the Road	X	X	X	X	X	X
		EVA	Emergency Vehicle Approaching	X	X	X	X	X	
		EVI	Emergency Vehicle in Intervention						
		RLX	Railway Level Crossing						
		UBR	Unsecured Blockage of a Road						
		AWWD	Alert Wrong Way Driving (HLN-						
		PTVC	Public Transport Vehicle Crossing						
		PTVS	Public Transport Vehicle at a Stop						
RWW Road Works Warning	RWW	LC	Lane Closure	X	X	X	X	X	X
		RC	Road Closure	X	X	X	X	X	X
		RM	Road Works - Mobile	X	X	X	X	X	X
		WM	Winter Maintenance						
		ROVI	Road Operator Vehicle in Intervention						
		ROVA	Road Operator Vehicle Approaching						
SI Signalized Intersections	SI	GLOSA	Green Light Optimal Speed Advisory						
		TLP	Traffic Light Prioritisation						
		SPTI	Signal Phase and Timing Information	X	X	X	X	X	X
		ISVW	Imminent Signal Violation Warning	X	X	X	X	X	
		EVP	Emergency Vehicle Priority	X	X	X	X		
			Traffic signal priority requested by designated vehicles						
PVD Probe	PVD	VDC	Vehicle Data Collection	X					
		EDC	Event Data Collection						
DAY 1.5 services			Traffic Information and smart routing	X					X
			Off Street Park Management & Information	X					X
			Vulnerable road user protection						
			Connected & Cooperative navigation in/out city						
			Information on fueling & charging stations for alternative fuel vehicles						
			Smart Slip Ramp	X					X
			Emergency brake light	X	X	X		X	X
Hybrid comms (MC30, DGT3.0) Services:			Roadworks (RWW)	X	X	X			X
			Incidents (HLN)	X	X	X			X
			V-16 signals	X					X
			Other PMVs	X					X
		SV	Stationary Vehicle (HLN)	X	X		X		
		OR	Obstacle on the Road	X	X		X		
		LC	Lane closure (RWW)	X	X		X		
		SPTI	Signal Phase and Timing Information	X	X	X	X		X
		ISVW	Imminent Signal Violation Warning	X	X	X	X		

The core objective of the evaluation is to better understand the effects of providing Day 1, Day 1.5 and hybrid services. Parameters and Key Performance Indicators (KPIs) are defined as the comparison between revealed measures with Day 1/Day 1.5/Hybrid Services and the baseline that is the current framework without Day 1/Day 1.5/Hybrid services.

The methodology has been based on FESTA Handbook – a methodology supported in the C-Roads WG3 Evaluation and Assessment Plan [RD.1]. It provided a framework defining how to execute FOTs (Field Operational Tests) in general.

The impact areas assessed by each sub-pilot is shown in Table 19 to Table 24:

Table 19 - Evaluation Areas investigated by SISCOGA Extended Pilot

Area	Priority	Research questions	KPIs
User Acceptance	++	++	++
Safety	++	++	++
Traffic Efficiency	++	++	++
Environment[1]	++	++	++
Organizational			
Socio-economy			
Technical	++	++	++

Key:

'++': 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.

Table 20 - Evaluation Areas investigated by Madrid Pilot

Area	Priority	Research questions	KPIs
User Acceptance	+	+	+
Safety	++	++	++
Traffic Efficiency	++	++	++
Environment	++	++	++
Organizational			
Socio-economy			
Technical	++	++	++

Table 21 - Evaluation Areas investigated by Cantabrian Pilot

Area	Priority	Research questions	KPIs
User Acceptance	+	+	+
Safety	+	+	+
Traffic Efficiency	+	+	+
Environment	+	+	+
Organizational			
Socio-economy			
Technical	++	++	++

Table 22 - Evaluation Areas investigated by Mediterranean Pilot

Area	Priority	Research questions	KPIs
User Acceptance	++	++	++
Safety	++	++	++
Traffic Efficiency	++	++	++
Environment	++	++	++
Organizational			
Socio-economy			
Technical	++	++	++

[1] Environment KPIs are taken into account in Phase 2.

Table 23 - Evaluation Areas investigated by DGT 3.0 Pilot (Siscoga Extension).

Area	Priority	Research questions	KPIs
User Acceptance	++	++	++
Safety	++	++	++
Traffic Efficiency	++	++	++
Environment[2]	++	++	++
Organizational			
Socio-economy			
Technical	++	++	++

Table 24 - Evaluation Areas investigated by DGT 3.0 Pilot (SATELISE).

Area	Priority	Research questions	KPIs
User Acceptance			
Safety	++	++	++
Traffic Efficiency	++	++	++
Environment			
Organizational			
Socio-economy			
Technical	++	++	++

Implemented C-ITS services and Use Cases

The list of services and use cases implemented by each sub-pilot shown in Table 25 to Table 30:

SISCOGA Extended pilot:

Table 25 - Day 1 Services and use cases investigated by SISCOGA Extended Pilot

Day 1 Service	Use case
In Vehicle Signage	Dynamic Speed Limit Information
	Embedded VMS “Free Text”
Hazardous Locations Notification	Accident Zone Warning
	Traffic Jam Ahead Warning
	Stationary Vehicle Warning
	Weather Condition Warning
	Animal or Person on the Road
	Emergency Vehicle Approaching
Road Works	Road Works Warning

[2] Environment KPIs will be taken into account in Phase 2.

Signalized Intersections	Signal Phase and Timing Information
	Imminent Signal Violation Warning
	Emergency Vehicle Priority
Probe Vehicle Data	Vehicle Data Collection

Table 26 - Day 1.5 Services and use cases investigated by SISCOGA Extended Pilot

Day 1.5 Service	Use case
Hazardous Locations Notification	Emergency Break Light

Madrid pilot:

Table 27 - Day 1 and Day 1.5 Services and use cases investigated by Madrid Pilot

Service	Use case
Road Works Warning	Lane Closure (RWW – LC)
	Road Closure (RWW – RC)
Hazardous Location Notification	Traffic Jam Ahead (HLN-TJA)
	Stationary vehicle (HLN - SV)
	Weather Condition Warning (HLN-WCW)
In Vehicle Signage	Dynamic Speed Limit Information (IVS-DSLI)
To be developed by WG2-TF2	
Emergency brake light	V2I Service
Emergency vehicle approaching	V2I Service
Traffic information & smart routing	Day 1.5 Service
Off street parking	Day 1.5 Service

Hybrid services [source MC30 and DGT3.0 platform]

- V16 signals
- Road works warnings
- Incidents
- Other PMVs

Cantabrian pilot:

Table 28 - Day 1 and Day 1.5 Services and use cases investigated by Cantabrian Pilot

Day 1 / 1.5 Service	Use case
Road Works	Road Works Warning
Hazardous Locations Notification	Traffic Jam Ahead Warning
	Stationary Vehicle Warning
	Weather Condition Warning
In Vehicle Signage	Emergency break light
	Probe Vehicle Data
Traffic information & Smart routing	Day 1.5 Service
Off Street Park Management & Information	Day 1.5 Service

Mediterranean pilot:

Table 29 - Day 1 and Day 1.5 Services and use cases investigated by Mediterranean Pilot

Day 1 / 1.5 Service	Use case
In Vehicle Signage	Dynamic Speed Limit Information
	Text Free Message
Hazardous Locations Notification	Traffic Jam Ahead Obstacle on the Road Weather Condition Warning Stationary Vehicle
Road Works	Lane closure Road Closure
Probe vehicle data	traffic data acquisition
Shockwave dumping	Shockwave dumping detection
Smart Slip Road	Smart Slip Road
Information on fueling & charging stations for alternative fuel	Information about fueling stations

DGT3.0 pilot. SISCOGA Extension:

Table 30 - Day 1 Services and use cases investigated by SISCOGA Extended Pilot for DGT 3.0 Pilot

Day 1 Service	Use case
Hazardous Locations Notification	Stationary Vehicle Warning
	Obstacle on the Road
	Dangerous Situation
Road Works	Road Works Warning
Signalized Intersections	Signal Phase and Timing Information
	Imminent Signal violation Warning

DGT3.0 pilot. SATELISE

The Smartphone application of the user is able to show all the notices and incidents published by DGT3.0 platform and SCT:

- Services from DGT3.0 platform:
    - V16 signals
    - Road works warnings
    - Incidents
    - Other PMVs
- Services from SCT: Any service information published there: Static road data; Dynamic road data; Real-time traffic information; Adverse weather conditions; Safety Related Traffic Information.

4.2. UK

The UK's C-Roads (InterCor) Pilot was carried out in the South-East of England on a corridor that extends 110km from Greenwich in London to Dover. The route incorporates urban, inter-urban and rural roads that provided a variety of operational environments in which to develop, test and evaluate in-vehicle signage, road works warning and signalized intersection services.

The pilot was implemented with both ITS-G5 and Cellular communication channels and achieved interoperability across borders with all InterCor partners. Further, hybrid communications were very effective, and the cellular system was able to support all services piloted.

The following Day-1 services and related use cases in the UK that were evaluated are summarized in this report are listed in Table 31.

Table 31 - Day-1 Services Use Cases in the UK

Day-1 service	Use case
Road Works Warning (RWW)	Lane Closure (and other restrictions)
In-Vehicle Signage (IVS)	Dynamic Speed Limit Information
	Embedded VMS "Free Text"
	Dynamic Lane Management
Signalized Intersection (SI)	Green Light Optimal Speed Advisory (GLOSA)d
Probe Vehicle Data (PVD)[3]	Traffic Data Collection[4]

The UK evaluation team focused on high quality user acceptance and gathered extensive subjective impacts from 58 drivers on how the services improved their driving experience and provided useful information that prepared them for their drive ahead.

The pilot evaluation teams were set up so drivers' behavior could be observed with and without C-ITS warnings, with the intention of comparing the difference between drivers in control (no C-ITS) and drivers in treatment (with notifications). However, with low driver numbers and the influence of existing ITS signage drawing statistically significant conclusions was challenging. (To offset those effects, analysis was supplemented by the following:

- Use of subjective impact from user surveys and interviews;
- Individual driver objective measurements based on subjective feedback to observe if following a notification, the driver showed any speed adaptation

[3] Not currently part of the C-Roads WG3 Use Case Evaluation List.
[4] For ITS-G5 only – technical evaluation only

4.3. The Netherlands

The following Day-1 services and related use cases in the Netherlands that were evaluated are summarized in this section are listed in Table 32.

Table 32 - Day-1 Services Use Cases in The Netherlands

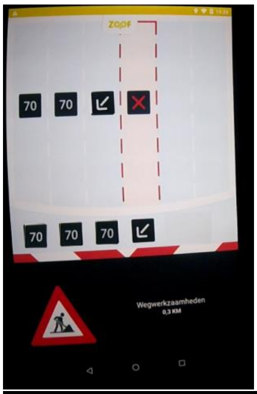
Day-1 service	Use case
Road Works Warning (RWW)	Closure of a lane
In-Vehicle Signage (IVS)	In-Vehicle Signage Dynamic Speed Limit Information
Signalized Intersection (SI)	Green Light Optimal Speed Advisory (GLOSA)d

User acceptance and safety were identified as impact areas to be evaluated for each use cases. Rating the service by gaining the user's response is how user acceptance is measured. User acceptance is key for the fast deployment of C-ITS services and provision of added value to the driver, which is one of the main objectives of these pilots.
The HMI influences driving behavior and ultimately speed leading to a safer or less safe road environment. The hypothesis is that the service could result in lower driving speeds, which has a positive impact on road safety. Traffic efficiency and environment are not measured, because it can only be regarded as a knock-on effect resulting from lower driving speeds. Therefore, the main focus is not on these two impact areas.
Table 33describes the evaluation context of the use cases RWW and IVS.

Table 33 - RWW and IVS – Evaluation's context 1

Location of Test Site(s)	• Hybrid services; motorway A16 in The Netherlands in both directions between Rotterdam and Dordrecht • Cellular only; Flitsmeister app datalogging which is functional in the whole of the Netherlands. For impact evaluation the data from the corridor Rotterdam-Venlo was used, including the motorway connections to Belgium.
Type of Testing	• 14 persons in naturalistic driving tests • 140 persons during 7 nights of controlled testing • For Flitsmeister app: about 500 users driving with the Flitsmeister app (without baseline).
Counterfactual method used	*Alternating (control / treatment group)* During controlled testing participants were requested to drive two trips. One trip in which the baseline measurement (without HMI) was obtained and one trip in which the treatment measurement (with HMI) was obtained. The order was varied between drivers.

Road conditions and factors that might influence driver behaviors (e.g. issues with the road surface).	During a number of the Controlled tests the sunset was taking place. These tests lasted until around midnight. There were no issues regarding road conditions, apart from the planned roadworks. For the Naturalistic tests the road conditions were not recorded.
Presence of speed enforcement systems / specific highways regulations / enforcement activity.	On this route no specific enforcement systems were present. For the Naturalistic tests there is no information about enforcement activities.
Speed of other vehicles in the area (i.e. to gauge if traffic was free-flowing).	During the Controlled tests the participants were driving in free flow conditions due to the (relatively) low traffic volumes during the night. During Naturalistic tests the traffic conditions varied.
External signage (physical traffic signage and signals).	In the A16 study area there are gantries with overhead VMS panels (matrix signals for each lane). These regulate lane use and speed limits and are located approximately 600 meters apart. Although for the Naturalistic group the study area was not confined to the A16 pilot area it can be assumed that the road conditions these participants encountered were similar in terms of traffic management systems and physical road configurations.
Road geometry (such as the presence of any corners, tunnels etc.)	Near Dordrecht a tunnel (Drechttunnel) is present.
Speed limits.	On the entire route there is a fixed speed limit of 100 km/h, for the Naturalistic group the speed limit varied given the services were not confined to the A16 pilot area. Moreover, dynamic speed limits may have been applicable for both the Controlled and Naturalistic group which overrule the fixed speed limit.
Traffic volume.	The Controlled tests were always during night time with low traffic volume. Within the Naturalistic test participants drove in a variety of traffic volumes.
Recorded local weather.	During the Controlled tests there were no adverse weather conditions present. There was no rain reported. For the Naturalistic tests there is no information available concerning weather conditions.
Road management / road works information.	During the Controlled tests roadworks were planned. This included the closing of lanes and/or carriageways, together with a decreased speed limit. For the Naturalistic tests no information is available.

	Within the InterCor project two types of DENMs were supplied, the first type were based on static locations (based on a location and time range) and the second type of DENM's were moving since they were built into vehicles that were involved in the road works. These OBU transmitted the DENM messages.
In-vehicle dashcam footage.	Available, but not used for the evaluation.
Vehicle types involved (HGV / car etc.).	Passenger cars (Renault Clio and Megane)
Total number of vehicles.	• 14 on pilot site A16 (Controlled and Naturalistic) • Around 500 with the Flitsmeister app.
Number of each type of vehicle.	• All passenger cars on pilot site A16 • The Flitsmeister app is generally used in passenger cars but in general the vehicle type is not registered.
Type(s) of OBU.	OBUs with two types of HMI have been used during the Controlled and Naturalistic tests.   The Flitsmeister smartphone app shows in-vehicle signage, road works warnings, hazardous location notifications and time-to-green at specific junctions.

	
Types of test drivers	• For the pilot site A16: • Controlled test drivers supplied by a specialized company, divided randomly over the seven test nights. They had to drive the pilot site twice; once time without HMI and once with HMI (in random/varying order). • Naturalistic test drivers selected from Rijkswaterstaat employees that volunteered and were asked to use the equipped car to travel to and from home. The services and HMI were always active. • For the Flitsmeister app users: traffic information was given to drivers using the app. Data has been collected on a specific corridor only. The app could be downloaded for free.
Was the evaluation impacted by technical issues in respect of the warnings and information provided to drivers; if so please provide details.	In the tunnel section there was no cellular signal available for the OBUs

4.4. NordicWay 2

NordicWay 2 was a joint activity that included four Nordic Countries; Denmark, Finland, Norway and Sweden. It piloted and evaluated a variety of Day-1 and Day-1.5 C-ITS services in Finland, Norway and Sweden. All C-ROADS services were piloted by at least one use case in at least one country under the NordicWay 2 project (see Table 34). However, none of the services were piloted in all three countries. Service provision ecosystems and the aim of each pilot differed from one country to another and from one implementation to another.

Table 34 - Piloted NordicWay 2 use cases and corresponding C-ROADS services. Abbreviations: IVS = in-vehicle signage, PVD = probe vehicle data, CAD = connected and automated driving, CCN = connected and cooperative navigation.

	C-ROADS SERVICES	**NORDICWAY 2 USE CASES**	**FI**	**NO**	**SE**
Day-1 services	IVS	In-vehicle speed limit	x	x	-
	Hazardous location notifications (HLN)	Weather and road condition	x	x	-
		Slow or stationary vehicle	x	x	-
		Emergency vehicle approaching	-	-	x
		Traffic ahead warning	x	x	-
		Emergency brake light	-	x	-
		Cooperative collision warning	-	x	-
	Road works warning (RWW)	Road and lane closure	x	x	-
		Mobile roadworks	-	x	x
	Signalized intersections (SI)	Signal violation / intersection safety	-	x	-
		Time to green	-	-	x
		Green light optimal speed advisory (GLOSA)	-	x	x
		Traffic signal priority request	-	-	x
	PVD	Single vehicle data	x	x	-
Day-1.5 services	Traffic management	Traffic information & smart routing	x	x	-
		On-street parking information and management	-	x	-
		Information on alternative fuel vehicle fueling & charging stations	-	x	-
	CAD	Data collection for mapping of infrastructure readiness	-	x	-
	CCN in and out of the city	Dynamic access control of designated infrastructure	-	-	x
	Dynamically controlled zones	Dynamic environmental zone	-	-	x

The NordicWay 2 evaluation covered all the impact areas addressed in the C-ROADS Evaluation and Assessment Plan (see Table 35). It listed high-level research questions and indicators, or key performance indicators (KPIs) related to them. The evaluations included the quality of service in terms of technical performance, service ecosystems, user acceptance, socioeconomic impacts and the feasibility of C-ITS service provision for the Nordic countries. The evaluations were made as a joint effort by the evaluation partners of all four countries. For most aspects, the evaluation was use case agnostic. Therefore the results in this report are also summarized as a whole. For full methodology, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

Table 35 - C-ROADS evaluation areas and their coverage and priority in NordicWay 2

EVALUATION AREA	PRIORITY*
User Acceptance	++
Safety	++
Traffic efficiency	+
Environment	+
Organizational	++
Socio-economy	++
Quality of service	++

*Rating of priority:

'++': 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.

4.5. Czech Republic

In the Czech Republic, testing and evaluation was divided into several pilot sites (DT1 - DT5) in different areas. These areas included both urban and interurban areas, where the use-cases shown in Table 36 were tested and subsequently evaluated. The evaluation took place on sections of the D1, D11, D5 and D52 highway, in the ring road and in the city of Brno, at two railway crossings and in the cities of Ostrava and Plzeň with the help of city transport companies.

Table 36 - Day-1 Services and Use-cases in the Czech Republic

Day-1 service	Use case
Road Works Warning (RWW)	Lane Closure (LC)
Hazardous Locations Notification (HLN)	Emergency Vehicle in Intervention (EVA)
	Public Transport Vehicle Crossing (PTVC)
	Public Transport Vehicle at Stop (PTVS)
	Railway Level Crossing (RLX)
	Stationary Vehicle (SV)
	Slow Vehicle
Signalized Intersections (SI)	Intersection Signal Violation (ISV)

The evaluation of the implemented services focused primarily on obtaining information from 100 tested drivers using questionnaires before and after the ride, but also on collecting data on individual drivers' rides. Data from evaluation runs were used for impact assessment focused on the safety impact of C-ITS. The questionnaires were used to assess the user's opinion and how the service was accepted in the User acceptance. The results of the questionnaire were then used in the functional evaluation.

4.6. Hungary

User acceptance, safety and traffic efficiency were identified as impact areas to be evaluated in the use cases. User acceptance – including priori acceptability - is key for the fast deployment of C-ITS services and provision of added value to the driver, which is one of the main objectives of these pilots.

The HMI influences driving behavior and ultimately speed leading to a safer or less safe road environment. The hypothesis is that the service could result in lower driving speeds, which has a positive impact on road safety. Traffic efficiency and environment are measured and evaluated too.

The Day 1 and 2 data aggregation services have been simulated and evaluated to get an insight of the V2X network channel's load. No on-road tests were undertaken.

The impact areas, research questions addressed and the KPIs used were specified in the subchapter for GLOSA evaluation.

These Day-1 services and related use cases in Hungary are described and evaluated upon in this report.

Table 37 - Implemented Day 1 (or 2) services in Hungary

Day-1 (or 2) service	Use case
Signal Phase and Timing Information (SI)	Green Light Optimized Speed Advice (GLOSA)
Data aggregation services	Simple data collection, Probe Vehicle Data -Vehicle Data Collection (PVD-VDC), perception sharing

4.7. Slovenia

Slovenia's DARS Traffic Plus Pilot was carried out on a professional driving simulator with eye tracking capabilities (SmartEye) in the autumn of 2020. The pilot evaluated selected Hazardous Locations Notification use cases, which are presented in the Day-1 Services Use Cases table (see Table 38). Within this use cases, User acceptance and Safety were evaluated as impact areas, while additional conclusions for Traffic efficiency were assumed based on User acceptance and Safety results.
For the Slovenian pilot, the Hybrid ITS-G5 and Mobile application services were used, and the pilot testing was done on a mobile network. Mobile applications were freely available on both the Google Play and Apple App Store platforms. The main aim of the pilot was to evaluate possible HMI influences on driving behavior. The research premise was that well-informed and accurately informed drivers are safe drivers and drive with fewer driving violations. Special attention was given to the negative interference aspects of driving while using the application. Additionally, the pilot evaluated HMI interface features and explored possible options for the most effective and usable presentation of notifications.
The following Day-1 services and related use cases in Slovenia are summarized below.

Table 38 - Day-1 Services Use Cases in Slovenia

Day-1 service	Use case
Hazardous Locations Notification (HLN)	Accident Zone (AZ)
	Traffic Jam Ahead (HLN – TJA)
	Weather Condition Warning (HLN – WCW)
	Obstacle on the Road (HLN – OR)

The pilot evaluation study design and procedure was as follows: All drivers performed four driving sessions (driving scenarios). Validated and non-validated questionnaires with concluding interviews were used to evaluate the results. A professional driving simulator environment (used officially by the DARS company) was used in combination with eye tracking and video recording for detailed driving analysis. Each evaluation session lasted approximately 90 minutes. Of the 39 drivers who participated in the evaluation pilot, 33 successfully completed all the sessions. Participation was voluntary and adhered to the highest ethical standards in accordance with the research practice by the University of Ljubljana.
Four driving scenarios were designed to cover all the different topics of the evaluation pilot.

- Scenario 0 was designed to get drivers acquainted with the driving simulator and to gain a sense of driving in a simulator.
- In Scenario 1, drivers drove a car on a predetermined route. While driving, they encountered different traffic events (traffic jam, obstacle on the road, accident, weather condition).
- In Scenario 2, drivers drove a car on the same predetermined route. While driving, they encountered different traffic events and additionally used the DARS Traffic Plus application for event reporting and receiving notifications.

- In Scenario 3, drivers drove a car while using the DARS Traffic Plus application for event reporting and receiving notifications. The main aim of this scenario was to test the most suitable form of providing traffic event notifications.

In all scenarios, the drivers were advised to comply with all driving regulations and speed limitations.
For Scenarios 1 and 2 counterbalancing was undertaken to minimize the influence of the scenario sequence on the results (minimize the learnability factor). Half of the drivers first drove without the help of a mobile application, while the other half drove first with the help of a mobile application.

Figure 4 - Driving simulator test environment

In the pilot evaluation, we used a professional driving simulator owned and developed by the Slovenian company PannaPlus (see Figure 4). The driving simulator used in the evaluation was used in multiple simulator driving evaluations for Slovenian motorway operator DARS and the Ministry of Infrastructure. The Simulator was equipped with the Smart Eye tracking system, especially suited for driving behavior research. The driving route used in the evaluation consisted of a mixture of highways, local and trunk roads. The simulator algorithm generates surrounding traffic to provide a realistic and constant environment for each of the use cases.
During the pilot evaluation, the environment conditions were controlled. Air temperature, lighting, noise volume were maintained to a consistent level.

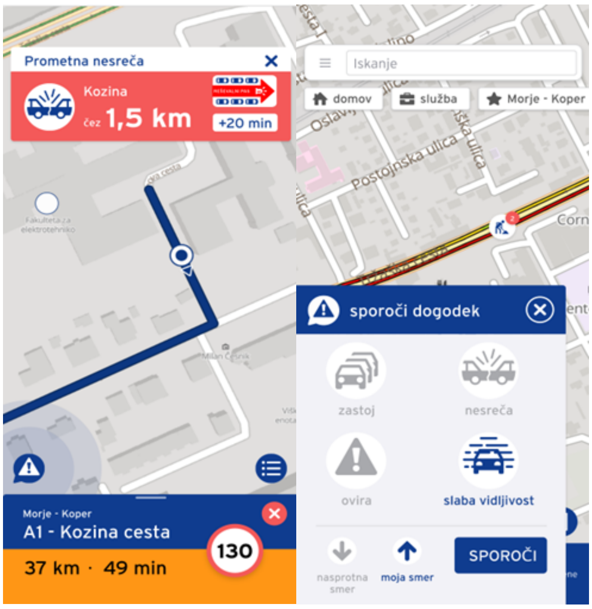


Figure 5 - The DARS Traffic Plus application (left screen: receiving HLN events notifications, right screen: reporting HLN events)

The DARS Traffic Plus application (see Figure 5) supported Slovenia's selected hazardous location notification Day-1 use cases (i.e. Accident Zone, Traffic Jam Ahead, Weather Condition Warning, and Obstacle on the Road). Drivers had the ability to report detected HLN use cases on the road or receive notifications about the HLN use cases ahead of them on the road.

Participants in the pilot evaluation were selected to represent a representative group of real-life drivers. Thirty-nine (39) drivers altogether participated in the evaluation, of which 20 were female and 19 were male. All of the participants had signed informed consent and had the option to stop the evaluation session at any time during the evaluation. Thirty-three (33) drivers successfully completed the evaluation; of those, 16 were female and 17 were male. Six drivers did not complete the evaluation due to simulator sickness effects.

All drivers were healthy, with adequate vision for driving (including glasses and contact lenses) and a valid driving license. The mean age value for drivers (n = 33) was 35.61 years (SD 10.69 years), with a minimum age of 22 and a maximum age of 62 years. The majority of the drives had secondary education or university degrees in engineering or social sciences. 57.6 % of drivers reportedly use their car's hands-free phone system, while 15.2 % of drivers prefer to have the phone held in hand. The most used mobile application in the traffic domain was Google Maps, with 97.6% of the drivers. The DARS Traffic Plus application was used by 27.3% of the drivers. Next were in-car-built navigation devices, with 21.2% of the users. Only one driver was a professional driver; the other drivers were non-professional drivers. On a yearly basis, 30.3% of drivers complete less than 10,000 km, 39.4% complete between 10,000 and 20,000 km, and 30.3% complete more than 20,000 km. 72.7% of drivers consider themselves to be dynamic drivers who mostly drive within speed limits (84.7%). 69.7% of the drivers adapt braking to the current traffic conditions and perform 72.7% of the trips alone in the car without any passengers. The most used road category is the motorway, with 57.6 percent. They report that other drivers have little influence on their driving (72.7%) and get slightly irritated (81.8%) by dangerous situations on the road. For daily migration, 39.4% of drivers check traffic conditions before entering their car, 18.2% check them before driving, and an additional 18.2% check them while driving. Their main source of traffic information is mobile applications. Another 21.3% of drivers look for information on web portals, while 39.4% do not look for daily driving information. In the case of one-time migrations, drivers check the traffic information 75.8% of the time before entering the car.

4.8. Italy

In Italy, evaluation activities were developed based on an ex-ante approach, on modelling activities and on an ex-post assessment. The study focused on C-ITS services as a stand-alone system and also in a joined implementation with the systems Truck Platoon (TP) and Highway Chauffeur (HC). The opportunity to test these additional services was permitted due to the involvement of vehicle manufacturers IVECO and Centro Ricerche Fiat within C-Roads Italy. The impact areas investigated were Safety, Traffic Efficiency and Environment. All the evaluated Services and their respective Use Case are listed in Table 39. The impact areas investigated were Safety, Traffic Efficiency and Environment. All the details concerning the evaluation and assessment activities in Italy can be accessed in [RD.5]. A synthesis of these activities is reported hereby.

Table 39 - Day-1 Services Use Cases in Italy

Day-1 service	Use case
Road Works Warning (RWW)	Closure of a lane (LC)
In-Vehicle Signage (IVS)	Dynamic Speed Limit Information (DSLI)
Hazardous Location Notification (HLN)	Stationary Vehicle (SV)
	Traffic Jam Ahead (TJA)
	Weather Condition Warning (WCW)
Signalized Intersection (SI)	Green Light Optimal Speed Advisory (GLOSA)

The ex-ante analysis developed a literature review, providing a synthesis and a critical analysis of results and studies presented by scientific papers and projects.
The modelling activities were developed using the tool PTV Vissim, involving the drafting of specific script to simulate the services/use-cases considered (i.e. C-ITS, TP, HC). The ex-ante analysis allowed results for the impact assessment and provided useful indications to inform the design of the field tests at the Pilot sites.
The ex-post evaluation was carried out collecting data from vehicles driving with and without C-ITS warnings. The driving activities were of interest to the motorway managed by the road operators involved in the project: A22-Autostrada del Brennero, CAV-Concessioni Autostradali Venete, Autovie Venete. Data collected were elaborated and processed so to investigate the changes in driving behaviors and, based on these changes, the impact the C-ITS Use Cases simulated.

Concerning the evaluation and assessment of the expected KPIs on mobility, the following general approach was adopted, fine-tuned with respect to the individual Use Case considered.

$$\text{KPIs} = \text{REACTION} \times \text{EFFECTIVENESS} \times \text{TARGET}$$

- **Reaction**: it translates how much the drivers are actually reacting once informed by the C-ITS service. Its quantification is assessed based on the field tests developed.
- **Effectiveness**: it represents how much the recorded reaction is effective towards the objective considered (for example accident reduction). Its quantification is assessed based on the field tests developed as well as on literature references and expert judgment.
- **Target**: it is the quantification of the addressed element (i.e. number of accidents, hours spent in traffic congestion, tons of CO_2 emitted, …).

Impacts described by these KPIs can be considered as a direct or indirect effect of the implementation of a Use Case.
A direct effect is recorded for those impact areas specifically targeted by a Use Case while an indirect effect can be defined as the consequence of an impact of a Use Case on safety.
Whenever a direct impact on safety is recorded (i.e. a road accident is avoided), positive indirect effects are recorded also for traffic efficiency (avoided congestion) and for environment (reduced fuel consumptions and less CO_2 emissions).
Indirect impacts on traffic efficiency are assessed considering that a road accident is causing the closure of the carriageway for a time period (i.e. 2 hours). Adopting a model based on input-output diagrams theory, the quantification of the possible delays that the vehicles impacted are suffering is made possible. These delays are supposed to be avoided by the deployment of the Use Cases.
The reduced congestion leads also to environmental benefits (i.e. reduced fuel consumptions and CO_2 emissions). Adopting consumptions and emissions factors, the estimation of environmental impacts can be provided.
Details concerning the assessment of the single Use Cases are presented in the dedicated chapters. Common hypothesis applied to all the impact areas are the following:

- A market penetration equal to 100% is supposed; i.e. all the vehicles are equipped with C-ITS services deploying the Use Case considered.
- The analysis considers the deployment of the Use Cases on the Italian highway network; i.e. data about traffic and safety are referred to this context.

The final step of the evaluation activity in Italy is the assessment of Socioeconomic impacts. These were estimated through the attribution of a monetary cost to the impacts for the KPIs considered.

4.9. Belgium/Flanders

The main objective of the C-Roads Flemish pilot was to operate and assess the deployment of cloud based 'virtual infrastructure' for an effective deployment of C- ITS services connecting road users with the Traffic Management Centre (TMC) while allowing the TMC to directly interact with end users. The pilot also provided an opportunity to upgrade Traffic Information Services and Traffic Management Services.
Existing cellular based 3G-4G/LTE mobile communication networks were used in combination with the HERE Location Cloud and the local Traffic Management Centre's applications.
Use-cases implemented are listed in Table 40.

Table 40 - Day-1 Services Use Cases in Belgium

Day-1 service	Use case
Road Works Warning (RWW)	Road Works
In-Vehicle Signage (IVS)	Dynamic Speed Limit Information (DSLI)*
Hazardous Location Notification (HLN)	Temporarily slippery road
	Reduced visibility
	Stationary Vehicle
	Accident area
	Obstacle on the road
	Traffic jam ahead warning

The main goal was to have approximately 1000 test-users. The test period was initially scheduled from March/April 2020 until the end of the year. However, due to COVID-19 restrictions, the test-period was shortened and held between September and November 2020.
Before starting the large-scale pilot many smaller validation tests or smaller tests were held, as follows:

1. May-July 2019: Pre-testing with simulated (fictive) message to test the (technical) functionality of the system
2. August-September 2019: Tests with live messages
3. October-November 2019: pre-piloting no. 1 with 10 test-users focused on final technical aspects before launch of large-scale pilot
4. August-September 2020: pre-piloting no. 2 with 10 test users focused on pilot procedures (registration, survey, etc.)
5. September-November 2020: Large-scale pilot test.

Different actions were planned to recruit 1000 users:

- A recruitment bureau was contacted and the decision was made to pay our users 20 euros for their contribution to the test. The test-drivers received the fee only when completing the full test-period, answering two surveys and conduct at least 10 trips. All these activities were monitored. 17,500 possible candidates (with drivers' license) were contacted by the recruitment bureau twice.

- Tractebel did an internal mailing within the Urban department to participate in the pilot (around 500 users).
- E-mail campaign by ITS Belgium with a total of 3704 recipients wherefrom 836 people opened the subscription link.

In total we had 636 persons that had responded and installed the app. Only 480 respondents completed the full pilot which means that they also filled in both surveys.

The research activities focused on the functional evaluation and the user acceptance.

4.10. Germany

Germany as a Member State will contribute to the C-Roads cooperation with findings from the implementation and operation of seven different C-ITS use-cases, which were deployed in two different pilot sites and harmonized by the Federal Highway Research Institute (BASt).

The national action promotes the future rollout/larger scale deployment of C-ITS in the whole of Germany by deploying new and extending already existing C-ITS services. The following goals were achieved in this project:

- provided a deployment pattern for the rollout of these C-ITS services in Germany according to EU regulations and standards and in line with the recommendations/outputs of the "C-ITS platform"
- demonstrated of long-term viability and scalability of C-ITS (in terms of technology, financial sustainability, governance) as well as in conjunction with legacy systems
- encouraged the German automotive industry to equip their cars with appropriate devices and thus stimulation of end-users to buy V2X-enabled cars to benefit from the services

Building upon the experience of previous C-ITS projects and fundamental research studies, the evaluation focus of the C-Roads Germany project in terms of evaluation was set on two studies for the services RWW and GLOSA.

Table 41 - Use-cases evaluated at different pilot sites in Germany

Use-case	Pilot Hessen	Pilot Lower Saxony	Evaluation Study
RWW	X	---	X
PVD	X	X	---
EVA	X	---	---
MVW	X	X	---
IVS	---	X	---
SWD	X	---	---
TJW	X	---	---
GLOSA	X	---	X

4.11. Austria

Overall, the evaluation and impact assessment of C-ITS services in Austria takes places in a very dynamic environment for connected vehicles, because in parallel to the C-Roads Austria specific evaluation, the Austrian motorway operator ASFINAG has started the full operational roll-out of C-ITS on his network - and on some of the segments involved. Traffic related events are already coded and sent out via C-ITS stations to the equipped series vehicles. Here, the working assumption for this aspect is that the impacts for these series vehicles in regular driving and travels are similar to the effects found in the evaluation and assessment methods, documented in this report.

During the field tests, it is possible to measure or calculate different sets of parameters that can reveal a different behavior of the driver because of the reception of additional information via C-ITS services.

For the Austrian results within this report, only User Behavior of single drivers and vehicles are measured, as it can be assumed that the overall impact on the traffic flow on specific motorway segments of the road during a field test would be negligible – at least within this first stage of C-ITS deployment, where the number of drivers involved is low.

These measurements of changes in User Behavior, thanks to the use of Day 1 C-ITS, provide a first indication of the impacts for the drivers of single vehicles, at a field test scale, of the C-Roads implementation. The C-ITS related additional impacts on the overall traffic will be shown at a later point in time when the percentage of connected and fully informed vehicles in the overall traffic will be higher. The Use Cases considered are listed in

Table 42 - Day-1 Services Use Cases in Austria

Day-1 service	Use case
Road Works Warning (RWW)	Road Works
In-Vehicle Signage (IVS)	Dynamic Speed Limit Information (DSLI)

For this study, the following impact areas have been taken into consideration:

- Traffic Efficiency
- Road Safety
- Environmental
- User Acceptance

The most prominent area of evaluation was the User Acceptance of C-ITS Services. This topic is also related to the questionnaires, filled out by the drivers, to judge the results and influence of C-ITS-messages from a user perspective. As an additional tool in the method, the questionnaires of the test drivers have also been combined with the data parameters collected during their test drives in the C-ITS mobile lab. This combination of data and questionnaires provides additional evidence as well as insights of C-ITS services delivered in C-Roads on public roads.

Table 43 - Impact Areas considered in Austria

Impact Areas			
Traffic Efficiency	Safety	Environment	User Acceptance
++	++	++	+++

The report results from contributions of the Austrian Pilot, based on output obtained during ITS-deployment as well as during evaluation and impact assessment tasks in connection to C-ITS-Services. Those have been carried out by C-Roads-related activities and others during the last 6 years.

4.12. France

France has worked on different use cases from different services. Results produced by France during C-Roads project are listed in table x. The table indicates the results that are summarized in this report which they mainly concern impact of C-ITS services on User Acceptance, Safety, Traffic Efficiency, Environment, Socio-Economical, and sanitary areas. For more details on other results and methodology please refer to the French C-Roads reports indicated in the table.

Table 44 - Impact Areas considered in France

Impact area	Use case	Reference to French report	Summarized in this report	Description
Traffic and Environment	GLOSA and Dynamic Speed Limit	C-Roads_2.3.7.5 - Methodology and tools to assess the services associated to C-ITS in traffic network C-Roads_2.3.7.6 - Experimentation and simulations design of the C-ROADS services C-Roads_2.3.7.7 - Performance analysis and recommendations on use cases C2 and G1	Yes	*Studies of the impact on Road traffic (fluidity, congestion, consumption, etc.) for different situations, real and simulated (scaling up)*
Social and economic	C-ITS as a bundle	C-Roads_2.3.6.1 – Social an economic Impacts C-Roads_2.3.6.2 – Social an economic Impacts : Results C-Roads_2.3.6.3 – Business model – Methodology C-Roads_2.3.6.4 – Business model – Results	Yes	*Social and economic impact studies (effects on road safety, environment, energy consumption, mobility...) consolidated by a benefit-cost analysis of C-ITS services*

User acceptance	Road operators use cases	C-Roads_2.3.5.2 - Ergonomics assessment of the embedded HMI in road operator vehicles C-Roads_2.3.5.6.b – User acceptance for Coopits services : Pre test methodology	Yes	*Assess the user acceptance of the new C-ITS services proposed to users and road operators' agents and the impacts on the organization of the road operator activity*
Safety	Level crossing	C-Roads_2.3.4.1b – Methodology / Tools / Experimentation for level crossing use cases (K1, K2, K3 et B1b) C_Roads_2.3.4.2b – Analysis of the attention demand among french road operators during interaction tasks with the traffic reporting application	Yes	*Evaluation of the impacts of the HMI terminal device* *supporting C-ITS services on distraction and user behavior*
Sanitary	C-ITS as a bundle	C-Roads_2.3.2.2 b – Methodology for assessment of RF electromagnetic exposure of P2V device in the I3 use case (workers in the field) C-Roads_2.3.2.3 b - Results and RF electromagnetic exposure assessment of P2V device in the I3 use case (workers in the field)	Yes	*State of the art and the regulations - Electromagnetic field exposure - Evaluating the health risks and making recommendations if necessary*
Regulatory	Level corssing, Accident on the road, In-Vehicle Signaling.	C-Roads_2.3.8.3 Legal Impacts - Case 1: Level crossing use case : Road Side Unit	No	*Studies of the impacts of the deployment of C-ITS services on the legal*

		(RSU) failure - fatal accident C-Roads_2.3.8.4 Legal Impacts - Case 2: Accident not reported by safety staff or traffic management center C-Roads_2.3.8.5 Legal Impacts - Case 3: Contradictory road signs: Variable Message Signage (VMS) / C-ITS C-Roads_2.3.8.6 Legal Impacts - Case 4: Non-intervention of a road operator patrol: over-accident		*responsibilities of the actors*
Functional and technical evaluation	RWW, GLOSA, Hazardous Events	C-Roads_2.3.3.2 – Coopits Smartphone Technical Evaluation	No	*Functional and technical evaluation of the C-ITS system to assess the ability of the communication* *infrastructure to meet the functional specifications of the provided services (use cases)*

Presented results are obtained from a combination of real tests, driving simulators, and digital traffic and wireless communication systems simulators.

5. Road Works Warning

5.1. Safety

This section provides a list of the road works warning use-cases evaluated from a safety perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Italy, Spain, NW2, UK, Austria, Portugal, Germany and the Czech Republic.

5.1.1. Spain

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure
- RWW-RC: Roadworks Warning - Road Closure
- RWW-RM: Roadworks Warning - Roadworks Mobile

Evaluation method

Depending on the use case (LC, RC or RM), the mentioned impact investigation safety area led to different questions/sub-questions:
Questions about what the Pilot is investigating are presented hereunder.
Main Research Question:

- Is safety affected by changes in driver behavior due to RWW use case?

Sub Research Questions:

- How does the RWW service affect the number of accidents in the use case?
- How does the RWW service affect the accidents severity in the use case?
- How does the RWW affect to the (safety) conduction in the use case?
- How does the RWW service affect the sense of security of drivers/passengers and the workforce in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Data coming from vehicles equipped with C-ITS Services was collected through different data sources, including CAN Bus data, GPS, On Board Units, ITS Stations and/or traffic monitoring systems on the road.
In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data, as well as the .pcap files, were collected, noting that not all the sub-pilots collected the same data:

- Time reference. Source: GPS (ms since 01/01/1970)
- Vehicle speed. Source: Can Bus data or GPS data (km/h)
- Engine status. Source: Can Bus
- Acceleration/Deceleration. Source: Can Bus data, GPS data or accelerometer (m/s2)
- Vehicle position (latitude, longitude, altitude, heading). Source: GPS data
- Number of GNSS available satellites. Source: GPS data
- Horizontal dilution of precision (HDOP). Source: GPS data
- Accumulated distance. Source: Can Bus data
- Angle of the steering wheel. Source: Can Bus data

- Brake system activated. Source: Can Bus data
- Accumulated fuel consumption. Source: Can Bus data
- Timestamp of the notification to HMI (ms since 01/01/1970)
- Event Detected timestamp (repetition). Source: DENM timestamp (ms since 01/01/1970)
- Event Detected timestamp (new/update/end). Source: DENM Detection time (ms since 01/01/1970)
- Event Reference timestamp (new/update/end). Source: DENM Reference time (ms since 01/01/1970)
- Source of the event. Source: DENM (station type - OBU/RSU/HMI-)
- Vehicle identifier. Source: DENM (Station ID)
- Event identifier. Source: DENM (Sequence number)
- Type of event. Source: DENM (Cause code, sub cause code)
- Event position. Source: DENM (Event latitude, Event longitude, Event latitude)
- Event distance. Source: DENM (Distance)
- Event speed limit. Source: DENM (speedLimit)
- Event heading. Source: DENM (semiMajorOrientation)
- Destination of the event. Source: DENM (Vehicle Role)
- Event Detected timestamp. Source: IVIM timestamp (ms since 01/01/1970)
- Source of the event. Source: IVIM (station type - OBU/RSU/HMI-)
- Vehicle identifier. Source: IVIM (Station ID)
- CategoryCode. Source: IVIM (signal identification)
- Nature. Source: IVIM (signal identification)
- ExtraText field. Source IVIM.

The evaluation of 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 (baseline).
Depending on the sub-pilot, different approaches have been deployed to establish the baseline. Refer to the C-Roads Spain Final Evaluation Report (M42)_v1.1 [RD.3] to have more details.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS RWW v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of Key Performance Indicators (KPIs) considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation were obtained. The KPIs that were calculated in each of the sub-pilots are presented in Table 1, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in the table below, the results presented with an asterisk (*) are extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 45 - RWW Safety. Spain.

KPI	Use Case	Pilot	Summary
Change in speed adaptation	RC	Madrid	10.41%
	LC	Andalusian - Mediterranean	-56.6%
Change in speed standard deviation	RC	Madrid	-16.67%
	LC	Andalusian - Mediterranean	118.5%
Change in average speed	LC	Andalusian - Mediterranean	10.1%
		Catalan -Mediterranean	-3.0% (-1.4%*)
		DGT 3.0 SATELISE	4%
		DGT 3.0 SISCOGA	0%
	RC	SISCOGA Extended	Naturalistic study: -6%
Change in instantaneous accelerations	RC	Madrid	0 %
	LC	Andalusian - Mediterranean	19.1%
		DGT 3.0 SATELISE	10%
Change in instantaneous decelerations	RC	Madrid	-33.33%
	LC	Andalusian - Mediterranean	10.3%
		DGT 3.0 SATELISE	-22%
		DGT 3.0 SISCOGA	-49%
Change in maximum steering angle	RC	Madrid	-20.29%
Lane change point (point where the vehicle performs the lane change maneuver)	RC	Madrid	912.50 m
Number of lane changes	RC	Madrid	-37.85%
	LC	Catalan -Mediterranean	-15.1*%
Avg speed from reception of the C-ITS message until road works location	LC	Catalan -Mediterranean	94km/h*

5.1.2. UK

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

In developing the objective impact methodology within InterCor, the following key indicators were considered:

- Change in speed as per Table 46below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 46 - RWW safety evaluation methodology

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1. Do drivers slow at an earlier point after receiving road works warnings? 2. Do drivers drive in a less erratic way after receiving RWW? 3. Do the drivers comply with the advice given by the service?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews

Early results from the lead InterCor partner showed the change in behavior between control and treatment groups during controlled testing was extremely difficult to measure / see in the data. It was therefore decided in the UK and in another countries yet to evaluate objective impact, to further adapt the methodology to mitigate what was thought to be the following causes:

- Small test fleet sizes (UK had a slightly smaller fleet than the Dutch InterCor partner);
- Still not enough event data to see the relatively small change in behavior compared to the control group of drivers;
- The effect of existing ITS signage on the behavior of the control fleet was potentially larger than anticipated; as a result control groups were not a true neutral behavior due to the presence of existing ITS message signs directly in the driver's eyeline (gantry or roadside message signs) and still influencing their behavior, thereby lessoning the impact of the treatment group (with C-ITS warnings enabled).

This was partially mitigated by the following additional analyses given the time constraints of the evaluation and reporting deadlines on the InterCor Project:

In the UK Pilot[5], use of extensive subjective impact from user surveys and individual interviews and matching of individual driver objective OBU common log data measurements to subjective feedback given enabled targeted reviews of objective data for individual drivers. Based on this approach we then plotted vehicle speed before and after receiving the HMI warning around these specific events to validate the driver subjective data.

Another partner on InterCor simulated a ‘naked roads’ scenario by turning gantry signs off (done in the Belgium pilot with success as results showed a measurable difference between the control and treatment group behaviors for the IVS dynamic speed limit information use case). These can be viewed in the InterCor Milestone 13 report here: https://intercor-project.eu/library/

Data collected

The Data logging service developed in the UK Pilot covered the requirement to log system interactions and in particular message exchange as defined by InterCor logging format for communication and application logs.

A summary of the logging service includes:

- Centralized storage of OBU and HMI message logs,
- Message transaction logs from Unified Interchange Node,
- Message transaction logs for Cellular Service,
- Centralized storage of RSU logs,
- Centralized IVS, RWW and PVD service message transaction logs.

The logging service used Azure log analytics and Azure datalake for persistent storage of data. The log system complied in most respects to InterCor data logging format v0.0.7 and InterCor common application log format v0.5.1.

For the purposes of the evaluation, the OBU was required to log reception and transmission of all C-ITS messages as well as the functionality and behaviors of the OBU/HMI after receiving these C-ITS messages. The OBU logging service captured C-ITS messages during each test run in the form of .pcap files. Once the OBU was rebooted, usually following a test / experiment, the OBU logging service converted these .pcap files into a series of CSV files which were more readable and more pertinent to the evaluation use cases.

The format of these CSV files was derived from the “InterCor Common Application Log format” and the InterCor Common Communication Log Format” which was established as part of the InterCor programme. The InterCor programme specified these formats, as either CSV files or as a relational database, to enable a common approach to the evaluation and support the sharing of data between InterCor partners.

A key design criterion for the data logging service was the ability to trace unique message logs through the system. This would enable end to end message propagation delay calculations to be carried out. It was not possible due to particular limitations in the RSU and the MQTT protocol in the cellular service to support UUID types[6].

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[5] Note: This adapted method was applied to all use cases evaluated by the UK.

[6] Additional CSV logs were specified that were simpler to implement and better able to support the UK evaluation tasks. These were:

Comm-xer log:

Providing identifying details of the OBU (stationid), when the C-ITS message was sent or received, communications type (ITS-G5 or Cellular), message type (CAM, IVI, DENM, SPAT or MAP), message action (received or sent) and an XML representation of the logged C-ITS message.

Co-financed by the Connecting Europe Facility of the European Union

Evaluation results – Field tests

Although the UK RWW objective impact result discussed below is inconclusive in terms of a pure example of objective impact, we have included it as a valid example where we analyzed the in-car data of a specific driver at a specific point in time during a controlled test event (FTE) using the OBU data. Further analysis of contextual factors indicated the actual change in speed was most likely due to other contextual factors or was at best inconclusive. However, given the strong subjective impact results of drivers slowing for roadworks, we believe a larger scale test would reveal elements of speed adaptation that could be directly measured from the vehicle OBU data.

Measuring an objective change in driver behavior is complex and this example illustrates the value of access to contextual data to aid the ability to make the correct conclusions from the data by knowing wider contextual factors in force at the time of the test event, thus avoiding coming to the wrong conclusion or a 'false positive'.

In the example below (see Figure 6), the first warning displayed a distance of 841m to the start of the roadworks. However, it was confirmed from other traffic data that the queueing traffic was about 750m long back towards the event position. Therefore, the driver under test appeared to slowed down to join the queue immediately after the first RWW warning. So, it is difficult to suggest that they changed their behavior as a result of the reaction to the RWW advice and not due to seeing the traffic building ahead.

This is not to say drivers wouldn't have an objective change we can measure, but during this limited RWW test, the data wasn't able to definitively show the changes were all due to the HMI warning itself. It certainly would have alerted drivers to the RWW ahead and this can be set further back if traffic queuing is known to happen to ensure drivers are alert and slowing well before meeting any potential queue that forms due to the RWW event which is a direct safety benefit.

Comm-uper log:

Providing the same information as the Comm-xer log but the C-ITS message logged in Abstract Syntax Notation One (ASN1) format instead of XML.

HMI log:

Providing the status of what services were presented on the HMI and when, the status of the blanking service , and an XML representation of what the HMI displayed.

All these logs were uploaded via cellular communications to the cloud-based data repository / datalake provided by an Azure service

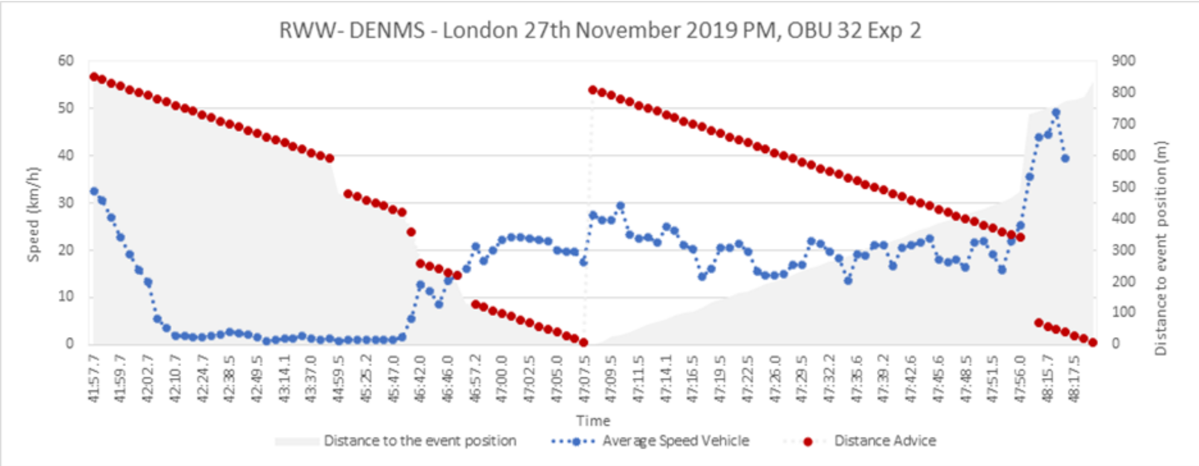

Figure 6 - Comparison of Distance advice and average vehicle speed

A summary of the subjective Impact is provided in section 5.4.2 .

Almost half the participants agreed that RWW service can contribute to improving driver alertness in road works situations, evidenced by 47% of drivers saying they felt more alert to the presence of roadworks with the information appearing in-vehicle.
In addition, 53% felt it was more effective in bringing attention to the driver in the vehicle than signs on the roadside.
29% of the participants reported having reduced their speed after seeing RWW, which may suggest that the technology has the potential to be effective in encouraging speed management if it provided more accurate information.
Reduced speed is likely to have a positive safety impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of the roadworks.

Evaluation results – KPIs on Mobility

Although there were no directly measured safety KPIs, RWW exhibited implied primary benefits from the behavioral changes of the drivers and measured speed adaptation.

5.1.3. Netherlands

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

In developing the objective impact methodology within InterCor, the following key indicators were considered:

- Change in speed as per Table 47 below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 47 - RWW safety evaluation methodology

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1.Do drivers slow at an earlier point after receiving road works warnings? 2.Do drivers drive in a less erratic way after receiving RWW? 3.Do the drivers comply with the advice given by the service?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews

The user groups that have been identified in this evaluation are almost equal to that of the evaluation of the IVS service however no analysis has been done on data from the Flitsmeister smartphone application. Therefore, for the RWW service, the following user groups were originally intended to be available:

- Controlled test drivers
  - Without HMI (baseline)
  - With HMI (treatment)
- Naturalistic test drivers
  - With HMI (treatment)
  - No baseline

For specific testing of the RWW service, controlled test drivers were supplied by a specialized company that were divided randomly over the seven test nights. They had to drive the pilot site twice; the first time without the HMI and followed by with HMI (in random/varying order). During the Controlled tests roadworks were planned. This included the closing of lanes and/or carriageways, together with a decreased speed limit. In the pilot area there were gantries with overhead VMS panels (matrix signals for each lane). These regulate lane use and speed limits and are located approximately 600 meters apart. During a longer period, naturalistic drivers also received RWW messages.

Data collected

Based on the key indicators, mainly speed information was collected, in combination with the context of position, time, in car messages and the context of the situation on the road.

Evaluation results – Field tests

RQ1 Do drivers slow at an earlier point after receiving RWW?

InterCor DENM logdata was analyzed to evaluate the RWW service. Contrary to the IVS service, in which a specific desired behavior (e.g. speed limit) is communicated, DENM messages are meant to warn of (dangerous) traffic situations downstream. Although the specification of the DENM message allows the road operators and service providers to include a max speed, the max speed value was not used for DENM messages. The RWW service depicts a pictogram with the traffic sign for roadworks on the HMI when the drivers approached a situation in which a DENM message was sent out. For the impact analysis only, true positive DENM warnings were considered. This means that messages for traffic driving in the opposite direction, or messages that are not relevant were disregarded.

The Roadworks Warning Service (RWW) became operational only at the last stage of the pilot due to technical challenges. Due to this delay, it was decided that the services would not be tested in baseline mode (without HMI) to retrieve as much data with the HMI as possible. The impact assessment of the RWW service has been conducted in a similar methodology to the IVS service by processing individual speed trajectories that included 30 seconds before the RWW message and 30 after displaying the message. Based on these trajectories, speed distribution graph were generated which were summarized in median speed plots and statistical t-tests.

When analyzing the speed information it became apparent that initially the Controlled drivers were driving in relatively similar speed range (median < 100 km/h). Around 25 seconds before the DENM warning the speed range starts to deviate. This speed range deviation then fluctuated (both decreased and increased) irregularly and continued in the same manner to 30 seconds after the DENM warning.

The mean speed did not change significantly before and after the DENM. Therefore, it cannot be concluded that the DENM was an influential factor in driver speed. However, it was visually notable that the mean speed of the drivers was generally decreasing even before the DENM. This could be caused by the RWW service but could also be caused by the fact that the drivers already saw the upcoming roadwork. Lastly, the VMS gantries could already be signaling warnings or a temporary (lowered) speed limit.

Looking at the results, it became apparent that the Naturalistic drivers were driving at relatively similar speed ranges before and after the DENM warning. However, the mean speeds before and after the RWW warning were significantly different and the mean speed increased after the message was issued (from 91,1 to 91,3 km/h). However, since no baseline situation without HMI was recorded it cannot be determined whether it was solely the HMI or the existing VMS gantry system (or a combination of both) that were the influential factors affecting driver speed.

RQ2 Do drivers drive in a less erratic way after receiving RWW?

For the Controlled drivers, the mean speed did not change significantly, according to the T-test, before and after the RWW message. However, it was visually noticeable that the diversity of the speed of the drivers after the DENM warning increased slightly. This could be caused by the RWW service but could also be caused by the fact that the drivers already saw the upcoming roadworks. Lastly also the VMS gantries could already be signaling warnings or a temporary (lowered) speed limit.

For the Naturalistic drivers, a significant change in speed before and after the messages was observed. However, in this case the mean speed actually increased which is not necessarily the intended effect of in-car information such as the RWW service. It became apparent that the distribution of speeds became narrower which indicated a more stable traffic flow. However due to the lack of a baseline situation it was not possible to test whether the HMI was the significant factor in this.

RQ3 Do the drivers comply with the advice given by the service?

Within the RWW service, no advice was given, only a message to raise the awareness of drivers of the upcoming traffic circumstances. Thus, it cannot be determined whether the drivers comply with the messages.

Evaluation results – KPIs on Mobility

There were no directly measured safety KPIs. Based on the analysis it could not be concluded whether the awareness messages influenced the drivers' speed and therefore it could neither be confirmed or otherwise that drivers were slowing down after receiving an RWW message. The measured differences in speed were not always significant and the context of the influence of VMS gantries or lack of baseline situation made it difficult to value the intended effect of in-car RWW messages.

5.1.4. Czech Republic

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The main consideration was on the following key indicators:

- Change in speed and acceleration as Table 48below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 48 - RWW safety evaluation methodology

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1. Do drivers slow at an earlier point after receiving road works warnings? 2. Do drivers drive in a less erratic way after receiving RWW? 3. Do the drivers comply with the advice given by the service?	• Speed adaptation • Speed standard deviation • Instantaneous acceleration and deceleration • Objective Data linked to User Acceptance Driver Interviews

During the evaluation of the RWW scenario, it turned out that to assess the effect on the driver in real conditions at full operation, based on a comparison of the speed and acceleration of the vehicle was extremely difficult. A relatively small group of drivers were tested in each test, making it difficult to filter out the effect of C-ITS on the change in driver behavior from the change caused by traffic flow and other distractions. For this reason, additional emphasis was placed on the user acceptance part of the evaluation, where drivers expressed their subjective feedback on the execution and display of the report and whether its impact is rather positive or negative.
In assessing the effect of C-ITS on the driver's behavior, the driver's behavior before receiving the message and then his behavior after the message was displayed were taken into account. In this way, it was compared whether the driver changed his behavior after receiving the message and whether they improved their speed to adapt to the situation.

Data collected

The data used for the impact assessment were gathered with a logging device capturing communication between vehicle and infrastructure. One logging device; OBU Comsignia ITS OB4 was placed inside the testing vehicle during the testing phase logging simultaneously real-time communication. Journeys were also logged via a GPS data logger in case of data loss as a backup option. This situation did not occur and the data from the OBU communication was used for reasons of better sampling frequency. An OBD2 can bus logging device was also used to record the data from the vehicle. However, the data from this recording unit was not used due to the incompatibility of the protocols with the car.

Evaluation results – Field tests

In relation to DT1 impact assessment of RWW use-cases two 10 sec time windows were compared in which showed similar behavior of drivers before the RWW message was shown and after. Drivers had similar mean speed, minimum and maximum speed. The difference was in driver's acceleration comparison. Drivers tended to decelerate after the arrival of the RWW message, in contrast to the previous 10 seconds, when drivers accelerated on average. The similar results of driver's speed may be due to the ongoing traffic jam during testing of the RWW scenario, which was caused by lane restrictions due to road works.

In relation to DT3 impact assessment of RWW use-cases, the general tendency of drivers was to decelerate after the RWW message notification (-0.17 m/s^2). The mean speed after the RWW message differs by approximately 10 km/h, the drivers had lower mean maximum (122.02 Km/h vs 117.05 Km/h) and minimum speed (108.10 Km/h vs 94.14 Km/h). The speed dispersion turned out to be greater after receiving the DENM message, which showed different reactions of drivers. Acceleration comparison showed similar mean values around 0, but greater variance of acceleration values after receiving the RWW message, more centered on negative values, i.e., on the deceleration.

5.1.5. Germany

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The assessment of safety impacts was one of the steps in a wider assessment context of the economic viability of the Road Works Warning service. The safety impact assessment was built on an analysis of the impact scope and impact magnitude.

- The scoping step has analyzed the (three) most frequent accident patterns when approaching (short term) road works sites. These patterns comprise collisions with road works safety trailers themselves, collisions in merging and weaving sections upstream before lanes will be closed and even more upstream rear-end collisions. The analysis has confirmed that short term road works are one of the riskiest road environments. There are approximately 100 accidents per year related to short term road works on motorways in the Federal State of Hessen alone. Scaled up to include all Germany motorways the number of related accidents amounts to approximately 800 per year.
- The safety impact originates from earlier and more explicit warning. The evaluation has not performed own data logging and measurements. It took advantage of earlier evaluation studies performed in large scale Field Operational Tests in Germany (partly as contribution to European C-ITS FOTs).
- Earlier and more explicit warnings translate into changes in speed and acceleration while subjective impact data from user surveys on the usefulness of the warning have complemented the findings. Main figures introduced to the assessment are the potential of a 30% reduction of casualties and the statement that two thirds of the users perceive RWW as a service enhancing the road safety.

Data collected

As described, the data collected did not take place in the C-Roads pilot, rather existing data was re-examined and assessed.

Evaluation results – Field tests

The safety impact assessment was embedded in the wider scope of assessing the economic viability, taking likely market penetration patterns and hybrid communication approaches. As an example, the safety impacts for 2025 are estimated to be approximately €87.5 M per year. More than 90% of the benefits can be attributed to reducing personal damage, with 5% related to property damage only and nearly 5% due to reduction of accident caused congestion. The safety impacts have contributed strongly to the positive overall assessment results of viable benefit-cost results already from the very beginning of the deployment phase.

5.1.6. Italy

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The field tests were carried out on the A28 freeway between Conegliano and Godega di Sant'Urbano, which has two lanes of traffic and an emergency lane. The behaviour of both light and heavy vehicles was analysed when approaching real road worksites where the slow lane (on the right) was closed, with the consequent need for vehicles to move to the fast lane to pass through the worksite and, if necessary, to slow down in order to comply with the gradually decreasing speed limits on entering the worksite.
The tests took place in two dedicated daily sessions: 11 and 25 November 2021; a total of 25 transits were simulated and monitored. The vehicles involved travelled the affected section several times, along which they encountered construction sites in positions not known in advance.
In some passages the C-ITS message receiving devices were switched off (C-ITS OFF): the driver could notice the presence of the construction site just downstream only through the fixed construction site signs. In other passages the C-ITS message receiving devices were switched on (C-ITS ON): drivers were thus informed in advance of the presence of the construction site, of the need to change lane and of the reduced speed limits in the vicinity of the construction site.

Data collected

The analysis of vehicle behavior in the presence of road construction sites was differentiated by heavy vehicles and light vehicles; the data collected were also divided into two groups: C-ITS ON and C-ITS OFF.
The field test indicator KPIs calculated for each passage are as follows:

- lane change: start and end point of lane change [m], start and end time of lane change [time], extent [m] and duration [sec] of lane change, maximum steering angle during lane change [rad]
- slowdown: whether or not the slowdown took place [yes/no], start and end point of the slowdown [m], start and end time of the slowdown [time], extent [m] and duration [sec] of the slowdown, speed before the start and at the end of the slowdown [km/h], absolute speed change [km/h] and percentage [%], average deceleration [m/s^2], standard deviation of instantaneous decelerations [m/s^2] and maximum instantaneous deceleration [m/s^2]
- braking: (brake pedal pressure phase): braking or not [yes/no], braking start and end point [m], braking start and end time [time], braking extension [m] and duration [sec], maximum braking torque [Nm]
- speed adaptation:
  - punctual speed [km/h] at the following sections (as well as average speed [km/h] between successive pairs of sections): first road works warning sign (-696 m from start of carriageway restriction), start of 110 km/h speed limit (-576 m), start of 90 km/h speed limit (-456 m), start of 60 km/h speed limit (-216 m), start of carriageway restriction (0 m)
  - minimum recorded speed [km/h] on each of the above stretches and absolute difference [km/h] between the average recorded speed on each of the above stretches and the respective speed limit

Next, the average value of the above indicators was calculated for each of the two scenarios (C-IST OFF and C-IST ON) for comparison purposes.

Evaluation results – Field tests

Heavy vehicles

The main Field Tests KPIs for heavy vehicles are listed in the table below.

Table 49 - RWW-LC - Field tests KPIs - Heavy vehicles

RWW - Closure of a Lane - Heavy vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	C-ITS OFF	C-ITS ON	Abs. Var.	Var. %
LANE CHANGE				
Maneuver duration [s]	3,1	3,6	+0,5	+16%
Maneuver length [m]	74	66	-9	-11%
Maneuver start point [m] (0 m = event point)	-178	-272	-93	-
Maneuver end point [m] (0 m = event point)	-104	-206	-102	-
Max steering angle [rad]	0,107	0,072	-0,035	-32%
SLOWDOWN				
Slowdown performed [%]	30%	100%		
Maneuver duration [s]	6,0	32,7	+27	+445%
Maneuver length [m]	114	610	+496	+434%
Maneuver start point [m] (0 m = event point)	-130	-715	-585	-
Maneuver end point [m] (0 m = event point)	-16	-130	-114	-
Initial speed [km/h]	85	76	-9	-11%
Final speed [km/h]	73	60	-13	-17%
Speed reduction [km/h]	-12	-16	-4	+29%
Deceleration standard deviation [m/s²]	0,163	0,111	-0,052	-32%
Max instantaneous deceleration [m/s²]	0,38	0,41	+0,03	+8%

- lane change: with C-ITS ON the maneuver is started (-93m) and finished (-102m) with a clear spatial advance compared to the C-ITS OFF scenario. In this way the vehicle can leave the lane affected by the closure with an improved safety margin. The maneuver is more compact (-9m/-11%) but performed in a longer time (+0,9s/+29%) thanks to a lower average speed; the lane change is also performed more smoothly, as evidenced by a lower value of the steering angle (-91%).
- slowdown: in the C-ITS ON scenario the slowdown starts (-585m) and ends (-114m) earlier than in the C-ITS OFF scenario and it is carried out much more gradually (greater spaces - +496m/+434% - and times - +27s/+445% and with a smaller standard deviation of the instantaneous decelerations - -32%), arriving at a speed of full compliance with the speed limits at the entrance of the restricted area of the carriageway. On the contrary, with C-ITS OFF the decelerations are carried out much closer to the beginning of the narrowing of the carriageway, with short duration and length. The reduction in speed is not sufficient to fully respect the speed limits at the entrance to the site.

Light vehicles

The main Field Tests KPIs for light vehicles are listed in the table below.

Table 50 - RWW-LC - Field tests KPIs - Light vehicles

RWW - Closure of a Lane - Light vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	**C-ITS OFF**	**C-ITS ON**	**Abs. Var.**	**Var. %**
LANE CHANGE				
Maneuver duration [s]	5,3	4,2	-1,1	-20%
Maneuver length [m]	139	103	-35	-25%
Maneuver start point [m] (0 m = event point)	-308	-675	-367	-
Maneuver end point [m] (0 m = event point)	-170	-556	-386	-
Max steering angle [rad]	0,146	0,092	-0,054	-37%
SLOWDOWN				
Slowdown performed [%]	75%	100%	-	-
Maneuver duration [s]	10,3	15,0	+4,7	+45%
Maneuver length [m]	319	372	+53	+17%
Maneuver start point [m] (0 m = event point)	-233	-414	-181	-
Maneuver end point [m] (0 m = event point)	86	-42	-128	-
Initial speed [km/h]	124	107	-17	-14%
Final speed [km/h]	95	75	-20	-21%
Speed reduction [km/h]	-29	-32	-3	+10%
Deceleration standard deviation [m/s²]	0,442	0,698	+0,257	+58%
Max instantaneous deceleration [m/s²]	1,85	2,37	+0,52	+28%
BRAKING				
Braking performed [%]	50%	100%	-	-
Braking duration [s]	6,5	9,2	+2,7	+42%
Braking length [m]	173	324	+151	+88%
Braking start point [m] (0 m = event point)	-116	-442	-326	-
Braking end point [m] (0 m = event point)	57	-119	-175	-
Brake torque max [Nm]	1890	1949	+59	+3%
SPEED ADAPTATION				
Average speed [km/h]:				
before 110 km/h section	111	98	-13	-12%
110 km/h section	113	103	-10	-9%
90 km/h section	115	87	-28	-24%
60 km/h section	107	84	-23	-22%
Deviation from speed limit [km/h]:				
110 km/h section	+3	-7	-	-
90 km/h section	+25	-3	-	-
60 km/h section	+47	+24	-	-

- lane change: with C-ITS ON the maneuver is started (-181m) and finished (-128m) in advance compared to the C-ITS OFF scenario, thanks to the advance notice provided by the cooperative messages. Thus, the vehicle is able to leave the lane affected by the closure with an improved safety margin. The maneuver is shorter both in terms of time (-1,1s/-20%) and space (-35m/-25%); the lane change is also performed more smoothly, as highlighted by a lower value of the steering angle (-37%).
- slowdown: the magnitude of slowdown in terms of speed reduction is similar in the two scenarios (-32km/h and +10% more reduction for C-ITS ON), although with C-ITS OFF it starts and ends with higher speeds. In the C-ITS ON scenario the slowdown starts (-181m) and ends (-128m) spatially earlier than in the C-ITS OFF scenario and the maneuver is performed much more gradually (in more dilated space - +53m/+17% - and time - +4,7s/+45%), although less smoothly (higher standard deviation of instantaneous decelerations - +58% and higher peak of maximum deceleration - +28%).

Evaluation results – KPIs on Mobility

Concerning the evaluation and assessment of the expected KPIs on mobility, the following general approach was adopted (see chapter 4.8)

KPIs = REACTION x EFFECTIVENESS x TARGET

Considering both data from heavy and light vehicles, the following observations were deployed:

- **Reaction**: reaction recorded if the slowdown maneuver in the C-ITS ON scenario is starting and ending before the C-ITS OFF scenario.
  The slowdown maneuver met the defined criteria for the definition of a relevant reaction in the 75% (0,75) of the passages with C-ITS ON (9 cases out of 12).
- **Effectiveness**: all the maneuvers analyzed were deployed in a smoother way and far in advance with C-ITS ON with respect to the C-ITS OFF condition. The quantification of the effectiveness (based on an expert judgement), considering just the drivers who actually reacted, is assumed equal to 0,6 (with respect to accidents), 0,7 (injured people) and to 0,8 (fatalities).
- **Target**, considering road accidents in roadworks situations (i.e. accidents with temporary road signs or no road signs) on the Italian highway network (year 2019):
  - Accidents: 376
  - Injured: 582
  - Fatalities: 20

Thus, the estimated expected KPIs on mobility are reported in Table 51.

Table 51 - RWW-LC - Estimated KPIs on mobility - Safety

KPI			**% considering all the accident in Italy in a year**
Accidents	= 376 x 0,75 x 0,6 =	**-169**	- 0,10%
Injured people	= 582 x 0,75 x 0,7 =	**-306**	- 0,13%
Fatalities	= 20 x 0,75 x 0,8 =	**-12**	- 0,38%

5.1.7. Austria

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

During each drive, one RWW was received by all test drivers: a broken down vehicle was indicated to be blocking the right lane immediately behind a curve, so that a lane-change maneuver was necessary to avoid a crash.
A baseline measurement is possible, because it can be stated that the reception of the message without C-ITS – as visible in the graphic above -would be significant later, because the event as such is placed at the end of a (smooth) curve, which makes it impossible to detect it more than approximately 500m in advance.
The C-ITS message was transmitted 1000m before the actual place of the reported incident, which is approx. 50 sec of driving (assuming a speed at the allowed limit of 80km/h).
Depending on the traffic situation, and also on the driver behavior, the lane change maneuver, performed by the drivers, started during the test drives between 800m and 500m in advance.
The complete maneuver was finished after a maximum of 300m before, so well in advance ahead of the actual event.

Data collected

15 test-drivers have driven along the defined stretch of the motorway, each of them received the “Broken down vehicle”-message, and since everyone drove it twice, a total of 30 tracks was received for this road-stretch.
Each of these tracks were made up out of the coordinates of approx. 700-800 CAMs, which are collected in the distance of approx. 1 km before the (virtual) obstacle.

Evaluation results – Field tests

The main conclusion of this speed- and lane-change check is that the selected method of comparing data from the single drives and analyzing them per service received and traffic environment experienced on the road has been shown to be very effective and delivers additional insights of the effect on driver behavior with C-ITS services!
The fact that there was always enough time to both change lane and adjust the speed never led to any critical situation, such as heavy breaks or forced lane changes.
Rear-end collisions are by far the number-one cause of accidents on motorways. On roads in Austria, “Inattention/Diversion” together with “Unattended Speed” make up more than 50% of all accidents in summary on all roads, and for more than 80% on motorways alone. (@ Statistik Austria, 2019)
Broken-down vehicle do – in most cases – not only require a speed-, but also a lane-change, which rises the danger of accidents. Consequently, with the possibility to place messages always well in advance before an incident, C-ITS is a perfect tool to avoid accidents - and possibly injuries or even deaths.

5.1.8. Summary

Evaluation results – Field tests

The main results regarding the impact area of safety in relation to the RWW service relate to speed and accelerations/decelerations, elements which were considered by all the Countries.

The **Spanish pilot** considered a wide range of KPIs, reporting different observations, referring to the Use Cases considered:

- Change in speed adaptation: The vehicles reduced their average speed with respect to the limit after the implementation of the RWW-RC (Benefit: 10.41%). On the other hand, the vehicles increased their average speed with respect to the limit after the implementation of the RWW-LC.
- Change in speed standard deviation: The service RWW-RC helped to reduce the amount of time vehicles exceeded the speed limit (Benefit: -16,67%). The service RWW-LC did not show a reduction.
- There was a reduction in the average speed during the implementation in RWW-RC.
- The service RWW-LC showed different results in the sub-pilots, so no common conclusion could be drawn. Different roads were analyzed in the sub-pilots that may have resulted in diverse results.
- Change in instantaneous accelerations: An increase was shown for RWW-LC (Andalusian and DGT3.0 sub-pilots) and no impact in Madrid pilot.
- Change in instantaneous decelerations: the number of times that the vehicles braked harshly was reduced in the service RWW-RC for the Madrid pilot and also detected in the service RWW deployed in DGT3.0 pilot (Benefit: -49% in the best case).
- The Average speed from reception of C-ITS message until road works location in Catalan sub-pilot was 94 km/h.

The changes in speed were less meaningful for pilots in UK and NL, both considering RWW-LC. In the **UK** the analysis of contextual factors indicated the actual change in speed was most likely due to other contextual factors (e.g. queues) or was at best inconclusive. In the **NL**, the mean speed did not change significantly before and after the reception of the C-ITS message. Therefore, it was concluded that the warning did not appear to be an influential factor in driver speed.

The same Use Case was also tested in **CZ**, with meaningful results especially for the Subpilot DT3, with recorded decreased minimum, maximum and average speed (this last decreased around 5 km/h) after RWW message notification. Acceleration comparison showed similar mean values around 0, but greater variance of acceleration values after receiving the RWW message, more centered on negative values, i.e., on the deceleration.

The Spanish pilot also focused attention on other KPIs:

- A decrease in the maximum steering angle of the vehicles has been observed after the implementation of the RWW-RC service Benefit: -20,29%). This condition could be related to less sudden maneuvers.
- Number of lane changes: a reduction in the number of lane changes is appreciated in the evaluated services RWW-RC (Benefit: -37,85%) and RWW-LC (Benefit: -15,1%).

The Italian pilot reported a high number of Field Test KPIs highlighting significant benefit of the C-ITS message in terms of anticipated reaction and maneuvering and smoothness of the lane change. Both for light and heavy vehicles.

Heavy vehicles:

- lane change: with C-ITS ON the maneuver is started (-93m) and finished (-102m) before with respect to the C-ITS OFF scenario. The maneuver is more compact (-9m/-11%) but performed in a longer time (+0,9s/+29%) thanks to a lower average speed; the lane change is also performed more smoothly (the steering angle is -91%).
- slowdown: in the C-ITS ON scenario the slowdown starts (-585m) and ends (-114m) earlier, it is carried out much more gradually (greater spaces - +496m/+434% - and times - +27s/+445% and with a smaller standard deviation of the instantaneous decelerations - -32%), arriving at a speed of full compliance with the speed limits at the entrance of the restricted area of the carriageway. In the C-ITS OFF scenario the reduction in speed is not sufficient to fully respect the speed limits at the entrance to the site.

Light vehicles:

- lane change: with C-ITS ON the maneuver is started (-181m) and finished (-128m) in advance compared to the C-ITS OFF scenario, thus with an improved safety margin. The maneuver is shorter both in terms of time (-1,1s/-20%) and space (-35m/-25%); the lane change is also performed more smoothly (the steering angle -37%).
- slowdown: the slowdown in terms of speed reduction is relevant (-32km/h and +10% more reduction for C-ITS ON). In the C-ITS ON scenario the slowdown starts (-181m) and ends (-128m) spatially earlier and the maneuver is performed much more gradually (in space - +53m/+17% - and time - +4,7s/+45%), although less smoothly (higher standard deviation of instantaneous decelerations - +58% and higher peak of maximum deceleration - +28%).

In Austria, the lane change maneuver, performed by the drivers, started during the test drives between 800m and 500m in advance with respect to the event. There was always enough time to both change lane and adjust the speed and it never led to any critical situation, such as heavy breaks or forced lane changes.
In the UK, feedback about safety impacts from the RWW service were also collected through interviews to the users: 29% of the participants reported having reduced their speed after seeing RWW, which may suggest that the technology has the potential to be effective in encouraging speed management if it provided more accurate information.
Moreover, half the participants agreed that RWW service could contribute to improving driver alertness in road works situations, evidenced by 47% of drivers saying they felt more alert to the presence of roadworks with the information appearing in-vehicle.
In addition, 53% felt it was more effective in bringing attention to the driver in the vehicle than signs on the roadside.
Finally, Italy estimated an overall yearly impact on safety, considering a 100% C-ITS penetration rate as reported in Table 52.

Table 52 - RWW-LC - Estimated KPIs on mobility - Safety

KPI		% considering all the accident in Italy in a year
Accidents	**-169**	- 0,10%
Injured people	**-306**	- 0,13%
Fatalities	**-12**	- 0,38%

5.2. Traffic Efficiency

This section provides a list of the road works warning use-cases evaluated from a traffic efficiency perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Italy, Spain, NW2, UK, Austria, Portugal

5.2.1. Spain

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure
- RWW-RC: Roadworks Warning - Road Closure
- RWW-RM: Roadworks Warning - Roadworks Mobile

Evaluation method

Questions about what the Spanish pilot investigated are presented hereunder depending on the use case:
Main Research Question:

- Is traffic efficiency affected by changes in driver behavior due to RWW use case?

Sub Research Questions:

- How does the RWW service affect to the journey time in the use case?
- How does the RWW service affect to the traffic flow in the use case?
- How does the RWW service affect to the speed in the use case?
- How does the RWW service affect the lane changer maneuver in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

The data collected used to evaluate the different impact areas are the same for all of them. Refer to Chapter 4.1 to check the data collected in the Spanish pilot.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS RWW v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.

Evaluation results – KPIs on Mobility

Global results of impact evaluation were obtained. The KPIs that were calculated in each of the sub-pilots are presented in Table 53, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

Note that in Table 53, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

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Table 53 - RWW Traffic Efficiency. Spain.

KPI	Service	Use Case	Pilot	Summary
Change in the event time	RWW		DGT 3.0 SATELISE	-12%
Travel time (since the C-ITS message reception till the event -e.g. road works-)	RWW	RC	Madrid	0.63%
		LC	Andalusian - Mediterranean	-11%
			Catalan -Mediterranean	+1,7%*
		RM	Bizkaia -Cantabrian	15.5%
Number of stops along routes where C-ITS has been implemented	RWW	RC	Madrid	0%
		RM	Bizkaia -Cantabrian	2.53%
Duration of stops along routes where C-ITS has been implemented	RWW	RC	Madrid	0%
		RM	Bizkaia -Cantabrian	0.16%
Change in instantaneous accelerations/decelerations	RWW	RC	Madrid	-25%
		LC	Andalusian - Mediterranean	14%
Change in average speed	RWW	RC	Madrid	-3.78%
		LC	Andalusian - Mediterranean	10.1%
			Catalan -Mediterranean	-3.0% (-1.4%*)
Difference between the average speed of the vehicle and the speed limit	RWW	LC	Catalan -Mediterranean	-109.6%
Change in traffic flow	RWW	LC	Catalan -Mediterranean	2,4%*

5.2.2. UK

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.2 (Safety – UK).

Table 54 - RWW traffic efficiency evaluation methodology

Area	Priority	Research questions	KPIs
Traffic Efficiency	+ Secondary Area	See User Acceptance	Subjective Impact only

Data collected

Refer to Section 5.1.2 (Safety – UK).

Evaluation results – Field tests

Road Works Warning has the potential to produce traffic efficiency impacts from earlier speed and lane change maneuvers.
Initial results on measured driver behavior can be found in Section 5.1.2 (Safety - UK).

Subjective Impact Summary (refer to section 5.4.2 for more details)

29% of the participants reported having reduced their speed after seeing a RWW warning message, which may suggest that the technology has the potential to be effective in encouraging speed management if it provided more accurate information.

Reduced speed is also likely to have a positive traffic efficiency impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of the roadworks, reducing any shockwaves from sudden braking.

Evaluation results – KPIs on Mobility

Although there were no directly measured Traffic Efficiency KPIs, RWW exhibited implied secondary benefits from the behavioral changes of the drivers and measured speed adaptation.

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5.2.3. Italy

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The case study location was the Italian motorway A22. The A22 comprises of two lanes with an enforceable speed limit of 130 km/h. In addition, heavy vehicles must comply with an overtaking ban and are, therefore, limited to the slow lane.

The road segment chosen for the analysis was on A22 (103 + 500 Km − 107 Km) northern direction. One of the main reasons for selecting this section was that no ramp was present between the two loop sensors, thereby enabling the traffic model to be calibrated and validated robustly.

The cooperative message about the lane closure was received by the equipped vehicles (CVs) 1500m in advance while un-equipped vehicles become aware of the roadworks around 700m upstream and of the lane closure only 336m upstream. As an operational hypothesis, the CVs receive in advance only the message about the lane closure while the reduced speed limits are showed on the HMI as soon as each vehicle reaches the signalized sections.

The layout was reproduced within the modelling software to create a digital representation of the study area to enable the transferability of results. The chosen modelling tool was PTV VISSIM, a commercial simulation software that allows the evaluator to reproduce the longitudinal driving behavior on freeways.

The objective of the analysis was to frame the possible impacts arising from the reception of the C-ITS message way upstream from the traditional vertical signage; therefore, a set of microsimulations were carried out for different levels of market penetration. The presence of CVs among the light vehicles carried out for different levels of market penetration. The presence of CVs among the light vehicles was gradually increased to account for the following percentages: 10%, 20%, 33%, 40%, 50%, 66%, 80% and 100%; the key performance indicators (KPIs) obtained as outputs were the average speed through the lane closure segment for both lanes, the delay through the segment, the volume of vehicles passing through and the queue delay upstream of the bottleneck.

Data collected

Traffic data were received by A22 for two representative days with average traffic flows and not characterized by any unforeseen event (e.g. no accidents, no adverse weather conditions, etc.). These days being two working Fridays (one in March and the other one in May). The first day was used to calibrate the driving behavior of the three considered vehicle classes (light vehicles, commercial vehicles, and heavy gross vehicles) and the latter one was used to validate said behavior. The chosen control parameters were:

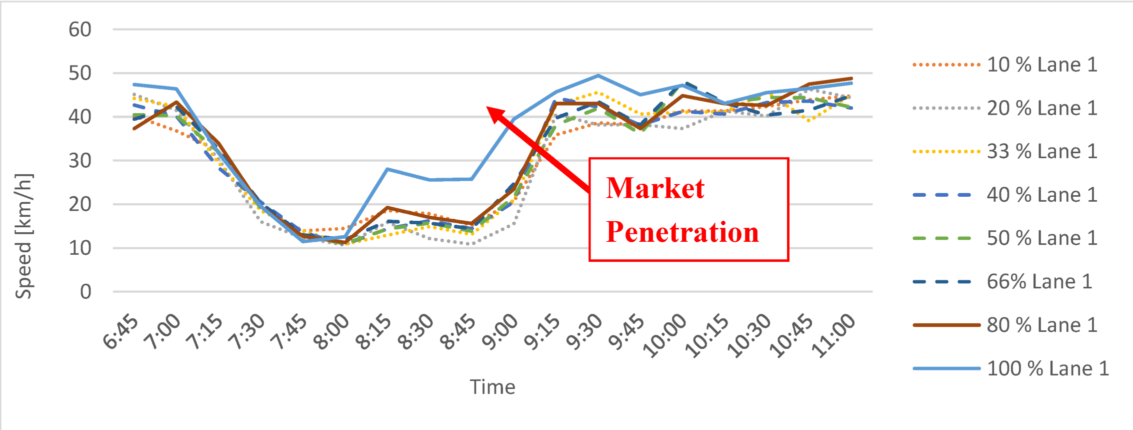
- the speed values (of both days)
- the traffic volumes on the downstream segment of the Friday in March.

Evaluation results – Field tests

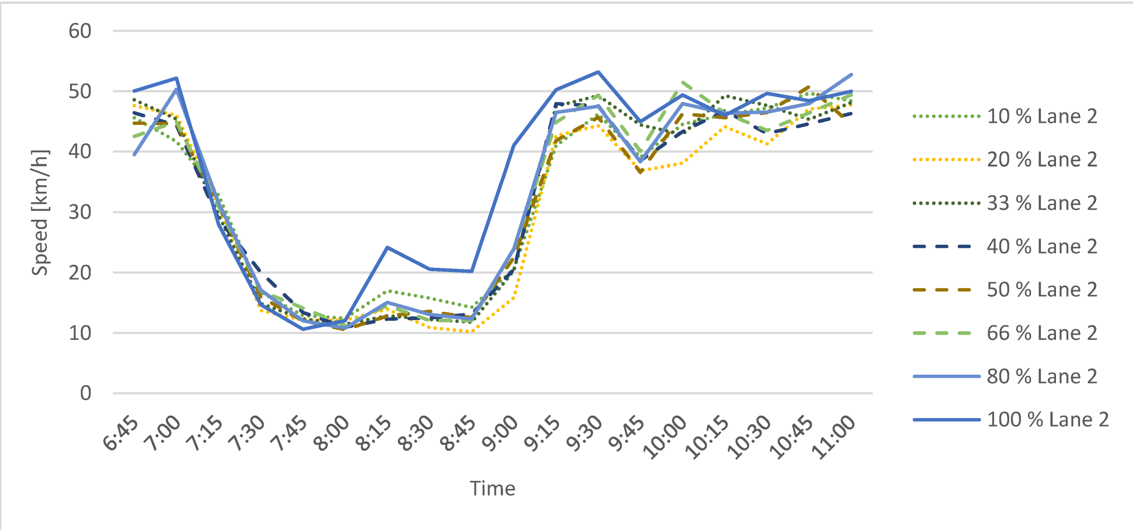
The aim of this analysis was to evaluate the possible impacts arising from the implementation of the use case roadworks warning - closure of a lane on the Italian highways through microsimulations.

The first research question investigated if the flow of vehicles arriving at the roadworks was able to enter in advance and with a higher speed thanks to the shift of connected vehicles to the fast lane due to the C-ITS message.

By comparing Figure 7 a and b, it was interesting to note how, on lane 1 (the closed lane), a positive trend arises with the increase of market penetration. In this case, in fact, for an increasing number of connected vehicles among the traffic flow, the speed for most of the simulation time increased as well; while, on lane 2 (the adjacent open lane), no defined trend was discerned. Still, the 100% market penetration (MP) scenario seemed to perform a different traffic dynamic on the open lane when compared to lower MP levels, achieving speeds higher by even 10 km/h.



(a)



(b)

Figure 7 - Driving speed 200 m upstream the lane closure: (a) slow lane and (b) fast lane.

Figure 8, on the other hand, represents the time spent by the upcoming vehicles with a speed value lower than 10 km/h and a headway value lower than 20m on the open lane, queueing from upstream.

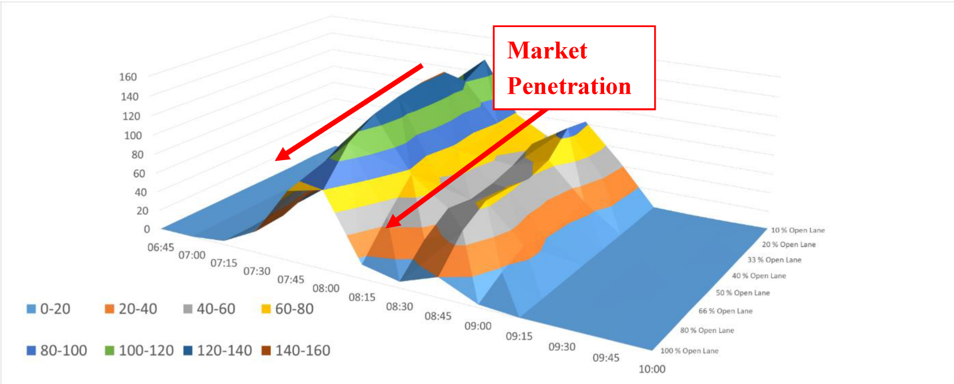


Figure 8 - Time in queue (s) on the open lane.

With the only exception of 20% MP, the queuing time at the entrance steadily decreased. For 100% MP, the difference in queue time reached values of 60s when compared to 10% MP during the first peak (140s vs 80s). Moreover, the second peak is kept under the minute (more than 80s at 10% but 20s at 100% MP). The singular nature of 20% market penetration arises also on the closing lane, as reported in Figure 9.

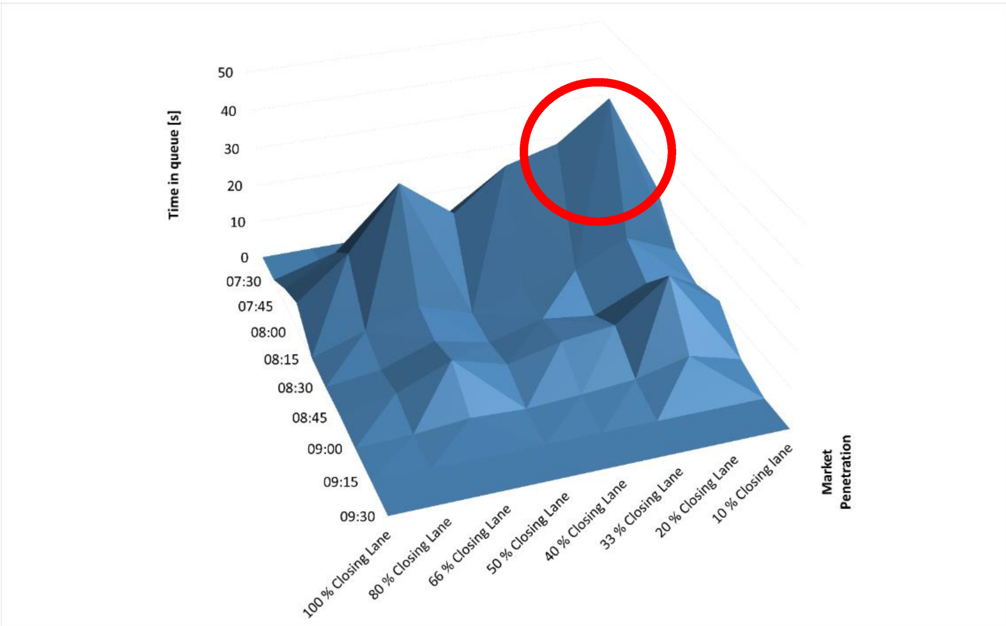


Figure 9 - Time in queue on the closing lane.

In fact, as it can be noticed from***Errore. L'origine riferimento non è stata trovata.***, the lower queue time at 20% MP on the open lane is reflected by an increase of queue time in the closing one (marked with a red circle). Therefore, the result is not simply a singularity but reflects a traffic dynamic that is triggered when 20% of the light vehicles on the closed lane shift to the open lane before reaching the closure. It can be hypothesized that this, in turn, makes it more difficult to merge for the remaining light vehicles, because they are traveling on a lane which is strongly affected by heavy and commercial vehicles. Their inability to merge, negatively affects the rest of the traffic on the closed lane by impacting on its overall speed (20% MP shows the lowest speed on the closing lane.
This result is noteworthy both in framing the possible impacts of connected vehicles on bottleneck dynamics and to warn about the intermediate phase, at which point a low

proportion of connected light vehicles behaved differently from the rest of the traffic can have disruptive effects difficult to foresee before implementing the system.

Analysis of Figure 10 indicates that the capacity of the bottleneck does not worsen, because the volumes that shift between the two lanes are perfectly symmetrical, and in no C-ITS scenario do vehicles end up entering the roadworks in the successive 15 minute slot. Still, in answering the first research question, it can be stated that the C-ITS message does not reduce the capacity of infrastructures ascribable to the A22; one for average traffic volumes; moreover, the average throughput is not directly affected, but two different dynamics can be triggered. For lower market penetrations, disruptions can arise, negatively affecting the closed lane more than they affect positively the open lane. For MP levels higher than 30%, the reduced number of lane changes and an increased separation among traffic compositions result in benefits that are higher for both lanes, reducing queue times. This benefit can amount up to 60s per vehicle on the open lane and to 40s on the closed lane during the peak hour.

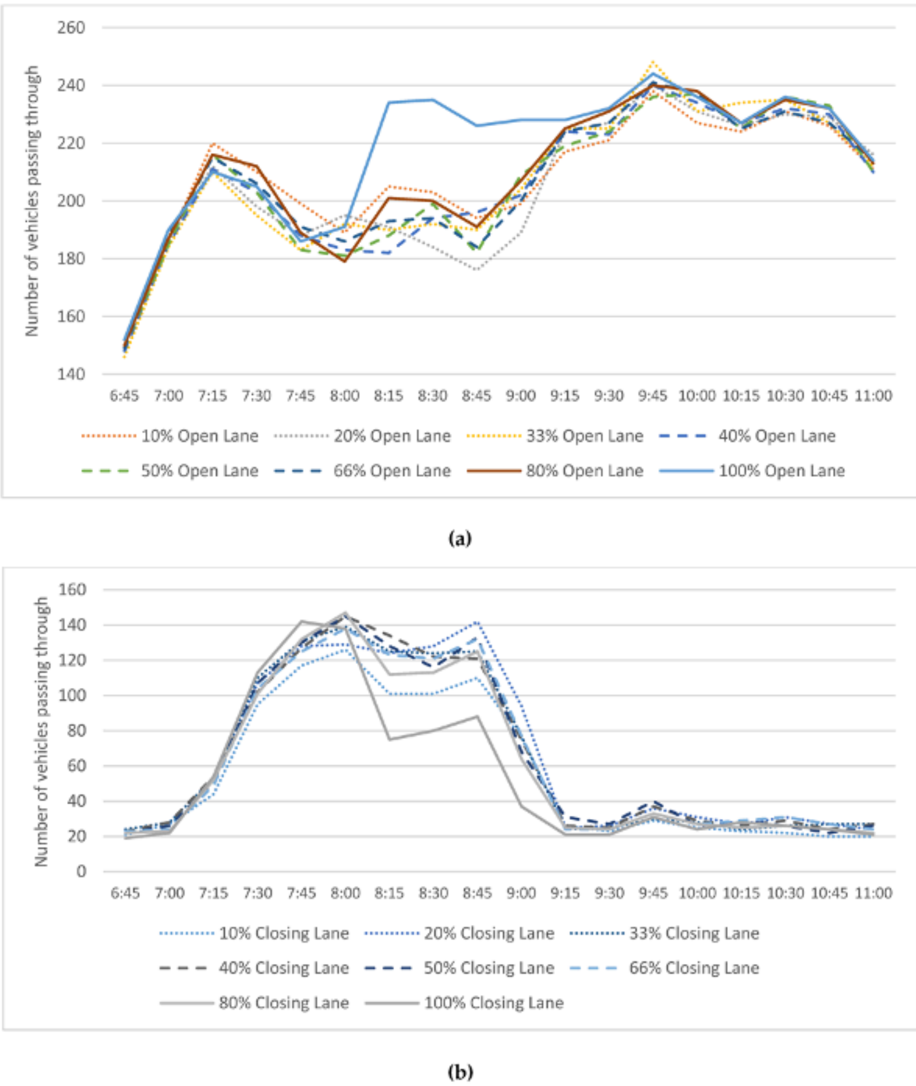


Figure 10 - Traffic volumes on the open (a) and the closing (b) lanes

The second research question investigates if the upstream traffic reorganizes itself in a way that is more efficient in terms of speed and travel time. To answer this, the delay between certain sections was calculated (see Figure 11). The chosen segment not too close or too distant from the lane closure and had a homogeneous speed limit of 90 km/h. In fact, the delay was calculated by comparing the theoretical travel time of the vehicles and their actual travel time during the simulations, the first depending on the desired speed distribution and the latter on the actual driving speed.

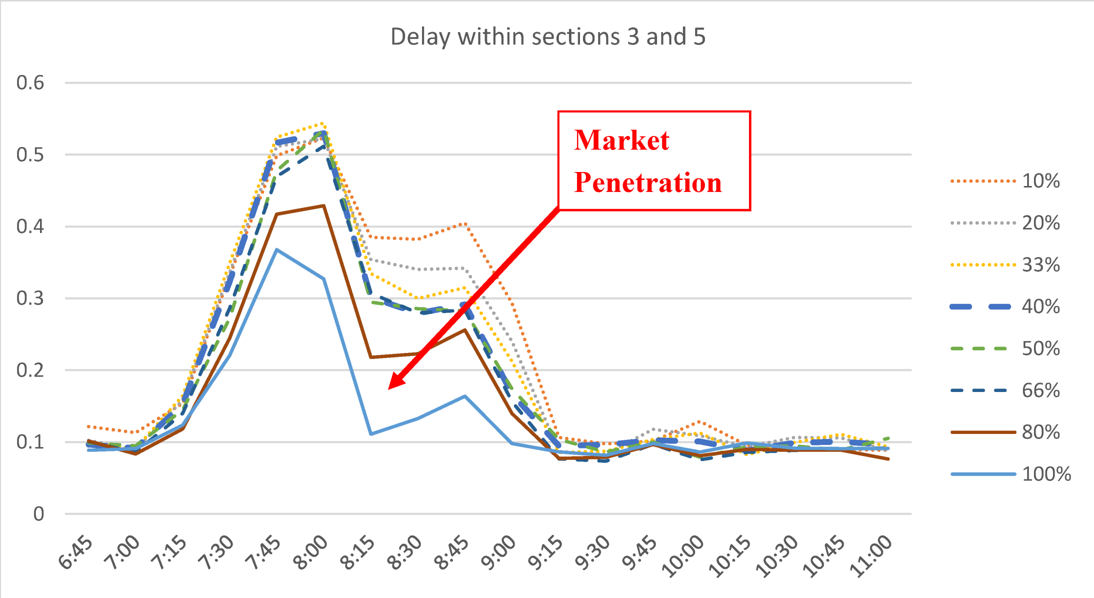


Figure 11 - Percentage of delay - comparison between desired speed and actual speed.

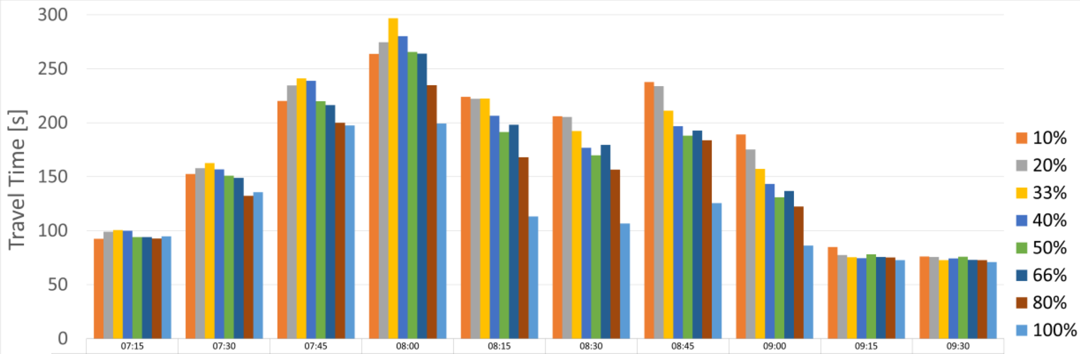
This last result shows that possible disruptions arise between 10% and 30% MP but from 30% MP up, the benefits upstream were much more linear. During the morning peak hour (07:00–08:00 a.m.), no strong benefit was identified for market penetrations lower than 80%, but, at the second peak (08:15–09:15 a.m.), a strong reduction in delay arose for each level of market penetration. This result indicated that, below certain levels of upcoming traffic volumes, the congestion due to roadworks could be reduced or actually avoided. Beyond a certain level of upcoming traffic volumes and for intermediate market penetration levels, this effect was not triggered at all, though, and no relevant difference was recorded. Still, it seems that the cooperative messages promote an earlier return to more efficient driving regimes, as it can be seen at 08:15 a.m. when the difference between 10% MP and 40% to 66% MP is equal to an almost 10% delay reduction. It was also interesting to note how, for these intermediate market penetration values, the delay was almost the same, which suggested a plateau in congestion recovery capacities that rise almost linearly between 10% and 40%, then do not improve until 66%. Beyond 66% MP, the positive effects start rising again, and the reduction in delay between 10% and 100% MP reaches almost 30%.

It was important to frame the impact on delay at peak hour, when the achievable benefits are higher. Nevertheless, it is useful to consider also the average delay recorded through the whole simulation period; this result is reported in Figure 40.

Table 55 - Average delay within the segments (3 - 5). MP: Market

MP	10%	20%	33%	40%	50%	66%	80%	100%
Average Delay	22,26%	21,03%	20,60%	19,60%	18,95%	18,33%	16,15%	13,60%

As it can be seen from Table 55, the delay decreases steadily with the increase of the market penetration, reaching a difference equal to 8.66% between 10% and 100% MP levels. This result is notable because it shows that the benefits of the C-ITS use case RWW - closure of a lane arise upstream of the lane closure, and higher market penetrations achieve higher benefits than 10% and 20% market penetrations. Still, it is worth reporting the absolute average values of travel time and how they change with market penetration, since simple percentages do not allow to frame the actual magnitude of the results. In Figure 12, the travel times from certain sections are reported; it should be highlighted how they cannot be directly related with Table 55, since the table refers to a different section.



	07:15	07:30	07:45	08:00	08:15	08:30	08:45	09:00	09:15	09:30
10%	92,56	152,54	220,25	263,92	224,03	206,04	237,8	189,19	84,94	76,22
20%	99,08	158,03	234,52	274,71	222,24	205,43	234,01	175,15	77,56	75,66
33%	100,54	162,69	241,11	296,92	222,58	192,3	211,25	157,34	75,35	72,85
40%	99,95	156,75	238,97	280,21	206,55	176,73	196,73	143,28	74,49	74,41
50%	94,02	150,98	220,05	265,54	191,36	169,76	188,07	130,93	78,04	75,96
66%	94,04	149,04	216,32	264,01	198,16	179,46	192,79	136,74	75,58	72,94
80%	92,71	132,23	200	234,79	167,96	156,68	183,83	122,4	75,11	72,75
100%	94,89	135,68	197,57	199,28	113,12	106,73	125,61	86,18	72,76	71,04

Figure 12 - Travel time from Section 1 to Section 7.

As it can be seen, higher market penetration levels constantly perform better within the congested hours, with the 100% MP scenario performing travel times 65s lower than the 10% one in the most congested 15 min. This result in tandem with the findings on delay should allow to answer the second research question about the traffic upstream. Regardless of the scenario or the traffic dynamic arising at the roadworks entrance, by limiting the number of lane changes and de facto removing unnecessary maneuvers for connected vehicles, a decrease of travel time was achieved. Moreover, an interesting trend can be found in Figure 12, between 10% and 33% MP levels; the trend is increasing when traffic volumes are higher (7.30 – 8.00) but is decreasing again (to a higher MP corresponding a shorter travel time) when the peak fades (8.00 – 9.30). It is likely that, leading vehicles performing lane changes in advance tend to be more aggressive and to disrupt the traffic on the open lane even more upstream than they would do without the C-ITS message. This, in turn, slightly worsens the performance of the network before the roadworks during peak hours, when available time gaps on the open gap are fewer and the maneuvers more aggressive. Moreover, these vehicles shifting to the open lane could cause the lane change of other vehicles (unequipped for the reception of cooperative messages) towards the closed lane, actually nullifying the effects of the C-ITS. These effects are prevalent at lower market penetration levels but are more than offset with greater levels of market penetration.

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure (joint implementation with Highway Chauffeur)

Evaluation method

The assessment is achieved through traffic simulations carried out with the VISSIM software and a specific Python script implemented to consider the joint implementation of the technologies considered: Highway Chauffeur (L3 vehicles) and C-ITS (UC: RWW-LC).

The road network chosen for the simulations was a 2-lane, 7.5 km long road branch on the A22 infrastructure with no on- and off-ramps. For calibration of traditional traffic, traffic data provided by A22 were used,. The layout of RWW-LC considered is reported in Figure 13.

Figure 13 - RWW-LC Layout

The main assumption of the simulation was that the L3 vehicles were the only ones able to receive the C-ITS message; no traditional vehicle received the information about the lane closure downstream.

Three different scenarios were considered:

- No C-ITS scenario: baseline, considered that no vehicle (traditional and L3) received C-ITS warnings about lane closure;
- Joint scenario 1 (696 m): the C-ITS message received by L3 vehicles is used only to replicate physical signaling along the road and upstream of the lane closure. The broadcasting range was set 696 m upstream of the actual lane closure, when L3 vehicles were then aware of the closure and could modify their behavior accordingly.
- Joint scenario 2 (1500 m): the C-ITS message received by L3 vehicles is received far upstream of the lane closure. The broadcasting range was set to 1500m upstream of the actual lane closure, when L3 vehicles were then aware of the closure and could modify their behavior accordingly.

Other meaningful hypotheses are the following:

- In both the C-ITS scenarios, the L3 vehicles on the open lane are able to keep driving because, to enter the roadwork, no lane change is required. From section 1 until the start of the roadworks, these vehicles will not enter the closed lane.
- In both the C-ITS scenarios, the L3 vehicles on the closed lane receives the message and start the take-over maneuver, in order to re-engage the human driver.
- The vehicles unequipped for the reception of cooperative messages discover about the lane closure when reaching Section 4, 336 m ahead of the lane closure. This reflects the vertical signals ahead of a roadwork designed in the simulation.

The effect of Increased market penetration of L3 & C-ITS equipped vehicles was considered.

Data collected

For each simulation carried out, the following output was defined and obtained:

- the speed on each of the lanes through the segment upstream the closure, 175m long;
- the delay of the traffic on a 240m long segment starting 610m upstream of the closure

Evaluation results – Field tests

The reception of the C-ITS message by L3 vehicles improved the driving speed at the roadworks entrance both during the peak hour and during the off-peak. This trend perfectly aligned with the rate of Market Penetration change.

In the Joint Scenario 1, an increase in speed at the bottleneck equal to around 10km/h on both lanes for lower values of Market Penetration (30 ÷ 40%) was recorded. This value grew up to 20km/h on the closing lane and to 30km/h on the fast lane for higher Market Penetration values.

The Joint Scenario 2 provided similar results, even though the Market Penetration needed to achieve them was lower by 10% (20 ÷ 30% is enough to achieve change similar to the ones arising with a broadcasting range of 696 m).

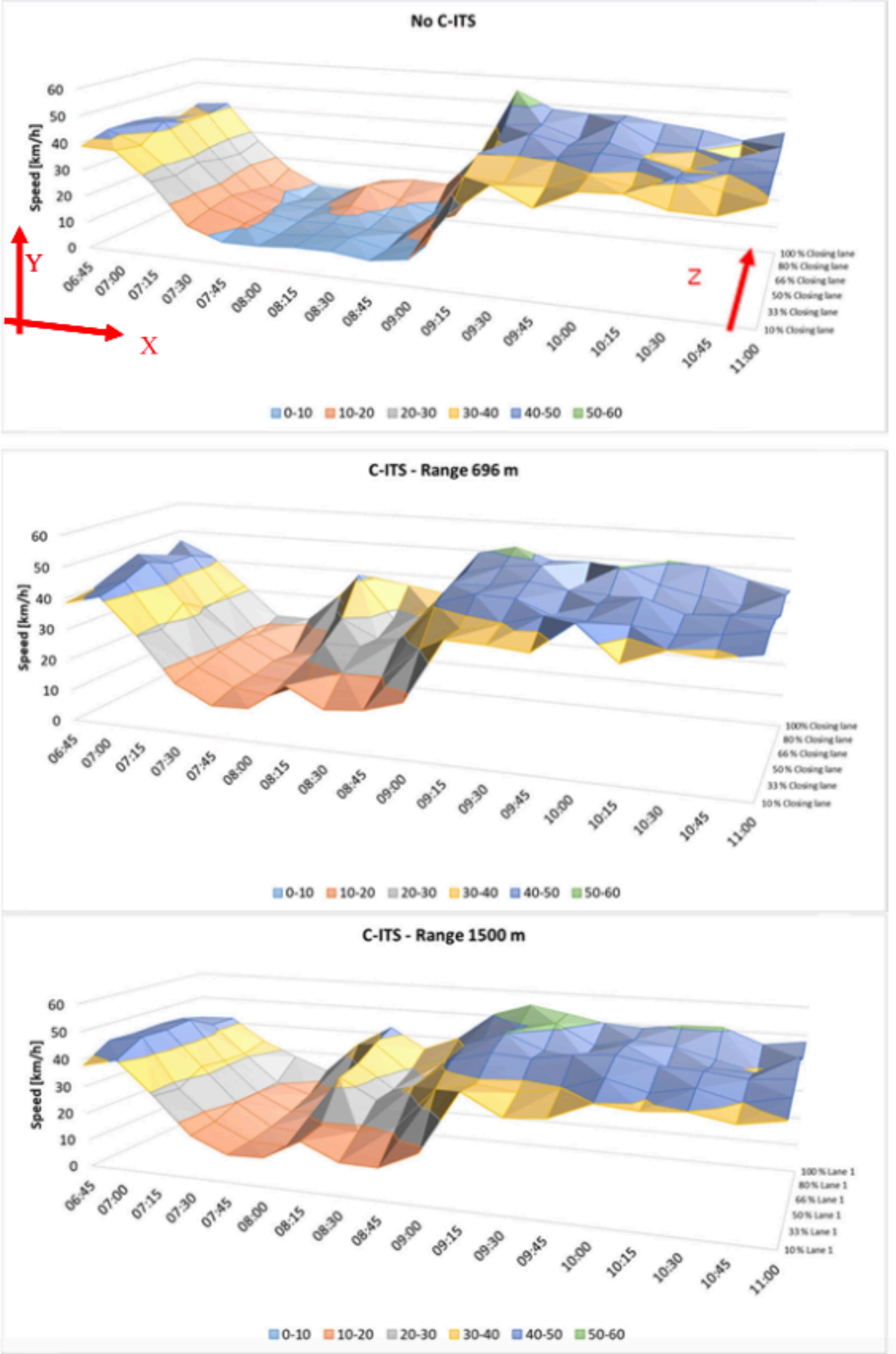


Figure 14 - Scenario comparison; speed on the closed lane

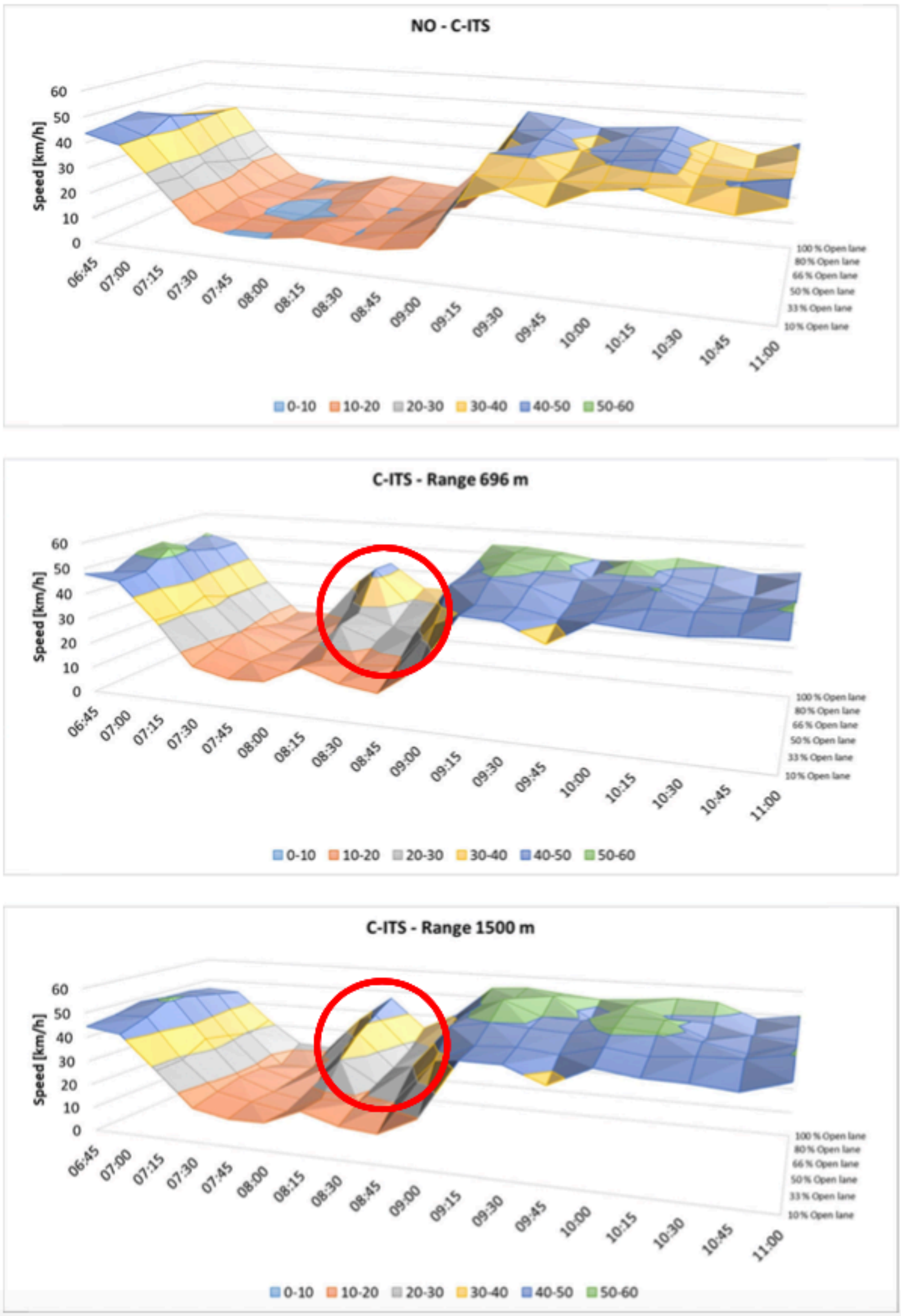


Figure 15 - Scenario comparison; speed on the open lane

Table 56 shows the average delay faced by the vehicles in the three scenarios considered. Delays were estimated as increased travel time compared to the free flow travel time and thus reported in percentages.

Table 56 - Average delays between section 3 and 5. Extra time compared to free flow travel time.

	10% MP	33% MP	50% MP	66% MP	80% MP	100% MP
NO C-ITS	23.26%	23.84%	22.54%	22.57%	19.54%	14.25%
Scenario 1 - 696 m	17.34%	15.81%	12.65%	11.47%	9.69%	8,27%
Scenario 2 - 1500 m	18.61%	14.36%	11.93%	10.26%	9.68%	8.75%

Evaluation results – KPIs on Mobility

The estimation of direct effect on traffic efficiency assumed that 600 roadworks with closure of a lane are deployed yearly on the Italian highway network. Moreover, the modelling activities estimated the average effectiveness of the Use Case towards the reduction of delays, assessed for a 100% market penetration equal to 38,9% (8,66 percentage points of delay reduction with respect to a delay increase of 22,26% at 10% MP; see Table 55).
According to the approach adopted, the assessment detailed in Table 57 were provided.

Table 57 - RWW-LC - Estimated KPIs on mobility - Traffic Efficiency - Direct impacts

	2 lanes	3/4 lanes	Notes
Average delay	12,9 [min]	negligible	Faced by each vehicle
Average delay per roadworks with Lane Closure (all vehicles involved) - No C-ITS	521 [h]		Contribution weighted on the features of the highways (n. of lanes)
Average reduction in delay	38,9 %		Estimation by modelling activities
Average delay per roadworks with Lane Closure (all vehicles involved) - C-ITS	203 [h]		
Total delay saved	**121.614 [h]**		Considering 600 events

Indirect impacts on traffic efficiency are assessed considering that a road accident is causing the closure of the carriageway for a time period (i.e. 2 hours). Adopting a model based on input-output diagrams theory, the quantification of the possible delays that the vehicles impacted are suffering is made possible. These delays are supposed to be reduced by the deployment of the Use Cases.

The estimation of indirect effect on traffic efficiency (safety related) assumed that 169 events of traffic congestion due to road accident were avoided thanks to the Use Case.
According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 58.

Table 58 - RWW-LC - Estimated KPIs on mobility - Traffic Efficiency - Indirect impacts

	2 lanes	3/4 lanes	Notes
Average delay	132,4 [min]	94,7 [min]	Faced by each vehicle
Average delay per accident (all vehicles involved)	6.889 [h]		Contribution weighted on the features of the highways (n. of lanes)
Total delay saved	**1.165.610 [h]**		Considering 169 events

5.2.4. Austria

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.7(Safety – Austria).

Data collected

Refer to Section 5.1.7 (Safety – Austria).

Evaluation results – Field tests

Road Works Warning has the potential to produce traffic efficiency impacts from earlier speed and lane change maneuvers.
Initial results on measured driver behavior can be found in Section 5.1.26 (Safety - Austria).

Evaluation results – KPIs on Mobility

The smoothness of the speed-change throughout the whole length of the evaluated motorway-stretch is a good indication for the positive effect of this kind of C-ITS message. Though the average volume of traffic was not equally high at all the different drives, the smoothness of speed-change was always equally fine. Moreover, this effect can also be seen at the smoothness of lane changes.

With this more or less constant speed, combined with proper lane-changes, which were also very smooth during all drives, rolling traffic was always effective in the sense of "showing no effects which could lead to disturbances", such as traffic jams.

Even more than Road works, broken-down vehicle are a very likely source for congestions, because unlike road-works, their appearance is not plannable, neither in regards of locations nor time. Since congestions are the main cause for high economic, traffic-related costs, C-ITS messages play an important role in reducing congestion-related expenses.

5.2.5. Summary

Evaluation results – Field tests (Extended)

RWW use cases that were investigated with respect to their impact on traffic efficiency include Lane Closure (Spain, UK, Italy, Austria), Road Closure (Spain), and Road works Mobile (Spain) and specific outcomes in terms of different KPIs are summarized below:

- Impact on Travel Time: The results of KPI related to travel time are very different across use cases. But, the results are consistent with the previous KPIs analyzed in the safety evaluation. Those sub-pilots that showed an increase in travel times and a reduction in average speeds, from a safety point of view is a good result but not necessarily from the traffic efficiency point of view. As safety is the primary concern in this use case, the values indicate a good performance. The type of road network (urban or interurban) and the service could be a reason for some variations in the results. On the other hand, simulation-based experiments conducted on motorways in Italy with different levels of market penetration of connected vehicles showed a steady decline in travel time delay with increase in market penetration, especially beyond 20% and during the peak periods with high traffic congestion. This results in an estimated direct impact of 121.614 h of delay savings and indirect impact (avoiding accidents) of 1.165.610 h of delay savings over a period of one year.

- Impact on Number of Stops and Queues: Routes where the C-ITS service (RWW) were implemented showed more or less neutral impact in terms of number of stops and duration along routes. The simulation-based experiments conducted on several motorways in Italy with different market penetrations of connected vehicles indicated a reduction in the queuing time with increased market penetration rate for the RWW-LC use case. However, some instabilities were observed at low market penetrations (20%) which may be due to a low proportion of connected light vehicles behaving differently from the rest of the traffic producing disruptive effects. These effects were difficult to foresee before implementing the system in the field and require further investigation.

- Impact on Homogeneity (Acceleration/Deceleration & changes in Average Speed): Most of the use cases deployed in Spain implied a benefit in the reduction of the instantaneous acceleration/deceleration. The field tests conducted in Austria also indicated smoother and earlier slowdown and lane change maneuvers which can contribute to reducing the impact on formation of congestion.

- Impact on Speed: The result of the KPI change in average speed is not comparable between services or sub-pilots. As indicated before, the type of road network may have an influence on the performance. The average speed of the vehicle, however, remains lower than the speed limit for the RWW-LC use case. About one-third of the drivers in the UK pilot reported a speed reduction upon receiving a RWW message which showed that the service can potentially improve speed management in work zones.

- Impact on Traffic Flow: The change in traffic flow was not significant in the RWW-LC use case.

Evaluation results – KPIs on Mobility (Extended)

This table summarizes and reflects the main trends in the findings over the various tests and analysis undertaken by each country. The color describes the positive/neutral/negative evolution of the KPI under consideration. When quantitative values / windows (percentage) of benefits are available, it is written within the cell in addition to the color indicator.

Please pay attention to the fact that negative effects on some KPI might be expected and completely explainable. For instance, Dynamic Speed Limit voluntary reduces the speed upstream to avoid congestion propagation and capacity drop due to traffic heterogeneities.

Based on Italy's assumptions, the implementation of RWW-LC (Lane Closure) services might contribute to avoid around 169 accidents per year on the motorways' infrastructures. Therefore, it is assumed that, indirectly, RWW-LC could save around 1,165,610 supplementary hours of delay per year in Italy

	KPI	Travel Time	Congestion	Traffic Homogeneity	Capacity	User acceptance
Use cases	Market Penetration Rate level	Average Travel Time [TT] / Average Speed [S] / change in Delays [D]	Number of stops [SN] / stops or queuing duration [SD] / etc	change in instantaneous Acceleration [Acc] / in Average Speed (S)	Traffic Throughput	Rate of users intending to response or strongly compliant (safer behaviour)
RWW-LC	low	Sp: ▼ -11% [TT], ▲ +10,3% [S] UK: ▼ [S] It: ▼ -4,8% [TT]	It: = [SD]	Sp: ▲ +14% [Acc] It: ▲ differences between lanes	It: instabilities	UK: 29%
	high	Sp: ▲ +2% [TT] It: ▲+15% [S], ▼ [-5,2%; -7%] [TT]	It: ▼-50% [SD]	It: ▼ differences between lanes	Sp: ▲ 2,4% It: ▲	
RWW-RC	low	Sp: ▲ + 0,69% [TT], ▼-3,78% [S]	Sp: 0%[SN], 0% [SD]	Sp: ▼-25% [Acc],		
	high					
RWW-RM	low	Sp: ▲+15,5% [TT]	Sp: ▲ +2,53%[SN], ▲ +0,16% [SD]			
	high					

Legend

- Colors:

Not Concerned	Variable benefits	Positive benefits	No significant changes	Negative Benefits

- Countries under consideration: Spain (Sp) / United Kingdom (UK) / Italy (It)/ Austria (Au).

5.3. Environment

This section provides a list of the road works warning use-cases evaluated from an environmental perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Italy, Spain, NW2, UK, Austria, Portugal

5.3.1. Spain

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure
- RWW-RC: Roadworks Warning - Road Closure
- RWW-RM: Roadworks Warning - Roadworks Mobile

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is environment affected by changes in driver behavior due to RWW use case?

Sub Research Questions:

- How does the RWW service affect the fuel consumption in the use case?
- How does the RWW service affect the CO2 Emissions in the use case?
- How does the RWW service affect the emissions of other pollutants (NO_x, PM, CO, etc...) in the use case?
- How does the RWW service affect to the traffic flow in the use case?

Data collected

The data collected was used to evaluate all the different impact areas. Refer to Chapter 5.1.1 to check the data collected in the Spanish pilot.
In the case of Madrid sub-pilot, this evaluation was achieved using traffic simulations. Please, refer to the following annexes of [RD.3]:

- Annex 1-C-Roads: Estimation of traffic emissions in the M-30 ring road (Madrid)
- Annex 2-C-Roads Services Evaluation using traffic simulation

In the case of Cantabrian sub-pilot, for the calculation of the indicators, taking into account that only the HMI of the mobile application was used, the GPS location was used to determine the distance travelled. Based on the distance travelled and the average consumption of the vehicles in circulation, it was been possible to estimate the average fuel consumption and from this value the corresponding CO_2 emissions.
A correlation was also established between vehicle speed and NO_x particles.
Moreover, the Mediterranean sub-pilot uses the characteristics of the vehicles to estimate the impacts on environment: fuel consumption, carbon dioxide emissions and pollutant emissions.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS RWW v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation were obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 59, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

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Note that in Table 59, the results presented with an asterisk (*) are extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 59 - RWW Environment. Spain.

KPI	Service	Use Case	Pilot	Summary
Change on fuel consumption and CO_2 emissions	RWW	LC	Andalusian - Mediterranean	9%
			Catalan -Mediterranean	-1.5% (+4.6%*)
			Madrid[7]	0,5% (200m scenario 1) 0,7% (1000m scenario 1) 1,3% (200m scenario 2) 0,2% (1000m scenario 2) 0% (200m scenario 3) -7,9% (1000m scenario 3) -14,1% (200m scenario 4) -18,8% (1000m scenario 4)
			DGT 3.0 SISCOGA	-12%
			SISCOGA Extended	Naturalistic study: -30%
Change on pollutant emissions NO_x	RWW	LC	Andalusian - Mediterranean	15.9%
			Catalan -Mediterranean	-3.5% (+4.3%*)
			Madrid[7]	0,3% (200m scenario 1) 0,6% (1000m scenario 1) 1,9% (200m scenario 2) 1,4% (1000m scenario 2) -0,2% (200m scenario 3) -4,7% (1000m scenario 3) -15,4% (200m scenario 4) -12,7% (1000m scenario 4)
Change on pollutant emissions PM2.5	RWW	LC	Andalusian - Mediterranean	21.4%
			Catalan -Mediterranean	1.6% (+9.2%*)
			Madrid[7]	-0,4% (200m scenario 1) -0,3% (1000m scenario 1) -0,2% (200m scenario 2) -0,8% (1000m scenario 2) -0,4% (200m scenario 3) -7,9% (1000m scenario 3) -18,9% (200m scenario 4) -22,7% (1000m scenario 4)

[7] Refer to C-Roads_Spain_Final_Evaluation_Result_Madrid_Pilot_v1.2 docx of [RD.3] to have details about scenarios.

5.3.2. UK

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.2 (Safety – UK).

Table 60 - RWW environment evaluation methodology

Area	Priority	Research questions	KPIs
Environment	+ Secondary Area	See User Acceptance	Subjective Impact only

Data collected

Refer to Section 5.1.2 (Safety – UK).

Evaluation results – Field tests

Road Works Warning has the potential to produce environmental impacts from earlier speed and lane change maneuvers avoiding flow breakdown due to better traffic flow and therefore lower fuel consumption for a given journey (no sitting in queues for long periods). Initial results on measured driver behavior can be found in Section 5.1.2 (Safety - UK).

Subjective Impact Summary (refer to section 5.4.2for more details)

Reduced speed as cited in 5.4.2 of nearly one third of drivers surveyed can also have an indirect environmental impact (through reduced emissions).
Although safety is the main intended impact of RWW, a reduction of excessive speed and early lane changes when approaching roadworks as gleaned through the extensive user acceptance data, could reduce queuing and hence reduce localized environmental impacts due to congestion.

Evaluation results – KPIs on Mobility

Although there were no directly measured Environmental KPIs, RWW exhibited implied secondary benefits from the behavioral changes of the drivers and measured speed adaptation.

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5.3.3. Italy

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.6 (Safety - Italy)

Data collected

Refer to Section 5.1.6 (Safety - Italy)

Evaluation results – Field tests

Refer to Section 5.1.6 (Safety - Italy)

Evaluation results – KPIs on Mobility

Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency. Consumption and emission factors are adopted as reported in Table 61.

Table 61 - Consumption and emission factors

Consumption factors	**[l/km]**
Congestion - Light vehicle consumption	0,105
Congestion - Heavy vehicle consumption	0,48
Free Flow - Light vehicle consumption	0,07
Free Flow - Heavy vehicle consumption	0,32
Emission factors	**[kg CO_2/l]**
Emission Factor - Gasoline	2,34
Emission Factor - Diesel	2,61

The estimation of direct effect on environment was based on the direct impacts on traffic efficiency, always assuming that 600 roadworks with closure of a lane are deployed yearly on the Italian highway network.

Table 62 - RWW-LC - Estimated KPIs on mobility - Environment - Direct impacts

Total Delta Gasoline	- 486.447 [l]
Total Delta Diesel	- 686.276 [l]
Total Average Delta Emissions	- 2.929 [CO_2 ton]

The estimation of indirect effect on traffic efficiency (safety related) assumed that 169 events of traffic congestion due to road accidents were avoided thanks to the Use Case. According to the approach adopted, these events could lead to the environmental impacts detailed in Table 63.

Table 63 - RWW-LC - Estimated KPIs on mobility - Environment - Indirect impacts

Total Delta Gasoline	- 174.040 [l]
Total Delta Diesel	- 245.534 [l]
Total Delta Emissions	- 1.048 [CO_2 ton]

5.3.4. Austria

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.7(Safety – Austria).

Data collected

Refer to Section 5.1.7 (Safety – Austria).

Evaluation results – Field tests

Road Works Warning has the potential to produce environmental impacts from earlier speed and lane change maneuvers, avoiding congestions due to better traffic flow and therefore lower fuel consumption for a given journey (no waiting in queues for longer periods). Initial results on measured driver behavior can be found in Section 5.1.26 (Safety - Austria).

Evaluation results – KPIs on Mobility

Generally, the main cause for an increase of emission is not so much a certain (eventually high) speed, but more the fact of frequent speed-changes.
Broken-down vehicles are often placed on dangerous positions, which gives a high probability of abrupt deceleration, but since the speed-changes within the evaluated area are within a very low range, CO2 (and other)-emissions are constantly low.
This is equally applicable for noise emissions.

5.3.5. Summary

Evaluation results – Field tests

The **Spanish pilot** considered a large number of KPIs and their evaluation.

Taking into account the summary results of Spain, the following main conclusions at the Spanish level were obtained:

- Change in fuel consumption and CO_2 emissions: The Madrid pilot evaluated this KPI by scenarios and simulations. There were fluctuations in the results depending on the type of assessment undertaken. The Andalusian sub-pilot had a positive value of 9%. In the rest of the sub-pilots where this KPI was evaluated, there was also a reduction in fuel consumption and CO_2 emissions. The best benefit is of -30%.
- Change on pollutant emissions NO_x: The previous comment also applied to this KPI. Andalusian sub-pilots had a positive value of 15.9% for LC use case. Depending on the scenario considered in Madrid, have a positive or negative value. Catalan sub-pilot presents a benefit of -3,5% and Madrid sub-pilot presents a benefit from -0,2% to -12,7% for scenarios 3 and 4.
- Change on pollutant emissions $PM_{2.5}$: A reduction was detected in the service RWW-LC in the Madrid sub-pilot for all the scenarios analyzed (Benefit between -0,4% to -22,7%). In other sub-pilots, such as the Mediterranean, the results were positive.

The **UK pilot** showed that the actual improvement in environmental factors was most likely due to other contextual factors, such as earlier speed and lane change maneuvers, which avoided flow breakdown due to better traffic flow, which therefore led to lower fuel consumption and noise reduction.

The **Italy** pilot considered the avoided congestions and are thus a consequence of impacts on traffic efficiency.

It showed consumption factors of up to 0,48l per km, and emission factors of up to 2,61kg CO_2/l.

Reducing traffic congestions due to less road accidents could additionally lead to savings of up to 245.000 l Diesel (174.000 for Gasoline) and to a reduction of more than 1000 tons of CO_2

The **Austrian** pilot also proved that Road Works Warning has the potential to produce positive environmental impacts from earlier speed and lane change maneuvers, avoiding congestions due to better traffic flow and therefore lower fuel consumption. Additionally, it was shown, that the use of C-ITS-tools lead to a very low range of speed-changes within the evaluated area, and consequently, CO_2 (and other)-emissions are constantly low

5.4. User Acceptance

This section provides a list of the road works warning use-cases evaluated from a user acceptance perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2, UK, Portugal, Czech Republic, Belgium-FL

5.4.1. Spain

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure
- RWW-RC: Roadworks Warning - Road Closure
- RWW-RM: Roadworks Warning - Roadworks Mobile

Quantitative Test Results (Surveys)

The initial questionnaire issued to pilot participants at the beginning of the trial collected information on: gender, age, level of completed schooling, occupation, monthly net incomes, profile as driver (if they have an own car, how many km/year they drive, if they are professional drivers, if they share transport and, finally, what is their level of knowledge about C-ITS and their thoughts about how they think they might change their driving behavior in response to the use-case.

After several weeks testing this system, participants provided feedback about the use of the C-ITS service. The structure of the questionnaire was as follows:

- General Service information (and expectation). The variables to analyze in this section are the next:
  - Perceived Efficiency taking into consideration a general perspective, environment, safety and traffic efficiency.
  - Perceived usability. This factor was analyzed using a system usability scale.
  - Workload. In this case it was used the Rating Scale Mental Effort (RSME).
  - Perceived usefulness and satisfaction through Van der Laan Scale.
  - Equity.
  - Willingness to pay.

Please, refer to Annex 3 – "User Acceptance Questionnaire" of the report from Spain [RD.3] for more information regarding the complete questionnaire used in the Spanish Pilot as well as the KPIs list that can be extracted from.

Together with the questions related to general driver and service information explained before, the participants also provided feedback about RWW service in particular, in two different phases:

- Before testing started (pre-test RWW specific questions)
  - Roads Works Warning will contribute to feeling at ease whilst driving
  - With Roads Works Warning service in my car I would feel more secure whilst driving
  - With Roads Works Warning service in my car I would distract my attention from traffic
  - I am comfortable providing my position data as part of the Roads Works Warning service
  - I would like to have Roads Works Warning service permanently in my vehicle
  - I would be willing to pay to have access to Roads Works Warning information
- After several weeks testing this system (post-test RWW specific questionnaire)

- Perceived effectiveness: Scores between 1 and 10 on the following:
    - Availability (Was the service available when the service was needed?)
    - Correctness (Was the information correct when the service was active?)
    - Completeness (Was the information complete when the service was active?)
    - Consistency (Was the service consistent and easy to understand when the service was active?)
    - Accuracy (Was the service accurate (geographical accuracy)?)
    - Up-to-dateness (Was the service up-to-date? Was the service available right on time?)

Moreover, participants were asked to identify the reasons if the effectiveness issues were lower than five points:

- Why service was not available? (Availability score < 5)
- Why service was not correct? (Correctness score < 5)
- Why service was not complete? (Completeness score < 5)
- Why service was not consistent? (Consistency score < 5)
- Why service was not accurate? (Accuracy score < 5)
- Why service was not up to date? (Up-to-dateness score< 5)

Other specific questions for the RWW service will have into account the next issues:

- Percentage of participants who notice the icon on the screen
- Perception frequency & usage frequency
- Perceived RWW acceptance

Some questions that were asked of the participants were to analyze the influence of the service on behavior and trip quality and to know the proposed improvements to the service:

- I feel using the service, it influenced in my behavior. If so, how?
- I think the services improved my overall trip quality. If so, how?
- What improvements would you introduce in the service?

Qualitative Test Results (Interviews)

Several specific questions have been asked to the participants during pre-tests and post-tests in the different sub-pilots. The following tables summarize the results of them.

Table 64 - RWW User Acceptance. SISCOGA Extended sub-pilot.

KPI		Estimated Value of KPI (%)
RWW acceptability (pre-test)	RWW will contribute to feeling at ease whilst driving	78% users believed that the RWW will contribute to feeling at ease whilst driving.
	With RWW service in my car I would feel more secure whilst driving	67% agree or totally agree with this statement.
	With RWW service in my car I distract my attention from traffic	74% thought that they would not distract their attention.
	I am comfortable providing my position data as part of the RWW service	Only 11% were not satisfied with sharing their location, around one third (30%) expressed a neutral opinion and 60% had no problem for sharing this information.
	I would like to have RWW service permanently in my vehicle	26% of them said that they are agree with it and 48% are totally agree). 18,5% of them provided a neutral answer and 7% were disagreed
	I would be willing to pay to have access to RWW information	Although around 40% is not in agreement to pay for it, half of the sample (47%) were neutral to this question
RWW acceptance (post-test)	RWW will contribute to feeling at ease whilst driving	11% of them expressed that they were not agreed with that. While 60% answered with a neutral answer and, 20% was agree and 9% was absolutely agree.

	With RWW service in my car I would feel more secure whilst driving	18% of them agreed with this sentence and 9,09% was totally agree. It is necessary to indicate that around 62,82% of them provided a neutral answer. Only 11% were opposed with this idea
	With RWW service in my car I distract my attention from traffic	Only around 4% considered that this service could distract their attention from their attention from the traffic, and 36% disagreed with this affirmation. Around 42% was neutral for this statement after testing the service. 18,18% was totally opposed
	I am comfortable providing my position data as part of the RWW service	30% believed that there is no problem for sharing their position. Around 65% provided a neutral answer and only 5% is not agreed with this idea
	I would like to have RWW service permanently in my vehicle	20% is totally agreed. Around 40% of respondents is agreed with that. Around 33% of them was neutral. Only 9% differed with this statement
	I would be willing to pay to have access to RWW information	Around half of the sample expressed themselves negatively and around 27% said that they were totally disagree. 42% answered "neutral". 11% of them considered to pay for having access to this service
Users that noticed the RWW icon on the screen		40%
RWW perceived frequency during the test		30% of drivers noticed the RWW sometimes while 12% saw it hardly ever and around 35% never appreciated the information
RWW perceived usage during the test		38% Never 9% hardly ever 24% Sometimes 18% Very often 9% Always
RWW influence in driver behavior		11% users judged that using the service had not influenced in their behavior. 60% of users felt neutral, and around 29% answered positively
RWW improvement in overall trip quality		29% agreed and 15% was totally agreed. Around half of the sample had a neutral opinion
RWW perceived effectiveness		60 points

Table 65 - RWW User Acceptance. Madrid sub-pilot.

KPI	Estimated Value of KPI (%)
RWW acceptability (pre-test)	65.42
RWW acceptance (post-test)	77.08
Users that noticed the RWW icon on the screen	62.50
RWW perceived frequency during the test	58.75
RWW perceived usage during the test	58.75
RWW influence in driver behavior	64.62
RWW improvement in overall trip quality	43.08
RWW perceived effectiveness	54.63

Table 66 - RWW User Acceptance. Cantabrian sub-pilot.

KPI		Estimated Value of KPI (%)
RWW acceptability (pre-test)	RWW will contribute to feeling at ease whilst driving	65% was neutral, 30% of user agreed, and 5% strongly disagreed
	With RWW service in my car I would feel more secure whilst driving	70% of users were neutral and 30% agreed
	With RWW service in my car I distract my attention from traffic	45% disagreed, 40% of users were neutral, and 15% agreed
	I am comfortable providing my position data as part of the RWW service	55% of users were neutral, 30% agreed and 15% disagreed
	I would like to have RWW service permanently in my vehicle	60% of users agreed, 20% were neutral, 10% disagreed and strongly disagreed and 5% strongly agreed
	I would be willing to pay to have access to RWW information	70% disagreed and 30% was neutral
RWW acceptance (post-test)	RWW will contribute to feeling at ease whilst driving	Neutral answer. Selected for 75% of drivers
	With RWW service in my car I would feel more secure whilst driving	selected by 70% of drivers
	I would like to have RWW service permanently in my vehicle	45% agree

	I would be willing to pay to have access to RWW information	40% disagree
Users that noticed the RWW icon on the screen		85% of drivers did not notice (50%) or are not sure (35%) if they saw the RWW icon or alert on their screen. 15% noticed it
RWW perceived frequency during the test		
RWW perceived usage during the test		Some of users used it very often (10%), but normally they used it sometimes (40%), or even never (30%)
RWW influence in driver behavior		
RWW improvement in overall trip quality		The general answers were "neutral", 70% of drivers, although the influence was lower in the behavior (10%) and greater in the trip quality (20%).
RWW perceived effectiveness	Availability	4,90
	Correctness	4,95
	Completeness	4,9
	Consistency	4,9
	Accuracy	5,2
	Up to dateness	5,15

Table 67 - RWW User Acceptance. Catalan sub-pilot.

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	52.9
Perceived usage during the test	51.4
Perceived effectiveness	64.7
Perceived acceptance	54.3
Perceived acceptance pre-test	51.0

Table 68 - RWW User Acceptance. Andalusian sub-pilot.

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	65.45
Perceived usage during the test	67.27
Perceived effectiveness	63.03
Perceived acceptance	63.94
Perceived acceptance pre-test	65.15

Table 69 - RWW User Acceptance. DGT3.0 sub-pilot. SISCOGA Extension. DGT3.0 participants

KPI		Estimated Value of KPI (%)
RWW acceptability (pre-test)	RWW will contribute to feeling at ease whilst driving	16% Disagree 5% Neutral 42% Agree 37% Totally Agree
	With RWW service in my car I would feel more secure whilst driving	Around 68% of them were agreed or totally agreed with this statement.
	With RWW service in my car I distract my attention from traffic	Around 57% of the drivers felt that they would not distract their attention from traffic while around 21% presented an impartial answer for this statement, and 21% of them contemplated that it could distract their attention
	I am comfortable providing my position data as part of the RWW service	11% were not satisfied with sharing their location, around 21,5% stated a neutral opinion and 68% did not mind.
	I would like to have RWW service permanently in my vehicle	26% of them said that they are agree with it and 31,58% are totally agree. 26% of them provided a neutral answer and 11% were disagreed.
	I would be willing to pay to have access to RWW information	Although around one third is totally disagree paying for it, one third was neutral to this question. Only a 10% is totally agree with the idea of charge for the service.
RWW acceptance (post-test)	RWW will contribute to feeling at ease whilst driving	Around 47% totally agree 32% Agree 16% Neutral
	With RWW service in my car I would feel more secure whilst driving	21% of the users agreed with this sentence and around 36% was totally agree. It is necessary to indicate that around 36% of them provided a neutral answer. Only 6% were opposed with this idea.

	With RWW service in my car I distract my attention from traffic	Around 21% thought that this service could distract their attention from their attention from the traffic, while 21% disagreed with this affirmation. Around one quarter was neutral for this statement after testing the service. 31,5% was total opposed.
	I am comfortable providing my position data as part of the RWW service	63% of the users felt that there is no problem for sharing their position. Around 26% provided a neutral answer and only a minimum percentage is not agreed with this idea (11%)
	I would like to have RWW service permanently in my vehicle	8% is totally agreed that they would like to have RWW information permanently in their vehicle. Around one quarter is agreed with that. Around 11% of sample was neutral. Only 6% differed with this statement
	I would be willing to pay to have access to RWW information	5% of the sample expressed themselves negatively and around 16% said that they were totally disagree. 47% answered "neutral". Around one third of them considered to pay for having access to this service.
Users that noticed the RWW icon on the screen		61%
RWW perceived frequency during the test		40% of drivers noticed the RWW sometimes and around 5% always. Around 40% never saw it while 16% hardly ever observed the RWW information
RWW perceived usage during the test		
RWW influence in driver behavior		17% judged that using the service had not influenced in their behavior. Half of users felt neutral, but 33% answered positively
RWW improvement in overall trip quality		Half of the sample was neutral and around 44% thought that it increased the value of the trips
RWW perceived effectiveness		54 points

Table 70 - RWW User Acceptance. DGT3.0 sub-pilot. SISCOGA Extension. HMI type participants

KPI		Estimated Value of KPI (%)
RWW acceptability (pre-test)	RWW will contribute to feeling at ease whilst driving	Around 70% of the drivers considered that the RWW will contribute to feeling at ease whilst driving. Around 20% of drivers were totally agree with this affirmation
	With RWW service in my car I would feel more secure whilst driving	Around half of the drivers were agreed or totally agreed with this statement. Around 40% provided a neutral answer.
	With RWW service in my car I distract my attention from traffic	Around half of the drivers felt that they would not distract their attention from traffic while around one third presented an impartial answer for this statement, and 20% of them contemplated that it could distract their attention
	I am comfortable providing my position data as part of the RWW service	20% were not satisfied with sharing their location, around one third stated a neutral opinion and half of the sample did not mind.
	I would like to have RWW service permanently in my vehicle	40% of them said that they are agree with it and 10% are totally agree. 12% of them provided a neutral answer and 12,5% were disagreed
	I would be willing to pay to have access to RWW information	80% is not in agreement to pay for it and 20% were neutral to this question
RWW acceptance (post-test)	RWW will contribute to feeling at ease whilst driving	30% of sample was agreed. Only 10% of them expressed that they were not agreed with that. While 60% replied with a neutral answer
	With RWW service in my car I would feel more secure whilst driving	20% of them agreed with this sentence and around 10% was totally agree. It is necessary to indicate that around 60% of them provided a neutral answer. Only 10% were opposed with this idea
	With RWW service in my car I distract my attention from traffic	Only 10% thought that this service could distract their attention from their attention from the traffic, while 40% disagreed with this affirmation. Half of the drivers was neutral for this statement after testing the service. 40% was total opposed.
	I am comfortable providing my position data as part of the RWW service	40% felt that there is no problem for sharing their position. Half of the sample provided a neutral answer and only a minimum percentage is not agreed with this idea (10%)
	I would like to have RWW service permanently in my vehicle	20% is totally agreed that they would like to have RWW information permanently in their vehicle. 30% is agreed with that. 40% of sample was neutral. Only 10% differed with this statement
	I would be willing to pay to have access to RWW information	20% of the sample expressed themselves negatively and one third said that they were totally disagree. 40% answered "neutral". Around 10% of them considered to pay for having access to this service.
Users that noticed the RWW icon on the screen		70%

RWW perceived frequency during the test		40% of drivers noticed the RWW sometimes, 30% of them saw it hardly ever and other one third never observed it
RWW perceived usage during the test		
RWW influence in driver behavior		10% judged that using the service had not influenced in their behavior. 70% of users felt neutral, but 20% answered positively
RWW improvement in overall trip quality		60% of the sample was neutral and one third thought that it increased the value of the trips
RWW perceived effectiveness		58 points

The following table conclude the user acceptance evaluation in the different sub-pilots related to specific questions about general service information (and expectation). Refer to Annex 3 – "User Acceptance Questionnaire" of the report from Spain [RD.3] to check the questions asked to the participants.

Table 71 - User Acceptance. Spain.

KPI	Pilot	Summary
Perceived Efficiency General	SISCOGA Extended	70 (naturalistic study)
	Madrid	57.78
	Bizkaia -Cantabrian	37,5% Neutral 33,75% Agree
	Galicia -Cantabrian	39,38 (HLN-WCW) 53,21 (HLN-EBL)
	Andalusian - Mediterranean	60.45
	Catalan -Mediterranean	67,86
	DGT 3.0 SISCOGA	Total: 73 HMI: 67,5 HMCU: 78,13
Perceived Efficiency-Safety	SISCOGA Extended	72 (naturalistic study)
	Madrid	64.44
	Bizkaia -Cantabrian	40% Agree (HLN-SV; HLN-TJA; RWW-RM) 30% Neutral (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	50,00 (HLN-WCW) 46,67 (HLN-EBL
	Andalusian - Mediterranean	68.18
	Catalan -Mediterranean	66,43
	DGT 3.0 SISCOGA	Total: 70 HMI:60 HMCU: 77
Perceived Efficiency-Environmental	SISCOGA Extended	77 (naturalistic study)
	Madrid	52.82
	Bizkaia -Cantabrian	38,35% Agree (HLN-SV; HLN-TJA; RWW-RM) 28,33% Neutral(HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	29,17 (HLN-WCW) 62,14 (HLN-EBL)
	Andalusian - Mediterranean	58.79
	Catalan -Mediterranean	54,29
	DGT 3.0 SISCOGA	Total: 74 HMI:73 HMCU: 75
Perceived Efficiency- Traffic efficiency	SISCOGA Extended:	70 (naturalistic study)
	Madrid	57.78
	Bizkaia -Cantabrian	38,33% Agree (HLN-SV; HLN-TJA; RWW-RM) 30% Neutral (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	38,33 (HLN-WCW) 55,24 (HLN-EBL)
	Andalusian - Mediterranean	70.3
	Catalan -Mediterranean	63,33

	DGT 3.0 SISCOGA	Total: 74 HMI: 65,33 HMCU: 80
Perceived Usability (System Usability Scale)	SISCOGA Extended:	74 (naturalistic study) Controlled tests: APR: 76 points EVA : 73 points EBL: 73 points
	Madrid	60.97
	Bizkaia -Cantabrian	43,5% Neutral (HLN-SV; HLN-TJA; RWW-RM) 26,5% Disagree (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	60,94 (HLN-WCW) 77,32 (HLN-EBL)
	Andalusian - Mediterranean	56.82
	Catalan -Mediterranean	52,57
	DGT 3.0 SISCOGA	Total: 70 HMI: 70,75 HMCU: 70,31
Workload (RMSE)	SISCOGA Extended:	23[8] (naturalistic study) Controlled tests: APR: 28 points EVA: 63 points EBL: 38 points
	Madrid	35.56
	Bizkaia -Cantabrian	30% Some effort (HLN-SV; HLN-TJA; RWW-RM) 10% Almost no effort (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	40,63 (HLN-WCW) 12,50 (HLN-EBL)
	Andalusian - Mediterranean	38.18
	Catalan -Mediterranean	29,86
	DGT 3.0 SISCOGA	Total: 17 HMI: 19 HMCU: 14,38
Perceived usefulness	SISCOGA Extended	56 (naturalistic study) Controlled tests: APR: 66 points EVA: 50 points EBL: 67 points
	Madrid	54.44
	Bizkaia -Cantabrian	43,89% scale 3 (HLN-SV; HLN-TJA; RWW-RM) 23,89% scale 4 (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	45,63 (HLN-WCW) 72,5 (HLN-EBL)
	Andalusian - Mediterranean	68.18
	Catalan -Mediterranean	66,86
	DGT 3.0 SISCOGA	Total: 51 HMI: 39 HMCU: 56,25
Perceived satisfaction	SISCOGA Extended:	48 (naturalistic study) Controlled tests: APR: 47 points EVA: 38 points EBL: 46 points

[8] RMSE scores are between 0 and 150. Low scores are better than big ones because it means that the participant did not need too much effort to use C-ITS services.

	Madrid	57.29
	Bizkaia -Cantabrian	43,89% scale 3 (HLN-SV; HLN-TJA; RWW-RM) 23,89% scale 4 (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	57,03 (HLN-WCW) 73,66 (HLN-EBL)
	Andalusian - Mediterranean	70.45
	Catalan -Mediterranean	61,43
	DGT 3.0 SISCOGA	Total: 46 HMI: 38,75 HMCU: 50
Equity	SISCOGA Extended:	46 (naturalistic study)
	Madrid	60.42
	Bizkaia -Cantabrian	32,5% Agree (HLN-SV; HLN-TJA; RWW-RM) 30% Neutral (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	76,56 (HLN-WCW) 89,28 (HLN-EBL)
	Andalusian - Mediterranean	52.27
	Catalan -Mediterranean	50,00
	DGT 3.0 SISCOGA	Total: 52 HMI: 54 HMCU: 51,25
Willingness to pay: percentage of users who are willing to pay	SISCOGA Extended:	7% of the users (naturalistic study)
	Madrid	22.22%
	Bizkaia -Cantabrian	General: 55% 30% (HLN-SV; HLN-TJA; RWW-RM)
	Galicia -Cantabrian	0% (HLN-WCW) 43% (HLN-EBL)
	Andalusian - Mediterranean	0% of users
	Catalan -Mediterranean	14% of users
	DGT 3.0 SISCOGA	Total: 12% HMI: 10% HMCU: 12,5%
Willingness to pay: 95% Price range of users willing to pay	SISCOGA Extended	3€ (naturalistic study)
	Madrid	6.33€
	Bizkaia -Cantabrian	3,6€ and 10€
	Galicia -Cantabrian	- (HLN-WCW) Range: 1 to 20€/month
	DGT 3.0 SISCOGA	Total: 4,34-1,65€ HMI: -- HMCU:3
Perceived effectiveness	SISCOGA Extended	Naturalistic study HLN Score: 63 points. RWW Score: 60 points. IVS Score: 60 points. SI Score: 77 points. Controlled tests: APR Score: 64 points EVA Score: 69 points EBL Score: 62 points

Conclusions

Focusing on **user acceptance** the final conclusions have been obtained:

- Perceived **Efficiency-General**: The general perceived efficiency was positive in all the pilots. It is worth highlighting a positive score of 70 points for the naturalistic study of SISCOGA Extended pilot and 78,13 (HMCU) for DGT3.0.

- Perceived **Efficiency-Safety**: The score of this KPI went from 30 (neutral values) to 77 points depending on the evaluated sub-pilot. Most of the results were positives.
- Perceived **Efficiency-Environmental**: The results of this KPI went from neutral (28,33) to positives values (77 points).
- Perceived **Efficiency-Traffic efficiency**: The lowest score received was 30 points (neutral value) and the best score was 80 points (HMCU, DGT3.0 sub-pilot).
- Perceived **Usability**: The scores of the perceived usability went from 26.5 to 77,32 points depending on the evaluated pilot. Note that there were more values with higher scores.
- **Workload (RMSE)**: The cognitive effort that the drivers needed to deal with the different C-ITS services went from almost no effort to too much effort depending on the sub-pilot and the service evaluated. The best score was for Bizkaia sub-pilot with 10 points, and the worse subservice evaluated was for EVA with 63 points for SISCOGA Extended sub-pilot. Probably, this value was because EVA service was evaluated in controlled tests where the participants had more workload due to the type of service being evaluated. In this case, they felt more mental effort because they were worried because of an emergency vehicle approaching and not for using C-ITS services.
- The perceived **usefulness** (from 23.89 to 72.5) and **satisfaction** (from 23.89 to 73.66) were well evaluated by users.
- **Equity**: The values went from 30 (neutral score) to 89.28 points in the use case HLN-EBL for Galicia sub-pilot.
- The percentage of users who were **willing to pay** went from 0 to 55% and the **price range** was between1 to €20/month.

In general, all perceptions went from neutral to positive.

5.4.2. UK

Use Cases considered

Evaluation	User Acceptance
Service	RWW LC
Research Question(s) or Use Cases evaluated.	RWW Use Case: Lane Closure or other restriction: How do end users rate this service and its influence on them? Quantitative Evaluation: Common set of User Acceptance used as agreed within InterCor Activity 4.4 using online survey (pre and post-test questionnaires to measure acceptability vs acceptance). Qualitative Evaluation: Driver interviews conducted following topic guide agreed in InterCor Activity 4.4. following testing.

Quantitative Test Results (Surveys)

Service	Road Safety	Traffic Efficiency	Environment
RWW	Minor indication of a change in behavior (See Qualitative results for more detail) 29% of participants reported slowing down the first time they saw the message. 29% of participants also reported increasing the distance to the car in front of them:	Over half of drivers felt that roadworks information was more effective in the vehicle. 88% of drivers would like advance information of roadworks, so they plan their journeys better.	Not measured Pollution levels may improve if RWW encourages smoother and less aggressive driving.

Qualitative Test Results (Interviews)

Service	Road Safety	Traffic Efficiency	Future Scenarios
RWW	"It gives you that anticipation and then you can change your behavior appropriately to slow down, maybe if you need to change lane, you have that perception of what's out there that could impact your journey."	"The message came up well in advance of those roadworks" "It made me aware that I would have to slow my speed." "I backed off a bit from the car in front and reduced my speed to wait and see what happens."	Most participants expressed they would be willing to receive roadworks messages if they were integrated into a Sat Nav. Information could be provided about how long the roadworks will be there for. Information could be provided about the type of roadworks that are taking place (e.g. carriageway restriction, local network, temporary etc.)

Further Qualitative Observations on RWW:

- Most participants did not find it distracting; they looked at the message 'for a second' and then looked back to the road

- Most participants reported that it was beneficial to receive the roadworks message, so they could be aware that there may be people and vehicles ahead. “It gives you that anticipation and then you can change your behavior appropriately to slow down, maybe if you need to change lane”
- The majority of participants slowed down the first time they saw the roadworks message
- One participant reported increasing the distance to the car in front of them: “I backed off a bit from the car in front and reduced my speed to wait and see what happens.”

Quotes from drivers:
All of these findings captured from the driver interviews were consistent with the user questionnaires but provided some extremely useful further insights into driver opinion and actions when experiencing the services for the first time.
“It gives you that anticipation and then you can change your behavior appropriately to slow down, maybe if you need to change lane, you have that perception of what's out there that could impact your journey.”
“The message came up well in advance of those roadworks”
“It made me aware that I would have to slow my speed.”
“I backed off a bit from the car in front and reduced my speed to wait and see what happens.”
“This message may ease driver frustration” which could have the effect of less aggressive driving and endemically safer driving behaviors.
Most participants reported that it was beneficial to receive the roadworks message, so they could be aware that there may be people and vehicles ahead.
“It gives you that anticipation and then you can change your behavior appropriately to slow down, maybe if you need to change lane”

Attitudinal Test Results

N/A

Conclusions

RWW provided a service to inform drivers of upcoming road works events including a distance countdown to and in roadworks, lane restrictions and speed limit information for the section of roadworks. The key impacts of the service were gleaned from subjective impact results summarized below.

Table 72 - RWW Impact Summary

Safety	Traffic Efficiency	Environment
Reduced speed combined with an increase in distance to the vehicle in front as indicated from the subjective impact from drivers is likely to have a positive safety impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of the roadworks.	Reduced speed is likely to have a positive traffic efficiency impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of the roadworks. Smoother driving will reduce the generation of shockwaves caused by heavy braking of drivers as they approach roadworks with lane restrictions.	A reduction of excessive speed & early lane changes when approaching roadworks could reduce queuing and hence reduce localized environmental impacts due to congestion.

Through interviews with drivers, the user acceptance team established a good subjective impact assessment of the service detailed in prior sections of this report.

Safety improvements showed strong potential from the deployment of the RWW service as a third of drivers surveyed said they would increase the distance between themselves and the vehicle in front as well as reducing their speed. The evidence for this was seen consistently in both surveys and interviews.

The responses showed that users valued the service and indicated that RWW increased their comfort and situational awareness. This should see a reduction in stress and possibly road rage, and therefore an increase in the safety of other road users.

The users also said that an audible warning would help prepare drivers in advance of roadworks. They also felt that the service should improve safety for other drivers and road workers alike and a third of drivers surveyed said they would increase the distance between themselves and the vehicle in front as well as reducing their speed.

Users believed that early presentation of RWW to truck drivers, in particular, would also see an increase in safety and reduced fuel consumption and emissions.

Care needs to be taken in the amount of information being presented. Too much all at the same time will be distracting as was found on one test. Major conurbations could present the driver with too many warnings because of the density of roadworks.

Smoother driving will reduce the generation of *shockwaves* caused by heavy braking of drivers as they approach roadworks with lane restrictions.

5.4.3. Netherlands

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Quantitative Test Results (Surveys)

The comparison between acceptability and acceptance was made using similar questions of the questionnaire posed before and after the driving experiment. The most interesting differences between the acceptability and acceptance are provided below.
When comparing the differences in the results of the acceptability and acceptance, some shifts in results were found. For instance, regarding the feeling of concern about unexpected delays, fewer participants seem to be sensitive after the test. Further, more participants indicated they felt the service was less useful after the test than before, although many kept a neutral position towards this statement after the test. The same holds for feeling more secure with the Road Works Assistant while driving. Similar results were found when assessing the potential effect on road safety as well as their change in behavior, implying that they indicated being more likely to adapt their speed before the test than after. The opinions on getting distracted shifted towards being more negative as well. The same applies for the willingness to pay for the service since fewer people appeared positive towards this after the test. Additionally, it appeared that participants were a bit less willing to share their position data after the test.
Conversely, after the test, participants indicated a slight increase in the trustworthiness of the information presented.

Perceiving and using the information

Among all participants, remarkably, 68.5% indicated that they did not see the road works warnings on the HMI, while 30.6% indicated having actively perceived the information. The rest claimed that they saw the information, but they did not pay attention to it.
When considering how many times the participants saw the information on the HMI, 50.8% indicated not having seen the information during the test, 21.8% indicated seeing the information 2-3 times during the test, 16.1% only saw the information once during the test and 5.6% did not recall exactly how many times. Considering the use of the presented information, 25% indicated using the information (almost) always, 10.5% indicated to use it sometimes, 9.7% used it regularly, while 12.9% did not recall using the information. Lastly, 41.9% indicated that they did not use the information.
Of all participants that indicated that they used the information during the test (45.2%), the use of the information differed (multiple answers were possible). 20% indicated that they used the information during the entire test drive, 18.8% indicated that they used the information mostly during disruptions, and 2.4% mostly during unknown routes. Around 8% of the participants indicated not recalling how they used the information.
Of all participants indicating that they did not use the information during the test (41.9%), 65.4% indicated that they did not see the information presented. Moreover, 28.8% indicated that they did not require the information and 5.8% indicated not knowing that this information was provided in the car, while 3.8% claimed that they prefer other sources of information or that they felt uncomfortable.

Influence of the service on behavior and trip quality

The influence of the RWW on the behavior and trip quality of the participants was measured using seven statements, which the participants were asked to rank between ‘totally disagree’ and ‘totally agree’.

When considering the trip quality, the majority of the participants indicated feeling more at ease while driving with the HMI showing the road works warnings, a considerable amount of people remained neutral towards this, while only a small fraction of the participants indicated not feeling so. Similarly, when considering how the RWW affected the feeling of ease when negotiating road works situations, the opinions were more in favor of being positive, however many indicated being neutral, having no opinion or disagreeing. When asked whether driving with the RWW made the participant feel more secure, the opinions were more divided; still the majority indicated feeling more secure, but many participants indicated feeling neither positive nor negative effects. Lastly, the majority of the participants indicated that the RWW made them more alert in road works situations.
For the changes in behavior, the effect of the RWW on the participants' vehicle speed and distance to their predecessor was considered. Although the majority of the participants indicated that they immediately increased the distance to the car in front of them after receiving information from the RWW, still a large proportion claimed to be neutral or having no opinion on this. Lastly, the effect on their speed adaptation was almost evenly split between 'neutral' and 'agree'.

Perceived value of the service

When considering the perceived value of the service, the majority of the participants indicated that they found the road works warning assistant service both useful, clear to understand, trustworthy, and that they were satisfied with the provided information. When considering the timeliness of presenting the information, the opinions were mainly positive, while a relatively large proportion of participants claimed to have no opinion on this.
Regarding having an effect on the improvement on road safety, the majority of the participants agreed with the statement. A less positive effect was found when assessing whether the information presented on the HMI provided more value than roadside information, where opinions were divided, and the majority did not agree to that or was neutral. Lastly, when considering recommending the service to others, most of the participants were positive but also a large proportion remained neutral or expressed no opinion while some less disagreed to that.

Improvements to the service

For this information, several participants claimed that there was no information on their screens. An interesting comment given by one participant was that they would prefer to listen to the information than to read it. Another comment was that they would prefer the position of the screen to be on their eyes level so that it is easier to look at it. Some participants indicated the desire for more realism in the provided information on the HMI; where the displayed information was too abstract. As before, it was also mentioned that the information from the VMS signs above the highways did not match the information on the HMI. Someone also expressed the preference to have simultaneously both three categories of information the HMI (for maximum speed, lanes and roadworks). Some participants also found the differences in the provided information regarding the speed limit, lane restrictions and road works unclear. As such, it is recommended to make a clear distinction between the three. Once more it was mentioned that the information should be presented earlier so that there is time for reaction, e.g. to choose an alternative route. Thus, it is clear from the comments made by the participants that a number of improvements to the service are needed in order to make it more useful and attractive.

General Remarks

Other remarks regarding the service are as follows. The majority of the participants indicated the desire for the HMI (with the RWW service) to be available permanently in their vehicle. When considering the provision of the participants' position data during the use of the service, the opinions were mostly positive, with the largest proportion agreeing to share this information (followed by a neutral and a negative opinion). Lastly, the large majority of the participants indicated that they would not be willing to pay for the service.

Conclusions

Regarding the RWW service, there was a considerable number of participants who indicated that they were actually not able to observe the information presented. This is probably because during the second series of tests, much fewer roadworks was actually in progress than expected, thus there were no relevant messages for the drivers. As a result, regarding the frequency, most of the participants indicated that they never or almost never saw or used the presented information. Those who claimed to have seen and used the information, they did it either in every ride or mainly during disruptions. No significant effect was noticed with respect to their reaction to the message presented for increasing the distance to the car in front of them or their speed adaptation. In general, participants were positive regarding the usefulness and trustworthiness of the service. Some participants found the differences in the provided information regarding the speed limit, lane restrictions and road works unclear.

5.4.4. Czech Republic

The user acceptance questionnaire was divided into several parts:

- Driver profiles
- General questions
- Questions before an evaluation drive
- Questions after the evaluation drive

During the evaluation, emphasis was placed on the selection of tested drivers, which considered age, education and driving experience. This information was obtained through a questionnaire on the driver's profile and general questions. Subsequent questionnaires before and after the evaluation process included questions dealing with the general opinion of C-ITS. The next part of the questionnaire focused on the specific test scenario. The three main questions about the acceptability of the HMI and RWW, safety and traffic efficiency were very positive, most drivers had a positive opinion and would like information on warnings before working on the road. Drivers also thought that such information would increase safety and ensure the flow of traffic on the road.
The question related to whether drivers registered roadworks warning was evaluated as positive. 84% of the evaluated drivers indicated the timeliness of registration on time in the questionnaire, 8% described it as too late and 8% as too early.
The next questions focused mainly on perceived usability, usefulness, efficiency, and satisfaction. The answers in this section were mostly positive. The question of what drivers thought of C-ITS was mixed, with a neutral overall result. The vast majority of drivers indicated that they thought they had more time to prepare for a road event and that the information was useful to them.

The overall results of user acceptance are considered positive in terms of C-ITS. The drivers always said that the information was successfully shown, was useful, it increased an overview of the situation while approaching road works. Information about road works also increased an overview of the road bottleneck. However, several drivers did not focus on the bottleneck beginning in terms of C-ITS. The drivers would often welcome some more information about road works, typically its length and the relevant speed limit.

5.4.5. Belgium/Flanders

Use Cases considered

RWW: The drivers were given a generic common RWW.

The objective of the warning was to help drivers to drive and to approach the work-site more safely. This warning should reduce the incidents (accidents) when approaching road works.

Quantitative Test Results (Surveys)

An acceptability and an acceptance survey was conducted during the pilots. Due to practical reasons the acceptance survey focused more on the total C-ITS service instead of a specific warning or service. The most interesting results are presented within this section.

Table 73 - Acceptability results on RWW (before using the service)

Road works warning assistant

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I am concerned about the unexpected events linked to road works on my route.	2,53%	17,05%	16,42%	46,95%	17,05%
I would like to receive information on the road works on my route during my journey.	0,21%	0,63%	6,96%	57,59%	34,60%
An in-vehicle “roadwork warning assistant” would be helpful.	0,00%	1,06%	6,99%	56,57%	35,38%
With a roadwork warning assistant, I would feel more comfortable while driving.	0,21%	8,26%	24,36%	49,15%	18,01%
A “roadwork warning assistant” would make me feel safer while driving.	1,06%	11,44%	31,36%	40,04%	16,10%
With a "Roadwork warning assistant" available, I would be less concerned about the works (and the resulting disturbances)	0,00%	6,82%	16,42%	57,14%	19,62%
A "roadwork warning assistant" would distract my attention from traffic.	9,13%	45,22%	29,72%	14,44%	1,49%
Thanks to a road works warning assistant, I would be more alert when approaching road works	0,43%	3,19%	12,55%	60,00%	23,83%

Road works warning assistant

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Whenever I receive information from the “Road Works Warning Assistant”, I immediately reduce my speed.	0,21%	9,17%	21,75%	52,24%	16,63%
Whenever I receive information from the Road Works Warning Assistant, I immediately increase my distance from the previous vehicle.	0,64%	6,64%	20,34%	54,39%	17,99%
I have no problem sharing my location data for the benefit of a "Roadwork warning assistant".	1,92%	5,13%	13,46%	50,00%	29,49%
I always want to be informed in my vehicle of road works on my route.	0,43%	3,43%	11,37%	54,94%	29,83%
I am willing to pay for information on road works	30,84%	39,61%	19,70%	7,49%	2,36%

The results of the acceptability survey showed that expectations of RWW were rather high. It was surely stated that it would be helpful, give more comfort while driving, more awareness and certainly would have an influence on the speed reduction. Although the benefits of RWW were indicated by the respondents, there was no willingness to pay for the information.

The drivers indicated that they received RWW the most compared to other warnings, however 24% stated that these warnings were not relevant to them while driving. This could be explained as some warnings were relevant to drivers in the opposite direction due to a bug in one of the test waves.
The drivers were asked if the information had any impact on their driving. When the entered road work warnings, 1 out of 2 drivers stated that they changed their driving behavior.

Qualitative Test Results (Interviews)

Interviews with drivers were also conducted, but some remarks were given on RWW by the drivers:

- Too many irrelevant warnings from other roads.
- Warnings of road works that had not yet started
- Warnings of road works or incidents in the opposite direction
- Only warnings of some road works when you are in the neighborhood of the road works and not before.

Conclusions

Overall RWW was rather well accepted, however due to some errors and bugs, the acceptance of RWW was influenced negatively. Nevertheless, the overall performance quality of the C-ITS service was measured. The perceived quality of the service was measured by four parameters: understanding the information; accuracy; relevancy and reliability.

66% of the respondents stated that the information was good and understandable. On the accuracy of the information, 46% agreed that it was accurate but 22% had a neutral opinion and around 20% did not find the information accurate enough.
62% stated that the information was relevant and 59% found the service information reliable. It was noticed that still a large group of the respondents remained neutral about this.

5.4.6. Austria

The questionnaire, where the answers were used for evaluation, contained three parts:

- The pre-test questionnaire included the definition of the profile sample for the drivers who participated in the evaluation test drives.
- In addition, the pre-test questionnaire included questions to define how much participants are already informed about C-ITS.
- Then the actual drive took place, and following up on this, a post-questionnaire was provided to participants with the aim of obtaining main opinions and feelings about how they perceived the use and information used during the pilot drive.

In a later stage, the, results of the questionnaire are evaluated and presented.
This evaluation considers the calculation of different (general) service information; with the specific services through C-Roads phase one - that is Hazardous Location Notification (HLN), Road Works Warning (RWW) and Signalized Intersection (SI).
As for User-Acceptance concerning RWW, the following results can be seen:

Pre-test Questions: Road Works Warning (RWW)

- Question 1: Roads Works Warning will contribute to feeling at ease whilst driving. There was no “Disagree” of whatever kind, three voted “Neutral”, a majority of eleven persons “Agree” and four even “Strongly Agree”, bringing it to an average score of 3,87.
- Question 2: With Roads Works Warning service in my car, I would feel more secure whilst driving.
  This question received exactly the same scoring, and consequently also an average of 3,87.
- Question 3: With Roads Works Warning service in my car, I would distract my attention from traffic.
  This question received an average score of 2,4 – having one “Strongly Disagree”, nine “Disagree”, three ”Neutral”, two “Agree” and no “Strongly Agree”.
  Though this seems to be a very low value, it is not expressing rejection of RWW-services in the car. In fact, it is stating that “distraction of attention” is not a severe issue, and consequently, it should be seen as a support of RWW-services in cars. If this questions was scored “reverse” (with “Strongly Agree” as 1 and “Strongly Disagree” as 5), then the score would be 3,6 – which is a good, comparable number.
- Question 4: I am comfortable providing my position data as part of the Roads Works Warning service to Road Operators (i.e. ASFINAG).
  With no “Strongly Disagree” and only one “Disagree” versus eight “ Agree” and even four “Strongly Agree”, the answers to this statement got a high-score of 4,0.
- Question 5: I am comfortable providing my position data as part of the Roads Works Warning service to Car manufacturer.
  One “Strongly Disagree” and four “Disagree” show a relative weak total agreement, though there are still seven “Neutral” and three “Agree”. The average score of this is therefore - with 2,8 - slightly negative.
- Question 6: I would like to have Roads Works Warning service permanently in my vehicle.
  There is a significant agreement to this statement, with no “Disagree” of any kind, and only five “Neutral”, but nine “Agree” and one “Strongly Agree”.
  The average score is 3,73.

- Question 7: I would be willing to pay to have access to Roads Works Warning information.
  "Willingness to pay" was never something to be strongly supported and the answers to question are underlining this, again.
  While three "Strongly Disagree" and six "Disagree" (so a total of 60%), three are "Neutral" and only three persons "Agree" (no one with "Strongly Agree").
  The average score is a clear low 2,4.

Summary:

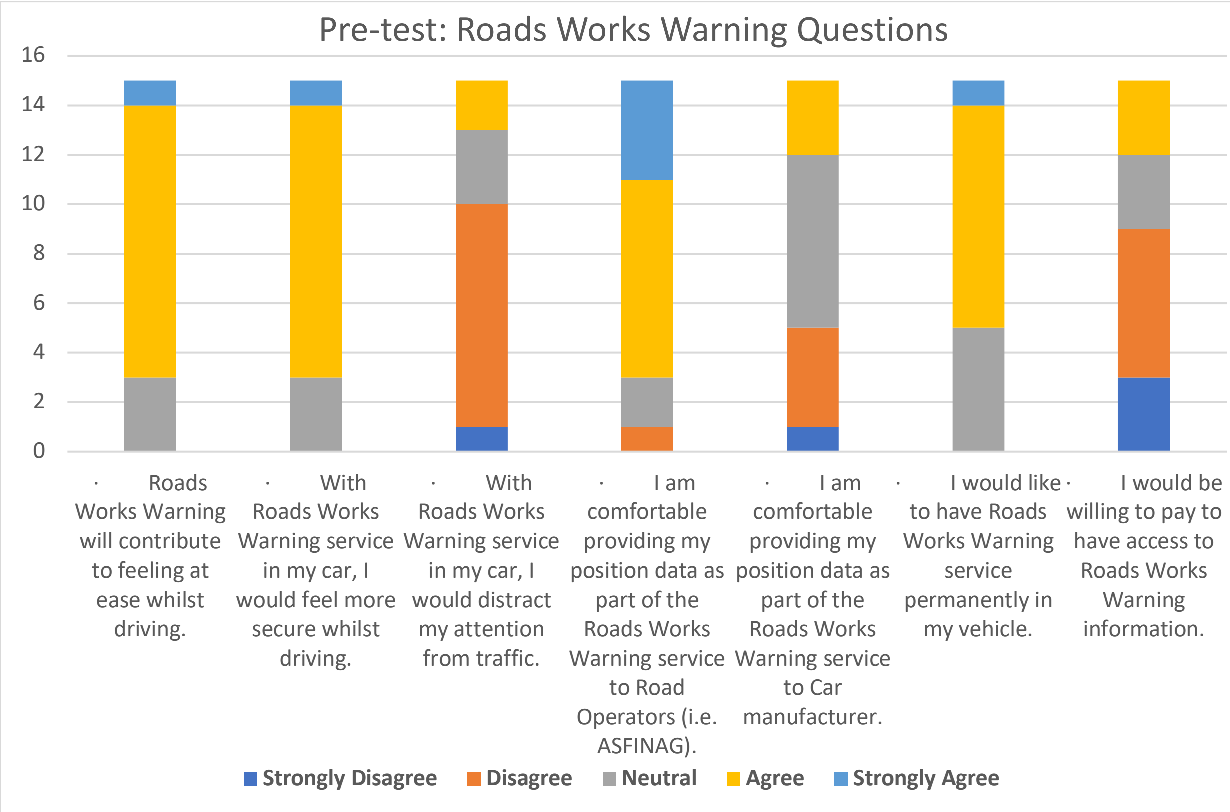


Figure 16 - Pre-test: Roads Works Warning Questions

Question	Average score
Roads Works Warning will contribute to feeling at ease whilst driving.	**3,87**
With Roads Works Warning service in my car, I would feel more secure whilst driving.	**3,87**
With Roads Works Warning service in my car, I would distract my attention from traffic.	**2,4**
I am comfortable providing my position data as part of the Roads Works Warning service to Road Operators (i.e. ASFINAG).	**4**
I am comfortable providing my position data as part of the Roads Works Warning service to Car manufacturer.	**2,8**

I would like to have Roads Works Warning service permanently in my vehicle.	**3,73**
I would be willing to pay to have access to Roads Works Warning information.	**2,4**

5 out of 7 questions show a very positive attitude towards RWW-services in the car, with scores high in between 3,5 and 4.

Only statements concerning privacy ("providing position data to OEMs") and payments ("willing to pay to have access") are generally not very much supported and show a tendency of disagreement.

Questions after Trial: Road Works Warning (RWW)
Within this set of questions, which had to be answered after the evaluation test drive, the following results were provided in regards to Road Works Warning

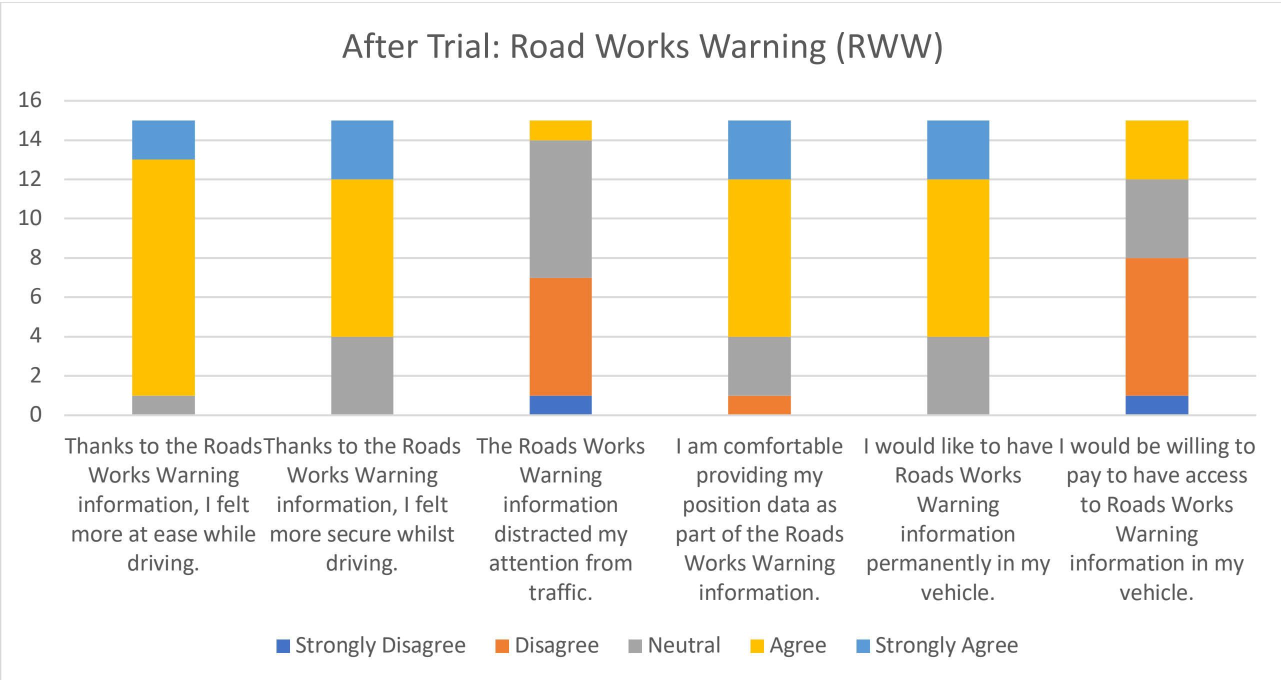


Figure 17 - Answers after Trial: Average score of Roads Works Warning Questions

Specific questions: Roads Works Warning	Average score
Thanks to the Roads Works Warning information, I felt more at ease while driving.	**4,07**
Thanks to the Roads Works Warning information, I felt more secure whilst driving.	**3,93**
The Roads Works Warning information distracted my attention from traffic.	**2,53**
I am comfortable providing my position data as part of the Roads Works Warning information.	**3,87**
I would like to have Roads Works Warning information permanently in my vehicle.	**3,93**
I would be willing to pay to have access to Roads Works Warning information in my vehicle.	**2,6**

Figure 18 - Average Score After Trial: Road Works Warning

The feeling of ease while driving was the one with the highest quote – 4,07, but also the score for the feeling of being safe and secure got a remarkable high quote of 3,93. Also, the rest of the statements got a high agreement – again with the exception of "Willingness to pay", where the majority was rather negative in doing so.

The similarity of questions, which were asked to the drivers before and after the drives, gave the possibility to have a comparison between these two set of questions and to see if there are any significant changes.

So, for each of the four evaluated services, a comparison was performed based on the feedbacks and questionnaires received from the participants.

Comparison of Questions Before and After: Road Work

Table 74 - Comparison of Questions Before and After Trial: Road Work

Specific questions: Roads Works Warning	Before	After	Delta
Thanks to the Roads Works Warning information, I felt more at ease while driving.	3,87	4,07	0,2
Thanks to the Roads Works Warning information, I felt more secure whilst driving.	3,87	3,93	0,06
The Roads Works Warning information distracted my attention from traffic.	2,4	2,53	0,13
I am comfortable providing my position data as part of the Roads Works Warning information.	4	3,87	-0,13
I would like to have Roads Works Warning information permanently in my vehicle.	3,73	3,93	0,2
I would be willing to pay to have access to Roads Works Warning information in my vehicle.	2,4	2,6	0,2

As for RWW, there is clear tendency that the general feeling towards the use of this information increased.
Interestingly, the willingness to provide position data felt from 4 to 3,87, but all other number increased.

5.4.7. Summary

Of the drivers that noticed the RWW information during testing it was found by the majority to be useful. The participants said it increased awareness and helped them to be alert and prepare for the roadworks, with 83% of drivers feeling more alert in Flanders for example. It was reported in some countries that drivers found RWW to be more effective than roadside signage. Drivers also stated that getting advanced information would help them to plan their journey better. In Austria, 5 out of 7 questions showed a very positive attitude towards RWW-services in the car, with scores high in between 3,5 and 4.

A large number of participants thought that it would improve safety and would like the service to be available permanently and made them feel more at ease whilst driving.

The majority of participants were unconcerned that position data should be shared with the service provider with 79% of Belgian users saying they had no problem with data sharing. However, willingness to pay for the service in its own right was again quite low in the range 10-30%. In a sample of 15 drivers in Austria, willingness to share data was typically high with road operators but noticeably lower with respect to car OEMs.

Spain's User's opinions of RWW differed greatly from before and after testing began. Most felt that before testing, that RWW would help them to feel more at ease and more secure, but this reduced significantly after testing. This feeling was reflected in the results from other nations. There is a variety of reasons for the fall in confidence, which include a lack of information about the roadworks to the size of text on the HMI.

Having said that there was a drop in acceptance, there is still a great deal of enthusiasm for the service with pilot participants from the Netherlands stating "…they found the road works warning assistant service both useful, clear to understand, trustworthy …", and the UK noting "Most participants expressed they would be willing to receive roadworks messages if they were integrated into a Sat Nav".

In general, the perceived efficiency and effectiveness of the service was high with around two thirds of Spain's users agreeing. Just over two thirds of Belgian drivers reported reducing speed and increasing the gap between themselves and the car in front. 29% of UK drivers surveyed said they would increase the distance between themselves and the vehicle in front as well as reducing their speed. In Flanders about 50% stated that they changed their driving behavior.

Drivers reported slowing a little and/or increasing the space between themselves and the car in front. In Madrid 65% of drivers felt it had an influence on their behavior and 69% of Belgian users said they immediately reduced their speed and 72% increased the distance between themselves and the vehicle in front.

Although testing of RWW was limited, 29% of participants in the UK reported slowing down the first time they saw the message and the same number was reported for increasing the distance to the car in front of them. During interviews some users believed that early presentation of RWW to truck drivers, in particular, would also see an increase in safety and reduced fuel consumption and emissions.

Some participants from the Netherlands found the differences in the provided information regarding the speed limit, lane restrictions and road works unclear in terms of the HMI.

But in some countries, it was reported that drivers found RWW to be more effective than the roadside signage.

In some cases in Spain about a fifth of drivers found it distracting but overall most were unconcerned or not distracted by the service. After testing, users from the Netherlands felt it was more distracting than when surveyed before. Whereas most UK participants did not find it distracting; stating at one interview that "they looked at the message 'for a second' and then looked back to the road". A low distraction score was seen in the Austrian Pilot.

The majority of the Netherlands participants agreed with the statement that RWW has an effect on the improvement on road safety. The RWW service was well accepted among

Belgian users, however due to some errors and bugs the numbers were arguably lower that they could have been.
The majority of participants in the Netherlands indicated the desire for the RWW service to be available permanently in their vehicle.
A large majority of the participants indicated that they would not be willing to pay for the service, with only a small percentage indicating a positive response in terms of willing to pay which has been seen for other services.
In Madrid 65% of drivers felt it had an influence on their behavior and 69% of Belgian users said they immediately reduced their speed and 72% increased the distance between themselves and the vehicle in front.
For a significant number of users RWW helped to improve their feelings of comfort and being at ease while driving. In Spain on the SISCOGA Extension, around 70% of the drivers considered that the RWW service will contribute to feeling at ease whilst driving. 67% of Belgian users felt more comfortable, with 77% saying they would be less concerned about roadworks when armed with this information. This was also seen pre and post test in the Austrian pilot with high scores for both feeling at ease and secure.
Czechia drivers would welcome more information about road works, typically its length and the relevant speed limit (which was provided in HMIs in other pilots and well received by users). This was echoed by UK drivers, where 88% of drivers would like advance information of roadworks, so they can plan their journeys better.
Other feedback that could help increase acceptance and reduce distraction included:

- Too many irrelevant warnings from other roads.
- Warnings of road works that had not yet started
- Warnings of road works or incidents in the opposite direction
- Only warnings of some road works when you are in the neighborhood of the road works and not before.

An interesting comment given by one participant from the Netherlands was that they would prefer to listen to the information than to read it. Another comment was that they would prefer the position of the screen to be on their eye level so that it is easier to look at it. Some participants indicated the desire for more realism in the provided information on the HMI; where the displayed information was too abstract.*
*Further detailed aspects around HMI and Quality of Service are more fully discussed in the Functional Evaluation section of this report which follows.

5.5. Functional Evaluation

This section provides a list of the road works warning use-cases evaluated from a functional evaluation perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, UK, Austria, Czech Republic, Belgium-FL

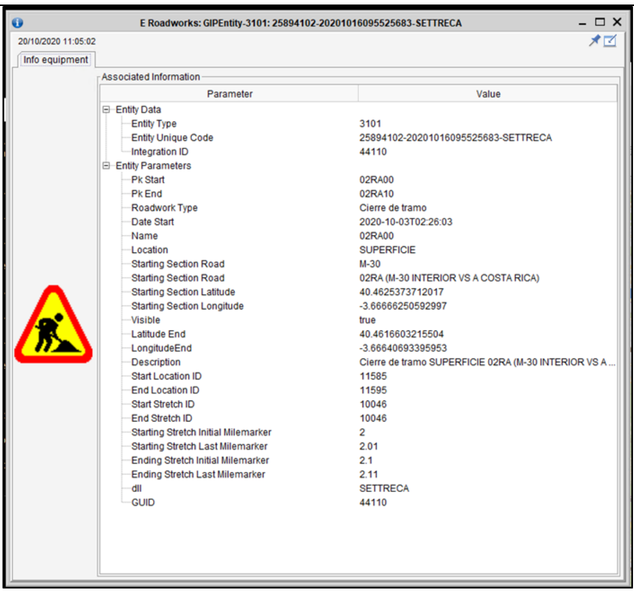
5.5.1. Spain

- RWW-LC: Roadworks Warning - Lane Closure
- RWW-RC: Roadworks Warning - Road Closure
- RWW-RM: Roadworks Warning - Roadworks Mobile

Table 75 shows the functional evaluation of the lane closure use-case. Refer to [RD.3] the final evaluation result of Spain for information on the other use cases.
Table 75 details the feedback obtained from the implementation in the Madrid and Andalusian sub-pilots.

Table 75 - RWW-LC Functional evaluation. Spain. Madrid sub-pilot

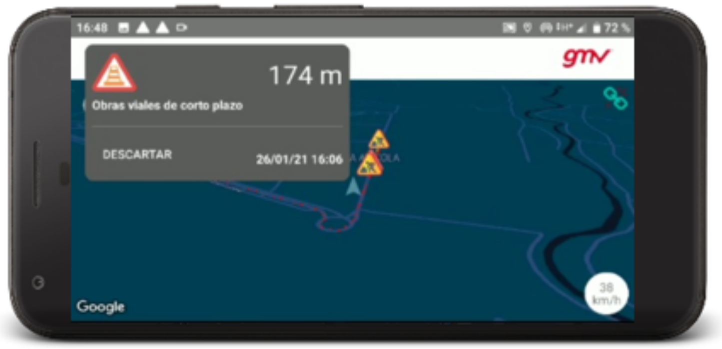
Service	RWW (LC)
Lessons Learned	[GMV deployment] The service RWW-LC was implemented in all the OBUs and HMIs agreed on the project. These developments together with the possible logs of HMI and OBU enabled analysis of all the impact areas, technical KPIs and user acceptance. A web application was implemented to store the logs for the analysis. Although initially it was not planned to have Internet on the OBUs for the project, later, we needed to have an Internet connection in order to send the logs to the server (HMI and OBU logs about the events received from the RSUs) for the subsequent analysis and also to update the security certificates. It was a challenging challenge. To fulfil these functionalities, the HMI was used as a bridge to provide the Internet connection to the OBU. For this, a Wi-Fi zone of the Smartphone was activated and the drivers were advised not to forget to activate this. As lessons learned, include a modem with an integrated SIM or modem with hub connection would simplify the current implementation. Another option could be to manage the certificates through the network itself (send the certificates through the RSUs to the OBUs). [INDRA hub deployment] In this case the implementation had two sources of information: 1. Sitrem and Settre as internal information events confirmed by Calle-30 2. Inrix information events The problem with having different data sources was that the same information could be duplicated, so it had to be processed, to send key and reliable information to the drivers. The following picture shows an image of a roadworks event registered at the C.ITS HUB



[Kapsch deployment]
RWW is a specific service that is quite sensitive for drivers. One of the project goals was to demonstrate that once the driver received this information, they became immediately aware and cautious about the restrictions they were about to find in front of them. Inherent advantages of ITS-G5 communications was to make it possible to inform about those incidents without the need of any DMS infrastructure available. It was important, then to define a large detection zone in order that drivers were warned with enough advance time for them to adapt driving to the expected road conditions.
Kapsch deployed this pilot with a full set of field equipment that was key to fulfilling project requirements. At Gateway level, receiving all sets of messages from different services from TMC provided the capability of disseminating to appropriate RSUs in order to reach with RWW information to all sets of OBUs available in the pilot. One challenging issue was properly defining accurate segments to accurately inform drivers in real time. ITS-G5 short range communications allowed minimum latency to reach driver with expected information. Full standard compliance for ITS-G5 provided interoperability with future systems deployed.
Already detected and managed existing Car2Car systems available in market and deployed in vehicles. During the pilot care was taken to provide consistent information to those users, not involved in pilot scope.

HMI*

The Smartphone as HMI for the GMV deployment in the Madrid pilot was the main device used by the participants to receive feedback about the user acceptance for the RWW-LC service. The GMV C-ROADS App showed the road works warning, lane closure notification and the distance to reach the event. Also, the end date of validity of the event was shown. These data were appreciated by the participants.



Kapsch deployed in all test vehicles included in this Pilot with an OBU and an HMI done with a tablet that is paired through a Bluetooth connection. All tablets had an app devoted to HMI purposes that provided all received info to the driver. For RWW service, the next screenshot shows an example of how this information was provided to the driver.

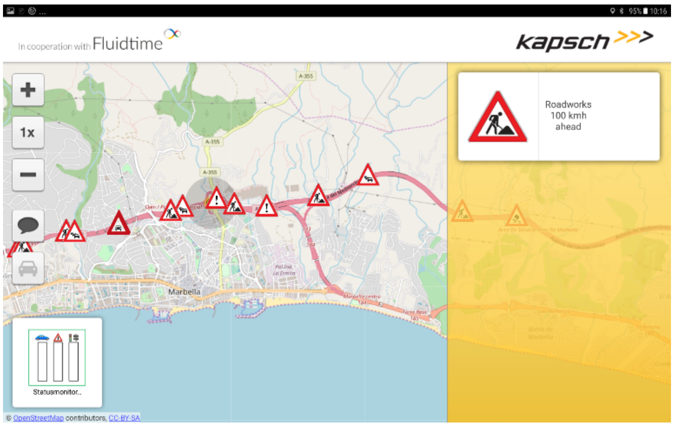
	
Quality of the Service	If the event has a trace/eventHistory, the event was shown to the user in the HMI when the vehicle entered the zone. If the event did not have trace/eventHistory, it was shown within the relevanceDistancevalue. The user had enough time to react. In some instances, the location received from different sources for the same event were a little different, which could be distinguished. In these cases, the information was sent separate incidents. In general terms, users behavior was affected by this notification in different ways: Paying more attention to the events Decreasing the velocity to change the lane before the area of the event Paying more attention to the traffic status and the road Trying to drive being aware and more confident Users feel more confident in their driving behavior without unexpected events.
Added Value of the Service	Participants of GMV C-ROADS application expressed a common added value for all the services: notifications with text-to-speech could be more beneficial instead of a sound notification. Anyway, the sound alerted the user and the information provided on the HMI was enough to identify the event with a simple glance. As an added value of the service, the HMI showed the distance to reach the event. The Kapsch HMI provided text-to-speech capabilities. Simply touching selected event or IVS, HMI read the associated text.

Table 76 - RWW-LC Functional evaluation. Spain. Andalusian sub-pilot

Service	RWW-LC
Lessons Learned	<u>Nature of the messages</u>: Regarding the nature of the messages, in the case of the RWW-LC use case, we tested the service with real warning messages taking the opportunity that the concessionaire is carrying out construction works in the road section under test, and more specifically in the tunnels. This provided the opportunity to test the performance of the service in a real situation. <u>Deployment of RSUs</u>: since it was a brownfield site, the road-side equipment was installed on existing infrastructure, mainly CCTV and lighting poles, and connected to existing power supplies at ITS cabinets or lighting switchgear cabinets. This fact was a constraint when placing the RSU that prevented 100% coverage in the section, as originally designed. It is estimated that in the case of a greenfield, the positioning of devices can be more flexible, and the objective of the design can be achieved more accurately. Another constraint was the use of existing variable message signs (VMS) for the installation of RSUs. The possibility of installing RSUs on existing VMS gantries was not feasible, since it involved a modification of the structure characteristics, and the adaptation and certification of the construction project would be necessary, an option that was not contemplated in this installation. <u>Lessons learned from drivers</u>: in general, for all the deployed services and use cases, when the events are downloaded from the RSUs, all the warning icons messages that apply to the test section were shown on the global map, which in some cases implied an excessive density of messages that tended to be distracting to the driver. Several drivers suggested showing only the events that coincide with the direction of travel of the vehicle. Driver distraction was a key issue and an important safety concern for road operators to support the mass roll of out of these new services.

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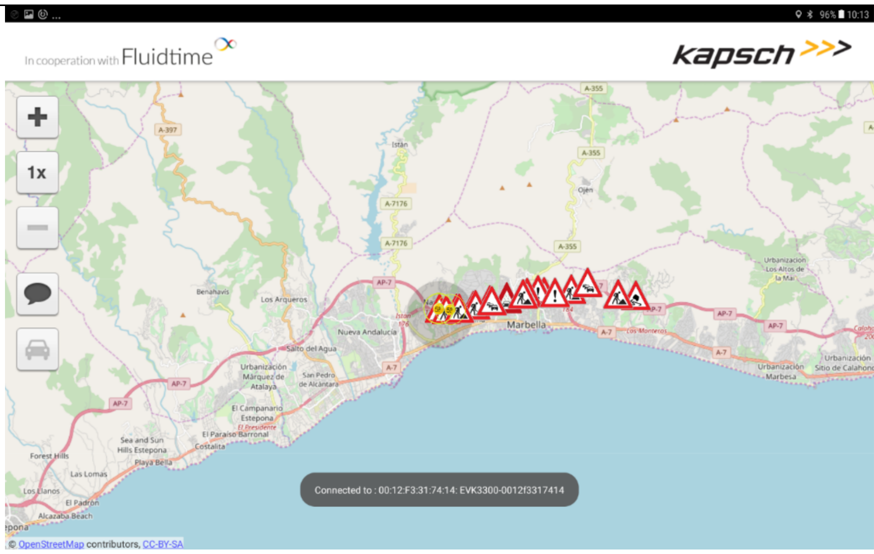
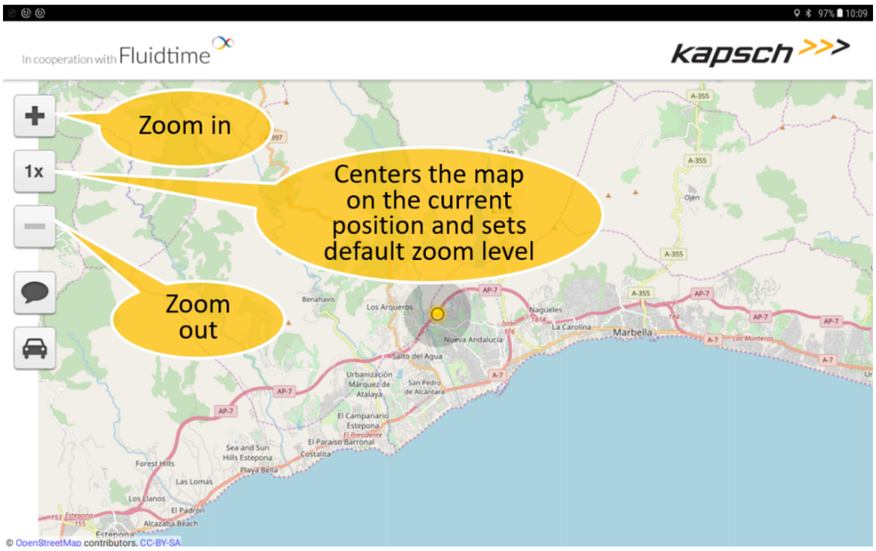
<tr><td></td><td>

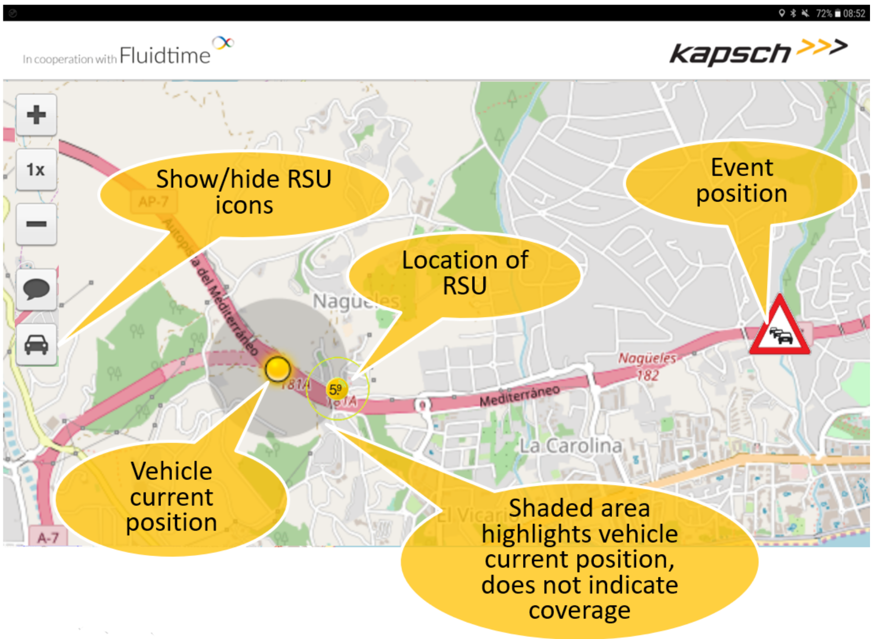
<u>Cellular Communication module</u>: the OBU offered the possibility to be equipped with a cellular module to provide back-office connectivity for the remote download of logs, version upgrades or security certificates handling. In this case, this function was not incorporated, so it was extremely difficult to update the software and handle the security certificates. In fact, the security layer was not activated in the on-board units due to the impossibility of updating the certificates on a regular basis. This was an improvement point that must be addressed in future versions.
<u>Accuracy of locations</u>: The accuracy of the alignment of the messages with the start and end of the works area depended to a great extent on the accuracy of the information provided by the back office. Consideration should be given to using a back-office system that has a georeferenced map. </td></tr>
<tr><td>HMI*</td><td> The OBU App and Graphical Interface was designed just for testing and demonstration purposes. The OBU App must not be used for operational safety support in vehicles on the road. There was no guarantee that the displayed information on the tablet was linked to real situations/events on the road. The driver always must focus on the road and must not rely just on the information from the OBU Graphical Interface.
<u>General HMI</u>:


<u>Main Functions</u>: </td></tr>
</table>

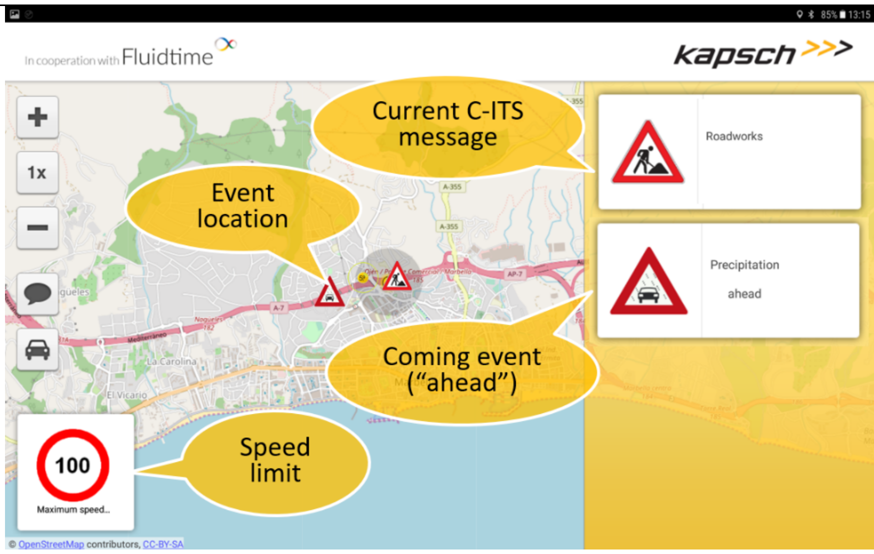
Zoom Controls



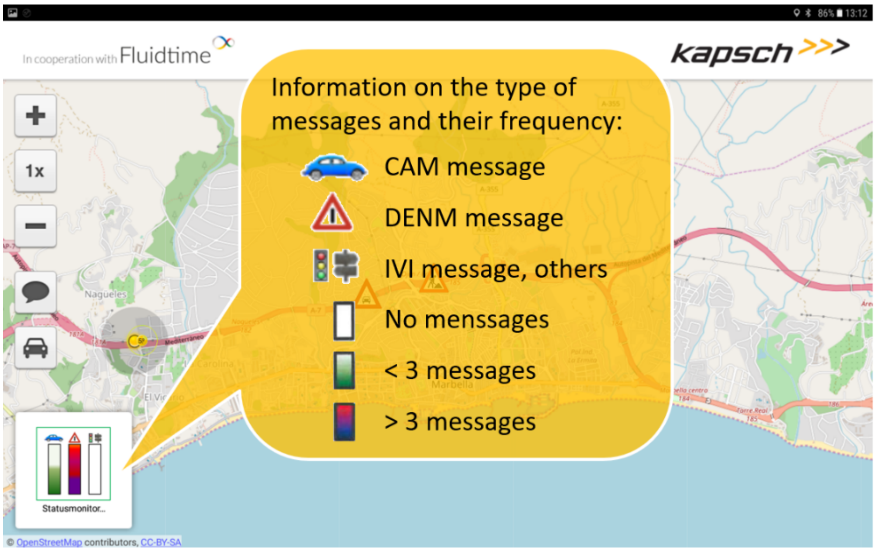
RSU Locations:



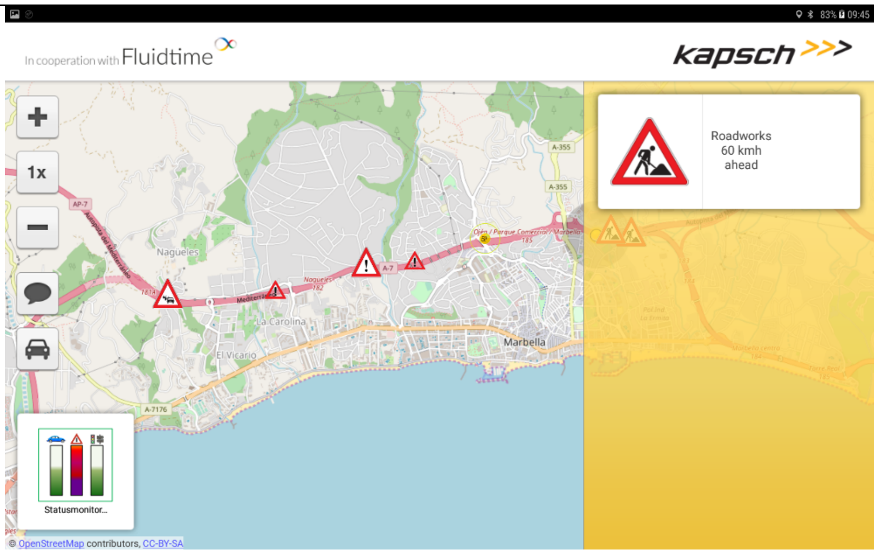
Events and information display:

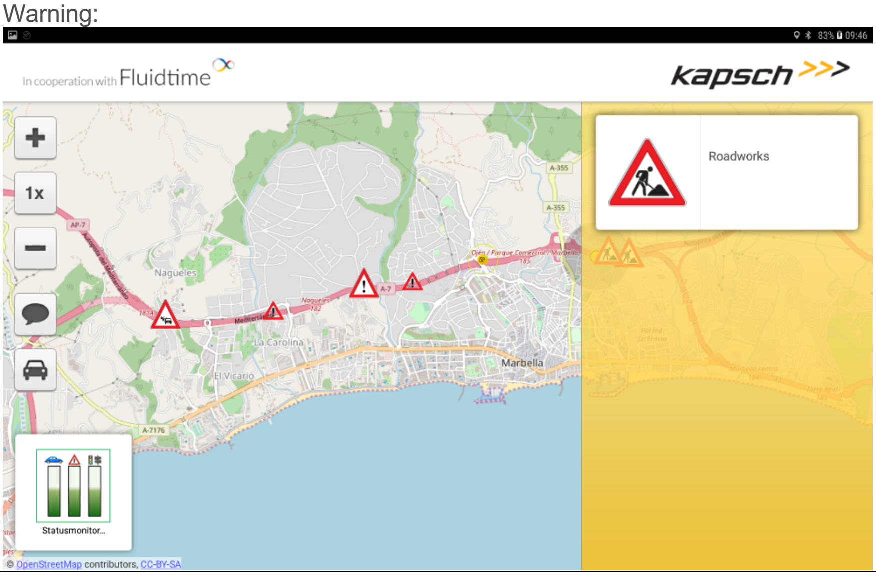


Status Monitor:



Examples:
Pre-warning:

<table>
<tr><td></td><td>


Warning:


</td></tr>
<tr><td>Quality of the Service</td><td>
The pre-warning and warning messages just appeared on the screen of the app at the moment as loaded in the C-ITS platform. The information is available during a variable time slot that was adjusted to the length of the pre-warning and warning zones. The accuracy of the distances was the accuracy of GPS, in a radius of 15m.

<u>Positioning and Time</u>: The position of the vehicle and time synchronization of the system relied on the GNSS-systems, using the GPS system as the time base. The OBU included an internal multi-constellation GNSS receiver which supported GPS, Glonass and Galileo GNSS systems. The current position, with corresponding timestamp, of the vehicle was stored in the “Facility Layer DataBase” where it could be extracted and used by both the communication stack and applications that were interfacing the facility layer of the communication stack.

<u>Event Location</u>: All events, and specifically each Situation Record, needed a location where the messages were active. These fields were very sensitive, and the coordinates needed to be indicated in the correct order. It is recommended to prepare and review the coordinates for an event before creating the message.

First of all, it was necessary to identify the areas where the message will be active. Including some previous warning points for drivers, known as ‘Previous Advise’, and some historical end points that served to expand the event, ‘History Points’.
</td></tr>
</table>

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	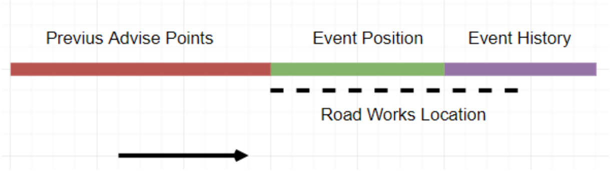 The definition of each area is as follows: Previous Advice Points: Notification points prior to the event. It was mandatory to indicate only one start and one end, but optionally, in the intermediate field, up to 22 more warning points could be indicated to drivers. The maximum distance between two coordinate points of 1.8kms and the minimum distance of 25 meters. This area was also known as “Trace”. Event Position: It was a single point and it was used to indicate where the event was located (it did not have a start and end). Event History: This last section was used to extend the position of the event or the information to the drivers. For example, as the maximum distance between two location points was 1.8kms, if the event took place over a greater distance, as usually happened with RWW, with the History could be extended. It had two mandatory points, one initial and one final, as well as an intermediate one that worked in the same way as in the previous notice points. If you did not want to extend the event, it was recommended to place these points at a distance of 50 meters respectively from the end of the event position. How Event is Displayed: when a message was received, a small icon (in this use case a traffic sign) was shown on the map at the event position. If the vehicle current position was approaching the event, a window on the right side showed the information: “Roadworks ahead”. If the vehicle’s current position was inside the event the information, then it switched from “Roadworks ahead” to “Roadworks”. The window on the right side just showed if the following conditions of the message were fulfilled: The OBU calculated the heading based on the difference of the trace point that was most far away of the event position (last trace point in the list of the trace in the MESSAGE) and the event position. When the vehicle passed the trace point that was furthest away from the event position it compared the own heading with the calculated heading. If the own heading was inside a tolerance angle of +/- 25°, compared to the calculated heading, the event was shown in the right menu. Event Validity: the event remained active from the StartDateTime (when the event started) until EndDateTime (when the event ended). The validity of the message could be extended more than 24 hours. Message ID: All messages had a unique numeric identifier (ID Situation Record), which could be used to change the parameters of the message. If a message was sent with an existing ID, if the previous message with the same ID was active, then the new message replaced the first one, making the parameters of the latter effective. This functionality was very useful when reducing, extending or cancelling messages. This programming of the start and end date and time was very useful in the RWW use case since generally this type of event could be scheduled in advance. Likewise, the service as designed allowed total flexibility to shorten or extend the duration of the event according to its evolution. It also allowed the cancellation of the event. Impact - Restricted Lanes: it was possible to indicate the number of lanes affected by the incident, but it was an ineffective feature since the distance between lanes is below the error allowed by the GPS positioning (15m). Message with speed management: the operator had the option of reporting a road works with speed management, i.e. with a recommended or mandatory speed. The affected area coincides with the coordinates of the event, which limited the flexibility with which the area can be signaled and it was proven more effective to combine it with a Dynamic Speed Limit Information (IVS-DSLI) message that allowed a greater division of the affected section.
Added Value of the Service	The RWW-LC use cases was found to be particularly useful to drivers. It allowed them to prepare for the coming events, adapting speeds and lane changing well in advance of the event. This definitively improved traffic flow and efficiency, increased safety and thus reduced fuel consumption and emissions. Most participants reported that they found the messages to be helpful as they gave the driver more time to think and increased awareness of the road conditions.

5.5.2. UK

Service / Use Case	RWW (LC)
Lessons Learned	The accuracy of back office systems supplying roadworks location information needs to be improved to ensure RWW warnings aligned exactly with the start and finish of roadworks. On the day variations meant that one test had the roadworks showing as starting later on the HMI, but this was due to roadworks being set out differently to the system plan due to a local on road safety decision.
HMI	Care needs to be taken in the amount of information being presented. Too much, all at the same time will be distracting as was found on one test. Major conurbations could present the driver with too many warnings because of the density of roadworks. Other useful information that could be provided on the device cited by users during interviews includes accident information, congestion and diversion routes.
Quality of the Service	Technical evaluation validated that the RWW service gave advanced warning in the detection zone and revoked the warning when passing the event location or the crash absorber. Similar to IVS performance, on average, all warnings were first presented a few seconds after entering the trace and revoked a few seconds after passing the event position. Warnings were presented when the vehicle was within several tens of meters from the zone and event positions of DENMs. Warnings were not presented or revoked when vehicles were further away or leaving the trace, for example when entering parallel roads. *Presentation of warnings:* The RWW warnings did not have to be aligned to existing physical roadworks signage and could therefore be shown in advance. Varying the relevance zone depending on the specific situation can provide greater informational relevancy. When in the roadworks a countdown to the end of roadworks was found to be very helpful in reducing stress. *Technical Summary*: For measuring the reliability of the advice, four experiments from the logs of OBUs were analyzed. 100% of the displayed advice in the Detection Zone was found to be true. 94.5% of the displayed advice in the relevance zone was found to be true. There were six false positives observed in the Relevance Zone.
Added Value of the Service	Users felt they had an increased situational awareness and of the current road information which increased a feeling of comfort (the countdown to and in roadworks was mentioned during interviews as useful). This should see a reduction in stress and possibly instances of ‘road rage’, and therefore an increase in the safety of other road users. 88% of drivers would like advance information of roadworks, so they could plan their journeys better.

5.5.3. Czech Republic

The objective of this use-case was to warn drivers about road works in front them. The evaluation was carried out with the road works as a real event. There were several recommendations by the drivers and evaluators to improve:

- to show RWW event before vertical road signs,
- to add an information about lane guidance,
- to add base maps,
- to add information about planned end of road works,
- to inform drivers about a speed (maximum and recommended),
- to add lane widths.

One of the evaluated drivers had an issue with the Road works warning causing a traffic jam in front of the bottleneck. The information about RWW was no longer important for him and causing unnecessary distraction during the ride. The driver would rather be informed about the traffic jam (Use case TJA).

Drivers were generally satisfied with the way they were informed about the Road works warning event and the HMI display. Some of the drivers would like to have a countdown every 100 meters. The current HMI changes the countdown to roadworks every second. They also said that this countdown increased the disturbance of the HMI. Some of the drivers would welcome larger letters on the HMI and a graphical representation of the situation. Drivers have several times recommended a better disposition of the lane layout and the notification of the RWW location.

5.6. Socio-economics

The explicit assessment of socio-economic impact with respect to the individual Use Case was developed by Italy (RWW-LC), based on the impacts estimated on the KPIs on mobility. The economic values considered for this operation are reported in Table 77. Further details are available in [RD.5].

Table 77 - Monetary value of KPIs considered

KPI	Value	Unit of measure
Accidents resulting in injured or fatality	0,011	M€
Injured	0,042	M€
Fatality	1,504	M€
Value of time	20	€/hour
Cost of CO_2 Emitted	100	€/ton

Table 78 summarises the impacts on the KPI on mobility and their economic conversion.

Table 78 - RWW-LC - Estimated socioeconomic impacts

	KPI	Economic Impact [M€ saved]
Direct Safety Impact	-169 accidents	1,86
	-306 Injured	12,90
	-12 fatalities	18,05
Indirect Traffic Efficiency Impact	-1.165.610 hours in congestion	23,31
Direct Traffic Efficiency Impact	-121.614 hours in congestion	2,43
Indirect Environmental	- 1.048 CO_2 ton	0,10
Direct Environmental	- 2.929 CO_2 ton	0,29
	Total	**58,95**

Furthermore, the socio-economic impact was addressed with qualitative assessment summarizing the findings with respect to factors affecting safety, efficiency and environment and whether these changes are positive or negative from socio-economics viewpoint.

Impact area	Indicator	Effect	Socio-economic impact
Safety	Average speed	average speed is not comparable between services or sub-pilot	?
	Instantaneous accelerations	No impact for RC Increase for LC	0 -
	Instantaneous decelerations	Reduction for LC Reduction for RC	+ +
	Speed adaptation	Reduction for RC Inconsistent for LC (in Italy it was observed a more gradual speed adaptation)	+ ?
Efficiency	Total travel time	Reduction for LC Almost no impact for RC	+ 0
	Number and duration of stops and queues	Almost no impact for RC	0
	Change in instantaneous accelerations/decelerations	Reduction for RC Reduction for LC	+ +

	Difference between the average speed of the vehicle and the speed limit	Average speed is not comparable between services or sub-pilot Reduction for LC (about 1/3 users in UK)	? +
	Traffic flow	Slight increase for LC, not significant result Indirect positive impacts for Italy (services could save up to 1,165 k hours/year)	-
Environment	Fuel consumption	Reduction for RWW-LC	+
	CO2 emissions	Reduction RWW-LC (1 pilot case with increases)	+
	NOX emissions	Increase RWW-LC in 1 pilot case, reduction in 2 pilots	?

6. In Vehicle Signage

6.1. Safety

This section provides a list of the in-vehicle signage use-cases evaluated from a safety perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: NL, Spain, UK, Austria, Germany, Portugal, Czech Republic, NW2.

6.1.1. Spain

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“
- IVS-SWD: In Vehicle Signage - Shock Wave Damping

Evaluation method

Depending on the use case, the mentioned impact investigation safety area could lead to different questions/sub-questions:
Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is safety affected by changes in driver behavior due to IVS use case?

Sub Research Questions:

- How does the IVS service affect the number of accidents in the use case?
- How does the IVS service affect the accidents severity in the use case?
- How does the IVS affect to the (safety) conduction in the use case?
- How does the IVS service affect the sense of security of drivers/passengers and the workforce in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS IVS v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered that were evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation were obtained. The KPIs that were calculated in each of the sub-pilots are presented in Table 79, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 79, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 79 - IVS Safety. Spain.

KPI	Service	Use Case	Pilot	Summary
Change in speed adaptation	IVS	DSLI	Andalusian - Mediterranean	143.4%
		EVFT	Andalusian - Mediterranean	42%
Change in speed standard deviation	IVS	DSLI	Andalusian - Mediterranean	-25.1%
		EVFT	Andalusian - Mediterranean	0.7%
Change in average speed	IVS	DSLI	Andalusian - Mediterranean	-4.8%
		EVFT	Andalusian - Mediterranean	0.7%
			Catalan -Mediterranean	-2,8%
		SWD	Catalan -Mediterranean	0.02%*
Change in instantaneous accelerations	IVS	DSLI	Andalusian - Mediterranean	-60%
		EVFT	Andalusian - Mediterranean	-19%
Change in instantaneous decelerations	IVS	DSLI	Andalusian - Mediterranean	-57.1%
		EVFT	Andalusian - Mediterranean	-0.8%
Amount of time vehicles exceed the speed limit		SWD	Catalan -Mediterranean	-0,18%*
		EVFT	Catalan -Mediterranean	-100.0%

6.1.2. UK

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-DLM: In Vehicle Signage - Dynamic Lane Management
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“

Evaluation method

In developing the objective impact methodology within InterCor, the following key indicators were considered:

- Change in speed as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1. Do drivers comply with the speed limit after receiving the information? 2. Do different drivers behave/ respond differently to the information?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews

In the UK Pilot, use of extensive subjective impact from user surveys and individual interviews and matching of individual driver objective OBU common log data measurements to subjective feedback given, enabled targeted reviews of objective data for individual drivers. Based on this approach, it was possible to plot vehicle speed before and after receiving the HMI warning around these specific events to validate the driver subjective data.

For the IVS use cases tested, initial impact analysis focused on extracting subjective impact data from the qualitative and quantitative data extracted from the user acceptance surveys and driver interviews conducted at each Focused Test Event. However, it was not possible to match this up to objective on road data, partly due to some data lake data upload technical issues and partly due to the limited time remaining on the project to carry out the extensive data filtering and processing of OBU data to find definitive cases of drivers slowing when receiving IVS related warnings.

However, we believe that with the ‘naked roads’ set up carried out by the Belgium partner in InterCor there would be measurable changes in drivers receiving C-ITS warnings for IVS-DSLI as the subjective impact detailed in Section 6.4.2 User Acceptance (UK) indicated drivers were minded to reduce their speed on receiving warnings when reviewing their post-test responses. The results of the InterCor ‘naked road’ tests are detailed in the InterCor Milestone 13 report.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

No objective impact results were recorded for the IVS service from UK testing. However, these were combined with other InterCor Member State IVS common use case results which formed part of the InterCor Milestone 13 Report which included both objective and subjective impact for the IVS-DSLI use case[9].

Subjective Impact Summary (refer to section 6.4.2 for more details)

IVS Dynamic Speed Limit information:

The large number of participants who intended to reduce their speed in response to the technology prior to testing it (63%) suggests that dynamic speed limit information has the potential to influence behavior change if it provided drivers with more accurate and relevant information.

Reduced speed is likely to have a positive safety impact as drivers have more time to assess the situation and increased braking times if vehicles around them perform unexpected maneuvers.

Key observations from driver interviews that are Safety related included:

- Some participants reported that they paid more attention to the Dynamic Speed Limit information in the car than they would when it is displayed on the gantry.
- Participants also felt more aware of the speed limits at all times
- Dynamic Speed Limit information improved their preparedness when entering a different speed limit zone and this made them check their speed: "probably more than I would have done", according to one participant

IVS Dynamic Lane Change Management:

Lane advice service saw an increase from 63% before testing to 75% after testing of respondents agreeing or strongly agreeing that it would improve safety.

A further increase in safety should be seen with a reduction in roadside furniture and infrastructure and a resulting reduction in installation and maintenance risks; albeit this potential benefit would not be realized until penetration rates are significant.

The large majority of participants disagreed that IVS - Lane Signage would distract their attention from traffic, so in terms of the warning to the driver in the vehicle it didn't appear to have a negative effect. With the signage being easily interpretable compared to existing road signage that drivers are already used to seeing and processing.

Reduced speed is likely to have a positive safety impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of any lane restrictions.

Key observations from driver interviews that are safety related included:

- Participants commented that a lane change message was useful to encourage lane discipline.
- Quotes from drivers: "I was on the left-hand side, I had to move across, so it was quite handy as a little reminder to say to move over."

[9] Following a successful Belgium InterCor partner test to produce a true control group (no existing external ITS signage in the driver's eyeline), it would have been required to disable the signage on the roadside or test in an area without existing ITS signage but this was not possible in the timescales of the Pilot as this learning aspect was not fully apparent until the final evaluation stage was already underway. In the case of the UK, it would have required an alternative test site to be set up as disabling existing ITS signage when in active use wouldn't have been possible for safety reasons.

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Smoother lane changes (as per the RWW service), would help reduce the chance of accidents, especially when combined with speed reduction as indicated from the driver questionnaires/interviews for RWW and IVS Dynamic Speed Limit information.
All three use cases provided speed limit information with RWW and IVS Dynamic Lane Management provides lane restriction information and distance to the restriction via a countdown which appeared to influence the driver's attention especially when accompanied by an audible signal when conditions change.

IVS Embedded VMS:
See qualitative analysis in Section 6.4.2User Acceptance UK as although this service was not one of the Common InterCor Use cases but was evaluated from a User Acceptance aspect by the UK C-ITS Pilot evaluation team.
Key Observations from driver interviews that are safety related included:

- The majority of participants thought that Embedded VMS messages would be useful for HGV drivers, especially if there was also information about road width and height restrictions
- One participant found the Embedded VMS messages particularly useful because it was raining, so they felt they were more likely to miss the messages on the gantry and wanted to concentrate on driving safely.
- Ensuring drivers don't miss key signage e.g. debris in road would have a related safety benefit.

Evaluation results – KPIs on Mobility

Although there were no directly measured Safety KPIs, IVS exhibited implied benefits from the behavioral changes of the drivers recorded through the subjective impact evaluation.

6.1.3. The Netherlands

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

In developing the objective impact methodology within InterCor, we considered the following key indicators:

- Change in speed as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1.Do drivers comply with the speed limit after receiving the information? 2.Do different drivers behave/ respond differently to the information?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews

Technically the In-Vehicle Signage service worked on the A16 motorway in the Netherlands to convey variable message signs to drivers. IVS worked using either ITS-G5 with security, the IF2 data provisioning to service providers with cellular communication, and the hybrid system as piloted. IVS was piloted for a period of one year on the A16 motorway and included both technical and user tests. More than 96% of IVI messages received from the road side were presented to the driver on time and throughout the area where the IVI is valid (relevant), and revoked promptly when leaving this area.
InterCor IVI logdata was analyzed to evaluate the IVS service. The IVS service signaled a change in the speed limit that was determined by the road operator based on the actual traffic conditions (e.g. in case of traffic jams or road works) or specific time intervals (e.g. when the speed limit decreased for environmental purposes).
The A16 test site has a base (fixed) speed limit of 100 km/h. Based on an IVI message that contains the maximum speed for a certain relevance area the Human Machine Interface (HMI) showed the maximum speed as the corresponding traffic sign. The speed limits vary in accordance with the Dutch Motorway Traffic Management speed limits. These show 50 km/h during congestion, together with 70 km/h signs further upstream. For roadworks, typically 70 km/h is used, accompanied with 90 km/h further upstream. Lastly, for time specific dynamic speed limits typically only the adjusted speed limit is shown without any accompanying speeds upstream. For the IVS impact assessment, the measurements of all these (adjusted) dynamic speed limits were analyzed together as one general dataset.
For the impact analysis only true positive IVS warnings were considered. This meant that messages for traffic driving in the opposite direction, or messages that were not relevant were disregarded.
The different user groups that were identified in this evaluation are:

- Controlled test drivers (IVS + RWW)
  - Without HMI (baseline)
  - With HMI (treatment)
- Naturalistic test drivers (IVS + RWW)
  - With HMI (treatment)
  - No baseline

- Flitsmeister app service users (originally developed for the Talking Traffic project) (IVS + RWW)
    - With app (treatment)
    - No baseline

Data collected

Based on the key indicators mainly speed information was collected, in combination with the context of position, time, in car messages and the context of the situation on the road.

Evaluation results – Field tests

Within the impact assessment, data analysis was executed to derive the effect of the IVS service towards the user behavior and more specifically the speed. Based on the data of three different user groups (Controlled user group, Naturalistic user group and users of the Flitsmeister smartphone app) speed profiles were derived which provided the input for both median speed plots and statistical t-tests.

Based on the data analysis it became apparent that the behavior of users towards the speed limit speed of 50 and 70 km/h was different than the reaction towards a 90 or 100 km/h speed limit. For the first group the data analysis showed that, in general, the users from all groups were exceeding the speed limits. For the 50 km/h the difference between the limit and the observed speeds were that high that it might have been the case that the existing and active VMS gantries were providing conflicting information.

For the 90 and 100 km/h the data analysis showed that the Controlled and Naturalistic drivers were adhering to the speed limits, however, if comparison of the mean speeds from both HMI settings it became apparent that with the HMI active the mean speed was higher than without the HMI. This finding was striking because the opposite was expected given the nature and aim of the IVS service. The Flitsmeister data analysis showed that these users were exceeding the speed limit.

T-tests were performed to determine whether the mean speed significantly changed between the time interval -30 to -1 and 1 to 30 and whether the HMI was the determining factor for this change. From the results it became apparent that the speed behavior for the majority of the speed limits significantly changed before and after the IVS event, this indicated that the messages were sent out at point and time where the traffic situation significantly changed.

When comparing the data for the situation with and without HMI for the Controlled user group it became apparent that both speed profiles were only significantly different in the case of the 90 km/h speed limit. However, for this specific case the sample for drivers with no HMI consisted of 45 trajectories which was significantly less than all other samples. Based on the impact assessment no statistical evidence was found that the speed behavior was changed by the in-car information. It could also be possible that the users were relying on the information outside the car, because the existing roadside gantries with VMS matrix signs per lane were also active during the test periods.

For the 70, 90 and 100 km/h speed limits for both user groups it was observed that individual speed trajectories were collected with a speed of <50, in those cases it is very likely that the VMS system already would provide a speed limit of 50 km/h. Moreover, it was observed that these lower speeds were also collected in the period before the IVS message was sent out which indicates that the messages could have been sent earlier to the users.

The results from the speed increase for the 100 km/h speed limit can be explained by the fact that it can be regarded as the “end of all temporary speed limits” since this speed limit is equal to the legal fixed maximum speed on the A16. Thus, in practice this speed limit was not meant for drivers to decelerate but accelerate.

Evaluation results – KPIs on Mobility

Based on the impact assessment no statistical evidence was found that the speed behavior was changed by the in-car information. It could also be possible that the users were relying on the information outside the car, because the existing roadside gantries with VMS matrix signs per lane were also active during the test periods.

6.1.4. Italy

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

In the organized field tests, the aim was to evaluate how vehicles and drivers react to a punctual reduction of speed limits, starting from a specific point/kilometre section, compared to the standard speed limits on freeways (from 130 to 110 km/h for light vehicles, from 80 km/h to 60 km/h for heavy vehicles). The start of these reduced speed limits is indicated by fixed vertical signs and not by VMS.
Specifically, we wanted to analyze whether early warning of speed limit changes provided through C-ITS services can promote better speed limit compliance, both in terms of spatial anticipation of the adjustment and in terms of better adherence of speed to the limit.
The tests took place on the A22 freeway between Trento Nord and Bressanone Nord / Val Pusteria and between Trento Sud and Rovereto Sud.
Testing was held on November 10, 2021 (heavy vehicles) and on the dates of December 1, 3, and 23, 2021 (light vehicles); a total of 27 speed limit reduction events were tested.
The tests compared the behaviour of vehicles and drivers in the presence of two different scenarios: in the C-ITS OFF scenario the vehicles did not receive any C-ITS messages concerning speed limits and had therefore to rely on direct visual observations; in the C-ITS ON scenario the vehicles displayed in advance on the HMI, thanks to the reception of C-ITS messages, the warning of an imminent reduction of the speed limit. For the C-ITS ON scenario, in order to increase the statistical significance of the test, virtual events were also simulated: in these cases the speed limit reduction event was not real but only simulated through the broadcast of a C-ITS message containing the reduced speed limit and the relative kilometers of start and end of validity.

Data collected

The analysis of vehicle behavior in the presence of a "Dynamic Speed Limit Information" event was differentiated for heavy and light vehicles; the collected data was also divided into two groups: C-ITS ON and C-ITS OFF.
The field test indicator KPIs calculated for each passage are as follows:

- slowdown: whether or not the slowdown took place [yes/no], start and end point of the slowdown [m], start and end time of the slowdown [time], extent [m] and duration [sec] of the slowdown, speed before the start and at the end of the slowdown [km/h], absolute speed change [km/h] and percentage [%], average deceleration [m/s^2], standard deviation of instantaneous decelerations [m/s^2] and maximum instantaneous deceleration [m/s^2]
- braking: (brake pedal pressure phase): braking or not [yes/no], braking start and end point [m], braking start and end time [time], braking extension [m] and duration [sec], maximum braking torque [Nm]
- speed adaptation:
    - punctual speed [km/h] at the following sections (as well as average speed [km/h] between successive pairs of sections): -500 m before the start of validity of the reduced speed limit, -300 m, -200 m, -100 m, 0, +100 m, +200 m, +300 m, +500 m.
    - absolute difference [km/h] between the average speed recorded on each of the above stretches and the reduced speed limit

Next, the average value of the above indicators was calculated for each of the two scenarios (C-IST OFF and C-IST ON) for comparison purposes.

Evaluation results – Field tests

Heavy vehicles

Table 80 - IVS-DSLI - Field tests KPIs - Heavy vehicles

DSLI - Closure of a Lane - Heavy vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	**C-ITS OFF**	**C-ITS ON**	**Abs. Var.**	**Var. %**
SLOWDOWN				
Lane change performed [%]	100%	100%		
Maneuver duration [s]	24,0	10,0	-14,0	-58%
Maneuver length [m]	455	165	-290	-64%
Maneuver start point [m] (0 m = event point)	35	-225	-260	-
Maneuver end point [m] (0 m = event point)	490	-60	-550	-
Initial speed [km/h]	77,1	74,0	-3,1	-4%
Final speed [km/h]	61,5	59,2	-2,3	-4%
Speed reduction [km/h]	-16	-15	+1	-5%
Slowdown average deceleration [m/s²]	0,18	0,41	+0,23	+128%
SPEED ADAPTATION				
Average and minimum speed in different road segments [km/h] (0 m = event point):				
-500 > -300	80	71	-9	-11%
-300 > -200	80	74	-6	-8%
-200 > -100	78	70	-8	-10%
-100 > 0	77	60	-17	-22%
0 > +100	77	60	-17	-22%
100 > 200	74	62	-12	-16%
200 > 300	72	64	-8	-11%
300 > 500	67	62	-5	-7%
Deviation from speed limit [km/h] (0 m = event point):				
-500 > -300	+20	+11	-	-
-300 > -200	+20	+14	-	-
-200 > -100	+18	+10	-	-
-100 > 0	+17	+0	-	-
0 > +100	+17	+0	-	-
100 > 200	+14	+2	-	-
200 > 300	+12	+4	-	-
300 > 500	+7	+2	-	-

- slowdown: in the C-ITS ON scenario the slowdown starts (-260m) and ends (-550m) considerably earlier than in the C-ITS OFF scenario and it is carried out faster (-14s/-58%) and in shorter space (-290m/-64%), reaching a speed compliant with the speed limit even before entering the section with the reduced speed limit (section -100m/0m). On the contrary, in the C-ITS OFF scenario the slowdown occurs mostly after the start of the reduced speed limit and it lasts longer in duration and length, with not enough speed reduction to reach full speed limit compliance even after the end of the slowdown.

Table 81 - IVS-DSLI - Field tests KPIs - Light vehicles

DSLI - Closure of a Lane - Light vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	**C-ITS OFF**	**C-ITS ON**	**Abs. Var.**	**Var. %**
SLOWDOWN				
Lane change performed [%]	100%	100%		
Maneuver duration [s]	6,0	11,0	+5,0	+83%
Maneuver length [m]	156	323	+167	+107%
Maneuver start point [m] (0 m = event point)	344	-121	-465	-
Maneuver end point [m] (0 m = event point)	500	202	-298	-
Initial speed [km/h]	124	125	+1	+1%
Final speed [km/h]	113	107	-6	-5%
Speed reduction [km/h]	-11	-18	-7	+62%
Slowdown average deceleration [m/s²]	0,52	0,44	-0,08	-15%
SPEED ADAPTATION				
Average and minimum speed in different road segments [km/h] (0 m = event point):				
-500 > -300	127	126	-1	-1%
-300 > -200	128	126	-2	-2%
-200 > -100	128	124	-4	-3%
-100 > 0	126	115	-11	-9%
0 > +100	126	109	-17	-13%
100 > 200	125	109	-16	-13%
200 > 300	125	108	-17	-14%
300 > 500	120	108	-12	-10%
Deviation from speed limit [km/h] (0 m = event point):				
-500 > -300	+17	+16	-	-
-300 > -200	+18	+16	-	-
-200 > -100	+18	+14	-	-
-100 > 0	+16	+5	-	-
0 > +100	+16	-1	-	-
100 > 200	+15	-1	-	-
200 > 300	+15	-2	-	-
300 > 500	+10	-2	-	-
-500 > -300	+17	+16	-	-

- slowdown: in the C-ITS ON scenario the slowdown starts (-465m) and ends (-298m) considerably earlier with respect to the C-ITS OFF scenario and it is deployed more gradually (-15% deceleration), reaching a speed compliant to the speed limit at the entrance of the reduction zone. On the contrary, in the C-ITS OFF scenario the slowdowns are performed much further downstream and more abruptly; the speed reduction implemented is not sufficient for full compliance with the reduced speed limit.

Evaluation results – KPIs on Mobility

Concerning the evaluation and assessment of the expected KPIs on mobility, the following general approach was adopted (see chapter 4.8)

KPIs = REACTION x EFFECTIVENESS x TARGET

Considering data from light vehicles, more numerous and meaningful, the following observations were deployed:

- **Reaction**: reaction recorded if in the C-ITS ON scenario the speed is compliant with the speed limit within 100 m after the starting point of the speed limit. This condition was recorded in the 90% of the passages with C-ITS ON (19 cases over 21).
- **Effectiveness**: particularly cautionary values were considered for the characterization of the effectiveness. The quantification of the effectiveness (based on an expert judgement), considering just the drivers who actually reacted, is

assumed equal to 0,2 (with respect to accidents), 0,25 (injured people) and to 0,3 (fatalities).

- **Target,** considering road accidents with at least one vehicle speeding or exceeding speed limits on the Italian highway network (year 2019):
    - Accidents: 2.124
    - Injured: 3.305
    - Fatalities: 78

Then, the estimated expected KPIs on mobility are reported in Table 82.

Table 82 - IVS-DSLI - Estimated KPIs on mobility - Safety

KPI			% considering all the accident in Italy in a year
Accidents	= 2.124 x 0,90 x 0,2 =	-382	-0,22%
Injured people	= 3.305 x 0,90 x 0,25 =	-744	-0,31%
Fatalities	= 78 x 0,90 x 0,3 =	-21	-0,66%

6.1.5. Austria

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

The following key indicators were considered:

- Change in speed as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1.Do drivers comply with the speed limit after receiving the information? 2.Do different drivers behave/ respond differently to the information?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews
Area	**Priority**	**Research questions**	**KPIs**
Safety	++ (primary evaluation area for the pilot)	1.Do drivers comply with the speed limit after receiving the information? 2.Do different drivers behave/ respond differently to the information?	• Speed adaptation • Objective Data linked to User Acceptance Driver Interviews

During each drive, multiple C-ITS speed limit information services were received.
For the following evaluation, a speed limit of 100km/h was indicated, following an original limit of 80km/h, meaning that acceleration was possible only after the indicated location. Consequently, the area after the position of the message-receiving is evaluated - because that is where the speed-change usually takes place.
The message was sent 1000m before the actual place of the reported speed limit, which is approx. 50 sec of driving (assuming a speed at the allowed limit of 80km/h).
Again, this distance is not only giving way enough time to prepare a (smooth) acceleration, but the speed limit indication is also displayed on the VMS that can be seen by the driver. So even under perfect conditions, the driver would have not been able get the information so soon without the assistant of C-ITS, and thus reacting on the message so early.
Contradictious to the RWW, it is possible to perform a counterfactual method in this case:

- The sent-out messages are the same as the ones, which are displayed on the VMS.
- Consequently, it was possible to have drives where a baseline measurement (without HMI) was obtained. 10 drives were then performed with the treatment measurement (so with message from RSUs, displayed on the HMI), 10 without.

Although the messages were received approx. 1000m before the speed limit, the acceleration then typically can only start after the actual events - until then, there is still a valid speed limit of 80km/h.
Unlike the RWW, it is not 100% compulsory to reach the speed which is sent out. This message is a maximum speed limit information, it is well possible that the driver does not want to reach 100km/h – or is simply not able to do so due to for example heavy traffic.

Furthermore, it is also possible (though not legal) to exceed the speed limit information indicated before reaching the indicated speed limit point.
The main idea is then again to track each drive and then compare the individual reactions on the messages.

Data collected

Evaluating the reaction on a "Speed Limit"-message (CauseCode: Speed Limit, SubCauseCode: 100):
Ten test-drivers have driven along the mentioned stretch of the motorway, each of them received the "Speed Limit"-message, and since everyone drove this one twice, a total of 20 tracks was received for this road-stretch.
Each of these tracks were made up out of the coordinates of approx. 900-1000 CAMs, which are collected in the distance of approx. 1000m before the (virtual) obstacle.
This information is then used to see the track of each drive and the speeds within the given stretch.
Similar to previous evaluations, 2 types of reaction on the speed limit-information message are checked:

a. What can be stated concerning the driven speed - in the area after the event position has been passed?
b. What can be stated concerning the speed change?

Evaluation results – Field tests

According to the test, the average speed did not change significantly, neither in the area before or after the message, nor throughout the rest of the evaluated stretch of motorway.
The constant speed is a significant indication that such a warning message is sent out well in advance, meaning well before the event (the speed limit) is visible for the driver on the VMS.
In this specific case, the speed limit indicated on the VMS is also well visible in advance, though not so soon as indicated on the HMI via C-ITS.
Since the speed limit information is also placed on a VMS, and the start of the 100km/h is the same, there it is – in this specific case - hardly any advantage of a speed limit information via a C-ITS services. This is as well indicated in the evaluated speeds, which showed no significant difference.
It needs to be mentioned that VMSs in Austria are equipped with a legal validity of speed, so that the density of traffic is already integrated in the logic of the speed displayed on a VMS along an Austrian motorway.
This makes speed indication on VMS highly precise and consequently (again) lowers the additional advantage of C-ITS message along stretches, which are already equipped with VMSs.
However, it needs to be mentioned that the main factor for the advantage of C-ITS-messages is not only to the possibility to give the warning well in advance, but especially to adjust the point at which the warning is sent out, so that the driver can react perfectly in time.
This adjustment is especially valuable on critical (parts of) roads, where frequent changes of speed, traffic volume and curvature occur.
In this specific case of evaluation – straight stretched of motorway with clearly visible VMS-information - there was no critical point in terms of visibility, curvature or heavy traffic.
Consequently, on such a perfectly VMS-equipped motorway stretch, no major advantages of C-ITS messages versus those received from VMS could be proven.
But in general, also in terms of speed limits, the advantages of C-ITS messages, when given well in advance at the perfect point in time and distance, are clearly visible.

Evaluation results – KPIs on Mobility

Concerning KPI on safety, the following can be stated:

The fact that there was always enough time to adjust the speed never led to any critical situations.

Heavy breaks or forced lane changes, which are typical results of unexpected events, are the number one-cause for rear-end collisions, which are in return the number-one cause of accidents.

Therefore, although - in this very example - there is also a good VMS-equipment present, C-ITS is still a proper tool to avoid accidents with possible injuries or even deaths.

6.1.6. Summary

Evaluation results – Field tests

The main results regarding the impact area of safety in relation to the IVS service IVS relate to the analysis of speed and of the compliance of drivers with the communicated speed limits that are featured in the different Use Cases considered.

The **Spanish pilot** considered a large number of KPIs reporting different observations across the Use Cases considered:

- Change in speed adaptation: The vehicles reduced their average speed with respect to the limit after the implementation of the IVS. (Benefit: 143,4% for DSLI and 42% for EVFT)
- Change in speed standard deviation: The service IVS-DSLI (benefit: -25,1%) helped to reduce the amount of time vehicles exceeded the speed limit. The service IVS-EVFT has a neutral result for Andalusian-Mediterranean and it is significative for Catalan-Mediterranean sub-pilot with -100%.
- There was a reduction in the average speed during the implementation in DSLI (benefit. -4,8%) and EVFT in the case of Catalan sub-pilot. The result in the Andalusian sub-pilot for this last use case was neutral and the same for the use case SWD in the Catalan sub-pilot.
- Change in instantaneous accelerations and decelerations: There was a reduction in the use cases DSLI and EVFT. A more significant reduction was noted in the DSLI use-case (around -60%).

In the **Netherlands**, analyses were oriented to study the behavior of users towards speed limits, dealing with the IVS-DSLI use-case. Differences were observed considering lower speed limits (50 and 70 km/h) and higher speed limits (90 or 100 km/h). For the first group the data analysis showed that, in general, the users from all groups were exceeding the speed limits. For the 90 and 100 km/h the data analysis shows that the Controlled and Naturalistic drivers were adhering to the speed limits. Based on the impact assessment no statistical evidence was found that the speed behavior was changed by the in-car information. It could also be possible that the users were relying on the information outside the car, because the existing roadside gantries with VMS matrix signs per lane were also active during the test periods.

In the UK, feedback about safety impacts of the IVS service were also collected through interviews of the users, referring to different use-cases tested. Main outcomes of this approach were referred to IVS-DLCM, considered able to improve safety for the 75% of users, and to IVS-EVFT, considered useful for safety purpose especially for HGV drivers with information about road width and height restrictions.

The **Italian** pilot reported a high number of Field Test KPIs highlighting significant benefit of the C-ITS message in terms of anticipated reaction, smoother deceleration and higher compliance with the speed limits. Both for light and heavy vehicles.

Heavy Vehicles: in the C-ITS ON scenario the slowdown starts (-260m) and ends (-550m) considerably earlier than in the C-ITS OFF scenario and it is carried out faster (-14s/-58%) and in shorter space (-290m/-64%), reaching a speed compliant with the speed limit even before entering the section with the reduced speed limit (section -100m/0m). On the contrary, in the C-ITS OFF scenario the vehicles do not reach full speed limit compliance even after the end of the slowdown.

Light Vehicles: in the C-ITS ON scenario the slowdown starts (-465m) and ends (-298m) considerably earlier with respect to the C-ITS OFF scenario and it is deployed more gradually (-15% deceleration), reaching a speed compliant to the speed limit at the entrance of the reduction zone. On the contrary, in the C-ITS OFF scenario the speed reduction implemented is not sufficient for full compliance with the reduced speed limit.

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In **Austria** the motorway stretches where the field test took place was equipped with a high number of VMS dispatching the same message as the C-ITS. According to the test, the average speed did not change significantly, neither in the area before or after the message, nor throughout the rest of the evaluated stretch of motorway.
Consequently, on such a perfectly VMS-equipped motorway stretch, no major advantages of C-ITS messages versus those received from VMS could be proven. But in general, also in terms of speed limits, the advantages of C-ITS messages, when given well in advance at the perfect point in time and distance, are clearly visible.
Finally, Italy estimated an overall yearly impact on safety, considering a 100% C-ITS penetration rate as reported in Table 83.

Table 83- IVS-DSLI - Estimated KPIs on mobility - Safety

KPI		% considering all the accident in Italy in a year
Accidents	-382	-0,22%
Injured people	-744	-0,31%
Fatalities	-21	-0,66%

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6.2. Traffic Efficiency

This section provides a list of the in-vehicle signage use-cases evaluated from a traffic efficiency perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: France, Spain, UK, Austria, Portugal, NW2.

6.2.1. Spain

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“
- IVS-SWD: In Vehicle Signage - Shock Wave Damping

Evaluation method

Questions about what the Spanish pilot investigated are presented hereunder depending on the use case:

Main Research Question:

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

Sub Research Questions:

- How does the IVS service affect to the journey time in the use case?
- How does the IVS service affect to the traffic flow in the use case?
- How does the IVS service affect to the speed in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS IVS v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered that were evaluated in the Spanish pilot.

These annexes include the main research questions and the research hypotheses about the sub research questions.

Global results of impact evaluation were obtained. The KPIs that were calculated in each of the sub-pilots are presented in Table 84, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

Note that in Table 84, the results presented with an asterisk (*) are extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 84 - IVS Traffic Efficiency. Spain.

KPI	Service	Use Case	Pilot	Summary
Travel time (since the C-ITS message reception till the event -e.g. road works-)	IVS	DSLI	Andalusian - Mediterranean	10.9%
		EVFT	Andalusian - Mediterranean	41.2%
Number of stops along routes where C-ITS has been implemented	IVS	SWD	Catalan -Mediterranean	-39%*
Duration of stops along routes where C-ITS has been implemented	IVS	SWD	Catalan -Mediterranean	-17,2%*

Change in instantaneous accelerations/decelerations	IVS	DSLI	Andalusian - Mediterranean	-58.6%
		EVFT	Andalusian - Mediterranean	-9.6%
Change in average speed	IVS	DSLI	Andalusian - Mediterranean	-4.8%
			Catalan -Mediterranean	-8.0%
		EVFT	Andalusian - Mediterranean	0.7%
		EVFT	Catalan -Mediterranean	-2.8%
		SWD	Catalan -Mediterranean	0,02%*
Difference between the average speed of the vehicle and the speed limit (Change in speed adaptation)	IVS	DSLI	Catalan -Mediterranean	-60.7%
		EVFT	Catalan -Mediterranean	-92.4%

6.2.2. UK

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-DLM: In Vehicle Signage - Dynamic Lane Management
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“

Evaluation method

Evaluation method employed was as per that described in Section **Errore. L'origine riferimento non è stata trovata.** Safety – UK.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

Although there were no directly measured Traffic Efficiency KPIs, IVS use cases tested demonstrated implied benefits from the behavioral changes of the drivers. Subjective impact summaries for IVS were included here relevant to this specific evaluation area.

IVS Dynamic Speed Limit information:

The large number of participants who intended to reduce their speed in response to the technology prior to testing it (63%) suggests that dynamic speed limit information has the potential to influence behavior change if it provided drivers with more accurate and relevant information.

Reduced speed and maintaining it is likely to have a positive traffic impact as this is in effect a virtual version of Controlled Motorways where constant lower speeds are proven to increase the capacity of the road near flow breakdown conditions.

Key observations from driver interviews that are Traffic Efficiency related included:

- Some participants reported that they paid more attention to the Dynamic Speed Limit information in the car than they would when it is displayed on the gantry.
- Participants also felt more aware of the speed limits at all times
- Dynamic Speed Limit information improved their preparedness when entering a different speed limit zone and this made them check their speed: "probably more than I would have done”, according to one participant

A couple of participants found it extremely useful in situations where the speed limit changed from variable to national, especially if they were unfamiliar with the route.

In congested conditions this increased speed compliance could improve traffic flow as per the controlled motorways model, preventing flow breakdown by excessive speeding (and braking) in congested conditions. It can form part of a virtual controlled motorways service.

IVS Dynamic Lane Change Information:

The large majority of participants agreed that IVS - Lane Signage would not distract their attention from traffic, so in terms of the warning the driver in the vehicle it didn’t appear to have a negative effect with the signage being easily interpretable compared to existing road signage drivers are already used to seeing and processing.

Earlier changes of lane in a smooth and considered manner could see improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown.

Key observations from driver interviews that are Traffic Efficiency related included: Lane advice has the potential to increase efficiency by giving the driver more time to select the correct lane, thus reducing late stopping and blocking of lanes.
In congested conditions, earlier and smoother lane changes due to unplanned lane restrictions e.g. due to an on-road incident, could improve traffic flow as per the controlled motorways model, preventing flow breakdown by excessive speeding (and braking) in congested conditions. It can form part of a virtual controlled motorways service.

IVS Embedded VMS:
See qualitative analysis in Section 6.4.2 User Acceptance – UK as although this service was not one of the Common InterCor Use cases but was evaluated from a User Acceptance aspect by the UK C-ITS Pilot evaluation team.
Key observations from driver interviews that are Traffic Efficiency related included: Depending on the message displayed, there could be a secondary traffic efficiency benefit from warning drivers early of something in the road e.g. debris, animal or person, thus reducing sudden braking/lane changes, and also warning any traffic issues further down the road network that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue. This virtual message sign service has the ability to communicate with drivers where existing signage doesn't currently exist.

Evaluation results – KPIs on Mobility

Although there were no directly measured Safety KPIs, IVS exhibited implied benefits from the behavioral changes of the drivers recorded through the subjective impact evaluation.

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6.2.3. France

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

The key research questions targeted for the IVS-DSLI use-case included:

- What is the impact on traffic and environmental efficiency due to C-ITS services in lieu of Variable Message Signs (VMS)?
- Does the impact improve with increasing market penetration of C-ITS services?
- What is the minimum required market penetration rate required to significantly affect traffic macroscopic indicators, *i.e.* the average speed of the flow?
- What is the impact of coverage of RSU for providing information to the connected drivers?

According to the identified research questions, the selected key performance indicators (KPI) include the following: average speed and the pollutant emissions (CO_2 and NO_x).
For evaluating the IVS-DSLI use case, traffic micro-simulation was adopted solely due to the unavailability of data from field operational tests. First, the traffic micro-simulator SUMO was calibrated by optimizing a few driving behavior parameters based on the loop detector data of a section of A63 highway near Bordeaux from the year 2017. Then the model was validated based on the 2018 loop detector data for the same section when dynamic speed limit was implemented using variable message signs. The logic for implementing DSL was replicated as a Python script and applied using the Traffic Control Interface (TraCI) of SUMO. Finally, the VMS was removed, and the DSL logic was applied only to connected vehicles to observe the impacts with respect to different market penetrations.
Two factors related to connected vehicles were considered to investigate the effect on the KPIs. The first was to check the impact with respect to various levels of market penetration of connected vehicles. The second was related to the distance gap D_{gap} between the effective location to apply the instruction and the coverage of the RSU (see Figure 19). With this second factor, the underlying objective was to highlight the impact of gaps in the coverage of the road network by RSUs. It led to two possible configurations according to the assumptions made:

- *conservative broadcast process for RSU*: it assumed that the only C-ITS instructions that a RSU could broadcast were the ones about an event located within the range of the RSU's coverage area.
- *expansive broadcast process for RSU*: it assumed that an RSU could broadcast a C-ITS instruction about any event located within and downstream its coverage area.

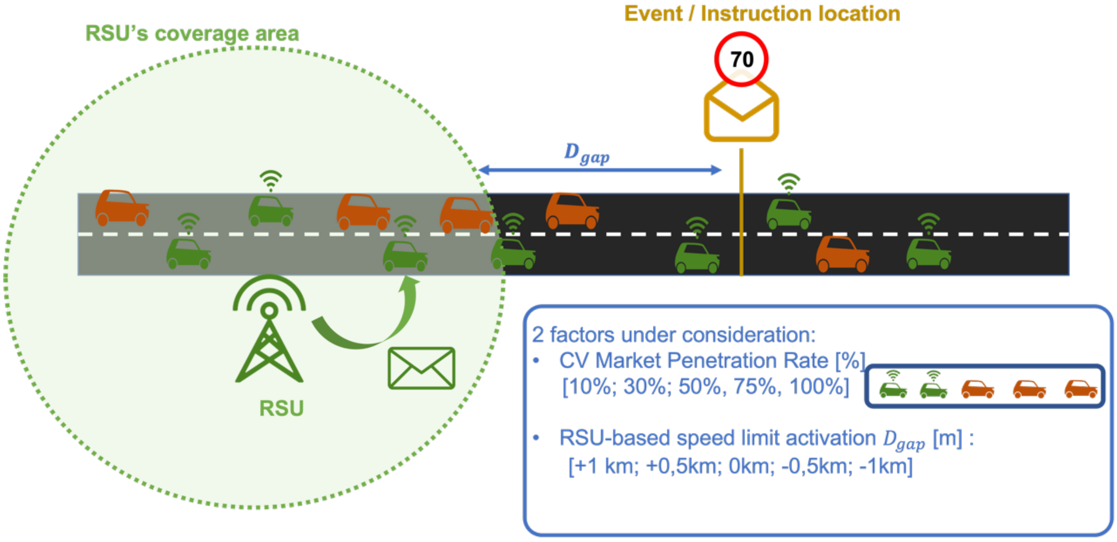

Figure 19 - Design of experiment for C2 use-case

Data collected

For the C2 use-case, the 2017 and 2018 loop detector data from a section of the A63 highway was used to extract speed and flow information for typical days with no adverse weather condition, no traffic incidents and no irregular fluctuations in the traffic flow. This information was used to calibrate and validate the traffic simulator. As mentioned previously, no information related to application of IVS-DSLI use-case from FOTs could be collected as the same had not yet been implemented within the C-ROADS project.

Evaluation results – Field tests

No specific field tests were performed for the IVS-DSLI use-case. The conclusions drawn on other field tests (e.g. GLOSA) were used to feature the driver's response time to stimuli within the simulation model.

Evaluation results – KPIs on Mobility

Dynamic speed limit information using in-vehicle signage is considerably effective in terms of traffic efficiency even at low market penetrations of connected vehicles. For example, as compared to a scenario with no dynamic speed limit operation, the average traffic stream speed is improved by about 25km/h during the peak periods of operation at 10% market penetration rate (MPR), and about 30km/h at market penetrations of 75% or higher. The impacts on traffic efficiency, in terms of average traffic stream speed, is more-or-less similar to speed limit instructions using VMS at MPR of 50% or higher (see Figure 20).

- **Operation based on Market Penetrations of connected vehicles**: In order to achieve meaningful impacts, it was recommended to keep speed limit instructions through variable message signs operational until a minimum CV market penetration of 30% was achieved. The findings suggested that, beyond 30% MPR, CVs may be able to influence the traffic stream performance substantially and the impacts may remain similar even if VMS is removed.
- **Distance Gap from Event Location**: In cases where a full coverage of the RSUs cannot be achieved along the motorway, providing speed instructions upstream of the event location was more effective than providing downstream. This was because, providing speed instructions downstream made it difficult to reduce the congestion at the on-ramp near the VMS location. However, providing the same to further upstream of the event location reduced effectiveness at low MPR. If the activation area was

too far upstream, it gave unequipped vehicles the opportunity to overtake CV, especially at lower market penetrations of CV, which made it less effective.

- **Message Notification Configuration:** With the expansive broadcast process for RSU, no significant differences were observed even with a D_{gap} of 5km upstream as compared to the previous approach with D_{gap} equal to 0km, except during situations of high merging traffic at high flow conditions, in a mixed traffic environment. Therefore, expansive broadcast strategy is more effective in comparison to conservative broadcast when the distance gap from event location is higher than 1km.

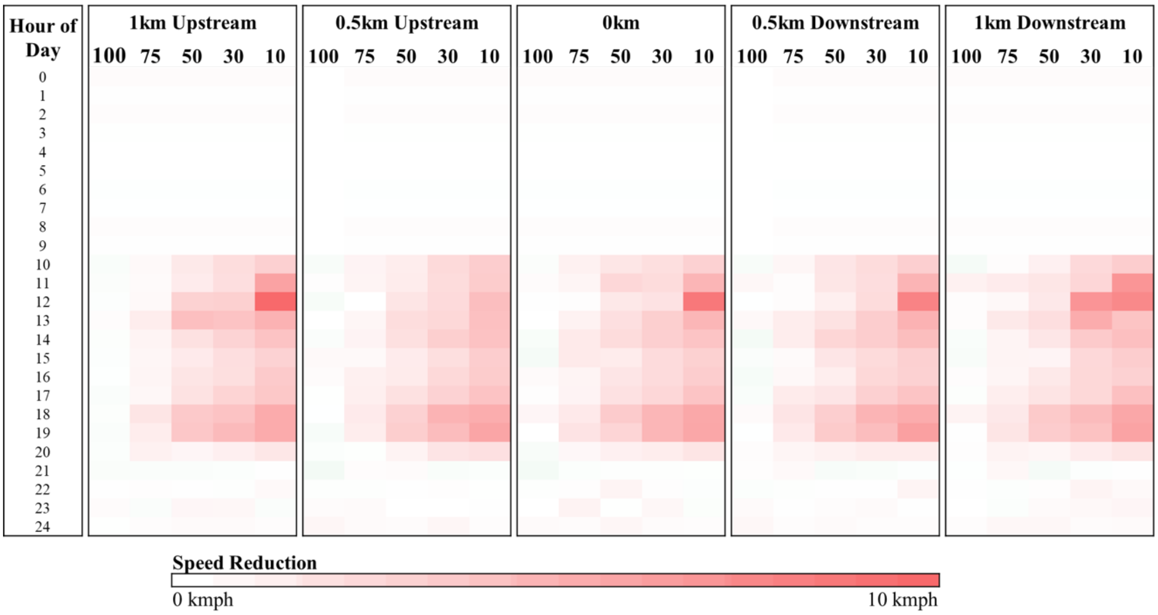

Figure 20 - Change in hourly average speeds for different scenarios (MPR and D_{gap}) of IVS in comparison to VMS for DSLI

6.2.4. Italy

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

Refer to Section 6.1.4 (Safety - Italy)

Data collected

Refer to Section 6.1.4 (Safety - Italy)

Evaluation results – Field tests

Refer to Section 6.1.4 (Safety - Italy)

Evaluation results – KPIs on Mobility

Indirect impacts on traffic efficiency are assessed considering that a road accident is causing the closure of the carriageway for a time period (i.e. 2 hours). Adopting a model based on input-output diagrams theory, the quantification of the possible delays that the vehicles impacted are suffering is made possible. These delays are supposed to be reduced by the deployment of the Use Cases.
The estimation of indirect effect on traffic efficiency (safety related) assumed that 382 events of traffic congestion due to road accident were avoided thanks to the Use Case. According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 85.

Table 85 - IVS-DSLI - Estimated EKPIs on mobility - Traffic Efficiency - Indirect impacts

	2 lanes	3/4 lanes	Notes
Average delay	81,7 [min]	74,3 [min]	Faced by each vehicle
Total Average delay per accident (all vehicles involved)	4.509 [h]		Contribution weighted on the features of the highways (n. of lanes)
Total delay saved	**1.723.958 [h]**		Considering 382 events

6.2.5. Austria

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

Evaluation method employed was as per that described in Section 5.1.7 Safety – Austria.

Data collected

The detailed information is given in Section 5.1.7, because the data collection approach was consistent for all KPIs concerning IVS.

Evaluation results – Field tests

An overview about the general results are given in Section 5.1.7.

Evaluation results – KPIs on Mobility

Concerning the KPI on Efficiency, the following can be stated:

The speed and speed-change throughout the whole length of the evaluated motorway-stretch is a good indication for the positive effect of this kind of C-ITS message. Though the average volume of traffic was not equally high at all the different drives, the smoothness of speed-change was always equally fine.

With this more or less constant speed-change, rolling traffic was always effective in the sense that no disturbances were obtained, and thus, no traffic jams could evolve from this. Since traffic jams are the main cause for high economic costs, C-ITS messages play an important role in reducing congestion-related expenses.

6.2.6. Summary

Evaluation results – Field tests

The IVS use cases that were investigated by different countries include Dynamic Speed Limit Information (Spain, UK, France, Italy, Austria), Embedded VMS “Free Text” (Spain, UK), Shock Wave Damping (Spain) and Dynamic Lane Management (UK).

The key impacts on traffic efficiency in terms of different KPIs are highlighted as follows:

- Impact on Travel Time: Significant improvements in travel time were observed for the DSLI and EVFT use cases. According to simulation on French Highways, the application of DSLI during peak periods might improve the average speed by about 25 km/h at MPR=10% up to 30 km/h for MPR of 75% or higher. The impact analysis made by Italy estimates an indirect impact of 1.723.958 h on delay savings considering accidents avoided over a period of one year.
- The number of stops and duration along routes where the C-ITS service SWD was implemented was drastically reduced (Benefit: -39%).
- The change in instantaneous accelerations and decelerations was reduced in all the use cases evaluated in Spain for IVS (DSLI with a benefit of -58,6% and the EVFT use case). Field tests in Austria also indicate a smoother speed change and a more homogeneous speed profile with the DSLI use case.
- Impact on Speed: The result of the KPI change in average speed decreased in the DSLI use case. It increased in SWD, but around the neutral value. The service EVFT did not show similar results in the Mediterranean pilot. The value of the difference between the average speed of the vehicle and the speed limit was negative for DSLI and EVFT use cases. DSLI improved driver preparedness when entering a different speed limit zone.
- Impact on Lane Changing: DLM displayed a potential to improve traffic efficiency by giving the driver more time to select the correct lane, thus reducing late stopping and blocking of lanes. In congested conditions and with unplanned lane restrictions, informed lane changes conducted early and smoothly can improve traffic flow.

Evaluation results – KPIs on Mobility

This table summarizes and reflects the main trends in the findings over the various tests and analysis undertaken by each country. The color describes the positive/neutral/negative evolution of the KPI under consideration. When quantitative values / windows (percentage) of benefits are available, it is written within the cell in addition to the color indicator.

Please pay attention to the fact that negative effects on some KPI might be expected and completely explainable. For instance, Dynamic Speed Limit voluntary reduces the speed upstream to avoid congestion propagation and capacity drop due to traffic heterogeneities. Italy highlighted some indirect impacts in terms of accident avoidance due to the implementation of use case IVS-DSLI. It is estimated that this use case might avoid around 382 accidents on Italian motorways per year. Therefore, 1,723,958 hours of delays could be saved.

	KPI	Travel Time	Congestion	Traffic Homogeneity	User acceptance
Use cases	Market Penetration Rate level	Average Travel Time [TT] / Average Speed [S] / change in Delays [D]	Number of stops [SN] / stops or queuing duration [SD] / etc	Variations in instantaneous Acceleration [Acc] / in Average Speed [S]	Rate of users intending to response or strongly compliant (safer behaviour)
IVS-DSLI	low	Sp: ▲+10,9% [TT] Fr: ▲+35% [S], versus Variable Message Signs: ▼-7%		Sp: ▼-58,6% [Acc], ▼ [-4,8%; -8%] [S]	UK: 63%
	high	Fr: ▲+42% [S], versus Variable Message Signs: =			
IVS-EVFT	low	Sp: ▲+41,2% [TT]		Sp: ▼-9,6% [Acc], ▼ [-2,8%; +0,7%] [S]	
	high				
IVS-SWD	low				
	high		Sp: ▼-39% [SN]; ▼-17,2% [SD]	Sp: ▲+0,02% [S]	

Legend

- Colors:

Not Concerned	Variable benefits	Positive benefits	No significant changes	Negative Benefits

- Countries under consideration: Spain (Sp) / United Kingdom (UK) / France (Fr)/ Italy (It) / Austria (At).

6.3. Environment

This section provides a list of the in-vehicle signage use-cases evaluated from an environmental perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: France, Spain, UK, Austria, Portugal, NW2

6.3.1. Spain

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-EVFT: In Vehicle Signage - Embedded VMS "Free Text"

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

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

Sub Research Questions:

- How does the IVS service affect the fuel consumption in the use case?
- How does the IVS service affect the CO2 Emissions on the use case?
- How does the IVS service affect the emissions of other pollutants (NO_x, PM, CO, etc...) in the use case?
- How does the IVS service affect noise levels in the use case?

Data collected

The data collected that was used to evaluate the different impact areas are the same for all of them. Refer to Chapter 5.1.1 to check the data collected in the Spanish pilot.
The Mediterranean sub-pilot used the characteristics of the vehicles to estimate the impacts on environment: fuel consumption, carbon dioxide emissions and pollutant emissions.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS IVS v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation were obtained. The KPIs that were calculated in each of the sub-pilots are presented in Table 86, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 86, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 86 - IVS Environment. Spain.

KPI	Service	Use Case	Pilot	Summary
Change on fuel consumption and CO_2 emissions	IVS	DSLI	Andalusian - Mediterranean	-3%
			Catalan -Mediterranean	-2.8%
		EVFT	Andalusian - Mediterranean	0.5%
			Catalan -Mediterranean	-1.2%
Change on pollutant emissions NO_x	IVS	DSLI	Andalusian - Mediterranean	-7%
			Catalan -Mediterranean	-6.7%
		EVFT	Andalusian - Mediterranean	1.4%
			Catalan -Mediterranean	-2.8%
Change on pollutant emissions PM2.5	IVS	DSLI	Andalusian - Mediterranean	3.9%
			Catalan -Mediterranean	4.7%
		EVFT	Andalusian - Mediterranean	-0.1%
			Catalan -Mediterranean	1.5%

6.3.2. UK

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-DLM: In Vehicle Signage - Dynamic Lane Management
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“

Evaluation method

Evaluation method employed was as per that described in Section **Errore. L'origine riferimento non è stata trovata.** Safety – UK.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

Although there were no directly measured Environmental KPIs, IVS use cases tested demonstrated implied benefits from the behavioral changes of the drivers.
Any of the use cases which resulted in reduced speed or smoother driving as cited in 0 could also have a secondary environmental impact (reduced fuel consumption and therefore reduced emissions). As such, subjective impact summaries for IVS have been included here relevant to this specific evaluation area.

IVS Dynamic Speed Limit information:
The large number of participants who intended to reduce their speed in response to the technology prior to testing it (63%) suggested that dynamic speed limit information had the potential to influence behavior change.
Reduced speed and maintaining it is likely to have a positive traffic impact, which in turn could produce an environmental impact by reduced fuel consumption and lower emissions.
Key observations from driver interviews that are Environmental impact related included:
Dynamic Speed Limit information improved their preparedness when entering a different speed limit zone and this made them check their speed: "probably more than I would have done”, according to one participant
In congested conditions this increased speed compliance could improve traffic flow as described, which in turn will reduce fuel consumption and reduce emissions.

IVS Dynamic Lane Change Information:
Earlier changes of lane in a smooth and considered manner could see improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown, which in turn could produce an environmental impact by reduced fuel consumption and lower emissions.
Key observations from driver interviews that are Environmental impact related included:
Lane advice has the potential to increase efficiency by giving the driver more time to select the correct lane, thus reducing late stopping and blocking of lanes.
In congested conditions earlier and smoother lane changes due to unplanned lane restrictions e.g. due to an on-road incident, could improve traffic flow as per the controlled motorways model, preventing flow breakdown by excessive speeding (and braking) in congested conditions. It can form part of a virtual controlled motorways service. In turn this could reduce fuel consumptions and emissions

IVS Embedded VMS:
See qualitative analysis in Section 6.4.2 User Acceptance – UK as although this service was not one of the Common InterCor Use cases but was evaluated from a User Acceptance aspect by the UK C-ITS Pilot evaluation team.
Key observations from driver interviews that are Environmental impact related included: Depending on the message displayed, there could be a secondary traffic efficiency benefit from warning drivers early of something in the road e.g. debris, animal or person, thus reducing sudden braking/lane changes, and also warning any traffic issues further down the road network that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue.
This could also produce a secondary environmental benefit.

Evaluation results – KPIs on Mobility
Although there were no directly measured Safety KPIs, IVS exhibited implied benefits from the behavioral changes of the drivers recorded through the subjective impact evaluation

6.3.3. France

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Please refer to Section 6.2.3.

Evaluation method

Please refer to Section 6.2.3.

Data collected

Please refer to Section 6.2.3.

Evaluation results – Field tests

Please refer to Section 6.2.3.

Evaluation results – KPIs on Mobility

The PHEMlite emission model integrated with SUMO was used to obtain the emission outputs. Results with reference to IVS-DSLI use-case are further summarized below and shown in Figure 21:

- While comparable speed profiles are observed in many scenarios of IVS-DSLI use case (with reference to VMS), there are some visible differences in terms of CO_2 and NO_x emissions with varying degrees of market penetration (MP) of connected vehicles (CVs).
- While the trends are similar for both CO_2 and NO_x emissions, the gains are higher for NO_x emissions at high market penetrations of CV, while CO_2 emission gains are higher at low MPR.
- Although the emission performance in a fully connected environment is similar to that for a VMS (Variable Message Sign), there is an increase in emissions as the market penetrations of connected vehicles are reduced, primarily due to the speed oscillations of the unequipped vehicles. These findings, are, of course, based on the primary assumption that the drivers are fully compliant to the speed instructions, and, in reality, the variations in compliance to the speed instructions through different means of communications will affect the overall emission performances. It is encouraging to note that, even with a market penetration as low as 10% of connected vehicles in the traffic stream, there is a substantial improvement in emission performance as compared to the case where no dynamic speed limits are implemented.

Co-financed by the Connecting Europe Facility of the European Union

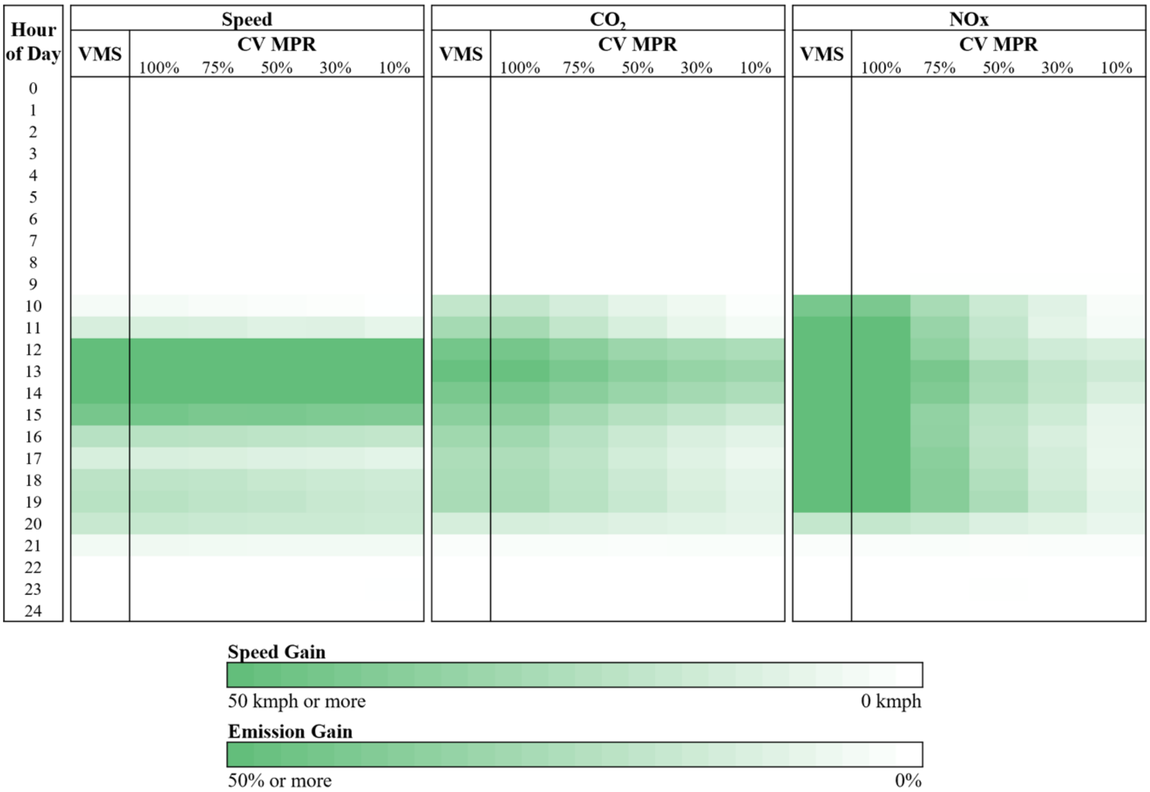

Figure 21 - Summary of Impact of C2 use-case on traffic and environment performance

6.3.4. Italy

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

Refer to Section 6.1.4 (Safety - Italy)

Data collected

Refer to Section 6.1.4 (Safety - Italy)

Evaluation results – Field tests

Refer to Section 6.1.4 (Safety - Italy)

Evaluation results – KPIs on Mobility

Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency. Consumption and emission factors are adopted as reported in Table 87.

Table 87 - Consumption and emission factors

Consumption factors	[l/km]
Congestion - Light vehicle consumption	0,105
Congestion - Heavy vehicle consumption	0,48
Free Flow - Light vehicle consumption	0,07
Free Flow - Heavy vehicle consumption	0,32
Emission factors	**[kg CO_2/l]**
Emission Factor - Gasoline	2,34
Emission Factor - Diesel	2,61

The estimation of indirect effect on environment was based on the indirect impacts on traffic efficiency, assuming that 382 events of traffic congestion due to road accident were avoided thanks to the Use Case.
According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 88.

Table 88 - RWW-LC - Estimated EKPIs on mobility - Environment - Indirect impacts

Delta Gasoline per accident	- 1.028 [l]
Delta Diesel per accident	- 1.451 [l]
Total Average Delta Emissions per accident	- 6,19 [CO_2 ton]
Total Average Delta Emissions	- 2.368 [CO_2 ton]

6.3.5. Austria

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Evaluation method

Evaluation method employed was as per that described in Section 5.1.7 Safety – Austria.

Data collected

The detailed information is given in Section 5.1.7, because the data collection approach was consistent for all KPIs concerning IVS.

Evaluation results – Field tests

An overview about the general results are given in Section 5.1.7.

Evaluation results – KPIs on Mobility

As for KPI on Emissions, these are the most important results that were obtained:
The main cause for an increase of emission is not so much a certain (eventually too high) speed, but more the result of frequent speed-changes.
The speed-changes within the evaluated area are within a very low range, leading to low CO_2 (and other)-emissions.
This is equally true for noise emissions.

6.3.6. Summary

Evaluation results – Field tests

The IVS use cases that were investigated by different countries include Dynamic Speed Limit Information (Spain, UK), Embedded VMS "Free Text (Spain, UK) and IVS Dynamic Lane Change Information (UK) as well as the French output of the PHEMlite emission model (integrated with SUMO)

Although there were no directly measured Environmental KPIs, the tested IVS use cases demonstrated the implied benefits because of the behavioral changes of the drivers.

Any use case that resulted in reduced speed or smoother driving could also have a secondary environmental impact, such as reduced fuel consumption and consequently therefore reduced emissions as well as reduced noise emissions.

Depending on the message displayed, there could be a secondary traffic efficiency benefit from warning drivers early of something in the road, such as debris, animal or persons.

Consequently, this reduces sudden braking/lane changes and also warns traffic issues further down the road network that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue.

The **Spanish pilot** considered a large number of KPIs and their evaluation.

Taking into account the summary results of Spain the following main conclusions at the Spanish level have been obtained:

- Change in fuel consumption and CO_2 emissions: the result of this KPI indicated a reduction for IVS-DSLI use case in all the pilots where this KPI was evaluated (Benefit of -3% in the best case). In the case of EVFT, the Catalan sub-pilot detected a reduction and the result in the Andalusian sub-pilot was neutral.
- Change on pollutant emissions NO_x: There was a reduction on the pollutant emissions in DSLI use case (Benefit of -7% in the best case). In the case of EVFT for the Catalan sub-pilot, there was also a reduction but for this same use case in Andalusian sub-pilot, the result was 1,4%.
- Change on pollutant emissions $PM_{2.5}$: A reduction was detected in the service EVFT for the Andalusian sub-pilot (-0,1%), but it was a result of 1,5% in Catalan sub-pilot. For the service IVS-DSLI, the result was positive without benefit.

The key impacts on environment in terms of different KPIs are highlighted as follows:

- Impact on Speed: Slight improvements in travel time were observed with an increasing MPR
- Impact on CO_2 emissions: there was a decrease in emissions as the market penetrations of connected vehicles increased, primarily due to the speed oscillations of the unequipped vehicles
- Impact on NO_x emissions: there was a significant decrease in emissions with rising market penetration. Again, this was mainly due to the speed oscillations of the unequipped vehicles

With all these statements, it's worth noting that, even with a market penetration as low as 10% of connected vehicles in the traffic stream, there was a substantial improvement in emission performance compared to the case where no dynamic speed limits were implemented.

As for the **UK pilot,** it can be stated that although there were no directly measured Safety KPIs, IVS exhibited implied benefits from the behavioural changes of the drivers recorded through the subjective impact evaluation.

Key observations from driver interviews that are Environmental impact related included secondary traffic efficiency benefit from warning drivers early of something in the road e.g.

debris, animal or person, thus reducing sudden braking/lane changes, and also warning any traffic issues further down the road network that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue.
The **French pilot** used an emission model to obtain the emission outputs.
Results include:

- There are visible differences in terms of CO_2 and NO_x emissions with varying degrees of market penetration (MP) of connected vehicles (CVs).
- Gains are higher for NO_x emissions at high market penetrations of CV, while CO_2 emission gains are higher at low MPR.
- There is an increase in emissions as the market penetrations of connected vehicles are reduced, Even with a market penetration as low as 10% of connected vehicles in the traffic stream, there is a substantial improvement in emission performance as compared to the case where no dynamic speed limits are implemented.

Environmental impacts in the **pilot of Italy** considered the avoided congestions and are thus a consequence of impacts on traffic efficiency. Consumption factors show reduction of up to 0,48l/km and emission factors show saving of up to 2,61 kg Cos per liter
The estimation of indirect effect on environment was based on the indirect impacts on traffic efficiency.
Consequently, these events could lead to a reduction of up to 1,45l per avoided accident and show a potential reduction of total emissions of 2.368 tons of CO2.
As for the **Austrian pilot**, these are the most important results that were obtained:
The main cause for an increase of emission is not so much a certain (eventually too high) speed, but more the result of frequent speed-changes. The speed-changes within the evaluated area are within a very low range, leading to low CO2 (and other)-emissions.
This is equally true for noise emissions.

6.4. User Acceptance

This section provides a list of the in-vehicle signage use-cases evaluated from a user acceptance perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: NL, Spain, UK, Portugal, NW2.

6.4.1. Spain

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text“
- Radar & tunnel Information (DGT3.0 platform)

Quantitative Test Results (Surveys)

The initial questionnaire issued to pilot participants at the beginning of the trial collected information on: gender, age, level of completed schooling, occupation, monthly net incomes, profile as driver (if they have an own car, how many km/year they drive, if they are professional drivers, if they share transport and, finally, what is their level of knowledge about C-ITS and their thoughts about how they think they might change their driving behavior in response to the use-case.

After several weeks testing this system, participants provided feedback about the use of the C-ITS service. The structure of the questionnaire was as follows:

- General Service information (and expectation). The variables to analyze in this section are the next:
  - Perceived Efficiency taking into consideration a general perspective, environment, safety and traffic efficiency.
  - Perceived usability. This issue was analyzed using a system usability scale.
  - Workload. In this case the Rating Scale Mental Effort (RSME) was used.
  - Perceived usefulness and satisfaction through Van der Laan Scale.
  - Equity.
  - Willingness to pay.

Please, refer to Annex 3 – “User Acceptance Questionnaire” of the report from Spain [RD.3] for more information regarding the complete questionnaire used in the Spanish Pilot as well as the KPIs list that can be extracted from.

Together with the questions related to general driver and service information explained before, the participants could also provide feedback about IVS service in particular, in two different phases:

- Before testing started (pre-test IVS specific questions)
  - IVS will contribute to feeling at ease whilst driving
  - With IVS service in my car I would feel more secure whilst driving
  - With IVS service in my car I would distract my attention from traffic
  - I am comfortable providing my position data as part of the IVS service
  - I would like to have IVS service permanently in my vehicle
  - I would be willing to pay to have access to IVS information

- After several weeks testing this system (post-test IVS specific questionnaire)
  - Perceived effectiveness: Scores between 1 and 10 on the following:
    - Availability (Was the service available when the service was needed?)
    - Correctness (Was the information correct when the service was active?)
    - Completeness (Was the information complete when the service was active?)

- Consistency (Was the service consistent and easy to understand when the service was active?)
- Accuracy (Was the service accurate (geographical accuracy)?)
- Up-to-dateness (Was the service up-to-date? Was the service available right on time?)

Moreover, participants would identify the reasons if the effectiveness issues are lower than 5 points:

- Why service was not available? (Availability score < 5)
- Why service was not correct? (Correctness score < 5)
- Why service was not complete? (Completeness score < 5)
- Why service was not consistent? (Consistency score < 5)
- Why service was not accurate? (Accuracy score < 5)
- Why service was not up to date? (Up-to-dateness score< 5)

Other specific questions for the IVS service will have into account the next issues:

- Percentage of participants who notice the icon on the screen
- Perception frequency & usage frequency
- Perceived IVS acceptance

Some questions are asked to the participants to analyze the influence of the service on behavior and trip quality and to know the proposed improvements to the service.

- I feel using the service, it influenced in my behavior. If so, how?
- I think the services improved my overall trip quality. If so, how?
- What improvements would you introduce in the service?

Qualitative Test Results (Interviews)

Several specific questions have been asked to the participants during pre-tests and post-tests in the different sub-pilots. The following tables summarize the result of them.

Table 89 - IVS User Acceptance. SISCOGA Extended sub-pilot.

KPI		Estimated Value of KPI (%)
IVS acceptability (pre-test)	IVS will contribute to feeling at ease whilst driving	Around 85% of them considered that the IVS will contribute to feeling at ease whilst driving. Around half of the sample were totally agree with this affirmation.
	With IVS service in my car I would feel more secure whilst driving	70% of the drivers felt that they would not distract their attention from traffic while around 18,5% offered a neutral answer for this statement, and 12% of them considered that it could distract their attention.
	With IVS service in my car I distract my attention from traffic	Around 70% of the drivers felt that they would not distract their attention from traffic while around 18,5% offered a neutral answer for this statement, and 12% of them considered that it could distract their attention.
	I am comfortable providing my position data as part of the IVS service	19% were not satisfied with sharing their location, around 26% expressed a neutral opinion and half of them (55,5%) did not mind.
	I would like to have IVS service permanently in my vehicle	33% of the users said that they are agree with it and 52% are totally agree. Only 4% of them provided a neutral answer and 12% were disagreed.
	I would be willing to pay to have access to IVS information	40% is not in agreement to pay for it, around half of them (47%) were neutral to this question. 13% is totally agree with the idea of pay for the IVS service
IVS acceptance (post-test)	IVS will contribute to feeling at ease whilst driving	Around 13% of them expressed that they were not agreed with that. While 61% answer back with a neutral answer and, 20% was agree and 6% was absolutely agree.
	With IVS service in my car I would feel more secure whilst driving	20% of them agreed with this sentence and 6% was totally agree. It is necessary to indicate that around 61% of them provided a neutral answer. Only 13% were opposed with this idea.
	With IVS service in my car I distract my attention from traffic	12% thought that this service could distract their attention from their attention from the traffic and, 22% disagreed with this affirmation. Around half of the sample was neutral for this statement after testing the service. Only 14% was totally opposed.

	I am comfortable providing my position data as part of the IVS service	23% thought that there is no problem for sharing their position. Around three quarters provided a neutral answer.
	I would like to have IVS service permanently in my vehicle	6% is totally agreed that they would like to have IVS information permanently in their vehicle. Over 30% is agreed with that. Around 40% of respondents was neutral. Only 12% differed with this statement.
	I would be willing to pay to have access to IVS information	12% of the sample expressed themselves negatively and around 35% said that they were totally disagree. 43% answered “neutral”. Only around 10% of them considered to pay for having access to this service.
Users that noticed the IVS icon on the screen		40% of drivers observed the icon on the screen as it can be seen in the next figure. A very low percentage (16%) was not sure if they noticed it and, 44% indicated not perceive it.
IVS perceived frequency during the test		One quarter of drivers noticed the IVS sometimes while 23% saw it hardly ever and around 35% never appreciated the information.
IVS perceived usage during the test		Around 41% expressed a negative opinion, while 23% of them used it very often. Similar percentage, 15% used it sometimes and other 15% hardly ever.
IVS influence in driver behavior		17% judged that using the service had not influenced in their behavior. Around 60% of users felt neutral, and around 23% answered positively.
IVS improvement in overall trip quality		13% of them disagreed but most of the sample considered the influence of the service on the trip (40% agreed and 13% was totally agreed). Around 32% had a neutral opinion.
IVS perceived effectiveness		60 points

Table 90 - IVS User Acceptance. Madrid sub-pilot.

KPI	Estimated Value of KPI (%)
IVS acceptability (pre-test)	67.08
IVS acceptance (post-test)	74.55
Users that noticed the IVS icon on the screen	46.15
IVS perceived frequency during the test	41.54
IVS perceived usage during the test	46.15
IVS influence in driver behavior	63.08
IVS improvement in overall trip quality	61.54
IVS perceived effectiveness	52.56

Table 91 - IVS User Acceptance. Catalan sub-pilot.

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	50.0
Perceived usage during the test	52.9
Perceived effectiveness	67.9
Perceived acceptance	57.1
Perceived acceptance pre-test	54.8
Influence on behavior and trip quality	65.0

Table 92 - IVS User Acceptance. Andalusian sub-pilot.

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	76.7
Perceived usage during the test	68.3
Perceived effectiveness	66.4
Perceived acceptance	65.8
Perceived acceptance pre-test	64.6
Influence on behavior and trip quality	70.8

Table 93 - IVS User Acceptance. DGT3.0 sub-pilot. SISCOGA Extension. DGT3.0 participants (HMCU)

KPI		Estimated Value of KPI (%)
IVS acceptability (pre-test)	IVS will contribute to feeling at ease whilst driving	33% of the users considered that the IVS will contribute to feeling at ease whilst driving. Around 55% of drivers were totally agree with this affirmation.
	With IVS service in my car I would feel more secure whilst driving	88% of the users were agreed or totally agreed with this statement.

	With IVS service in my car I distract my attention from traffic	66% of the drivers felt that they would not distract their attention from traffic while around 33% presented an impartial answer for this statement.
	I am comfortable providing my position data as part of the IVS service	88% were satisfied with sharing their location, around 11% stated a neutral opinion.
	I would like to have IVS service permanently in my vehicle	33,% of the users said that they are agree with it and 44% are totally agree. 11% of them provided a neutral answer and 11% were disagreed.
	I would be willing to pay to have access to IVS information	44% is not in agreement to pay for it, most of the sample (55%) were neutral to this question. Only a 10% is totally agree with the idea of charge for the service.
IVS acceptance (post-test)	IVS will contribute to feeling at ease whilst driving	22% of sample was agreed with the next statement: “Thanks to the IVS information I felt more at ease while driving”. Only 11% of them expressed that they were not agreed with that. While 66% replied with a neutral answer.
	With IVS service in my car I would feel more secure whilst driving	22% of the users agreed with this sentence. It is necessary to indicate that around 66% of them provided a neutral answer.
	With IVS service in my car I distract my attention from traffic	33% disagreed with this affirmation. Around 66% was neutral for this statement after testing the service.
	I am comfortable providing my position data as part of the IVS service	11% felt that there is no problem for sharing their position. Around 77% provided a neutral answer and only a minimum percentage is not agreed with this idea (11%).
	I would like to have IVS service permanently in my vehicle	22% is totally agreed that they would like to have IVS information permanently in their vehicle. 77,77% of sample was neutral.
	I would be willing to pay to have access to IVS information	11% of the sample expressed themselves negatively. 88% answered “neutral”.
Users that noticed the IVS icon on the screen		Half of the sample expressed that the notice the IVS information very often and 27,77% noticed it sometimes.
IVS influence in driver behavior		20% percentage of participants judged that using the service had not influenced in their behavior. 60% of users felt neutral, but a 20% answered positively.
IVS improvement in overall trip quality		70% was neutral while a 20% was totally agreed with that statement
IVS perceived effectiveness		60 points

Conclusions

Refer to 5.4.1 to have more global details about user acceptance regarding to perceived efficiency in general, perceived efficiency on safety, traffic efficiency and environmental, perceived usability, workload, perceived usefulness, satisfaction and effectiveness, equity and willingness to pay.

6.4.2. UK

Use Cases considered

Evaluation	User Acceptance
Service	IVS
Research Question(s) or Use Cases evaluated.	IVS use case 1: dynamic speed limit information How do end users rate this service and its influence on them? Quantitative Evaluation: Common set of User Acceptance used as agreed within InterCor Activity 4.4 using online survey (pre and post-test questionnaires to measure acceptability vs acceptance). Qualitative Evaluation: Driver interviews conducted following topic guide agreed in InterCor Activity 4.4. following testing.
	IVS use case 2: Lane Change Advice; How do end users rate this service and its influence on them? Quantitative Evaluation: Common set of User Acceptance used as agreed within InterCor Activity 4.4 using online survey (pre and post-test questionnaires to measure acceptability vs acceptance). Qualitative Evaluation: Driver interviews conducted following topic guide agreed in InterCor Activity 4.4. following testing.
	IVS use case 3: Embedded VMS; How do end users rate this service and its influence on them? Qualitative Evaluation: Driver interviews conducted following topic guide agreed in InterCor Activity 4.4. following testing.

Quantitative Test Results (Surveys)

Service	Road Safety	Traffic Efficiency	Environment
IVS Speed Signage:	72% of drivers said they used the speed assistant. 91% felt it wasn't distracting 64% thought it would improve safety	Not measured Traffic efficiency may improve if IVS speed encourages smoother and less aggressive driving.	21% stated that they adapted their speed immediately
IVS Lane Signage:	75% thought lane signage would improve safety 87% felt it wasn't distracting	62% thought it was more effective than roadside signage	Not measured Pollution levels may improve if RWW encourages smoother and less aggressive driving.
IVS Embedded VMS:	See Qualitative	See Qualitative	See Qualitative

Qualitative Test Results (Interviews)

Service	Road Safety	Traffic Efficiency	Future Scenarios
IVS Speed Signage:	Participants reported that they paid more attention to the IVS - than they would when displayed on the gantry "It makes you check whether you're doing the right speed." “Perhaps I would’ve gone over 50 if it wasn't flashing in my face.”	During high traffic volume situations, a better awareness of the correct speed should lead to better efficiency. “Makes you more aware of the speed you should be doing.”	Improve the accuracy and reliability of the messages. Testing in a more controlled environment is recommended to collected in-depth feedback about the quality of the service in specific scenarios (e.g. congestion, accident ahead etc.). Provide speed advice based on live traffic information and national speed advice separately. Improve the timeliness of the service and consistency between new speed advice and end of speed advice.
IVS Lane Signage:	When the provided information was relevant, participants found the service to be useful with potential to improve trip quality	"I was on the left-hand side, I had to move across, so it was quite handy as a little reminder to say to move over." Participants commented that a lane change message is useful to encourage lane discipline.	None provided
IVS Embedded:	Most participants reported that they found the service to be helpful, they gave the driver more time to think and increased awareness of the road conditions. VMS messages notifying of hazards influence driver behavior it is easier to anticipate changing lane or queues ahead and better manage their speed through congestion	When participants knew the time to a junction, it made them feel more aware and feel they had more time to change lanes. Better speed management in congestion should result in fewer start stop situations	Distance to the congested area or approximate length of the queue. Customizability of the services would be a key to the successful roll out of in-vehicle signage systems.

IVS Dynamic Speed Limit information:

- Some participants reported that they paid more attention to the Dynamic Speed Limit information in the car than they would when it is displayed on the gantry.
- Participants also felt more aware of the speed limits at all times
- Dynamic Speed Limit information improved their preparedness when entering a different speed limit zone and this made them check their speed: "probably more than I would have done”, according to one participant

Quotes from drivers:
“Makes you more aware of the speed you should be doing.”
"It makes you check whether you're doing the right speed."

“Perhaps I would’ve gone over 50mph if it wasn't flashing in my face.”

Although the UK pilot wasn’t able to measure objective speed adaptation for this service due to limits on how the controlled test could be set up to measure differences between the control / treatment groups[10] it was extremely useful to use the subjective impact data to inform on how drivers felt how the services were influencing their ‘normal’ driver behavior.

IVS Dynamic Lane Management:
Participants commented that a lane change message was useful to encourage lane discipline.
Quotes from drivers:
"I was on the left-hand side, I had to move across, so it was quite handy as a little reminder to say to move over."
Smoother lane changes (as per the RWW service), would help reduce the chance of accidents, especially when combined with speed reduction as indicated from the driver questionnaires/interviews for RWW and IVS Dynamic Speed Limit information.
All three use cases provide speed limit information with RWW and IVS Dynamic Lane Management provides lane restriction information and distance to the restriction via a countdown which appears to influence the driver’s attention especially when accompanied by an audible signal when conditions change.

IVS Embedded VMS:
The majority of participants thought that Embedded VMS messages would be useful for HGV drivers, especially if there was also information about road width and height restrictions
One participant found the Embedded VMS messages particularly useful because it was raining, so they felt they were more likely to miss the messages on the gantry and wanted to concentrate on driving safely.
Ensuring drivers don’t miss key signage e.g. debris in road would have a related safety benefit.

Attitudinal Test Results (Extended)
Participants in the Pilots were asked a series of questions about their attitudes to driving and the following is a summary of their responses:
The majority of respondents felt that driving fast was risky, stressful, and provided for very few advantages. They also felt it was expensive, harmful to the environment and increased the risk of serious accidents.
Most drivers thought that respecting speed limits reduced the chance of an accident, provided a more relaxing journey, and gave a feeling of being more in control. They felt that keeping to the statutory limits set, didn’t reduce their chance of arriving on time and they also thought it was better for the environment.
Most participants think that other drivers do not respect the speed limits and that they should.

[10] Following a successful Belgium InterCor partner test to produce a true control group (no external signage in the driver’s eyeline), it would have been required to disable the signage on the roadside or test in an area without existing ITS signage but this was not possible in the timescales of the Pilot as this learning aspect was fully apparent until the final evaluation stage was already underway.

Most respondents think they can keep to the speed limits even when others are not, but about 40 percent felt that they should adapt to the speed of others. The majority of drivers said they respect the speed limits and would continue to do so.

Conclusions

IVS provided a service to inform drivers with three use cases evaluated:

- Dynamic speed limit information;
- Dynamic lane management lane status information;
- Embedded VMS; including journey time, accident warnings, obstructions in road.

The key impacts of the IVS and respective use cases were gleaned from subjective impact results summarized below.

IVS Dynamic Speed Limit Information:

Table 94 - Dynamic Speed Limit Information Impact summary

Safety	Traffic Efficiency	Environment
Reduced speed from increased alertness of changing speed limits is likely to have a positive safety impact as drivers have more time to assess the situation and increased braking times if vehicles around them perform unexpected maneuvers.	Reduced speed and maintaining it is likely to have a positive traffic impact as this is in effect a virtual version of Controlled Motorways where constant lower speeds are proven to increase the capacity of the road near flow breakdown conditions	In congested conditions this increased speed compliance could improve traffic, which in turn will reduce fuel consumption and reduce emissions.

Participants stated that they were more likely to pay attention to the in-car speed signage which in turn made them more aware of the current speed limit.
The IVS speed service will need to be further enhanced to ensure it remains in line with temporary speed limits, some drivers noted the HMI reporting a higher speed limit when the variable speed had been adjusted to a lower speed.

- The large number of participants who intended to reduce their speed in response to the technology prior to testing it (63%) suggests that dynamic speed limit information has the potential to influence behavior change if it provided drivers with more accurate and relevant information.
- Reduced speed is likely to have a positive safety impact as drivers have more time to assess the situation and increased braking times if vehicles around them perform unexpected maneuvers.
- Reduced speed and maintaining it is likely to have a positive traffic impact as this is in effect a virtual version of Controlled Motorways where constant lower speeds are proven to increase the capacity of the road near flow breakdown conditions.
- Reduced speed and maintaining it is likely to have a positive traffic impact as discussed, which in turn could produce an environmental impact by reduced fuel consumption and lower emissions.

IVS Dynamic Lane Change Management:

Table 95 - IVS - Dynamic Lane Management Lane Status Information Impact Summary

Safety	Traffic Efficiency	Environment
Smoother lane changes would help reduce the chance of accidents, especially when combined with speed reduction as indicated from the driver questionnaires/interviews for RWW and IVS Dynamic Speed Limit information. Participants commented that a lane change message was useful to encourage lane discipline.	Earlier changes of lane in a smooth and considered manner could see improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown. In congested conditions earlier and smoother lane changes due to unplanned lane restrictions e.g. due to an on-road incident, could improve traffic flow.	Improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown, which in turn could produce an environmental impact by reduced fuel consumption and lower emissions.

- Lane Advice service saw an increase from 63% before testing to 75% after testing of respondents agreeing or strongly agreeing that it would improve safety.
- Reduced speed is likely to have a positive safety impact as drivers have more time to assess the situation and make smooth, safe lane changes ahead of any lane restrictions.
- The large majority of participants disagreed that IVS - Lane Signage would distract their attention from traffic, so in terms of the warning the driver in the vehicle it didn’t appear to have a negative effect with the signage being easily interpretable compared to existing road signage drivers are already used to seeing and processing.
- Earlier changes of lane in a smooth and considered manner could see improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown.
- Earlier changes of lane in a smooth and considered manner could see improvements in traffic efficiency, avoiding last minute lane changes which can cause shockwaves in congested conditions and lead to flow breakdown, which in turn could produce an environmental impact by reduced fuel consumption and lower emissions.

IVS Embedded VMS:

Table 96 - IVS - Embedded VMS Impact Summary

Safety	Traffic Efficiency	Environment
Ensuring drivers don't miss key signage due to obscuration or in poor visibility such as 'debris in road' would have a related safety benefit. Embedded VMS reportedly gave the driver more time to think and increased awareness of the road conditions.	When participants knew the time to a junction, it made them feel more aware and feel they had more time to change lanes. Better speed management in congestion should result in fewer start stop situations.	Early warning drivers e.g. debris, animal or person, reducing sudden braking/lane changes, warning of traffic issues further down the road network that might influence the driver taking an alternative route much earlier, before reaching the back of an existing traffic queue could also produce a secondary environmental benefit.

Many drivers wear spectacles for distance when driving, this can then make it difficult for them to see clearly any text displayed on the HMI. Messages that appear too often, particularly if they are not relevant to the journey, can be distracting and irritating to the driver. An example of this is the time to junction messages.

Embedded VMS reportedly gave the driver more time to think and increased awareness of the road conditions. Messages were found to be particularly useful for preparing the driver for the exit junction and congestion. These messages were seen as important in allowing the driver to adjust their speed, be more alert to possibility of stopped traffic and move across to the appropriate lane earlier. Drivers felt more at ease and less stressed due to the messages appearing on screen for longer. They also felt they would be useful in peak times and rural areas where there is limited signage.

- The majority of participants thought that Embedded VMS messages would be useful for HGV drivers, especially if there was also information about road width and height restrictions
- One participant found the Embedded VMS messages particularly useful because it was raining, so they felt they were more likely to miss the messages on the gantry and wanted to concentrate on driving safely.
- Ensuring drivers don't miss key signage e.g. debris in road would have a related safety benefit.

6.4.3. Netherlands

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Quantitative Test Results (Surveys)

Comparing Acceptability and Acceptance

The comparison between acceptability and acceptance was made using similar questions of the questionnaire posed before and after the driving experiment. The most interesting differences between the acceptability and acceptance are provided below.

When comparing the differences in the results of the acceptability and acceptance, some shifts in results were found (mostly towards the negative). For example, feeling at ease or more secure while driving with the HMI before the test was shown to be more positive than after the end of the test. Similar results were found when comparing statements regarding the feeling of alertness and perception of road safety. Furthermore, the majority appeared to feel that they got distracted by the IVS service, in contrast to their initial expectations.

Interestingly, the (perception of the) trustworthiness of the information presented on the HMI slightly increased after the test. Regarding the usefulness, even more people seemed to agree with that statement after the end of the test. Additionally, after the test, it appeared participants that would like to have the Speed Assistant permanently in their vehicle, are slightly less negative towards being willing to pay for the service after the test. Although it should be noted that the willingness to pay is still very low (neutral or below).

Perceiving and using the information

Most of the participants (77.9%) indicated to have noticed and also understood the maximum speed indication on the HMI, while around 16.8% of the participants indicated that they did not see the information on the screen at all. The rest (5.3%) indicated to have seen the information but not having paid attention to this information or not knowing what it was about.

Almost 53% of the participants indicated seeing the information 2-3 times during the test, 14.7% only saw the information once, while 11.6% did not recall how many times they saw the information. 17.9% of the participants indicated to never having seen the information on the maximum speed. Considering the use of the presented information, 36.8% indicated using the information (almost) always, 16.8% indicated that they used it frequently, 15.8% sometimes, while 24.2% indicated that they did not use the information. Lastly, 6.3% did not recall using the information.

Of all participants indicating **using** the information during the test (69.5%), the use of the information differed (where multiple answers were possible). Around 27% indicated that they used the information during the entire test drive, 29.5% indicated that they used the information mostly during disruptions, 6.3% mostly during unknown routes, while the rest did not know when they used it. Few claimed that they followed only the advice on the (road side) matrix boards.

Of all participants indicating that they did **not use** the information during the test (24.2%), where multiple answers were possible), 12.6% indicated not having seen the information on the HMI and 9.5% claimed that they did not know that there was this information in the car. Around 8% indicated that they did not require the information presented, 2.1% claimed that the information was not correct, while 1.1% preferred other information sources.

Influence of the service on behavior and trip quality

The influence of the speed signage on the behavior and trip quality of the participants was measured using five statements, which the participants were asked to rank between 'totally disagree' and 'totally agree'.

When considering the trip quality, the majority of the participants indicated feeling more at ease while driving with the HMI showing the maximum speed, while several of them were neutral towards this. A large proportion of the participants were also neutral to statements regarding feeling more secure while driving with the HMI, while an equal part indicated (strong) agreement towards this statement. The rest of them indicated disagreement towards this. Furthermore, around one third of the participants indicated that they were not distracted by the HMI, while some of them agreed and the rest remained neutral.

For the changes in behavior, the majority of the participants indicated being more aware when exceeding the speed limit as a result of displaying the speed on the HMI. Additionally, the large majority of the participants also indicated that they immediately reduced their speed after receiving a notification from the speed assistant.

Perceived value of the service

When considering the perceived value of the service, the majority of the participants indicated that they found the speed signage service both useful, clear to understand, trustworthy, and indicated that they were satisfied with the provided information. When considering the accurateness of the displayed information, again, most participants were positive. However, quite a few participants were neutral towards this statement or had no opinion, while also a few found that the information was not accurate in displaying the information. When considering the timelines of presenting the information, the opinions were divided, but still the majority found that the information was provided in a timely manner. For the effect on the road safety, most of the participants agreed to the statement of the Speed Assistant being an improvement to the road safety but a large proportion kept a neutral position towards this. A less positive effect was found when assessing whether the information presented on the HMI provided more value than roadside information, where the opinions were split and the majority did not agree to this, with many participants remaining neutral. Finally, most of the participants indicated that they would recommend the service to others.

Improvements to the service

From the comments made by the participants, several improvements to the service are provided below. First, several participants claimed that information was missing or not displayed on their screens or did not match with the information on the VMS sign above the road. Secondly, some participants indicated that the presented information was difficult to read, while it was recommended that it would have been clearer to display it in the form of road signs, using e.g. red border and white background with black letters. Thirdly, in the case of different speed limits for different lanes (in case of disturbances), some participants also indicated the desire for the HMI to also display the vehicle's current lane position. Another participant expressed the preference to constantly have the information over the maximum speed on the screen and not only during disturbances. A further recommendation for the display was to present the highway like in a normal GPS and not just with straight lines. Another indication was that during the test, the information from the HMI was not always correct and that the system needed about one minute to show the information on the screen while they would prefer it at least 2-3 km in advance. Some of the drivers also noticed that it was distracting to look at the screen inside the vehicle, especially due to the high brightness of the screen. Some of them also claimed that the information displayed as traffic signs on the road was enough. Apparently for one

participant it was not clear that the information from outside would be available in the car, so they did not pay attention at all.
According to the comments above, the service could be improved by providing the information displayed in a timely manner and by ensuring synchronization with the matrix (VMS) signs at all times in order to improve the reliability of the presented information. Moreover, to avoid confusion and distraction, the design of the interface as well as the display of the information could be improved and tested again in the future.

General Remarks

Other remarks regarding the service are as follows. The majority of the participants indicated the desire for the HMI (with the speed signage service) to be available permanently in their vehicle. When considering providing the participants' position data during the use of the service, the opinions were mainly positive towards agreeing to share this information while there were also many participants disagreeing or remaining neutral. Lastly, the clear majority of the participants indicated not being willing to pay for the service.

Conclusions

Regarding the IVS of speed and lane information, positively, most of the participants indicated to have seen, understood and used the information, either in every ride or mostly during disruptions, while it was mentioned that they found it useful to have, especially for emergency information inside the vehicle. In general, the participants indicated a positive effect on their driving behavior, related to the reaction to the information presented and to feeling more secure and at ease while driving. However, many were more negative after the test with respect to being distracted. Their comments for improvements mainly concerned the interface of the HMI but also the timeliness and correctness of the information presented.

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6.4.4. Austria

Use Cases considered

- IVS-DSLI: In Vehicle Signage - Dynamic Speed Limit Information

Quantitative Test Results (Surveys)

The questionnaire, where the answers were used for evaluation, contained three parts:

- The pre-test questionnaire included the definition of the profile sample for the drivers who participated in the evaluation test drives.
- In addition, the pre-test questionnaire included questions to define how much participants are already informed about C-ITS.
- Then the actual drive took place, and following up on this, a post-questionnaire was provided to participants with the aim of obtaining main opinions and feelings about how they perceived the use and information used during the pilot drive.

In a later stage, the, results of the questionnaire are evaluated and presented.

Questions before the Test Drive

There was a set of 7 questions for this service provided to the drivers before each drive, which results in the following score:

Question	Average score
In Vehicle Signage information will contribute to feeling at ease whilst driving.	**3,8**
With In Vehicle Signage information in my car, I would feel more secure whilst driving.	**3,73**
With In Vehicle Signage information service in my car, I would distract my attention from traffic.	**2,53**
I am comfortable providing my position data as part of the In Vehicle Signage information to Road Operators (i.e. ASFINAG).	**3,8**
I am comfortable providing my position data as part of the In Vehicle Signage information to car manufacturers.	**2,73**
I would like to have In Vehicle Signage information permanently in my vehicle.	**3,87**
I would be willing to pay to have access to In Vehicle Signage information.	**2,6**

There is a clear tendency towards an agreement of the implementation of HLN-services in a car, with an even higher tendency than RWW-related services.
Statements about privacy (“providing position data to OEMs”) and payments (“willing to pay to have access”) are generally slightly disregarded, with a score of 2,93 and 2,67 respectably.

Questions after the Test Drive
After the evaluation test drive, there was also a set of six statements to be quoted by the test drivers, very similar to the pre-test-questions:
These questions, which were presented after the test-drive, show the following score:

Specific questions: In Vehicle Signage (IVS)	**3,46**
Thanks to the In Vehicle Signage Information, I felt more at ease while driving.	**3,67**
Thanks to the In Vehicle Signage Information, I felt more secure whilst driving.	**3,73**
The In Vehicle Signage Information distracted my attention from traffic.	**2,53**
I am comfortable providing my position data as part of the In Vehicle Signage Information.	**3,53**
I would like to have In Vehicle Signage Information permanently in my vehicle.	**4**
I would be willing to pay to have access to In Vehicle Signage Information in my vehicle.	**2,27**

All answers concerning IVS show a positive tendency, again with the exception of "willingness to pay".
Also, in relation to the previous (RWW- and OHLN-) answers, the total agreement is high. Though the feeling of ease while driving was a bit lower than at other questions, the agreement to have this information permanently in the car shows a significant high quote of 4,0

Comparison of Questions Before and After
Finally, the similarity of questions, which were asked to the drivers before and after the drives, gave the possibility to have a comparison between these two set of questions and to see if there are any significant changes.
So, for each of the four evaluated services, a comparison was performed based on the feedbacks and questionnaires received from the participants.

Specific questions: In Vehicle Signage (IVS)	**Before**	**After**	**Delta**
Thanks to the In Vehicle Signage Information, I felt more at ease while driving.	3,8	3,67	-0,13
Thanks to the In Vehicle Signage Information, I felt more secure whilst driving.	3,73	3,73	0
The In Vehicle Signage Information	2,53	2,53	0

distracted my attention from traffic.			
I am comfortable providing my position data as part of the In Vehicle Signage Information.	3,8	3,53	-0,27
I would like to have In Vehicle Signage Information permanently in my vehicle.	3,87	4	0,13
I would be willing to pay to have access to In Vehicle Signage Information in my vehicle.	2,6	2,27	-0,33

There is generally a rather smaller agreement to specific questions about IVS. Also, the tendency is a little negative, with three questions that are answered more negative and only one with more positive statements. Two positions stayed on equal level.

6.4.5. Summary

The IVS service was widely used across all pilots, for example the UK recorded that 72% of drivers said they used the IVS speed assistant. Usage of the information displayed varied widely across the pilots, but the Netherlands saw 69.5% of drivers actively using the information. In Austria, there was generally a smaller agreement to specific questions about IVS with slightly lower scores on feeling at ease, feeling secure, sharing data, and willingness to pay. The latter two measures also decreased further slightly post testing. However, the desire to have the service permanently in the vehicle remained high, slightly increasing post-testing.

62% of UK drivers thought it was more effective than existing roadside signage. UK Drivers also felt more at ease and less stressed due to the messages appearing on screen for longer. In the Netherlands the majority of the participants indicated feeling more at ease while driving with the HMI showing the maximum speed. Significantly, Andalusia, Catalan and Madrid recorded that 71%, 65% and 63% respectively were influenced by the information.

In the Netherlands most of the participants indicated that they would recommend the service to others. Further, the majority of the users indicated the desire for the service to be available permanently in their vehicle. Although it is worth noting that there were considerable fewer Spanish participants wanting the IVS service on a permanent basis from the acceptance post test results.

Spain's user's opinions of IVS differed greatly from before testing began to after testing. Most felt that before testing, that IVS would help them to feel more at ease and more secure, but this reduced significantly afterwards. In contrast, most UK participants reported that they found the service to be helpful, they gave the driver more time to think and increased awareness of the road conditions.

In the Netherlands, feeling of being at ease or more secure while driving with the HMI during the pre-test survey was more positive than after the test. Similar results were found when comparing statements regarding the feeling of alertness and perception of road safety. Furthermore, the majority of users appeared to feel that they got distracted by the IVS service, in contrast to the initial expectations.

IVS Dynamic Lane Management in the UK saw an increase from 63% before testing to 75% after testing of respondents agreeing or strongly agreeing that it would improve safety. Of UK drivers when questioned, 62% thought it was more effective than roadside signage, 21% further stated that they adapted their speed immediately and around 70% thought it would improve safety.

69% of drivers in the Netherlands said they used the information provided by the service. For the effect on the road safety, most of the participants agreed to the statement of the Speed Assistant being an improvement to the road safety. UK Participants stated that they were more likely to pay attention to the in-car speed signage which in turn made them more aware of the current speed limit.

The majority of the Netherlands participants indicated that they found the speed signage service both useful, clear to understand, trustworthy, and indicated that they were satisfied with the provided information.

Across the countries who tested IVS most drivers felt the service was not distracting and in the UK as many as 91% of drivers said they were not distracted, although drivers in the Netherlands and Spain indicated that they were more distracted than they thought they would be in the pre-test questionnaire.

The perception of the trustworthiness of the information presented on the HMI in the Netherlands slightly increased after the test. Regarding the usefulness, more people agreed with that statement after the test which is a positive increase when comparing acceptability vs acceptance.

One UK participant found the Embedded VMS messages particularly useful when it was raining, they felt they were more likely to miss the messages on the gantry and wanted to concentrate on driving safely.
In the Netherlands most of the participants indicated that they would recommend the service to others. And the majority of the users indicated the desire for the service to be available permanently in their vehicle. Although there were considerable fewer Spanish participants wanting the service on a permanent basis.
Around 70% of Netherlands' participants indicated using the information. 27% said they used the information during the entire test drive, 29.5% indicated they used the information mostly during disruptions, 6.3% mostly during unknown routes. In Spain, Andalusia, Catalan and Madrid recorded that 71%, 65% and 63% respectively of drivers were influenced by the information. 72% of UK drivers said they used the speed assistant and 21% stated that they adapted their speed immediately.
In the Netherlands the majority of the participants indicated feeling more at ease while driving with the HMI showing the maximum speed and over 50% of Spain's participants said that it improved their trip quality.
Some aspects noted during interviews included that as many drivers wear spectacles for distance when driving, this could then make it difficult for them to see clearly any text displayed on the HMI. It was noted that for some drivers it would have been clearer to display it in the form of road signs, using for example a red border and white background with black letters and ensuring synchronization with the matrix (VMS) signs at all times.
Messages that appeared too often, particularly if they were not relevant to the journey, could be distracting and even irritating to the driver. An example of this were the time to junction messages in the UK pilot.
There was a general unwillingness to pay for IVS information, with a clear majority of the participants in the Netherlands not willing to pay for the service. This trend was seen across all services but particularly low with IVS. However, most drivers across all pilots who implemented IVS indicated general acceptance of the idea of sharing their positional data.

Driver Quotes:

- *"It makes you check whether you're doing the right speed."*
- *"Makes you more aware of the speed you should be doing."*
- *"I was on the left-hand side, I had to move across, so it was quite handy as a little reminder to say to move over."*

6.5. Functional Evaluation

This section provides a list of the in-vehicle signage use-cases evaluated from a functional evaluation perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, UK, Belgium/Flanders.

6.5.1. Spain

The Spanish pilot evaluated functional evaluation on most of the services deployed. Table 97shows the functional evaluation of IVS-DSLI. Refer to [RD.3] the final evaluation result of Spain to have more information about the rest of services and use cases in every sub-pilot.
Table 97 details the feedback obtained from the implementation in the Spanish pilot (Madrid and Andalusian sub-pilots).

Table 97 - IVS-DSLI Functional evaluation. Spain. Madrid sub-pilot

Service	Dynamic Speed Limit Information (IVS-DSLI)
Lessons Learned	[GMV deployment] The service IVS-DSLI was implemented in all the OBUs and HMIs agreed on the project. These developments together with the possible logs of HMI and OBU enabled analysis all the impact areas, technical KPIs and user acceptance. A web application was implemented to store the logs for the analysis. Although initially it was not planned to have Internet in the OBU for the project, later, we needed to have an Internet connection in order to send the logs to the GMV server (HMI and OBU logs about the events received from the RSUs) for the subsequent analysis and also to update the security certificates. It was a challenging challenge. To fulfil these functionalities, the HMI was used as a bridge to provide the Internet connection to the OBU. For this, Wi-Fi zone of the Smartphone was activated and the drivers were advised not to forget to activate this. As lessons learned, include a modem with an integrated SIM or modem with hub connection would simplify the current implementation. Another option could be to manage the certificates through the network itself (send the certificates through the RSUs to the OBUs). [Kapsch deployment] Kapsch deployed this pilot with a full set of field equipment that was key to fulfilling project requirements. At Gateway level, receiving all sets of messages from different services from TMC provided the capability of disseminating to appropriate RSUs in order to reach with IVS-DSLI information to all sets of OBUs available in the pilot. One challenging issue was properly defining accurate segments to properly inform drivers in real time. ITS-G5 short range communications allowed minimum latency to reach driver with expected information. Full standard compliance for ITS-G5 provided interoperability with future systems deployed. Already detected and managed existing Car2Car systems available in market and deployed in vehicles. During the pilot care was taken not to provide inconsistent information to those users, not involved in pilot scope.
HMI*	The Smartphone as HMI for the GMV deployment in the Madrid pilot was the main device used by the participants to receive feedback about the user acceptance for the IVS-DSLI service. The GMV C-ROADS App showed the instant speed all the time and also the icon with the speed limit information. The detection zone appeared in green and the relevance area is painted blue on the map. The user can adjust zoom levels on the map.

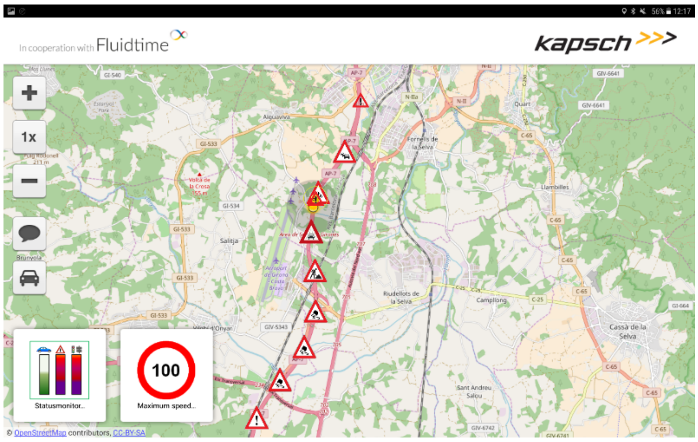
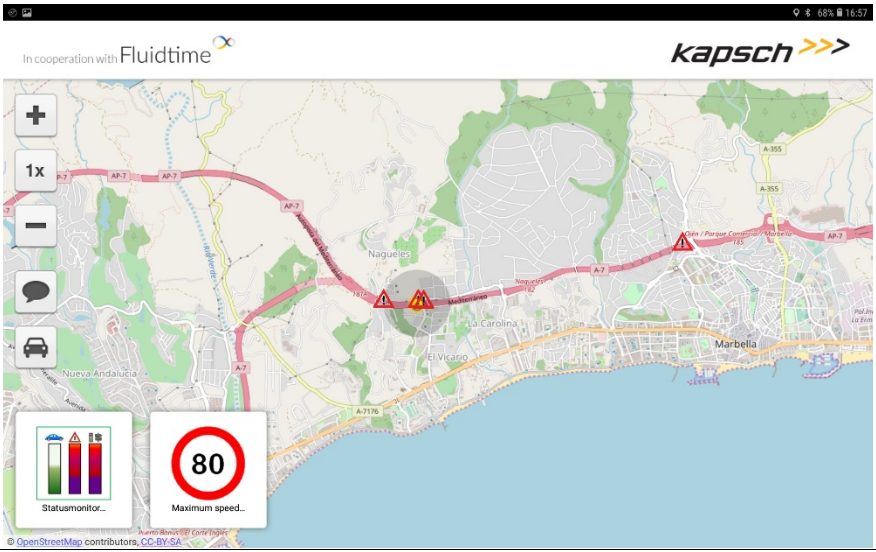
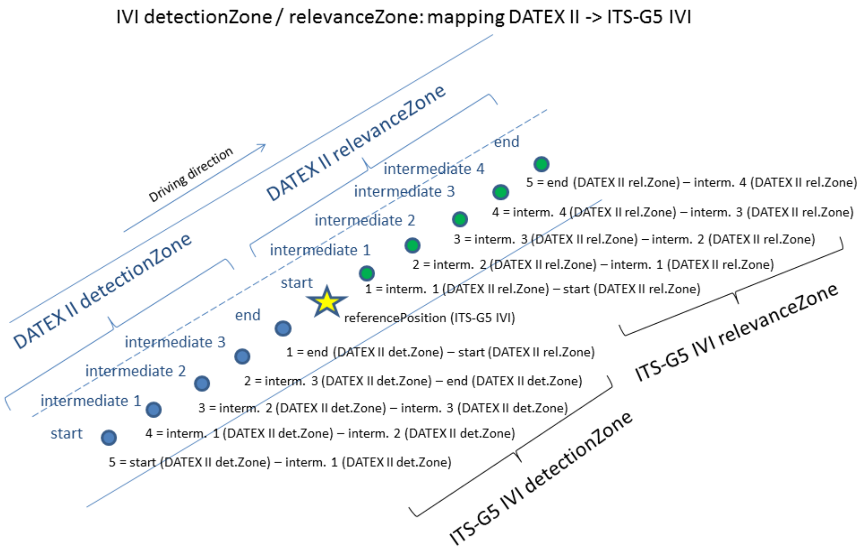
	 Kapsch deployed in all test vehicles included in this Pilot with an OBU and an HMI done with a tablet that is paired through a Bluetooth connection. All tablets had an app devoted to HMI purposes that provided all received info to the driver. For IVS-DSLI service, the next screenshot shows an example of how this information was provided to the driver. 
Quality of the Service	If the event received had relevance/detection traces, the notification in the HMI was shown to the user when the vehicle entered in the zone. The user had enough time to react.
Added Value of the Service	Participants of GMV C-ROADS application expressed a common added value for all the services: notifications with text-to-speech could be more beneficial instead of a sound notification. Anyway, the sound alerted the user and the information provided on the HMI was enough to identify the event with a simple glance. GMV App also showed the instant speed of the vehicle, so it could help the drivers to adjust their speed more easily. Kapsch HMI provided text-to-speech capabilities. Simply touching selected event or IVS, HMI read the associated text. This service was really useful in case of timely speed restrictions. Nowadays, this type of service is set manually by an operator, but in the case of Madrid city, the anti-pollution protocol set the maximum speed at 70 km/h, when usually it was set at 90/km/h. In a near feature, the integration of this kind of protocol will use this service for automating the information to the drivers.

Table 98 - IVS-DSLI Functional evaluation. Spain. Andalusian sub-pilot

Service	IVS-DSLI
Lessons Learned	Nature of the messages: In this case, and unlike the RWW use case, we did not have the opportunity to test the service with real events, so we have created "fake" events that have been sent to the vehicles on different situations. We must take into account that the ultimate goal of the pilot was to test the link between a back office and an OBU (via RSU in this specific sub-pilot) and then it was not needed to use a traffic information system in real time modus.

	The rest of the lessons learned from the use case RWW-LC apply to this use case.
HMI*	The same functions, issues and thoughts gathered for the RWW-LC use case in previous sections are applicable to the current use case. Below is a screen capture for this specific use case. 
Quality of the Service	Trigger of IVI Based Events  Detection zone: approach trace to the location of the IVI. The OBU uses it to decide if the IVI should be displayed: Maximum: 32 points Minimum: 10 points. (important, it must be enough for the OBU to decide) Separation distance between the points: 50m (fixed) Relevance zone: trace that indicates the relevance extension of the IVI message, and in which the OBU will show the IVI on the interface: Maximum 32 points Minimum: there isn't any requirement, but they are necessary for the OBU to know the section in which the IVI should be taught to the driver) Separation distance between the points: 50m (it can be more if necessary, to define an area of relevance greater than 32 points x 50 meters)) End Date Time. Unlike the RWW or HLN services, which have a start date and time, as well as an end, IVS messages only have an end time, so they will be immediately available in the RSUs from their generation and delivery until the time and finish date.

Added Value of the Service	The IVI message is sent out by an RSU and is intended to complement physical road signs and variable road signs. The sign contents will instead be displayed on the in-vehicle presentation unit. This use case provided speed limits in a more flexible way than conventional fixed signs installed on the road. The information was shown with greater anticipation of the event and with a variable frequency, complementing the information provided by the fixed signage. Embedded speed limit messages are helpful as they gave the driver more time to think and increased awareness of the road conditions. Participants stated that they were more likely to pay attention to the in-car speed signage which in turn made them more aware of the current speed limit. In one case, a regular driver of the test section reported that he had not been aware of a speed zone limited to 100 km/h until he used the service and saw the speed limit reflected on the system screen. An additional value is that the message is audible, which means less distraction for the driver.

6.5.2. UK

Service / Use Case	IVS (DSLI and DLM)
Lessons Learned	Ideally longer, larger pilots planned on 'naked roads' without the influence of existing ITS roadside equipment. This was particularly noticeable with the IVS DSLI service evaluation but affected IVS DLM also. The architecture of the shared C-ITS platform, performance of cellular communications and advances in service development (IVS in particular) mean that a wide scale roll out of connected vehicle services in the short medium term on Highways England's strategic road network is attainable. Data logging (common or not) is key to good evaluation results (***applies to all use cases)***. However, a key aspect is the ability to trace messages from source to destination for technical evaluation. Extracting KPI log data in the required format for evaluation was onerous. Consideration should be given to using a relational database to store and extract data for future Pilots, by using data software specialists to design and implement it based on the evaluation KPIs.
HMI	Participants expressed that if the system was integrated into a Satnav/vehicle display, this would be much more beneficial. Distraction is a key issue and integration could mitigate this. The ability to customize could improve the value of the service, as it helps to meet the needs of different profiles of road users and journey purposes. The HMI is key to acceptance of these services and users allowing data to be collected. Some areas that may help in this, include; full integration into existing mapping apps, icon/symbol size, audio alerts and customizability.
Quality of the Service	All IVI first warning messages were displayed on the HMI before entering the relevance zones. There were some issues related to the changes from left carriageway driving to right carriageway. For Embedded VMS it was observed that some messages persisted from past events due to latency in the existing back office system which was supplying the service messages so the quality of data would need to be improved for future roll outs. *Presentation of warnings:* The IVS warnings don't have to be aligned to a physical message sign and can therefore be shown in advance and for as long as they are relevant. They also can be used in areas where there are no message signs to fill gaps in message coverage. Varying the relevance zone depending on the specific situation can provide greater informational relevancy. *Technical Summary:* Technical evaluation of the pilot site on the M2 motorway confirmed that the information was displayed correctly 84% of the time, with incorrect information shown 11% of the time. All messages were shown in advance of the gantry with around 60% showing between 300m and 320m ahead of the gantry. In some later controlled tests, all messages were presented within the relevance zone, but the accuracy of the information was lower, with around 50% of the information being presented at the wrong location or because of matching errors due to issues with the back-office configuration.
Added Value of the Service	Participants stated that they were more likely to pay attention to the in-car speed signage which in turn made them more aware of the current speed limit. Drivers felt more at ease and less stressed due to the messages appearing on screen for longer. They also felt they would be useful in peak times and rural areas where there is limited signage.

	Most participants reported that they found the IVS - Embedded VMS messages to be helpful as they gave the driver more time to think and increased awareness of the road conditions. In addition to providing speed and lane advice, IVS is also capable of providing messages such as “Salting in progress” and embedded VMS messages. Environmental gains can be achieved via multiple paths; for instance, a reduction in roadside infrastructure would result in less concrete used, and in turn $C0_2$ gas which is a by-product. Other gains can be made from smoother driving and calmer drivers; both helping to reduce the production of harmful gases. During driver interviews, drivers felt that early presentation of IVS information to truck drivers in particular could see an increase in safety and reduced fuel consumption and emissions.

6.5.3. Belgium/Flanders

Summary	The road users received in-vehicle speed limit notifications as they drove. The message subject was the dynamic speed limit given by the road operator.
Desired behavior	The road users adapt their driving behavior to be compliant to the applicable driving speed limit. In the future the information may be used by Advanced Driver Assistance Systems for supported or automated driving or ISA (Intelligent Speed Adaptation).
Display/Alert principle:	IVS information shall be displayed to the road user and shall be consistent with the current valid dynamic traffic signs. The information needs to be displayed to the driver early enough and in the appropriate location
Functional constraints/dependencies:	How the information is presented to the road user is not part of the service description. It is left to the provider of the In-Vehicle Information system with HMI how information is presented. Information may be translated to the preferred language of the driver. The information presented by means of I2V is not legally binding: Information should be handled as 'convenience information' (or advisory) and presented accordingly to the road user, as currently done within navigation systems

Lessons learned

Lessons learned from implementing the service

The objective was to give the maximum speed limit all over the motorway network. The HERE app already provides the maximum speed limit for all motorway network sections. This information is updated by HERE every three months.

In the case of VMS with dynamic speed information the C-ITS service adapted the maximum speed limit of the section with the speed indication of the VMS sign. The dynamic speed information was given at the location where the gantry is located. It was not possible for HERE to use a IVIM with the relevance zone of the message. The relevance zone was from one VMS till the next VMS. For the last VMS, the relevance zone was until the fixed sign with maximum speed. Instead of a relevance zone a time out of 15 seconds was used on the information. But this did not work. It happened that the vehicle got into a traffic jam and had to wait (or drive slowly) in between two gantries. Then the speed information of the dynamic system disappeared (after 15 sec) and the original speed limit (120 km/h in Flanders) reappeared. This was of course wrong. Another problem was the validity of the speed limit of the last gantry. This was until the fixed sign with the maximum speed limit. This did not correspond with a time out of 15 seconds.

We have learned that information on dynamic speed limit must be linked to a relevance zone with a second IVI message.

By implementing the maximum speed service another problem was raised. A contractor put a fixed sign with a speed limit of 70 km/h along the motorway at the start of road works. The traffic center was not aware of this. Moreover, in the DATEX2 feed of the traffic center they give no information on the change of maximum speed with fixed signs. It meant that the service provider (HERE) was not informed. We had not foreseen a use case for fixed maximum speeds on a section. HERE was only updating the speed limits every three months.

We have learned that in order to implement a maximum speed service on the motorway network also the problem of temporally fixed signs must be solved. It is in the first place an action for the traffic center.

HMI

Due to the problems mentioned above it was decided not to integrate the service in the pilot with 1,000 users, but the service was implemented for the pre-pilot with 10 users.

Quality of the service

The message just appeared on the screen of the app at the moment the vehicle passed the gantry with the same information.
In case the vehicle was driving faster than the presented speed limit a sound message (ting) was given.
The information was available during a fixed time slot (15 sec). Normally the information should stay available until the next gantry or the next fixed speed sign, but relevance zone was not in the feed of the traffic center.

Added Value of the Service

On the Antwerp ring road there is a gantry with speed limit information at least every 500m. In this situation there was no added value of the in-vehicle service.
In case the distance between the gantries is higher, the driver felt confidence knowing the maximum speed.
The real added value was offered on sections without gantries. IVI can be used for shock wave damping. A much higher penetration of the service then in the pre-pilot and even the pilot in Flanders is needed to benefit from this service.

6.6. Socio-economics

The explicit assessment of socio-economic impact with respect to the individual Use Case was developed by Italy (IVS-DSLI), based on the impacts estimated on the KPIs on mobility. The economic values considered for this operation are reported in Table 99. Further details are available in [RD.5].

Table 99 - Monetary value of KPIs considered

KPI	Value	Unit of measure
Accidents resulting in injured or fatality	0,011	M€
Injured	0,042	M€
Fatality	1,504	M€
Value of time	20	€/hour
Cost of CO_2 emitted	100	€/ton

Table 100 summarises the impacts on the KPI on mobility and their economic conversion.

Table 100 - IVS-DSLI - Estimated socioeconomic impacts

	KPI	Economic Impact [M€ saved]
Direct Safety Impact	-382 accidents	4,19
	-744 Injured	31,40
	-21 fatalities	31,67
Indirect Traffic Efficiency Impact	-1.723.958 hours in congestion	34,48
Indirect Environmental	- 2.368 CO_2 ton	0,24
	Total	**101,98**

Furthermore, the socio-economic impact was addressed with qualitative assessment summarising the findings with respect to factors affecting safety, efficiency and environment and whether these changes are positive or negative from socio-economics viewpoint.

Impact area	Indicator	Effect	Socio-economic impact
Safety	Average speed	Decrease for DSLI (n Italy also for heavy vehicles) Inconsistent for EVFT	+ ?
	Speed standard deviation	Decrease for DSLI Slight increase for heavy vehicles Inconsistent for EVFT	+ - ?
	Instantaneous accelerations	Decrease for DSLI Decrease for EVTF	+ +
	Instantaneous decelerations	Decrease for DSLI Decrease for EVTF	+ +
	Speed adaptation	Decrease for DSLI Decrease for EVFT	+ +
Efficiency	Number and duration of stops and queues	Decrease for SWD Smooth speed change and speed profile with DSLI	+ +
	Total travel time	Significant improvements DSLI and EVTF	+
	Traffic flow	Avg speed decreased in DSLI Avg speed increased in SWD	+

		Indirect impact of 1723 k hours /year saved	-
Environment	Fuel consumption and CO_2 emissions	Decrease for DSLI Decrease for EVTF	+ +
	NO_X emissions	Decrease for DSLI Decrease for EVTF	+ +
	Pollutant emissions PM2.5	Increase for DSLI Decrease for EVTF	- +

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7. Hazardous Location Notification

7.1. Safety

This section provides a list of the hazardous location notification use-cases evaluated from a safety perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2, Belgium-Flanders, Germany, Czech Republic

7.1.1. Spain

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Stationary vehicle
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-APR: Hazardous Location Notification - Animal or person on the Road
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- HLN-EVA: Hazardous Location Notification - Emergency vehicle approaching

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is safety affected by changes in driver behavior due to HLN use case?

Sub Research Questions:

- How does the HLN service affect the number of accidents in the use case?
- How does the HLN service affect the accidents severity in the use case?
- How does the HLN affect to the (safety) conduction in the use case?
- How does the HLN service affect the sense of security of drivers/passengers and the workforce in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS OHLN v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation have been obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 101, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 101, the results presented with an asterisk (*) are extracted from a simulated environment and correspond to a technological penetration rate of 100%

(understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 101 - HLN Safety. Spain.

KPI	Service	Use Case	Pilot	Summary
Change in number of accidents (only vehicles involved)	HLN	WCW	Galicia -Cantabrian	-45%
Change in number of accidents with injuries	HLN	WCW	Galicia -Cantabrian	-100%
Change in speed adaptation	HLN	TJA	Madrid	148.45%
			Andalusian - Mediterranean	-29.9%
		SV	Catalan -Mediterranean	-101.3% (-31.8%*)
Change in speed standard deviation	HLN	TJA	Madrid	0%
			Andalusian - Mediterranean	24.5%
		SV	Madrid	0%
			Andalusian - Mediterranean	0.4%
			Catalan -Mediterranean	-85.7%
		WCW	Madrid	-33.33%
			Andalusian - Mediterranean	-100%
			Galicia -Cantabrian	-37.1%
			Catalan -Mediterranean	-100.0%
Change in average speed	HLN	AZ	SISCOGA Extended	Naturalistic study: -3%
			DGT 3.0 SATELISE	7%
		TJA	Andalusian - Mediterranean	4.5%
			SISCOGA Extended	Naturalistic study: -3%
		SV	Andalusian - Mediterranean	5.7%
			Catalan -Mediterranean	-5.9% (+27.1%*)
			DGT 3.0 SISCOGA	-6%
		WCW	Andalusian - Mediterranean	-21.2%
			Catalan -Mediterranean	-0,6%
			Galicia -Cantabrian	-2%
			SISCOGA Extended	Naturalistic study: -7% (Visibility) -7% (Precipitations)
		EBL	Galicia -Cantabrian	-7%
			SISCOGA Extended	Controlled tests: 11% G5, 17% cel
		APR	SISCOGA Extended	Controlled tests: 0% G5, 8% cel
		EVA	SISCOGA Extended	Controlled tests: 5% user vehicle, 27% emergency vehicle
Change in instantaneous accelerations	HLN	AZ	SISCOGA Extended	Naturalistic study: 0%
			DGT 3.0 SATELISE	7%
		TJA	Madrid	-20 %
			Andalusian - Mediterranean	-6.9%
		SV	Madrid	0%
			Andalusian - Mediterranean	23.3%
			DGT 3.0 SISCOGA	-82%
		WCW	Madrid	0%
Change in instantaneous decelerations	HLN	AZ	SISCOGA Extended	Naturalistic study: -45%
			DGT 3.0 SATELISE	19%
		TJA	Madrid	0%

			Andalusian - Mediterranean	-32.9%
			SISCOGA Extended pilot	Naturalistic study: -60%
		SV	Madrid	0%
			Andalusian - Mediterranean	15.9%
		WCW	Madrid	0%
			Andalusian - Mediterranean	-23.2%
			SISCOGA Extended	Naturalistic study: -78% (Visibility)
		EBL	Galicia -Cantabrian	-6%
			SISCOGA Extended	Controlled tests: -11% G5, -100% cel
		APR	SISCOGA Extended	Controlled tests: -7% G5, -47% cel
		EVA	SISCOGA Extended	Controlled tests: -11/ user vehicle, -23% emergency vehicle
Change in maximum steering angle	HLN	TJA	Madrid	32.52%
		SV	Madrid	59.88%
		WCW	Madrid	92.31%
Lane change point (point where the vehicle performs the lane change maneuver)	HLN	TJA	Madrid	927 m
		SV	Madrid	182 m
		WCW	Madrid	592.33 m
		APR	SISCOGA Extended	Controlled tests: -2% G5, -23% cel
		EBL	SISCOGA Extended	Controlled tests: -15% G5, -28% cel
Number of lane changes	HLN	TJA	Madrid	-7.62%
		SV	Madrid	-50%
		WCW	Madrid	-33.33%

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7.1.2. Czech Republic

Use Cases considered

- HLN-RLX: Hazardous Location Notification - Railway Level Crossing (within DT5 at the crossing in the town of Úřetice)
- HLN-EVA: Hazardous Location Notification - Emergency Vehicle Approaching
- HLN-SV: Hazardous Location Notification - Stationary Vehicle (on three sites, DT5, DT3 and DT1)
- HLN-PTVC: Hazardous Location Notification - Public Transport Vehicle Crossing (on the tram line in Pilsen)
- HLN-PTVS: Hazardous Location Notification - Public Transport Vehicle at Stop (bus stop in Pilsen)

Evaluation method

The main consideration was on the following key indicators:

- Change in speed and acceleration as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1. Do drivers slow at an earlier point after receiving road works warnings? 2. Do drivers drive in a less erratic way after receiving RWW? 3. Do the drivers comply with the advice given by the service?	• Speed adaptation • Speed standard deviation • Instantaneous acceleration and deceleration • Objective Data linked to User Acceptance Driver Interviews

During the evaluation of the HLN use-cases, it turned out that to assess the effect on the driver in real conditions at full operation, based on a comparison of the speed and acceleration of the vehicle was extremely difficult. A relatively small group of drivers were tested in each test, making it difficult to filter out the effect of C-ITS on the change in driver behavior from the change caused by traffic flow and other distractions. For this reason, additional emphasis was also placed on the user acceptance part of the evaluation, where drivers expressed their subjective feedback on the execution and display of the report and whether its impact is rather positive or negative.
In assessing the effect of C-ITS on the driver's behavior, the driver's behavior before receiving the message and then his behavior after the message was displayed were taken into account. In this way, it was compared whether the driver changed his behavior after receiving the message and whether they improved their speed to adapt to the situation. Such a methodology was used in the assessment of use-cases, which from a technical and organizational point of view could not be passed more than once with one driver. In the evaluation of RLX, SV and PTVC, drivers were measured driving with and without C-ITS unit were assessed.

Data collected

The data used for the impact assessment was gathered with a logging device capturing communication between vehicle and infrastructure. One logging device OBU Comsignia ITS OB4 was placed inside the testing vehicle during the testing phase logging simultaneously real-time communication. Journeys were also logged via a GPS data logger in case of data loss as a backup option. This situation did not occur and the data from the OBU communication was used for reasons of better sampling frequency. An OBD2 can bus logging device was also used to record the data from the vehicle. However, the data from this recording unit was not used due to the incompatibility of the protocols with the car.

Evaluation results – Field tests

Railway Level Crossing

Speed analysis of RLX use-case showed that drivers drove faster on average with C-ITS message “Attention, railway crossing!” (36.71 Km/h vs 37.8 Km/h). In the “Passing Train!” warning drivers drove slower (29.53 Km/h vs 28.41 Km/h), which may be due to the fact that they knew the information in advance and thus adapted their driving. However, this difference was not that significant. In the acceleration analysis, drivers had on average higher acceleration at “Attention, railway crossing!” using C-ITS (0.25 m/s^2 vs 0.49 m/s^2). In the “Passing Train!” warning C-ITS drivers had less deceleration using C-ITS (-1 m/s^2 vs -0.95 m/s^2). This, in turn, maybe due to the fact that the driver knew the warning in advance and did not have to brake so aggressively.

Slow Vehicle

The evaluation of speed analysis of the SV use-case (at the first site) showed similar speed behavior of drivers with and without C-ITS. Drivers tended to have higher speed (about 1.85 km/h) with C-ITS with lower differences between their speed according standard deviation (7.24 Km/h), as opposed to transit without C-ITS (8.53 Km/h). This was also applicable to their acceleration, with C-ITS drivers having smaller differences when driving, but also braking less. This may suggest increased awareness of the situation given by the SV message.

The second evaluation site of a comparison of safety KPIs for the use of SV showed similar driver behavior after the DENM message as before. The mean (111.11 Km/h and 110.52 Km/h), maximum (122.05 Km/h and 120.44 Km/h) and minimum speed (105.74 Km/h and 99.06 km/h) of drivers before the SV message turned out to be similar, with matching dispersion (13 Km/h). A similar trend was observed in the comparison of acceleration, where the only difference was the higher range of the acceleration of drivers after crossing a slow vehicle (2.82 m/s^2 vs 3.53 m/s^2). These findings pointed to the fact that the drivers had two more lanes to overtake, and the slow vehicle did not restrict them in any way. The SV reported at this time had little effect on the driver's behavior.

On the third evaluation site, unfortunately, the comparison of the impact assessment of SV was influenced by the proximity of the arrival ramp, so the drivers had a lower average speed of about 12 Km/h before the arrival of the SV message. This fact probably also affected the driver's acceleration, which was continuously increasing.

Emergency Vehicle Approaching

The comparison method of two-vehicle passes with and without C-ITS was impossible to perform due to time and organizational constraints. The Impact assessment of the EVA use-case showed a reduction in the speed of passing vehicles (by 6%) as well as acceleration from acceleration 0.18 m/s^2 to deceleration 0.21 m/s^2.

Public Transport Vehicle Crossing

Impact assessment of PTVC use-case showed the mean speed reduction (16.71 Km/h to 13.76 Km/h) as well as the reduction in maximum and minimum speed with C-ITS. This may indicate increased driver attention and caution when crossing the level crossing. In the journey with C-ITS, drivers had similar maximum acceleration and mean acceleration close to zero. The mean minimum acceleration was closer to zero in the journey with C-ITS (-0.16 m/s^2 vs -0.25 m/s^2) which could be an indication of less harsh deceleration maneuvers. On the boxplot and standard deviation, it was visibly more compact and similar behavior in the journey with C-ITS.

Public Transport Vehicle at Stop

The speed comparison of PTVS use-case evaluation before and after the DENM message showed lower mean speed (59.22 Km/h vs 55.21 Km/h), but greater speed range (27.16 Km/h vs 36.89 Km/h) and standard deviation. This indicated a different approach to PTVS notification from different drivers. This fact agrees with the answers in the questionnaires and the fact that the information about the stationary vehicle at the stop was transmitted relatively far. A change in acceleration in a similar vein to velocity shows a similar average acceleration (0.02 m/s^2 and -0.14 m/s^2),, but a lower minimum acceleration (-0.59 m/s^2 vs -0.98 m/s^2). We can also see a larger range and standard deviation on the boxplot after receiving the message.

7.1.3. Slovenia

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather Condition Warnings
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Evaluation method

The following key indicators were given special consideration:

- The main KPIs were changes in speed and acceleration, safety distance, and erratic steering wheel movement (as shown in the table below).
- Subjective impact data from user surveys on the influence of the service on driver behavior.

Area	Priority	Research questions	KPIs
Safety	++ (primary evaluation area for the pilot)	1. Do drivers respond to the HLN information notifications? 2. Does reporting HLN events impact driers safety? 3. Does receiving HLN notification impact drivers safety? 4. Do drivers drive in a less erratic way after receiving HLN? 5. Do the drivers comply with the advice given by the service? 6. Is the content of the received messages clear and concise?	• Speed adaptation • Safety distance • Instantaneous acceleration and deceleration • Objective Data linked to User Acceptance Driver Interviews • Understanding of received messages

Data collected

The driving simulator recorded 13 different quantitative driving parameters: driving too fast, driving too slow, erratic movement of the steering wheel, wrong way of driving, too short safety distance, detection of contacts with other vehicles, etc. The eye tracking system detected the time and location of drivers' eye views. Six areas of interest (AOI) were created: left screen, middle screen, right screen, dashboard, speedometer, and mobile phone. Validated questionnaires (User Experience Questionnaire – UEQ and meCUE 2.0) together with a non-validated questionnaire and a concluding interview were used to evaluate results.

Evaluation results – Field tests

Evaluation of results for HLN use cases was performed in two segments. The first segment of the results evaluation analyzed the data for the whole duration of the scenario. The second segment of the results evaluation analyzed only the intervals where HLN traffic events occurred. Statistical analysis was conducted to identify statistically significant differences and correlations.

We did not notice significant differences in the average times needed to complete Scenario 1 and Scenario 2 by the drivers. On average, drivers completed Scenario 1 in 520.34 seconds and Scenario 2 in 522.14 seconds. The main difference in time distribution recorded over the area of interest for particular scenarios was in the amount of time drivers were focused directly on the road ahead (i.e. middle screen). In Scenario 2 time focused on the road ahead was reduced to 434.62 seconds (SD = 53.63 seconds) from 456.84 seconds (SD = 51.12 seconds) in Scenario 1. The difference in time represents time spent focused on mobile application (23.57 seconds, SD = 14.7 seconds). Time spent focused on a mobile application represents 5.42 % of total mean time needed to complete the Scenario 2. Distribution of time area of interest in Scenario 2 is presented in Figure 22. We extrapolated that even while using the DARS Traffic Plus application, the drivers' focus was still mainly on the road ahead.

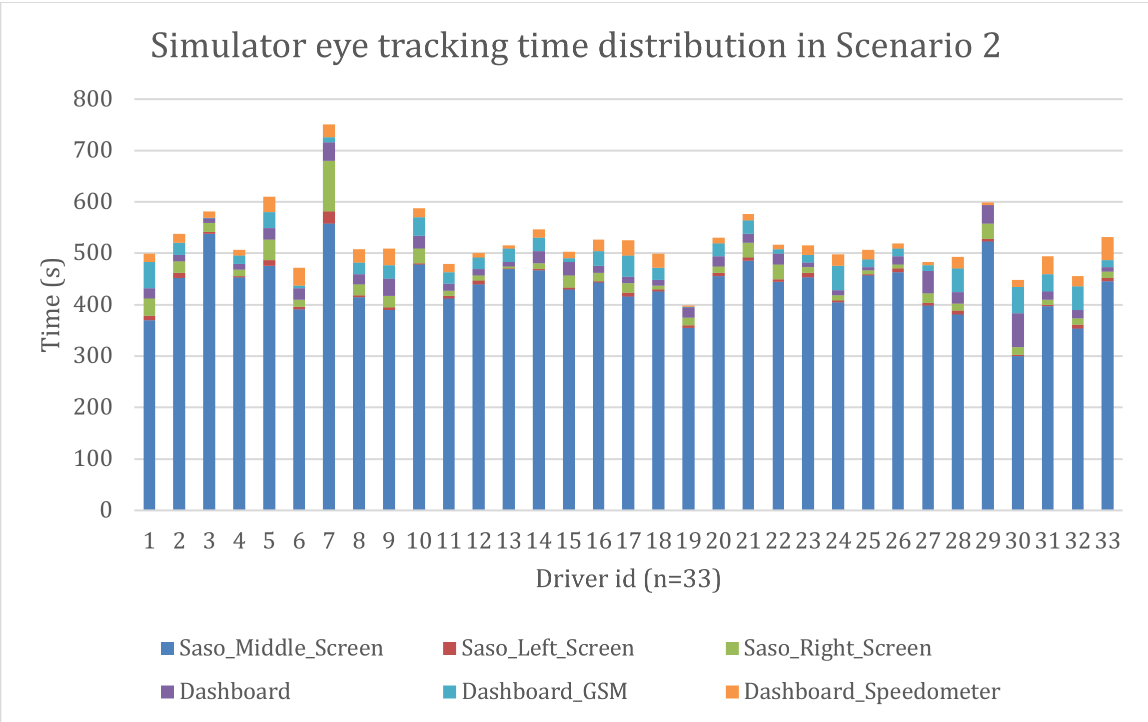

Figure 22 - Area of interest time distribution in Scenario 2

We performed statistical analysis for the frequency of simulator driving parameters and recorded the time distribution of views over the area of interest. Table 102 and Table 103 present the results. Tests of normality indicated that the data had a nonparametric distribution. Therefore, we used a nonparametric Wilcoxon signed-rank test to show significant differences in the results of Scenario 1 and 2.

We did notice significant differences (Table 103) in the frequency of simulator driving parameters for erratic movement of steering, hand braking, and driving too slow. The parameter occurrences were lower when drivers were driving with the help of the DARS Traffic application as indicated in Table 102.

Erratic movement of steering wheel S1 was reduced from 0.7 event (SD = 0.92 event) to 0.24 event (SD = 0.61 event) in Scenario 2. Number of events hard braking was reduced from 5.09 events (SD = 3.62 events) to 2.85 events (SD = 3.63 events) in Scenario 2. And number of events driving too slow was reduced from 8.73 events (SD = 4.71 events) to 7.39 events (SD = 8.3 events) in Scenario 2.

Table 102 - Frequency of events for simulator driving parameters for Scenario 1 and 2 (n=33).

Simulator driving parameter	Mean (number of events)	SD (number of events)
Erratic movement of steering wheel S1	0.70	0.918
Hard braking S1	5.09	3.617
Driving to slow S1	8.73	4.712
Erratic movement of steering wheel S2	0.24	0.614
Hard braking S2	2.85	3.633
Driving to slow S2	7.39	8.299

Table 103 - Wilcoxon signed-rand test for frequency of driving events for Scenario 1 and 2 (n=33).

Simulator driving parameter	Z	p
Erratic movement of steering wheel	-2.051b	0.05
Hard braking	-3.218b	0.001
Driving to slow	-2.579b	0.01

Additionally, we analyzed intervals where HLN traffic events occurred in Scenario 1 and 2. We detected a change in one simulator event parameter. This parameter was Driving too slow. The mean value of 2701.64 events (SD = 826.59 events) was reduced to 2462.15 events (SD = 1064.22 events) in Scenario 2 when drivers used the DARS Traffic Plus application. Furthermore, the test showed significant differences in time spent in HLN traffic event intervals: Z = -3.69, p = 0.001. Drivers spent less time in HLN traffic event intervals in Scenario 2. Results are presented in Table 104 and Table 105.

Table 104 - Frequency of events HLN traffic event intervals for Scenario 1 and 2 (n=33).

Simulator driving parameter	Mean (number of events)	SD
Driving to slow_S1	2701.64	826.59
Driving to slow _S2	2462.15	1064.22

Table 105 - Time duration and Wilcoxon signed-rand test HLN traffic event intervals for Scenario 1 and 2 (n=33).

Simulator driving parameter	Mean (number of events)	SD	Z	p
Driving to slow_S1	5.54	0.44	-3,690b	0.001
Driving to slow _S2	4.87	0.94		

One possible explanation for the reduction of driving time and simulator event parameter: Driving too slow is that the drivers adjusted their driving style ahead of the HLN traffic event. Drivers were informed about traffic events in advance through HLN notifications in

the DARS Traffic Plus application. They adjusted their driving style and, in advance, re-evaluated conditions on the road. When drivers were confronted with the same traffic events without advanced notifications, they had to adjust their driving style at the point of the traffic event location. We observed that drivers when driving with the DARS Traffic Plus application were driving less erratically and passed through HLN traffic events faster. While performing the pilot test, we did not detect any significant car accidents.
In Figure 23 we present results of the perceived influence of HLN notifications on drivers' safety. During the concluding interview, we asked drivers to rate their perceived influence on safety when receiving HLN traffic event notifications and reporting HLN traffic events. On a 5-point Likert scale, a value of 1 presented a strong negative influence on safety and a value of 5 presented a strong positive influence on safety.

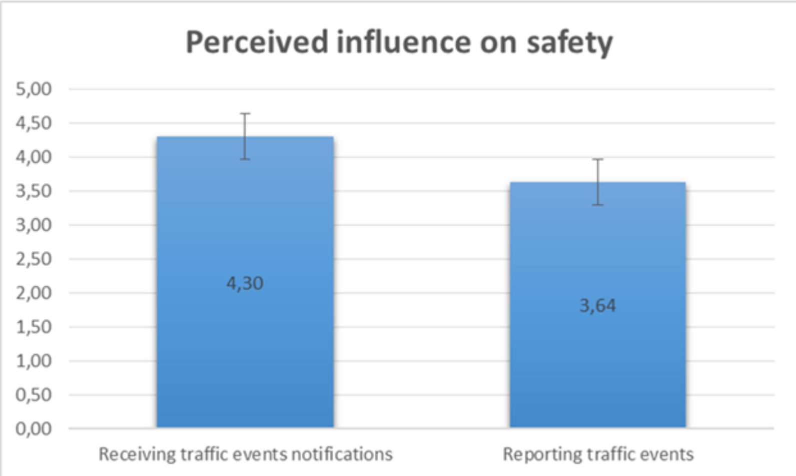

Figure 23 - Perceived influence of HLN notifications on safety

Drivers reported different values of perceived influence on safety when they were receiving traffic event notifications or when they were reporting traffic events. Higher marks received the functionality of receiving traffic event notifications, with a value of 4.30 on a 5-scale Likert scale. Lower values of perceived safety were given to reporting traffic notifications, with a value of 3.64 on a 5-point Likert scale. Both values are positive, but the values for receiving traffic event notifications is higher. The lower grade for reporting traffic notifications can be explained with active interaction with a mobile phone.
Drivers ranked HLN use cases for reporting traffic events in the following order. The most important HLN event use case was Accident Zone with 69.7 % of responses. Second most important HLN event use case was Traffic Jam Ahead with 18.2 %. The third most important HLN event use case was Obstacle on the Road with 9.1 % and the least important HLN event use case was Weather Condition Warning 3.0%.
Drivers ranked the HLN use cases for receiving traffic event notifications in the following order. The most important HLN event use case notification was the Accident Zone with 63.6 % of responses. The second most important HLN event use case notification was Traffic Jam Ahead with 27.3 %. The third most important HLN event use case notification was the Obstacle on the Road with 6.1 % and the least important HLN event use case notification was the Weather Condition Warning 3.0%.

Figure 24 - Eye tracking results - Heatmap HLN AZ

Figure 25 - Eye tracking results -Scanpath HLN AZ

Figure 24 and Figure 25 highlight two common representations of eye tracking data, on the pictures is shown HLN traffic event AZ (Accident Zone). The first representation is representation with heatmaps (Figure 24) and the second representation is with so-called scanpath graphs (Figure 25). A heatmap is a type of data visualization that displays aggregated information of view in a visually appealing way. Areas of greater focus are colored with wormer color. While scanpath represent saccadic eye movements while viewing and recognizing patterns.

From the pictures, we can conclude that the majority of focus while driving was on the traffic ahead of the vehicle. While only some focus is on the DARS Traffic Plus application and HLN traffic event.

Evaluation results – KPIs on Mobility

The Slovenian pilot fulfilled both areas of the initial set of KPIs. On one hand, the measured KPIs with results from the driving simulator, and on the other hand, KPIs coming from the subjective perception of the drivers.

Evaluation results show a positive influence on speed adaptation. Drivers adjusted their driving styles ahead of the HLN traffic event zone and not while driving inside the HLN traffic event zone. Drivers, upon receiving the HLN traffic notifications, adapted their driving speed to the traffic situation ahead of them and maintained constant speed through the whole traffic event. Drivers, who were not using the DARS Traffic Plus application and did not receive HLN notifications, were adjusting their speed near to the proximity of the traffic event. Their driving was more erratic and less fluent.

We did not notice significant differences in safety distance adaptation or adaptation of instantaneous acceleration and deceleration, but we did notice a small reduction in the

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number of too short safety distance occurrences. Nevertheless, we noticed a reduction in the erratic movement of the steering wheel. We contribute that to the fact that drivers were informed of the traffic situation ahead of them. They could prepare for that situation in advance. We also detected a measurable decrease in the number of hard braking events. That can be explained with the same reasoning as in the case of the erratic movement of the steering wheel. Drivers, when using the DARS Traffic Plus application, were informed in advance about HLN traffic events.

- We detected a 66% decrease in erratic movement of the steering when the DARS Traffic Plus application was used.
- Additionally, we detected a 44% reduction in hard barking when the DARS Traffic Plus application was used.
- A reduction in the number of hard braking events subsequently raised the driving speed. When drivers were using the DARS Traffic Plus application, there was a 15% less chance that they were driving too slow. We must note that this does not mean that they were speeding. Drivers were driving according to the speed limit.
- While performing the pilot test, we did not detect any significant car accidents.
- The prediction on people injured in traffic accidents is therefore not applicable to the Slovenian pilot test.

Driver interviews on the topic of User Acceptance showed positive results for perceived influence on safety. When comparing the functionalities for receiving traffic event notifications and reporting traffic events, the functionality for receiving traffic notifications received higher scores. Received traffic notifications provide drivers with a sense of safety and security. The functionality of reporting traffic events received a lower score, but still a positive score. Drivers understand that they should report traffic events when it is safe to do so. However, there were some hesitations about using a mobile phone while driving.

Drivers reported that the clarity of received messages was good, and the content was clear and understandable. In the majority of cases, drivers understood the message and meaning of the notifications. Using colors to indicate distance from the event was accepted as positive. Notifications should have some sound notifications.

The HLN Accident Zone event use case was the most important HLN event use case for reporting traffic events and for receiving traffic event notifications.

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7.1.4. France

In France, the infrastructure managed by SNCF (railway infrastructure manager) accounts for more than 15,000 level crossings on operated lines.
Level crossing accidents are the third leading cause of railway accidents. In average, each year on the SNCF National Rail Network (RFN), there are 100 to 150 collisions and 25 to 30 fatalities. Level crossing are the 3rd cause of fatalities for railway

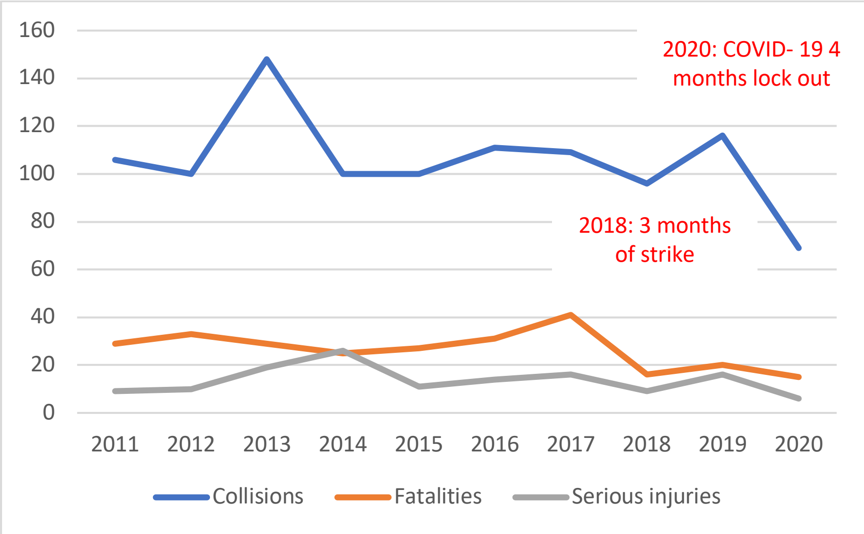

Figure 26 - Level crossing accidents

Even if over the past 20 years, level crossing accidents have been reduced by approximately 50%. The number of collisions and fatalities has remained almost constant, except the year 2018 marked by a drop in accidents but also by a pearly strike of transport of nearly three months.
The causes of collisions (collision between a train and a vehicle or a pedestrian) at LCs are of 3 types:
- Delinquency (zigzagging, non-compliance with road signs, queuing, excessive speed, alcohol, ...)
- driving error (engagement of the gauge, confusion between the roadway and the railroad, sun glare, loss of control of the vehicle, maneuver on LC, hold on LC)
- The distraction

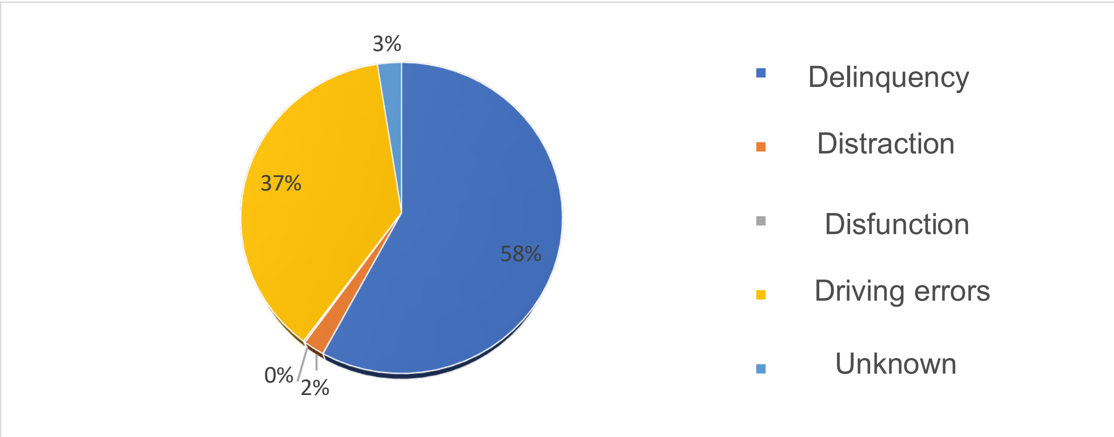

Figure 27 - Causes of accidents

Our hypothesis is the ITS service can act on the problem of driving error and distraction so around 40% of collisions

Use Cases considered

- HLN Railway Level Crossing according the LC is open, closed or out of order
- RWW- Road Closure according work in progress on LC blocking the road

Evaluation method

The behavioral study carried out by SNCF took place on a driving simulator dynamic in order to assess the impact of messages on lorry drivers as they approach Railroad Crossing.
SNCF designed the scenario for the route on a simulator based on different driving situations representative of accidents and / or incidents at level crossings.
At the same time, an analysis phase of the driving task made it possible to model the expert behavior of a road user near level crossings in situations where the LC is triggered or opened.
This analysis provided an understanding of the mental and physical actions implemented by a driver and integrate the mental operations mobilized and their cognitive level (models Higelé P., Hernja G., 2005a, 2008b). This analysis is also based on all levels the hierarchical approach to driving behavior. It is intended to model the approach to be said as an expert of a level crossing and to serve as a reference during the study.
As shown in Figure 28 the route includes all the situations in which the vehicle is equipped with a tablet to send various messages to the driver, if necessary. The course has a duration about 20 minutes.

Figure 28 - Simulation course

In order to let the subject get used to the driving simulator, the course included a phase of 3 to 4 minutes driving with straight line, gear shifting, stopping situations, or a bend without ambient traffic.

Apart from the adaptation driving phase, the rest of the routes were carried out with traffic ambient.
In addition to the 3 reference situations, the course includes 6 C-ITS crossing situations approaching a level crossing.

Data collected

The researchers developed the various observation and collection tools data (observation grids, interview guides, data from the simulator). they have also anticipated the data analysis by reflecting on the themes to be analyzed: feeling of simulator; knowledge of the LC environment; level of confidence in the system; current influence ...
Three types of triangulations have been favored:

- Triangulation of collection methods: use of three tools to study the phenomenon, i.e. various observations, explanatory interviews and interviews semi-directive.
- Triangulation of treatments: qualitative and quantitative treatments, qualitative treatment quantitative data and quantitative treatment of qualitative data.
- Researcher triangulation: discussion and comparison of qualitative data inferred by team members, discussion of partial results and conclusions.

Data were collected on 25 participants

Evaluation results – Field tests

Evaluation results are depicted in Figure 29 and Figure 30. Regarding messages in the passenger compartment, we observed that 8% of subjects declared that they were resistant to driving assistance devices and screens (GPS, smartphone application, etc.). These subjects therefore did not react to the messages they received.
When they leave room for doubt as to the arrival of a train, such as a level crossing at 150 meters, the messages must be extended by implementing complex reasoning.

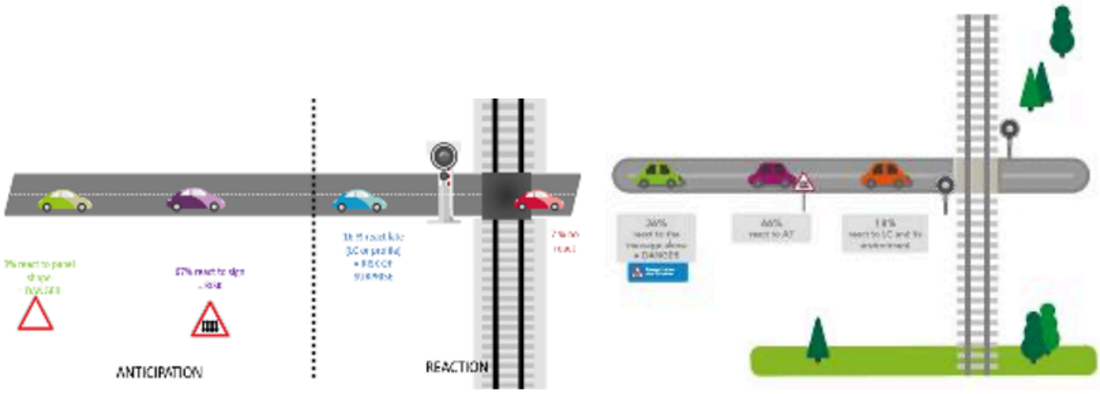

Figure 29 - Modeling of the behavior of subjects LC open without or with "LC at 200 meters" message

The behavior of the subjects is affected, with nearly 64% who then wait for a concrete element to decide on their behavior. These messages, even if they avoid the phenomenon of distraction and are complementary to the A7 sign (LC sign announcement), are then less effective.
When unequivocally, such as a "closed railway crossing", the messages caused an early slowdown in all subjects who saw the message. In this case, the subjects address a level crossing that they know is closed. The early indication of the level crossing closure leads to an adjustment of the speed and an observable result in accordance with the expert analysis, without needing to anticipate a risk as the probability of occurrence of a danger.

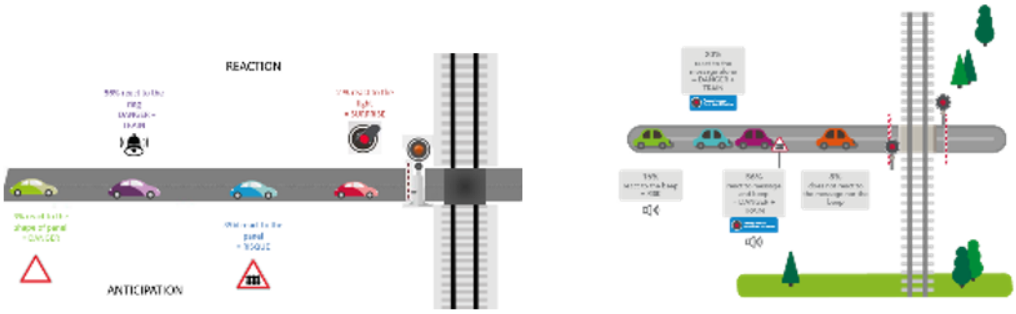

Figure 30 - Modeling of the behavior of subjects LC closed without message and with message

92% of subjects know even before the light signal and barriers are visible, that the LC will be closed, by modalities which may be different (beep, message, or beep + message).
For 8% of subjects, the information that the LC is closed can only come from equipment thereof (bell, lights, barrier).

Conclusion

Even if the simulator does not recreate real conditions (complex conditions involving other roads users, weather conditions, stress, panic, etc.), this behavioral study gives us a trend of the impact of messages at level crossings.
The majority of accidents occur when the LC goes from an open status to a closed status. Thus we think if the subject perceives the alert displayed on the dashboard, this allows him to adapt his speed to stop safely and could reduce of 40% of collisions.
However we can wonder about the perception of LC messages in an ITS message flow but this is the subject of a new study.

7.1.5. Italy

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather Condition Warning

Evaluation method

HLN-SV

The field tests simulated the presence of stationary vehicles (e.g. broken down) on the road in the slow lane, with the consequent need for incoming vehicles to change lanes to overtake the stationary vehicle and possibly to slow down. For safety reasons, the stationary vehicles were simulated by service vehicles of the freeway concessionaires and were not actually positioned in the slow lane (the safety risks were too high), but rather in the lay-by and/or emergency lane immediately adjacent to the slow lane.

The freeway sections involved in the test were the A57 (Mestre bypass) and the A4 between the junction with the A57 and San Donà di Piave. The test took place on October 6, 2021. A total of 44 events were simulated in 16 different locations.

On some stretches/time periods the C-ITS message receiving equipment was switched off (C-ITS OFF): the driver could only notice the stationary vehicle visually.

In other stretches/time periods the C-ITS message receiving devices were instead switched on (C-ITS ON): in this case the events encountered were therefore reported to the driver well in advance, together with the provision of the remaining distance in real time between his position and that of the stationary vehicle.

Drivers were asked to consistently travel in the rightmost lane (slow lane).

The sighting of service vehicles stopped on the side of the road had to be interpreted by drivers as if these vehicles were stopped in the slow lane of travel. Therefore, drivers had to behave as if there was a need to avoid colliding with these vehicles and therefore make a lane change to the left lane in good time and, if deemed necessary, adjust their speed.

HLN-TJA

In the test sessions organized, the aim was to evaluate how vehicles/drivers react to an alert, received via C-ITS message, regarding the presence of a traffic jam ahead (just downstream from the vehicle's position).

In particular, we wanted to analyse whether the receipt of a warning concerning an imminent situation of potential danger can generate a change in the behaviour of the driver and the vehicle aimed at arriving at the position of the potential event in conditions of greater safety (basically with a reduced speed compared to the normal driving speed, so as to be able to face the event safely and to be able to avoid sudden braking and/or steering manoeuvres at the last moment).

The tests were carried out on several freeway sections: A22 between Trento Nord and Bressanone Nord / Val Pusteria and between Trento Sud and Rovereto Sud, A28 between Conegliano and Godega di Sant'Urbano and A57 (Mestre beltway). The tests were held on 10-11 November 2021 for heavy vehicles and on the dates of 25 November and 1, 3, 23 December 2021 for light vehicles; a total of 16 events were tested for heavy vehicles and 22 events for light vehicles.

Since this type of event is difficult to reproduce by means of a controlled experiment, virtual/simulated traffic jam events were generated and the vehicles/drivers approaching the spatial position of the virtual event received the relevant C-ITS warning messages (C-ITS ON scenario).

Several transits related to the same event and to events that are like each other but located in different positions were analyzed.

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HLN-WCW

In the test sessions organized, the aim was to evaluate how vehicles and drivers react to an alert, received via C-ITS message, regarding the presence of bad weather conditions just downstream from the vehicle location (fog, snow, storm).

In particular, we wanted to analyse whether the receipt of a warning concerning an imminent situation of potential danger can generate a change in the behaviour of the driver and the vehicle aimed at arriving at the position of the potential event in conditions of greater safety (essentially with a reduced speed compared to the normal driving speed, so as to be able to face the event safely and to be able to avoid sudden braking and/or steering manoeuvres at the last moment).

The tests took place on the A22 freeway between Trento Nord and Bressanone Nord / Val Pusteria and on the A57 freeway (Mestre beltway). The tests were held on November 10-11, 2021 and involved only heavy vehicles; a total of 8 events were tested.

Since this type of event is difficult to reproduce by means of a controlled experiment, virtual bad weather conditions events were generated and the vehicles/drivers approaching the spatial position of the virtual event received the relevant C-ITS warning messages (C-ITS ON scenario).

Several transits related to the same event and to events that are like each other but located in different positions were analyzed.

Data collected

HLN-SV

The analysis of vehicle behavior in the presence of a stationary vehicle event was differentiated by heavy and light vehicles; the data collected were also divided into two groups: C-ITS ON and C-ITS OFF.

The field test indicator KPIs calculated for each passage are as follows:

- lane change: whether the lane change took place [yes/no], start and end point of the lane change [m], start and end time of the lane change [time], extent [m] and duration [sec] of the lane change, maximum steering angle during the lane change [rad]
- slowdown: whether or not the slowdown took place [yes/no], start and end point of the slowdown [m], start and end time of the slowdown [time], extent [m] and duration [sec] of the slowdown, speed before the start and at the end of the slowdown [km/h], absolute speed change [km/h] and percentage [%], average deceleration [m/s^2], standard deviation of instantaneous decelerations [m/s^2] and maximum instantaneous deceleration [m/^{s}2]
- braking: (brake pedal pressure phase): braking or not [yes/no], braking start and end point [m], braking start and end time [time], braking extension [m] and duration [sec], maximum braking torque [Nm]

Next, the average value of the above indicators was calculated for each of the two scenarios (C-IST OFF and C-IST ON) for comparison purposes.

HLN-TJA

The analysis of vehicle behavior in the presence of a “Traffic Jam Ahead” event was differentiated for heavy and light vehicles; the data collected all refer to a C-ITS ON scenario (with C-ITS receiving devices turned on).

The field test indicator KPIs calculated for each passage are as follows:

- slowdown: whether or not the slowdown took place [yes/no], start and end point of the slowdown [m], start and end time of the slowdown [time], extent [m] and duration [sec] of the slowdown, speed before the start and at the end of the slowdown [km/h], absolute speed change [km/h] and percentage [%], average deceleration [m/s^2], standard deviation of instantaneous decelerations [m/s^2] and maximum instantaneous deceleration [m/s^2]
- speed adaptation: punctual speed [km/h] at the following sections (as well as average speed [km/h] between pairs of successive sections): -500 m before the start of validity of the simulated event, -300 m, -200 m, -100 m, 0 m, +100 m, +200 m, +300 m, +500 m

Next, the average value of the above indicators was calculated for all the steps analyzed.

HLN-WCW
The data collected all refer to a C-ITS ON scenario (with C-ITS receiving devices turned on).
The field test indicator KPIs calculated for each passage are as follows:

- slowdown: whether or not the slowdown took place [yes/no], start and end point of the slowdown [m], start and end time of the slowdown [time], extent [m] and duration [sec] of the slowdown, speed before the start and at the end of the slowdown [km/h], absolute speed change [km/h] and percentage [%], average deceleration [m/s^2], standard deviation of instantaneous decelerations [m/s^2] and maximum instantaneous deceleration [m/s^2]
- speed adaptation: punctual speed [km/h] at the following sections (as well as average speed [km/h] between pairs of successive sections): -500 m before the start of validity of the simulated event, -300 m, -200 m, -100 m, 0 m, +100 m, +200 m, +300 m, +500 m

Next, the average value of the above indicators was calculated for all the steps analyzed.

Evaluation results – Field tests

HLN-SV

Heavy vehicles

Table 106 - HLN-SV - Field tests KPIs - Heavy vehicles

SV - Stationary Vehicles - Heavy Vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	**C-ITS OFF**	**C-ITS ON**	**Abs. Var.**	**Var. %**
LANE CHANGE				
Lane change performed [%]	86%	91%	-	-
Maneuver duration [s]	4,0	3,9	-0,1	-3%
Maneuver length [m]	87	86	-1	-1%
Maneuver start point [m] (0 m = event point)	-198	-265	-67	-
Maneuver end point [m] (0 m = event point)	-81	-179	-98	-
Max steering angle [rad]	0,155	0,127	-0,027	-18%
SLOWDOWN				
Slowdown performed [%]	5%	36%	-	-
Maneuver duration [s]	7,0	4,0	-3,0	-43%
Maneuver length [m]	132	80	-52	-39%
Maneuver start point [m] (0 m = event point)	-245	-201	+44	-
Maneuver end point [m] (0 m = event point)	-113	-121	-8	-
Initial speed [km/h]	83,9	78,1	-5,8	-7%
Final speed [km/h]	72,8	69,7	-3,1	-4%
Speed reduction [km/h]	-11,1	-8,3	+2,8	-25%
Deceleration standard deviation [m/s^2]	0,402	0,137	-0,265	-66%
Max instantaneous deceleration [m/s^2]	1,32	0,65	-0,67	-51%

SV - Stationary Vehicles - Heavy Vehicles - Comparison C-ITS OFF vs C-ITS ON				
BRAKING				
Braking performed [%]	5%	0%	-	-

- lane change: in the C-ITS OFF scenario, the driver, noticing the stationary vehicle too late, must renounce often to perform the lane change maneuver as he has less time to decide when to start it safely. In the C-ITS ON scenario the maneuver is started (-67m) and finished (-98m) clearly in advance compared to the C-ITS OFF scenario, thanks to the warning provided by the cooperative messages. Thus, the vehicle can move to the lane not affected by the event with a reasonable safety margin. The maneuver is also carried out more smoothly, as witnessed by a lower value of the steering angle (-18%).
- slowdown: in the C-ITS OFF scenario the slowdown generally starts further upstream than in the C-ITS ON scenario and resulting in a greater reduction in speed but with a higher final speed. In the C-ITS scenario the maneuver is shorter in term of space (-52m/-39%) and of time (-3s/-43%). In addition, the slowdown maneuver with C-ITS ON is smoother (deceleration standard deviation is -66%) and has lower instantaneous deceleration peaks (-51%).
- The analysis of the average timing of the lane change and of the slowdown maneuvers shows that with C-ITS ON the lane change begins before the slowdown, and the slowdown occurs during the lane change maneuver, but without ever using the brake pedal. On the contrary, with C-ITS OFF, vehicles almost always perform the lane change maneuver without slowing down; the few episodes of slowing down recorded are more irregular and involve the use of the brake pedal.

Light vehicles

Table 107 - HLN-SV - Field tests KPIs - Light vehicles

SV - Stationary Vehicles - Light Vehicles - Comparison C-ITS OFF vs C-ITS ON				
Field Test KPI	**C-ITS OFF**	**C-ITS ON**	**Abs. Var.**	**Var. %**
LANE CHANGE				
Lane change performed [%]	100%	100%	-	-
Maneuver duration [s]	3,6	2,9	-0,7	-21%
Maneuver length [m]	89	81	-8	-9%
Maneuver start point [m] (0 m = event point)	-171	-445	-274	-
Maneuver end point [m] (0 m = event point)	-81	-364	-283	-
Max steering angle [rad]	0,155	0,191	+0,036	+23%
SLOWDOWN				
Slowdown performed [%]	20%	100%	-	-
Maneuver duration [s]	13,0	10,2	-2,8	-22%
Maneuver length [m]	356	338	-18	-5%
Maneuver start point [m] (0 m = event point)	-250	-485	-235	-
Maneuver end point [m] (0 m = event point)	106	-147	-253	-
Initial speed [km/h]	103,7	103,0	-0,6	-1%
Final speed [km/h]	91,1	80,4	-10,6	-12%
Speed reduction [km/h]	-12,6	-22,6	-10,0	+79%
Deceleration standard deviation [m/s^2]	0,176	0,371	+0,194	+110%
Max instantaneous deceleration [m/s^2]	0,64	1,44	+0,80	+125%
Slowdown performed [%]	20%	100%	-	-
BRAKING				
Braking performed [%]	0%	86%	-	-

- lane change: in the presence of advance notice of the stationary vehicle event provided by the C-ITS service the lane change maneuver is started (-274m) and completed (-283m) further upstream of the event with respect to the C-ITS OFF scenario. The maneuver is also performed in less time (-0,7s/-21%) and space (-8m/-9%), resulting in a higher peak of the recorded steering angle value (+23%).

- slowdown: as for the lane change, in the C-ITS ON scenario the slowdown begins (-235m) and ends (-253m) further upstream than in the C-ITS OFF scenario and it is deployed in a shorter time (-2,8s/-22%) and space (-18m/-5%), even though the magnitude of the slowdown is much higher (+79%). Consequently, the instantaneous deceleration peak is also higher (+125%).

HLN-TJA

Table 108 - HLN-TJA - Field tests KPIs - Light vehicles

TJA - Traffic Jam Ahead - Light vehicles - 130 km/h and 110 km/h stretches		
Field Test KPI	**130 km/h**	**110 km/h**
SLOWDOWN		
Slowdown performed [%]	89%	100%
Maneuver duration [s]	9,0	4,7
Maneuver length [m]	259	132
Maneuver start point [m] (0 m = event point)	-136	-286
Maneuver end point [m] (0 m = event point)	123	-154
Initial speed [km/h]	121,9	106,7
Final speed [km/h]	95,5	91,2
Speed reduction [km/h]	-26,4	-15,5
Speed reduction [%]	-28%	-17%
Slowdown average deceleration [m/s²]	0,856	0,899
SPEED ADAPTATION		
Average speed in different road segments [km/h] (0 m = event starting point):		
-500 > -300	122	101
-300 > -200	122	102
-200 > -100	120	102
-100 > 0	110	99
0 > +100	102	100
100 > 200	99	102
200 > 300	101	104
300 > 500	105	104

Table 109 - HLN-TJA - Field tests KPIs - Heavy vehicles

TJA - Traffic Jam Ahead - Heavy vehicles	
Field Test KPI	**C-ITS ON**
SLOWDOWN	
Slowdown performed [%]	94,0%
No reaction [%]	6,0%
Maneuver duration [s]	13,5
Maneuver length [m]	276
Maneuver start point [m] (0 m = event point)	-328
Maneuver end point [m] (0 m = event point)	-52
Initial speed [km/h]	79,6
Final speed [km/h]	70,4
Speed reduction [km/h]	-9,2
Speed reduction [%]	-12%
Slowdown average deceleration [m/s²]	0,210
SPEED ADAPTATION	
Average speed in different road segments [km/h] (0 m = event starting point):	
-500 > -300	80
-300 > -200	76
-200 > -100	73
-100 > 0	71
0 > +100	70
100 > 200	71
200 > 300	72
300 > 500	73

The slowdown starts far in advance (-328m) and ends before (-52m) the event and the speed reduction is evident (-12%). A relevant part of the slowing down is deployed before the event point, showing that vehicles are preparing in time to meet the potential hazard in safer conditions. The reduced speed is maintained throughout the entire section where the hazard event is potentially present, although it tends to increase slightly as the end of the section approaches, when drivers, even visually, realize that there is no real hazard (events are fictitious) and therefore, although maintaining a cautious attitude, they gradually recover speed.

HLN-WCW

Table 110 - HLN-WCW - Field tests KPIs - Heavy vehicles

WCW - Weather Conditions Warning - Heavy vehicles	
Field Test KPI	**C-ITS ON**
SLOWDOWN	
Slowdown performed [%]	75,0%
Already moving at a safe speed [%]	12,5%
No reaction [%]	12,5%
Maneuver duration [s]	23,8
Maneuver length [m]	489
Maneuver start point [m] (0 m = event point)	-416
Maneuver end point [m] (0 m = event point)	73
Initial speed [km/h]	80,3
Final speed [km/h]	65,6
Speed reduction [km/h]	-14,8
Speed reduction [%]	-18%
Slowdown average deceleration [m/s^2]	0,179
SPEED ADAPTATION	
Average speed in different road segments [km/h] (0 m = event starting point):	
-500 > -300	80
-300 > -200	75
-200 > -100	71
-100 > 0	71
0 > +100	70
100 > 200	69
200 > 300	70
300 > 500	72

The slowdown starts far in advance (-416m) and the speed reduction is evident (-18%). A relevant part of the slowing down is deployed before the event point, showing that vehicles are preparing in time to meet the potential hazard in safer conditions. The reduced speed is maintained throughout the entire section where the hazard event is potentially present, although it tends to increase slightly as the end of the section approaches, when drivers, even visually, realize that there is no real hazard (events are fictitious) and therefore, although maintaining a cautious attitude, they gradually recover speed.

Evaluation results – KPIs on Mobility

Expected KPIs on mobility were assessed for the Use Cases HLN-SV and HLN-WCW.

HLN-SV

Concerning the evaluation and assessment of the expected KPIs on mobility, the following general approach was adopted (see chapter 4.8)

KPIs = REACTION x EFFECTIVENESS x TARGET

Considering both data from heavy and light vehicles, the following observations were deployed:

- **Reaction**: reaction recorded if the slowdown maneuver in the C-ITS ON scenario is starting and ending before the C-ITS OFF scenario.
  The slowdown maneuver met the adopted criteria for the definition of a relevant reaction in the 75% (0,75) of the passages with C-ITS on (9 cases over 12)

- **Effectiveness**: the maneuvers analyzed were deployed in a similar way, but completed far in advance, with C-ITS ON with respect to the C-ITS OFF condition. The quantification of the effectiveness (based on an expert judgement), considering just the drivers who actually reacted, is assumed equal to 0,5 (with respect to accidents), 0,6 (injured people) and to 0,7 (fatalities).
- **Target**, considering road accidents consistent with a Stationary Vehicle scenario (i.e. accidents involving at least one stationary/parking vehicles) on the Italian highway network (year 2019):
    - Accidents: 390
    - Injured: 619
    - Fatalities: 39

Then, the estimated expected KPIs on mobility are reported in Table 111.

Table 111 - HLN-SV - Estimated EKPIs on mobility - Safety

KPI			% considering all the accident in Italy in a year
Accidents	= 376 x 0,75 x 0,6 =	**-146**	-0,08%
Injured people	= 619 x 0,75 x 0,7 =	**-279**	-0,12%
Fatalities	= 39 x 0,75 x 0,8 =	**-20**	-0,65%

HLN-WCW

Concerning the evaluation and assessment of the expected KPIs on mobility, the following general approach was adopted (see chapter 4.8)

KPIs = REACTION x EFFECTIVENESS x TARGET

Considering data from heavy vehicles, the only ones involved in the test of this Use Case, the following observations were deployed:

- **Reaction**: reaction recorded if a slowdown maneuver in the C-ITS ON scenario is recorded. The deployment of a slowdown maneuver criteria for the definition of a relevant reaction, was recorded in the 75% of the passages with C-ITS ON (6 cases over 8).
- **Effectiveness**: the maneuvers analyzed were deployed in a smooth way. The quantification of the effectiveness (based on an expert judgement), considering just the drivers who actually reacted, is assumed equal to 0,6 (with respect to accidents), 0,7 (injured people) and to 0,8 (fatalities).
- **Target**, considering road accidents in bad weather conditions (i.e. accidents in condition of snow or hail or fog or wind) on the Italian highway network (year 2019):
    - Accidents: 124
    - Injured: 223
    - Fatalities: 5

Then, the estimated expected KPIs on mobility are reported in Table 112.

Table 112 - HLN-WCW - Estimated EKPIs on mobility - Safety

KPI			% considering all the accident in Italy in a year
Accidents	= 124 x 0,75 x 0,6 =	**-56**	-0,03%
Injured people	= 223 x 0,75 x 0,7 =	**-117**	-0,05%
Fatalities	= 5 x 0,75 x 0,8 =	**-3**	-0,09%

7.1.6. Summary

Evaluation results – Field tests

The main results regarding the impact area of safety in relation to the HLN service relate to the analysis of speed and accelerations/decelerations, elements which were considered by all the Countries.

The **Spanish pilot** considered a large number of KPIs reporting different observations, referring to the Use Cases considered:

- Change in speed adaptation: the results obtained for the TJA use case were not similar across the different test sites.
- It can be due to the different environments in both sub-pilots (E.g.: Madrid and Mediterranean-Andalusian). One of them is an interurban road and the other urban road. It affected this KPI.
- Change in speed standard deviation: The service HLN-WCW helped to reduce the amount of time vehicles exceeded the speed limit (Benefit -100% best case). The service TJA and SV did not show a reduction. Neutral values in the case of Madrid sub-pilot.
- There was a reduction in the average speed during the implementation in WCW.
- The services AZ, TJA, SV and EBL have different results in the sub-pilots, so a common conclusion cannot be achieved. Different roads are analyzed in the sub-pilots that has provided diverse results.
- Change in instantaneous accelerations: The number of times that the vehicles accelerate harshly reduced in the service HLN-TJA (Benefit: -20% best case). The rest of the use cases evaluated could not provide a common conclusion after the analysis of this KPI in the different sub-pilots.
- Change in instantaneous decelerations: the number of times that the vehicles braked harshly was reduced in the services TJA (-60% best case), WCW (-78% best case), EBL (-100% best case), APR (-47% best case) and EVA (-23% best case). There was an increase in the service SV. In the case of AZ, different results were obtained in the sub-pilots analyzed.
- An increase in the maximum steering angle of the vehicles was observed after the implementation of the HLN service. It was more significant in the HLN-WCW use case.
- Number of lane changes: a reduction in all the subservices where this KPI was evaluated (Benefit: -50% best case).

Speed was also considered in the **Czech Republic**, analyzing use-cases involving Public Transport systems. Concerning HLN-RLX, drivers drove faster on average with C-ITS message “Attention, railway crossing!”, with higher accelerations. In the “Passing Train!” warning drivers drove slower, with less decelerations. For HLN-PTVC, a reduction in the mean, maximum and minimum speed with C-ITS was recorded. The speed comparison of PTVS use-case evaluation before and after the display of the message showed slightly lower mean speed, but greater speed range and standard deviation.

Considering HLN-SV, no meaningful changes were recorded.

Slovenia assessed several HLN Day-1 service use cases, including HLN – AZ (Accident Zone), HLN – TJA (Traffic Jam Ahead), HLN – WCW (Weather Condition Warning), and HLN – OR (Obstacle on the Road). The Slovenian pilot fulfilled both areas of the initially set KPIs. On one hand, the measured KPIs with results from the driving simulator, and on the other hand, KPIs coming from the subjective perception of the drivers. Evaluation results show a positive influence on speed adaptation. Drivers adjusted their driving styles ahead of the HLN traffic event zone and not while driving inside the HLN traffic event zone.

No measurable differences in safety distance adaptation or adaptation of instantaneous acceleration and deceleration were noticed. Nevertheless, a reduction in the erratic movement of the steering wheel and a measurable decrease in the number of hard braking events was detected.

Drivers reported that the clarity of received messages was good, content was clear. Using colors to indicate distance from the event and sound notifications was accepted as positive. HLN Accident Zone event use case was the most important HLN event use case for reporting traffic events and for receiving traffic events notifications.

- A 66 % decrease was detected in erratic movement of the steering when the DARS Traffic Plus application was used.
- Additionally, it was detected a 44 % reduction in hard barking when the DARS Traffic Plus application was used.
- A reduction in the number of hard braking events subsequently raised the driving speed. When drivers were using the DARS Traffic Plus application, there was a 15 % less chance that they were driving too slowly. It must be noted that this does not mean that they were speeding. Drivers were driving according to the speed limit.
- While performing the pilot test, no significant car accidents were detected.
- The prediction on people injured in traffic accidents is therefore not applicable to the Slovenian pilot test.

Finally, in Spain considerations were provided considering the overall number of accidents in the route where the service WCW was implemented. A reduction was recorded. However, this result was not significant of the improvements brought about by the use of C-ITS, given the small number of vehicles participating in the project where this KPI was evaluated.

The **Italian** pilot reported a high number of Field Test KPIs highlighting significant benefit of the C-ITS message in terms of anticipated reaction and maneuvering far before the danger point and smoother decelerations. For all Use Cases considered.

Use Case HLN-SV - Heavy Vehicles

- Lane change: In the C-ITS ON scenario the maneuver is started (-67m) and finished (-98m) clearly in advance compared to the C-ITS OFF scenario. In the C-ITS OFF scenario, the driver must renounce often, for safety reason, to perform the lane change maneuver. In the C-ITS ON scenario the maneuver is also carried out more smoothly (the steering angle is -18%).
- slowdown: In the C-ITS scenario the maneuver is shorter in term of space (-52m/-39%) and of time (-3s/-43%). In addition, the slowdown maneuver with C-ITS ON is smoother (deceleration standard deviation is -66%) and has lower instantaneous deceleration peaks (-51%).The analysis of the average timing of the lane change and of the slowdown maneuvers shows that with C-ITS ON the lane change begins before the slowdown, and the slowdown occurs during the lane change maneuver, but without ever using the brake pedal.

Use Case HLN-SV - Light Vehicles

- Lane change: with C-ITS ON the lane change maneuver is started (-274m) and completed (-283m) further upstream of the event with respect to the C-ITS OFF scenario. The maneuver is also performed in less time (-0,7s/-21%) and space (-8m/-9%), resulting in a higher peak of the recorded steering angle value (+23%).
- Slowdown: as for the lane change, in the C-ITS ON scenario the slowdown begins (-235m) and ends (-253m) further upstream than in the C-ITS OFF scenario and it is deployed in a shorter time (-2,8s/-22%) and space (-18m/-5%), even though the

magnitude of the slowdown is much higher (+79%). Consequently, the instantaneous deceleration peak is also higher (+125%).

Use Case HLN-TJA - Heavy Vehicles
The slowdown starts far in advance (-328m) and ends before (-52m) the event and the speed reduction is evident (-12%). A relevant part of the slowing down is deployed before the event point, showing that vehicles are preparing in time to meet the potential hazard in safer conditions. The reduced speed is maintained throughout the entire section where the hazard event is potentially present.

Use Case HLN-WCW - Heavy Vehicles
The slowdown starts far in advance (-416m) and ends slightly after the event (+73m) and the speed reduction is evident (-18%). A relevant part of the slowing down is deployed before the event point, showing that vehicles are preparing in time to meet the potential hazard in safer conditions. The reduced speed is maintained throughout the entire section where the hazard event is potentially present.
Finally, Italy estimated an overall yearly impact on safety, considering a 100% C-ITS penetration rate as reported in Table 113.

Table 113 - HLN-WCW - Estimated KPIs on mobility - Safety

KPI		**% considering all the accident in Italy in a year**
Accidents	**-56**	-0,03%
Injured people	**-117**	-0,05%
Fatalities	**-3**	-0,09%

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7.2. Traffic Efficiency

This section provides a list of the hazardous location notification use-cases evaluated from a traffic efficiency perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2.

7.2.1. Spain

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Stationary vehicle
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-APR: Hazardous Location Notification - Animal or person on the Road
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- HLN-EVA: Hazardous Location Notification - Emergency vehicle approaching

Evaluation method

Depending on the use case, the mentioned impact investigation safety led to different questions/sub-questions:

Main Research Question:

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

Sub Research Questions:

- How does the HLN service affect to the journey time in the use case?
- How does the HLN service affect to the traffic flow in the use case?
- How does the HLN service affect to the speed in the use case?
- How does the HLN service affect the lane changer maneuver in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS OHLN v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.

These annexes include the main research questions and the research hypotheses about the sub research questions.

Global results of impact evaluation have been obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 114, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

Note that in Table 114, the results presented with an asterisk (*) are extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

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Table 114 - HLN Traffic Efficiency. Spain.

KPI	Service	Use Case	Pilot	Summary
Change in the event time	HLN	APR	SISCOGA Extended	Controlled tests: 12% G5, -2% cel
		EVA	SISCOGA Extended	Controlled tests: -32%
		EBL	SISCOGA Extended	Controlled tests: -24% G5, -11% cel
		AZ	DGT 3.0 SATELISE	3%
Travel time (since the C-ITS message reception till the event -e.g. road works-)	HLN	TJA	Madrid	-18.64%
			Andalusian - Mediterranean	-8.2%
			Bizkaia -Cantabrian	15.5%
		SV	Madrid	44.22%
			Andalusian - Mediterranean	-34.5%
			Bizkaia -Cantabrian	15.5%
		EBL	Galicia -Cantabrian	-11%
		WCW	Andalusian - Mediterranean	17.4%
Number of stops along routes where C-ITS has been implemented	HLN	TJA	Madrid	0%
			Bizkaia -Cantabrian	2.53%
		SV	Madrid	0%
			Catalan -Mediterranean	-61,7%*
			Bizkaia -Cantabrian	2.53%
		WCW	Madrid	0%
Duration of stops along routes where C-ITS has been implemented	HLN	TJA	Madrid	0%
			Bizkaia -Cantabrian	0.16%
		SV	Madrid	0%
			Catalan -Mediterranean	-88,0%*
			Bizkaia -Cantabrian	0.16%
		WCW	Madrid	0%
Change in instantaneous accelerations/decelerations	HLN	TJA	Madrid	0%
			Andalusian - Mediterranean	-20.8%
		SV	Madrid	0%
			Andalusian - Mediterranean	19.4%
		WCW	Madrid	0%
			Andalusian - Mediterranean	-27.1%
Change in average speed	HLN	TJA	Madrid	10.42%
			Andalusian - Mediterranean	4.5%
		SV	Madrid	-23.83%
			Andalusian - Mediterranean	5.7%
			Catalan -Mediterranean	-5.9% (+27.1%*)
		WCW	Andalusian - Mediterranean	-21.2%
			Catalan -Mediterranean	-0.6%
% change in peak period journey time	HLN	SV	Catalan -Mediterranean	-65,6%*
Difference between the average speed of the vehicle and the speed limit (Change in speed adaptation)	HLN	WCW	Catalan -Mediterranean	-110.8%
Change in traffic flow	HLN	SV	Catalan -Mediterranean	-0,5%*

7.2.2. Slovenia

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Evaluation method

The following key indicators were given special consideration:

- The main KPIs were changes in speed and acceleration, safety distance, and erratic steering wheel movement (as shown in the table below).
- Subjective impact data from user surveys on the influence of the service on driver behavior.

Area	Priority	Research questions	KPIs
Traffic Efficiency	(secondary evaluation area for the pilot)	1. Does receiving HLN notification impact Traffic Efficiency? 2. Do drivers drive in a less erratic way after receiving HLN? 3. Do the drivers comply with the advice given by the service? 4.	• Speed adaptation • Safety distance • Instantaneous acceleration and deceleration • Objective Data linked to User Acceptance Driver Interviews • Understanding of received messages

Data collected

The driving simulator recorded 13 different quantitative driving parameters: driving too fast, driving too slow, erratic movement of the steering wheel, wrong way of driving, too short a safety distance, detection of contacts with other vehicles, etc. The eye tracking system detected the time and location of drivers' eye views. Six areas of interest (AOI) were created: left screen, middle screen, right screen, dashboard, speedometer, and mobile phone. Validated questionnaires (User Experience Questionnaire – UEQ and meCUE 2.0) together with a non-validated questionnaire and a concluding interview were used to evaluate results.

Evaluation results – Field tests

We performed statistical analysis for the frequency of simulator driving parameters and recorded the time distribution of views over the area of interest. Table 115 and *Table 116* present the results. Tests of normality indicated that the data had a nonparametric distribution. Therefore, we used a nonparametric Wilcoxon signed-rank test to show significant differences in the results of Scenario 1 and 2.

We did notice significant differences (*Table 116*) in the frequency of simulator driving parameters for erratic movement of steering, hand braking, and driving too slow. The parameter occurrences were lower when drivers were driving with the help of the DARS Traffic application as indicated in Table 115.

Erratic movement of steering wheel S1 was reduced from 0.7 event (SD = 0.92 event) to 0.24 event (SD = 0.61 event) in Scenario 2. Number of events Hard braking was reduced from 5.09 events (SD = 3.62 events) to 2.85 events (SD = 3.63 events) in Scenario 2. And number of events Driving to slow was reduced from 8.73 events (SD = 4.71 events) to 7.39 events (SD = 8.3 events) in Scenario 2.

Table 115 - Frequency of events for simulator driving parameters for Scenario 1 and 2 (n=33).

Simulator driving parameter	Mean (number of events)	SD (number of events)
Erratic movement of steering wheel S1	0.70	0.918
Hard braking S1	5.09	3.617
Driving too slow S1	8.73	4.712
Erratic movement of steering wheel S2	0.24	0.614
Hard braking S2	2.85	3.633
Driving too slow S2	7.39	8.299

Table 116 - Wilcoxon signed-rand test for frequency of driving events for Scenario 1 and 2 (n=33).

Simulator driving parameter	Z	p
Erratic movement of steering wheel	-2.051b	0.05
Hard braking	-3.218b	0.001
Driving too slow	-2.579b	0.01

Additionally, we analyzed intervals where HLN traffic events occurred in Scenario 1 and 2. We detected a change in one simulator event parameter. This parameter was Driving too slow. The mean value of 2701.64 events (SD = 826.59 events) was reduced to 2462.15 events (SD = 1064.22 events) in Scenario 2 when drivers used the DARS Traffic Plus application. Furthermore, the test showed significant differences in time spent in HLN traffic event intervals: Z = -3.69, p = 0.001. Drivers spent less time in HLN traffic event intervals in Scenario 2. Results are presented in Table 117 and Table 118Table 105.

Table 117 - Frequency of events HLN traffic event intervals for Scenario 1 and 2 (n=33).

Simulator driving parameter	Mean (number of events)	SD
Driving too slow_S1	2701.64	826.59
Driving too slow _S2	2462.15	1064.22

Table 118 - Time duration and Wilcoxon signed-rand test HLN traffic event intervals for Scenario 1 and 2 (n=33)

Simulator driving parameter	Mean (number of events)	SD	Z	p
Driving too slow_S1	5.54	0.44	- 3,690b	0.001
Driving too slow _S2	4.87	0.94		

One possible explanation for the reduction of driving time and simulator event parameter: Driving too slow is that the drivers adjusted their driving style ahead of the HLN traffic event. Drivers were informed about traffic events in advance through HLN notifications in the DARS Traffic Plus application. They adjusted their driving style and, in advance, re-evaluated conditions on the road. When drivers were confronted with the same traffic events without advanced notifications, they had to adjust their driving style at the point of the traffic event location. We observed that drivers when driving with the DARS Traffic Plus application were driving less erratically and passed through HLN traffic events faster.

Evaluation results – KPIs on Mobility

Slovenia assessed several HLN Day-1 service use cases, including HLN – AZ (Accident Zone), HLN – TJA (Traffic Jam Ahead), HLN – WCW (Weather Condition Warning), and HLN – OR (Obstacle on the Road). The Slovenian pilot fulfilled both areas of the initially set KPIs. On one hand, the measured KPIs with results from the driving simulator, and on the other hand, KPIs coming from the subjective perception of the drivers. Evaluation results showed a positive influence on speed adaptation. Drivers adjusted their driving styles ahead of the HLN traffic event zone and not while driving inside the HLN traffic event zone.

- We did not notice any measurable differences in safety distance adaptation or adaptation of instantaneous acceleration and deceleration.
- Nevertheless, we detected a reduction in the erratic movement of the steering wheel and a measurable decrease in the number of hard braking events.
- We detected a 66% decrease in erratic movement of the steering when the DARS Traffic Plus application was used.
- Additionally, we detected a 44 % reduction in hard barking when the DARS Traffic Plus application was used.
- A reduction in the number of hard braking events subsequently raised the driving speed. When drivers were using the DARS Traffic Plus application, there was a 15% less chance that they were driving too slow. We must note that this does not mean that they were over speeding. Drivers were driving according to the speed limit.
- While performing the pilot test, we did not detect any significant car accidents.
- The prediction on people injured in traffic accidents is therefore not applicable to the Slovenian pilot test.

7.2.3. Italy

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather Condition Warning

Evaluation method

Refer to Section 7.1.5 (Safety – Italy).

Data collected

Refer to Section 7.1.5 (Safety – Italy).

Evaluation results – Field tests

Refer to Section 7.1.5 (Safety – Italy).

Evaluation results – KPIs on Mobility

Expected KPIs on mobility were assessed for the Use Cases HLN-SV and HLN-WCW.

HLN-SV

Indirect impacts on traffic efficiency are assessed considering that a road accident is causing the closure of the carriageway for a time period (i.e. 2 hours). Adopting a model based on input-output diagrams theory, the quantification of the possible delays that the vehicles impacted are suffering is made possible. These delays are supposed to be reduced by the deployment of the Use Cases.

The estimation of indirect effect on traffic efficiency (safety related) assumed that 146 events of traffic congestion due to road accident were avoided thanks to the Use Case. According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 119

Table 119 - HLN-SV - Estimated KPIs on mobility - Traffic Efficiency - Indirect impacts

	2 lanes	3/4 lanes	Notes
Average delay	81,7 [min]	74,3 [min]	Faced by each vehicle
Total Average delay per accident (all vehicles involved)	4.509 [h]		Contribution weighted on the features of the highways (n. of lanes)
Total delay saved	**659.471 [h]**		Considering 146 events

HLN-WCW

Indirect impacts on traffic efficiency are assessed considering that a road accident is causing the closure of the carriageway for a time period (i.e. 2 hours). Adopting a model based on input-output diagrams theory, the quantification of the possible delays that the vehicles impacted are suffering is made possible. These delays are supposed to be reduced by the deployment of the Use Cases.

The estimation of indirect effect on traffic efficiency (safety related) assumed that 56 events of traffic congestion due to road accident were avoided thanks to the Use Case.

According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in

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Table 120 - HLN-WCW - Estimated KPIs on mobility - Traffic Efficiency - Indirect impacts

	2 lanes	3/4 lanes	Notes
Average delay	81,7 [min]	74,3 [min]	Faced by each vehicle
Total Average delay per accident (all vehicles involved)	4.509 [h]		Contribution weighted on the features of the highways (n. of lanes)
Total delay saved	**251.613 [h]**		Considering 56 events

7.2.4. Summary

Evaluation results – Field tests

The different use cases evaluated for their impacts on traffic efficiency include Accident Zone (Spain, Slovenia), Traffic Jam Ahead (Spain, Slovenia), Stationary Vehicle (Spain, Italy), Weather Condition Warning (Spain, Slovenia, Italy), Animal or Person on the Road (Spain), Emergency Vehicle Approaching (Spain) and Obstacle on Road (Slovenia)

The impacts in terms of KPIs are summarized below:

- Impact on Travel Time: Analysis of KPIs related to travel time showed negative values for EBL (Benefit: -11%) use case and positive values for WCW. The results for the use cases TJA and SV were very different. But, the outcomes are consistent with the previous KPIs analyzed in the safety area. Those sub-pilots that obtained increases in travel times and reductions in average speeds, from the safety point of view is a good result but not necessarily from a traffic efficiency point of view. If the speed is decreased, it is normal that the travel time is increased. These values make sense and they are aligned with the safety improvement which is the primary objective in this case. The type of road network (urban or interurban) and the service may also have an impact on the results. Overall, percentage change in peak period journey time along routes where C-ITS has been implemented was -65,6%. A total delay savings of 659.471 h and 251.613 h for SV and WCW were estimated on the Italian highway network due to the indirect impacts of avoiding road accidents over a period of one year.
- The number of stops and duration along routes where C-ITS service SV was implemented in Catalan sub-pilot was drastically reduced (Benefit: -61,7%). This result was not the same in the other sub-pilot in Bizkaia and Madrid, where the result was more or less neutral. For other use cases, such as TJA and WCW, the result was neutral or a low positive value. A significant reduction in driving time was also observed in the driving-simulator based experiments conducted in Slovenia. The drivers adjusted their driving style and were able to re-evaluate the conditions on the road in advance.
- The change in instantaneous accelerations and decelerations was reduced in the use cases TJA (Benefit of -20% in the best case) and WCW (Benefit: -27,1% best case). The result in Andalusian sub-pilot was more considerable than in the Madrid sub-pilot which was neutral. In the SV use case, the outcomes in the Andalusian sub-pilot were positive and Madrid showed neutral values. The simulated experiments also displayed that driving was significantly less erratic when driving with DARS Traffic Plus application and the drivers passed through HLN traffic events faster.
- Impact on Speed: The result of the KPI change in average speed had positive values for the service TJA (Benefit : 20,42% best case). In the case of WCW it was not possible to derive a similar conclusion with reduction in the average speed as compared to the baseline. On the other hand, the difference between the average speed of the vehicle and the speed limit was negative for the WCW use case.
- Impact on Traffic Flow: The result of the KPI about the change in traffic flow was -0,5% in the case of HLN-SV.

Evaluation results – KPIs on Mobility

This table summarizes and reflects the main trends in the findings over the various tests and analysis drawn by country. The color describes the positive/neutral/negative evolution

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of the KPI under consideration. When some quantitative values / windows (percentage) of benefits are available, it is written within the cell in addition to the color indicator.
Please pay attention to the fact that negative effects on some KPI might be expected and completely explainable. For instance, Dynamic Speed Limit voluntary reduces the speed upstream to avoid congestion propagation and capacity drop due to traffic heterogeneities. Italy highlighted some indirect impacts in terms of accident avoidance due to the implementation of use cases HLN-SV and HLN-WCW. It is estimated that these use case might avoid on Italian motorways per year around 146 accidents for HLN-SV, respectively 56 accidents for HLN-WCW. Therefore, 659,471 hours of delays could be saved for HLN-SV, respectively 251,613 hours for HLN-WCW.

	KPI	Travel Time	Congestion	Traffic Homogeneity	Capacity
Use cases	Market Penetration Rate level	Average Travel Time [TT] / Average Speed [S] / change in Delays [D]	Number of stops [SN] / stops or queuing duration [SD] / etc	Variations in instantaneous Acceleration [Acc] / in Average Speed [S]	Traffic Throughput
HLN-TJA	low	Sp: [-19%; +16%] [TT] Slo: ▲ [S]	Sp: ▲ [0%; 3%] [SN]; 0% [SD]	Sp: ▼ [0; -20%] [Acc] ; ▲ [+5%; +10%] [S]	
	high				
HLN-SV	low	Sp: [-35%; +45%] [TT]	Sp: ▲ [0%; 3%] [SN]; 0% [SD]	Sp: ▲ [0%; 20%][Acc] ; ▼ [-24%; +5%] [S]	
	high		Sp: ▼-61,7% [SN]; ▼ -88% [SD]	Sp: ▲ +27,1% [S]	Sp: ▼ -0,5%
HLN-WCW	low	Sp: ▲ + 17,4% [TT] Slo: ▲ [S]	Sp: ▲ 0% [SN]; ▲ 0% [SD]	Sp: ▼ [0%; -28%] [Acc]; ▼ [-0%; -22%] [S]	
	high				

Legend

- Colors:

Not Concerned	Variable benefits	Positive benefits	No significant changes	Negative Benefits

- Countries under consideration: Spain (Sp) / Slovenia (Slo).

7.3. Environment

This section provides a list of the hazardous location notification use-cases evaluated from an environmental perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2

7.3.1. Spain

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Stationary vehicle
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-APR: Hazardous Location Notification - Animal or person on the Road
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- HLN-EVA: Hazardous Location Notification - Emergency vehicle approaching

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is environment affected by changes in driver behavior due to HLN use case?

Sub Research Questions:

- How does the HLN service affect the fuel consumption in the use case?
- How does the HLN service affect the CO_2 Emissions in the use case?
- How does the HLN service affect the emissions of other pollutants (NO_x, PM, CO_2, etc...) in the use case?
- How does the HLN service affect to the traffic flow in the use case?

Data collected

The data collected that was used to evaluate the different impact areas are the commented data in Chapter 5.1.1. Refer to this section to check the data collected in the Spanish pilot. In the case of Madrid sub-pilot, this evaluation was done using traffic simulations. Please, refer to the following annexes of [RD.3]:

- Annex 1-C-Roads: Estimation of traffic emissions in the M-30 ring road (Madrid)
- Annex 2-C-Roads Services Evaluation using traffic simulation

In the case of Cantabrian sub-pilot, for the calculation of the indicators, taking into account that only the HMI of the mobile application was used, the GPS location was used to determine the distance travelled. Based on the distance travelled and the average consumption of the vehicles in circulation, it was possible to estimate the average fuel consumption and from this value the corresponding CO_2 emissions. A correlation has also been established between vehicle speed and NO_x particles.
Moreover, the Mediterranean sub-pilot used the characteristics of the vehicles to estimate the impacts on environment: fuel consumption, carbon dioxide emissions and pollutant emissions.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS OHLN v1.1 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.

These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation was obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 130, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 130, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 121 - HLN Environment. Spain.

KPI	Service	Use Case	Pilot	Summary
Change on fuel consumption and CO_2 emissions	HLN	TJA	Andalusian - Mediterranean	3.3%
		SV	Andalusian - Mediterranean	8.6%
			Catalan - Mediterranean	-3.1% (-16.4%*)
			DGT 3.0 SISCOGA	-6%
Change on pollutant emissions NO_x	HLN	TJA	Andalusian - Mediterranean	8.3%
		SV	Andalusian - Mediterranean	6.6%
			Catalan - Mediterranean	-7.0% (-22.1%*)
		WCW	Andalusian - Mediterranean	-19%
			Catalan - Mediterranean	-0.7%
		No HLN services provided	Madrid	Refer to chapter 4.2 of [RD.3] to have more details depending on the scenario simulated.
Change on pollutant emissions PM2.5	HLN	TJA	Andalusian - Mediterranean	-0.8%
		SV	Andalusian - Mediterranean	14.8%
			Catalan - Mediterranean	+3.3% (-9.1%*)
		WCW	Andalusian - Mediterranean	-43.3%
			Catalan - Mediterranean	0.3%

7.3.2. Italy

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather Condition Warning

Evaluation method

Refer to Section 7.1.5 (Safety – Italy).

Data collected

Refer to Section 7.1.5 (Safety – Italy).

Evaluation results – Field tests

Refer to Section 7.1.5 (Safety – Italy).

Evaluation results – KPIs on Mobility

Expected KPIs on mobility were assessed for the Use Cases HLN-SV and HLN-WCW. Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency. Consumption and emission factors are adopted as reported in Table 122.

Table 122 - Consumption and emission factors

Consumption factors	**[l/km]**
Congestion - Light vehicle consumption	0,105
Congestion - Heavy vehicle consumption	0,48
Free Flow - Light vehicle consumption	0,07
Free Flow - Heavy vehicle consumption	0,32
Emission factors	**[kg CO_2/l]**
Emission Factor - Gasoline	2,34
Emission Factor - Diesel	2,61

HLN-SV

The estimation of indirect effect on environment (safety related) was based on the indirect impacts on traffic efficiency, assuming that 146 events of traffic congestion due to road accident were avoided thanks to the Use Case.
According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 123.Table 63

Table 123 - HLN-SV - Estimated EKPIs on mobility - Environment - Indirect impacts

Total Delta Gasoline	- 150.433 [l]
Total Delta Diesel	- 212.230 [l]
Total Average Delta Emissions	- 906 [CO_2 ton]

HLN-WCW

The estimation of indirect effect on environment (safety related) was based on the indirect impacts on traffic efficiency, assuming that 56 events of traffic congestion due to road accident were avoided thanks to the Use Case.

According to the approach adopted, these events could lead to the consequences on traffic efficiency detailed in Table 124.

Table 124 - HLN-WCW - Estimated KPIs on mobility - Environment - Indirect impacts

Total Delta Gasoline	- 57.396 [l]
Total Delta Diesel	- 80.974 [l]
Total Average Delta Emissions	- 346 [CO_2 ton]

7.3.3. Summary

Evaluation results – Field tests

The **Spanish pilot** considered a large number of KPIs and their evaluation.

Taking into account the summary results of Spain, following main conclusions at the Spanish level were obtained**:**

- Change in fuel consumption and CO_2 emissions: the result of this KPI indicated a reduction for HLN-SV use case in the Catalan and DGT3.0 sub-pilots (benefit of -6% in the best case), but Andalusian sub-pilot showed an increase of 8,6%. In the case of TJA, Andalusian sub-pilot detected an increase of 3,3%.
- Change on pollutant emissions NO_x: There was a reduction on the pollutant emissions in WCW use case (benefit: -19% in the best case). In the case of Madrid sub-pilot, it depended on the simulated environment. The TJA use case had an increase of 8,3% in Madrid sub-pilot. For the SV use case it was not possible to conclude common results.
- Change on pollutant emissions $PM_{2.5}$: A reduction was detected in the service TJA (Benefit: -0,8%). For the WCW use case the pollutant emissions were highly reduced in Andalusian sub-pilot (benefit: -43,35) and neutral in Catalan sub-pilot.

The pilot for **Italy** assessed environmental impacts by considering the avoided congestions and those are thus a consequence of impacts on traffic efficiency. Avoiding congestions lead to significant lower consumption factors, especially for heavy vehicles, potential emission saving are up to 2,61 kg CO_2 per liter.

The total average emissions savings are as high as 906 tons of CO_2 for the HLN-SV use case and 346 tons of CO_2 for the HLN-WCW use case.

7.4. User Acceptance

This section provides a list of the hazardous location notification use-cases evaluated from a user acceptance perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, Portugal, NW2, Belgium-Flanders, Czech Republic

7.4.1. Spain

Use Cases considered

- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Stationary vehicle
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-APR: Hazardous Location Notification - Animal or person on the Road
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- HLN-EVA: Hazardous Location Notification - Emergency vehicle approaching

Quantitative Test Results (Surveys)

The initial questionnaire issued to pilot participants at the beginning of the trial collected information on: gender, age, level of completed schooling, occupation, monthly net incomes, profile as driver (if they have an own car, how many km/year they drive, if they are professional drivers, if they share transport and, finally, what is their level of knowledge about CT-ITS and their thoughts about how they think they might change their driving behavior in response to the use-case.

After several weeks testing this system, participants provided feedback about the use of the C-ITS service. The structure of the questionnaire was as follows:

- General Service information (and expectation). The variables to analyze in this section are the next:
  - Perceived Efficiency taking into consideration a general perspective, environment, safety and traffic efficiency.
  - Perceived usability. This was analyzed using a system usability scale.
  - Workload. In this case the Rating Scale Mental Effort (RSME) was used.
  - Perceived usefulness and satisfaction through Van der Laan Scale.
  - Equity.
  - Willingness to pay.

Please, refer to Annex 3 – “User Acceptance Questionnaire” of the report from Spain [RD.3] for more information regarding the complete questionnaire used in the Spanish Pilot as well as the KPIs list that can be extracted from.

Together with the questions related to general driver and service information explained before, the participants could also provide feedback about HLN service in particular, in two different phases:

- Before testing started (pre-test HLN specific questions)
  - HLN will contribute to feeling at ease whilst driving
  - With HLN service in my car I would feel more secure whilst driving
  - With HLN service in my car I would distract my attention from traffic
  - I am comfortable providing my position data as part of the HLN service
  - I would like to have HLN service permanently in my vehicle
  - I would be willing to pay to have access to HLN information

- After several weeks testing this system (post-test HLN specific questionnaire)

- Perceived effectiveness: Scores between 1 and 10 on the following:
    - Availability (Was the service available when the service was needed?)
    - Correctness (Was the information correct when the service was active?)
    - Completeness (Was the information complete when the service was active?)
    - Consistency (Was the service consistent and easy to understand when the service was active?)
    - Accuracy (Was the service accurate (geographical accuracy)?)
    - Up-to-dateness (Was the service up-to-date? Was the service available right on time?)

Moreover, participants would identify the reasons if the effectiveness issues are lower than 5 points:

- Why service was not available? (Availability score < 5)
- Why service was not correct? (Correctness score < 5)
- Why service was not complete? (Completeness score < 5)
- Why service was not consistent? (Consistency score < 5)
- Why service was not accurate? (Accuracy score < 5)
- Why service was not up to date? (Up-to-dateness score< 5)

Other specific questions for the HLN service will have into account the next issues:

- Percentage of participants who notice the icon on the screen
- Perception frequency & usage frequency
- Perceived HLN acceptance

Qualitative Test Results (Interviews)

Some questions are asked to the participants to analyze the influence of the service on behavior and trip quality and to know the proposed improvements to the service.

- I feel using the service, it influenced in my behavior. If so, how?
- I think the services improved my overall trip quality. If so, how?
- What improvements would you introduce in the service?

Several specific questions have been asked to the participants during pre-tests and post-tests in the different sub-pilots. The following tables summarize the result of them.

Table 125 - HLN User Acceptance. SISCOGA Extended sub-pilot.

KPI		Estimated Value of KPI (%)
HLN acceptability (pre-test)	HLN will contribute to feeling at ease whilst driving	92% of the users considered that the HLN will contribute to feeling at ease whilst driving. Around 60% of drivers were totally agree with this affirmation.
	With HLN service in my car I would feel more secure whilst driving	Around 85% of them were agreed or totally agreed with this statement
	With HLN service in my car I distract my attention from traffic	Around 66% of the drivers felt that they would not distract their attention from traffic while around 15% presented an impartial answer for this statement, and 18% of them contemplated that it could distract their attention.
	I am comfortable providing my position data as part of the HLN service	22% were not satisfied with sharing their location, around 19% stated a neutral opinion and 60% did not mind.
	I would like to have HLN service permanently in my vehicle	37% of them said that they are agree with it and 48,15% are totally agree. 12% of them provided a neutral answer and 12,5% were disagreed.
	I would be willing to pay to have access to HLN information	60% were neutral to this question. Only a 7% is totally agree with the idea of charge for the service.
HLN acceptance (post-test)	HLN will contribute to feeling at ease whilst driving	Around 40% of sample was agreed. Only 4% of them expressed that they were not agreed with that. While 60% replied with a neutral answer.
	With HLN service in my car I would feel more secure whilst driving	26% of them agreed with this sentence and around 10% was totally agree. It is necessary to indicate that around 60% of them provided a neutral answer. Only 6% were opposed with this idea.

	With HLN service in my car I distract my attention from traffic	Only 6% thought that this service could distract their attention from their attention from the traffic, while 41% disagreed with this affirmation. Around 37% was neutral for this statement after testing the service. 16,5% was total opposed.
	I am comfortable providing my position data as part of the HLN service	37% felt that there is no problem for sharing their position. Around 54% provided a neutral answer and only a minimum percentage is not agreed with this idea (9%).
	I would like to have HLN service permanently in my vehicle	One quarter is totally agreed that they would like to have HLN information permanently in their vehicle. Over this percentage (46%) is agreed with that. Around one quarter of sample was neutral. Only 6% differed with this statement.
	I would be willing to pay to have access to HLN information	19% of the sample expressed themselves negatively and around 25,96% said that they were totally disagree. 41% answered “neutral”. Around 15% of them considered to pay for having access to this service.
Users that noticed the HLN icon on the screen		62% of participants saw the icon on the screen as it can be perceived in the next figure. A very low percentage (4%) was not sure if they noticed it and, 35% stated not perceive it.
HLN perceived frequency during the test		32% of drivers noticed the HLN sometimes while 15% saw it hardly ever, 7% of them noticed it very often and around 36% never appreciated the information.
HLN perceived usage during the test		34% of drivers noticed the HLN sometimes while 9% saw it hardly ever, and the same percentage, 9% of them noticed it very often and around 36% never appreciated the information.
HLN influence in driver behavior		15% considered that employing the service had not changed their behavior. 45% of users considered a neutral answer, and around 40% reacted positively.
HLN improvement in overall trip quality		Only 5% of them disagreed but most of the sample considered the influence of the service on the trip (45,45% agreed and 7% was totally agreed). Around 40% had a neutral opinion.
HLN perceived effectiveness		63 points

Table 126 - HLN User Acceptance. Madrid sub-pilot.

KPI	Estimated Value of KPI (%)
HLN acceptability (pre-test)	67.50
HLN acceptance (post-test)	75.62
Users that noticed the HLN icon on the screen	72.22
HLN perceived frequency during the test	50.00
HLN perceived usage during the test	51.11
HLN influence in driver behavior	64.62
HLN improvement in overall trip quality	43.08
HLN perceived effectiveness	53.43

Table 127 - HLN – TJA&SV User Acceptance. Cantabrian sub-pilot.

KPI		Estimated Value of KPI (%)
HLN acceptability (pre-test)	HLN will contribute to feeling at ease whilst driving	65% of users were neutral, 35% of user agreed.
	With HLN service in my car I would feel more secure whilst driving	60% of users were neutral, 30% agreed, and 10% strongly agreed
	With HLN service in my car I distract my attention from traffic	45% disagreed, 40% of users were neutral, and 15% agreed
	I am comfortable providing my position data as part of the HLN service	55% of users were neutral, 30% agreed and 15% disagreed
	I would like to have HLN service permanently in my vehicle	60% of users agreed, 20% were neutral, 10% disagreed and strongly disagreed and 5% strongly agreed
	I would be willing to pay to have access to HLN information	70% disagreed and 30% of users were neutral
HLN acceptance (post-test)	HLN will contribute to feeling at ease whilst driving	65% neutral 20% agree
	With HLN service in my car I would feel more secure whilst driving	60% neutral 25% agree
	With HLN service in my car I distract my attention from traffic	55% neutral 30% disagree
	I am comfortable providing my position data as part of the HLN service	55% neutral 25% agree

	I would like to have HLN service permanently in my vehicle	50% agree 35% neutral
	I would be willing to pay to have access to HLN information	45% neutral 30% disagree
Users that noticed the HLN icon on the screen		85% of drivers did not notice (40%) or are not sure (45%) if they see the HLN- TJA&SV icon or alert on their screen. 15% noticed it
HLN perceived frequency during the test		
HLN perceived usage during the test		HLN – TJA&SV service usage frequency, some of them used it very often or even always, but normally they used it sometimes, even never
HLN influence in driver behavior		
HLN improvement in overall trip quality		70% answered "neutral", although the influence was lower in the behavior (10%) and bigger in the trip quality (20%).
HLN perceived effectiveness	Availability	4,30
	Correctness	4,45
	Completeness	4,60
	Consistency	4,45
	Accuracy	4,45
	Up to dateness	4,65

Table 128 - HLN – WCW User Acceptance. Cantabrian sub-pilot.

KPI	Estimated Value of KPI (%)
HLN acceptability (pre-test)	53.81
HLN acceptance (post-test)	27.08
Users that noticed the HLN icon on the screen	75 % of the users noticed the HLN - WCW icon on the screen of their cars
HLN perceived frequency during the test	37,5
HLN perceived usage during the test	52,5
HLN influence in driver behavior	Most of the drivers didn´t perceive any influence in their driving behavior or the trip quality.
HLN improvement in overall trip quality	
HLN perceived effectiveness	54.17

Table 129 - HLN User Acceptance. Catalan sub-pilot.

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	52.9
Perceived usage during the test	50.0
Perceived effectiveness	68.6
Perceived acceptance	57.6
Perceived acceptance pre-test	51.9
Influence on behavior and trip quality	63.6

Table 130 - HLN User Acceptance. Andalusian sub-pilot

KPI	Estimated Value of KPI (%)
Perceived frequency during the test	52.7
Perceived usage during the test	60
Perceived effectiveness	62.1
Perceived acceptance	60.3
Perceived acceptance pre-test	66.3

Table 131 - HLN User Acceptance. DGT3.0 sub-pilot. SISCOGA Extension. DGT3.0 participants (HMCU)

KPI		Estimated Value of KPI (%)
HLN acceptability (pre-test)	HLN will contribute to feeling at ease whilst driving	Around 95% of them considered that the HLN will contribute to feeling at ease whilst driving.
	With HLN service in my car I would feel more secure whilst driving	Around 85% of them were agreed or totally agreed with this statement.
	With HLN service in my car I distract my attention from traffic	Around 58% of the drivers felt that they would not distract their attention from traffic while around 30% presented an impartial answer for this statement, and 11% of them considered that it could distract their attention.

	I am comfortable providing my position data as part of the HLN service	11% were not satisfied with sharing their location, around 22% expressed a neutral opinion and 68% did not mind.
	I would like to have HLN service permanently in my vehicle	46% of them said that they are agree with it and 37% are totally agree. 10,5% of them provided a neutral answer and only 5 were opposed to this idea.
	I would be willing to pay to have access to IVS information	Around 40% is not in agreement to pay for it, most of the sample (60%) were neutral to this question.
HLN acceptance (post-test)	HLN will contribute to feeling at ease whilst driving	Around 37% of sample was agreed with the next statement: "Thanks to the HLN information I felt more at ease while driving". Only 16% of them expressed that they were not agreed with that. While around half of the sample replied with a neutral answer.
	With HLN service in my car I would feel more secure whilst driving	37% of them agreed with this sentence and around 10% was totally agree. It is necessary to indicate that around 37% of them provided a neutral answer. Only 16% were opposed with this idea.
	With HLN service in my car I distract my attention from traffic	Only 11% thought that this service could distract their attention from their attention from the traffic, while 42% disagreed with this affirmation. Around 47% was neutral for this declaration after testing the service. Around one quarter was total opposed.
	I am comfortable providing my position data as part of the HLN service	Over half of the sample felt that there is no problem for sharing their position. Around 37% provided a neutral answer and only a minimum percentage is not agreed with this idea (11%).
	I would like to have HLN service permanently in my vehicle	37% is agreed with that. Around 20% of sample was neutral. Only 11% differed with this statement.
	I would be willing to pay to have access to HLN information	Only 5% of the sample expressed themselves negatively and around one quarter said that they were totally disagree. Around half of the sample answered "neutral". Around 15% of them considered to pay for having access to this service.
Users that noticed the HLN icon on the screen		Most of participants (61%) saw the icon on the screen as it can be perceived in the next figure. A very low percentage (11%) was not sure if they noticed it and, 28% stated not perceive it.
HLN perceived frequency during the test		44% of drivers noticed the HLN sometimes while 28% saw it hardly ever and around 20% never appreciated the information.
HLN perceived usage during the test		
HLN influence in driver behavior		Low percentage of participants (17%) judged that using the service had not influenced in their behavior. 28% of users felt neutral, and around 17% answered positively.
HLN improvement in overall trip quality		Only 17% of the users disagreed but most of the sample considered the influence of the service on the trip (38,88% agreed and 17% was totally agreed). Around 27% had a neutral opinion.
HLN perceived effectiveness		67 points

Table 132 - HLN User Acceptance. DGT3.0 sub-pilot. SISCOGA Extension. HMI type participants

KPI		Estimated Value of KPI (%)
HLN acceptability (pre-test)	HLN will contribute to feeling at ease whilst driving	60% Agree 40% totally agree
	With HLN service in my car I would feel more secure whilst driving	Around 70% of them were agreed or totally agreed with this statement.
	With HLN service in my car I distract my attention from traffic	Half of the drivers felt that they would not distract their attention from traffic while around one third presented an impartial answer for this statement, and 20% of them considered that it could distract their attention.
	I am comfortable providing my position data as part of the HLN service	22% were not satisfied with sharing their location, around one third stated a neutral opinion and half of the sample did not mind it. 20% of them were not comfortable with this idea.
	I would like to have HLN service permanently in my vehicle	60% of the users said that they are agree with it and 20% are totally agree). 10% of them provided a neutral answer and 10% were disagreed.
	I would be willing to pay to have access to HLN information	Half of the sample is not in agreement to pay for it, and the other half provided a neutral answer.

HLN acceptance (post-test)	HLN will contribute to feeling at ease whilst driving	Around 40% of sample was agreed with the next statement: "Thanks to the HLN information I felt more at ease while driving". 20% of them expressed that they were not agreed with that. While 40% replied with a neutral answer.
	With HLN service in my car I would feel more secure whilst driving	30% of them agreed with this sentence and around 10% was totally agree. It is necessary to indicate that around 40% of them provided a neutral answer. 20% were opposed with this idea.
	With HLN service in my car I distract my attention from traffic	20% thought that this service could distract their attention from their attention from the traffic, while half of the sample disagreed with this affirmation. One third was neutral for this declaration after testing the service. 20% was total opposed.
	I am comfortable providing my position data as part of the HLN service	40% felt that there is no problem for sharing their position. Other 40% provided a neutral answer and a low percentage is not agreed with this idea (20%).
	I would like to have HLN service permanently in my vehicle	30% of drivers is totally agreed that they would like to have HLN information permanently in their vehicle. 20% of participants is agreed with that. Around one third of sample was neutral. 20% differed with this statement.
	I would be willing to pay to have access to HLN information	10% of the sample expressed themselves negatively and 40% said that they were totally disagree. Other 40% answered "neutral". Only 10% of them considered to pay for having access to this service.
Users that noticed the HLN icon on the screen		Most of participants (60%) saw the icon on the screen as it can be perceived in the next figure. A low percentage (20%) was not sure if they noticed it and, the same proportion, 20% declared not perceive it.
HLN perceived frequency during the test		10% of drivers noticed the HLN while 40% of sample saw it sometimes. The other half had difficulties to see it, 30% of them saw it hardly ever and 20% never.
HLN perceived usage during the test		
HLN influence in driver behavior		70% of participants judged that using the service had not influenced in their behavior. 30% of respondents were neutral regarding this issue.
HLN improvement in overall trip quality		Half of the sample agreed with this statement, one third was neutral and only 20% of the disagreed.
HLN perceived effectiveness		65 points

Conclusions

Refer to 5.4.1 to have more global details about user acceptance regarding to perceived efficiency in general, perceived efficiency on safety, traffic efficiency and environmental, perceived usability, workload, perceived usefulness, satisfaction and effectiveness, equity and willingness to pay.

7.4.2. Czech Republic

Use Cases considered

- HLN-RLX: Hazardous Location Notification - Railway Level Crossing
- HLN-EVA: Hazardous Location Notification - Emergency Vehicle Approaching
- HLN-SV: Hazardous Location Notification - Stationary Vehicle (and Slow Vehicle)
- HLN-PTVC: Hazardous Location Notification - Public Transport Vehicle Crossing
- HLN-PTVS: Hazardous Location Notification - Public Transport Vehicle at Stop

Quantitative Test Results (Surveys)

We can divide the area of user acceptance into several parts:

- Driver profiles,
- General questions,
- Questions before an evaluation drive related to the relevant use-case,
- Questions after the evaluation driver related to the relevant use-case.

Railway Level Crossing

Before the evaluation drive, the drivers generally considered that information about “railway crossing” would be good to know and could generally improve safety.

The first questions after the drive were related to the message registration. All the drivers registered the information about a free crossing and only one driver did not understand the information well. 25% of drivers registered the information too early, on the other hand, 75% of drivers got the information on time.

The next questions focused mainly on perceived usability, usefulness, efficiency, and satisfaction and the overall results of user acceptance are considered positive in terms of C-ITS. The drivers always said that the information was successfully shown, was useful, it increased an overview of the situation while approaching railway crossings.

There was also one interesting question considering fear about the right state of railway signaling. It was seen that reliability, accuracy and timeliness are all very important at the beginning of C-ITS to ensure the quality of the service. People tend not to trust new services and this is crucial for the future development of C-ITS.

Stationary vehicle

The results of the before drive questionnaires showed that the drivers would like to have information about the stationary vehicle and thought that this information could increase safety.

The first questions after the drive related to the message registration. 25% of drivers did not get the information about the stationary vehicle due to some technical issues, 69% received the information, and the 6% received the information but did not pay attention to it, it was also interesting to note how the distribution of the time registration differed. 8% of drivers received the information too late while 15% of the drivers received the information too early. From these results it was concluded that various drivers have different needs in terms of C-ITS reception.

The next questions focused mainly on perceived usability, usefulness, efficiency, and satisfaction and it can be generally said that the information was useful and also the situation in the vicinity of the stationary vehicle was more clear.

Slow Vehicle

Drivers were very interested in this use-case. The drivers typically agreed with the safety factor of having this information in advance. The message registration differed among drivers: 22% get the information too early, 6% too late and 72% on time.
The results of questions regarding usefulness, satisfaction and safety were very positive in terms of C-ITS. They strongly agreed that the information about SSV was useful, increased their overview, and felt safer when approaching the slow vehicle. There was one more point that should be noticed. When the driver was driving in the fastest lane (3rd from the right edge), they did not notice the slow vehicle in the right lane and ignored it. They would rather not get the information.

Emergency Vehicle Approaching

The results regarding this use-case were ambiguous. The drivers were generally interested in having the information about emergency vehicle approaching. The main thing that was not clear was what exactly should be shown to the driver. Therefore, there is a large variance in HMI distraction-related responses. In general, drivers were in favor of this use case and would find it useful.
Drivers also pointed out that they had heard the emergency vehicle before they were told about the use case. However, if they could not see the emergency vehicle and had the information only from the HMI, most of them adjusted their speed and tried to make way for a smooth passage.

Public Transport Vehicle Crossing

Before the drive, the drivers generally considered that information about “public transport vehicle crossing” was good to know and could also generally improve safety and an overview of a crossing.
The first questions after the drive related to the message registration. 8% of drivers did not get the information about the public transport vehicle approaching crossing or get it too early, 61% registered the information on time, and the 23% received the information too late. It was also interesting how the distribution of the time registration differed. It can be concluded that various drivers had different needs in terms of C-ITS reception.
The overall results of user acceptance are considered positive in terms of C-ITS. The drivers always said that the information was successfully shown, was useful, it increased an overview of the situation while approaching tram crossings.

Public Transport Vehicle at Stop

The results showed that drivers were not so much interested in this use-case compared to the use-cases in other pilot sites. They considered this use-case useful, but the results have a big variance in usefulness or safety. This was partly caused by the type of stop at which the evaluation took place. It often happened that the driver did not even use the message from HMI because he thought that the bus was only parked there.
All drivers registered the message and 15% thought that they got the message too early. The rest received the information on time.

7.4.3. Slovenia

Use Cases considered

- HLN-AZ: Hazardous Location Notification - Accident Zone
- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-WCW: Hazardous Location Notification - Weather condition warnings
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Quantitative Test Results (Surveys)

Drivers recognized positive value in the DARS Traffic application, according to the results for the safety aspect of HLN use cases. To evaluate User acceptance aspects of HLN use cases, we used validated questionnaires (User Experience Questionnaire-UEQ, meCUE Questionnaire) and concluding interviews.

The User Experience Questionnaire was a fast and reliable questionnaire to measure the User Experience of interactive products. The scales of the questionnaire cover a comprehensive impression of user experience. Both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation) were measured[11].

The meCUE questionnaire allowed for the modular evaluation of key aspects of User Experience. The questionnaire consisted of five separately validated modules that relate to the perception of different product characteristics (usefulness, usability, visual aesthetics, status, commitment), to users' emotions (both positive and negative emotions) and to consequences (product loyalty and intention to use). The fifth module allowed for a global assessment of the product.[12]

We used the User Experience Questionnaire to evaluate User Acceptance of DARS Traffic Plus application. Scale scores of the UEQ questionnaire were measured on the seven-point Likert scale. Drivers completed the questionnaire after all driving scenarios. UEQ questionnaire covers six scales. The attractiveness scale covered the overall impression of the product. The Perspicuity scale covered how easy it was to get familiar with the product. Efficiency scale covered how users solved their tasks without unnecessary effort. The dependability scale covered how a user felt in control of the interaction. The stimulation scale measured how exciting and motivating it was to use the product. The novelty scale covered the design of the product - did it catch the interest of users?

All scale scores obtained in the UEQ questionnaire for Scenario 1 and 2 were positive (see Table 133 and Figure 31). Scale scores for Scenario 2 were higher than scale scores for Scenario 1. Results showed that driving with the DARS Traffic Plus application provided a better user experience than driving without the application. The highest scored scales in Scenario 2 were scale Perspicuity with a mean value of 2.12, SD = 0.55, scale Efficiency with a mean value of 1.91, SD = 0.58, and scale Stimulation with a mean value of 1.92, SD= 0.57. Based on scale scores, we concluded that the DARS Traffic Plus application offered a good user experience.

The purpose of Scenario 3 was to evaluate the most suitable form of providing traffic event notifications (Table 134 and Figure 32. In Scenario 3 we detected the highest marked scales values of all three scenarios. The Perspicuity scale was marked with a mean value of 2.15, SD = 0.62. Efficiency scale was marked with mean value of 2.01, SD = 0.45 and the Stimulation scale was marked with mean value of 2.05, SD = 0.48. High scale values indicate that it is easy to get familiar and learn to work with the DARS Traffic Mobile application. Drivers were also motivated to use the application in the future.

[11] https://www.ueq-online.org/

[12] http://mecue.de/english/background.html

Table 133 - UEQ questionnaire Scenario 1 and 2 results

	Scenario 1		Scenario 2	
UEQ Scale	**Mean value score**	**SD**	**Mean value score**	**Mean value score**
Attractiveness	1.74	1.00	1.88	0.77
Perspicuity	1.79	0.97	2.12	0.55
Efficiency	1.67	0.71	1.92	0.58
Dependability	1.19	1.02	1.46	0.61
Stimulation	1.84	0.92	1.92	0.57
Novelty	1.86	1.02	1.88	0.50

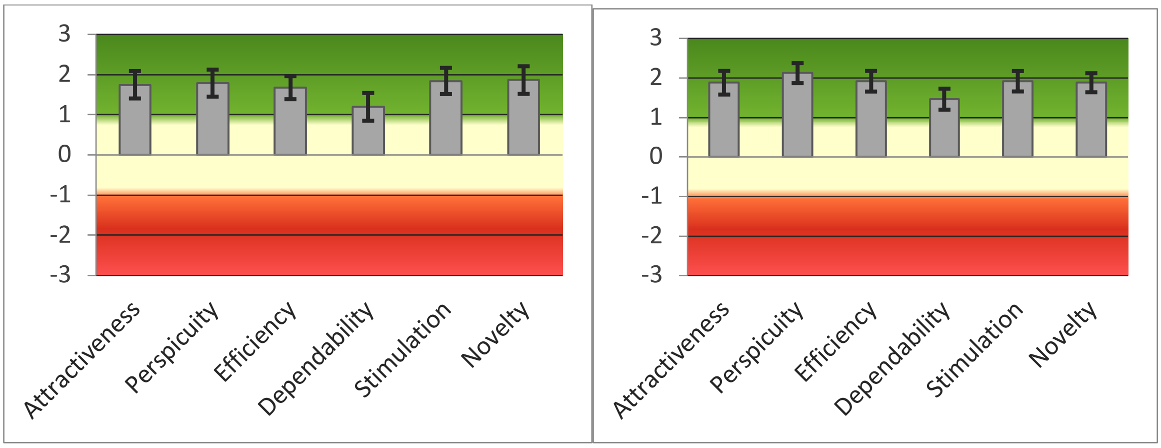

Figure 31 - UEQ questionnaire Scenario 1 and 2 results (left Scenario 1, right Scenario 2)

Table 134 - UEQ questionnaire Scenario 3 results

	Scenario 3	
UEQ Scale	**Mean value score**	**SD**
Attractiveness	1.93	0.64
Perspicuity	2.15	0.62
Efficiency	2.06	0.45
Dependability	1.80	0.53
Stimulation	2.05	0.48
Novelty	1.88	0.71

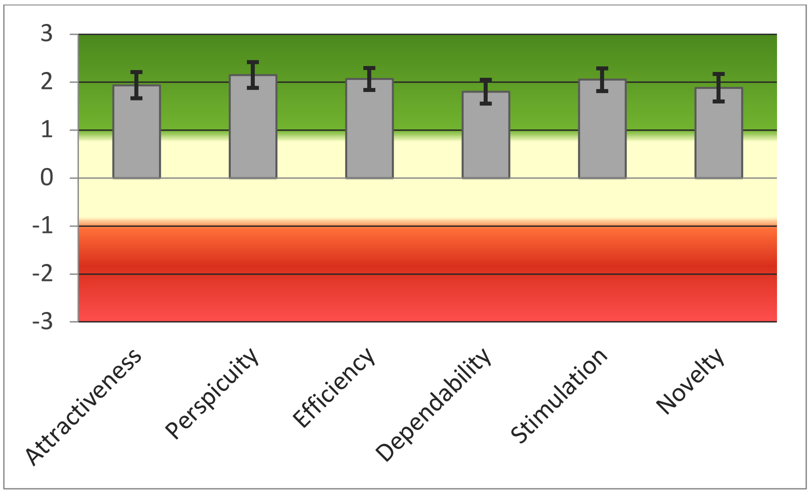

Figure 32 - UEQ questionnaire Scenario 3 results

In the meCUE questionnaire, we noticed measurable differences between the scales of Scenario 1 and Scenario 2 (see Table 135 and Figure 34). Scale scores were measured on the 7-point Likert scale. Scales of Usefulness in Scenario 1 received a score of 5.30, SD = 1.02 while scales of Usefulness in Scenario 2 received a score of 5.75, SD = 0.63. Scenario 1's scale of Usability received a score of 5.80, SD = 0.85, while Scenario 2's scale of Usability received a score of 5.95, SD = 0.62.Overall evaluation is measured on a 5-point Likert scale. Scale of Overall evaluation in Scenario 1 received a score of 3.1, SD = 1.6 while the scale of Overall evaluation in Scenario 2 received a score of 3.5, SD = 1.2. We concluded that the higher scale scores were given for the evaluation of driving experience with the DARS Traffic Mobile application in Scenario 2.

Table 135 - meCUE 2.0 questionnaire Scenario 1 and 2 results

	Scenario 1		Scenario 2	
Scale	**Mean value score (n=33)**	**SD**	**Mean value score (n=33)**	**SD**
Usefulness	5.30	1.02	5.75	0.63
Usability	5.80	0.85	5.97	0.75
Visual Aesthetics	5.43	0.95	5.72	0.62
Status	4.28	1.09	4.50	0.96
Commitment	2.72	1.12	2.97	1.06
Positive emotions	3.69	1.16	3.76	1.20
Negative emotions	2.60	1.06	2.38	0.94
Intention to use	4.27	1.40	4.68	1.16
Product loyalty	4.05	1.15	4.38	0.75
Overall evaluation	3.1	1.6	3.5	1.2

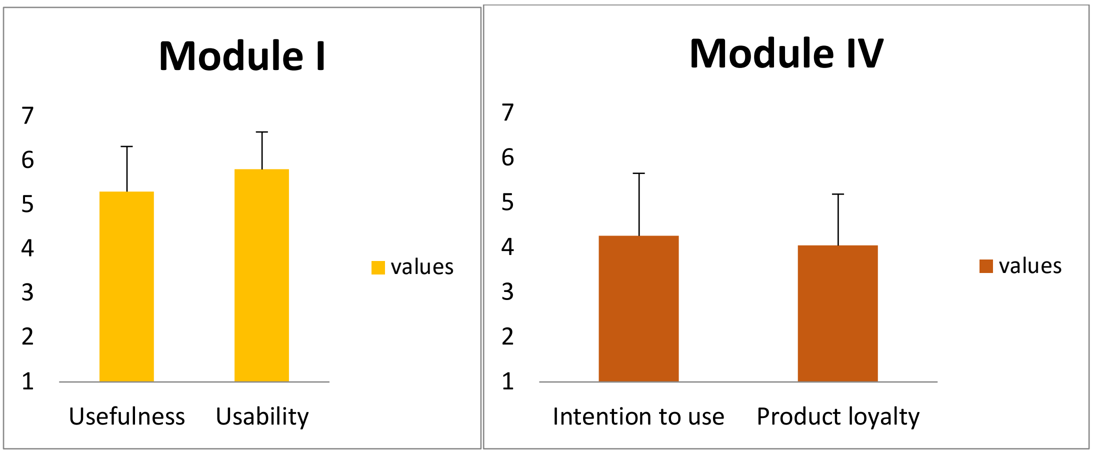

Figure 33 - meCUE questionnaire Scenario 1 results

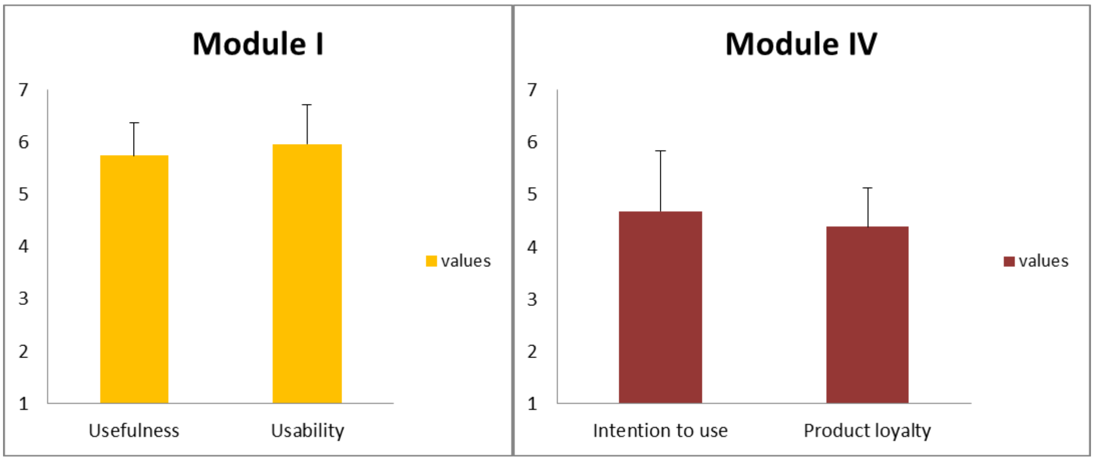

Figure 34 - meCUE questionnaire Scenario 2 results

We did not notice any significant improvement in scale scores for scenario 3 (see Table 136 and Figure 35). Results remained mostly at similar levels or were marginally lower. Scales of Usefulness (5.52, SD = 0.78) and Usability (5.87, SD = 0.75) were lower than in scenario 2. Scores of Product loyalty (4.48, SD = 1.17) and Overall evaluation (3.6, SD = 1.2) received marginally higher values.

Table 136 - meCUE 2.0 questionnaire Scenario 3 results

Scale Scenario 3	Mean value score	SD
Usefulness	5.52	0.78
Usability	5.87	0.75
Visual Aesthetics	5.85	0.63
Status	4.25	0.95
Commitment	2.92	1.05
Positive emotions	3.68	1.18
Negative emotions	2.50	0.79
Intention to use	4.83	1.19
Product loyalty	4.48	1.17
Overall evaluation	3.6	1.2

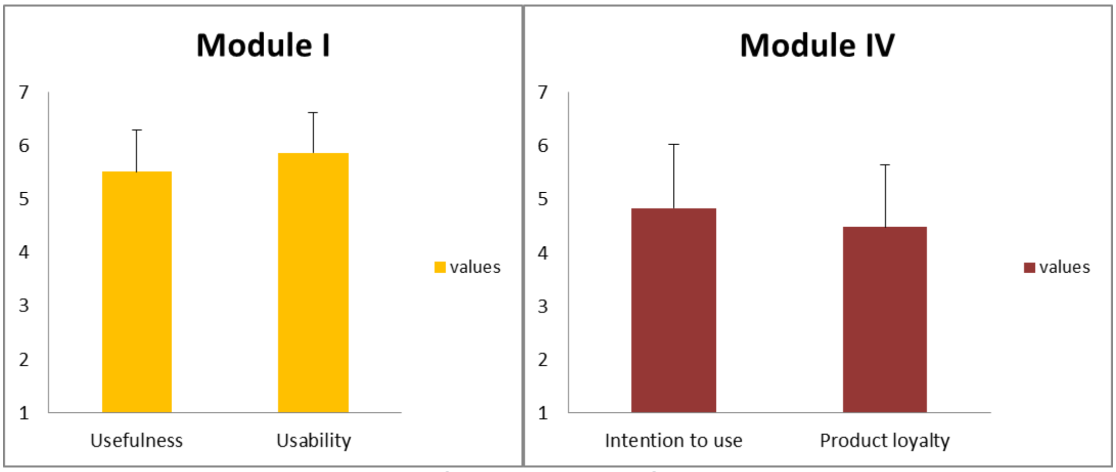

Figure 35 - meCUE questionnaire Scenario 2 results

Qualitative Test Results (Interviews)

In the concluding interviews, drivers were asked to mark some of the functionalities of the DARS Traffic Plus application. For marking, we used a 5-point Likert scale. A value of 1 presents strong disagreement with the statement, and a value of 5 presents strong agreement with the statement.
Drivers were asked to mark the adequacy of content when receiving notifications in the application for HLN use cases. Content was marked with a positive value of 4.06, SD = 0.83. Additional sub questions indicate that the selected icons, text information, and colors used in the notifications were clear and understandable. In general, the selected color palette (mean value of 4.61, SD = 0.56) and clarity of the icons (mean value of 4.64, SD = 0.6) used in the application were found satisfactory.
The perceived level of the DARS Traffic Plus application's user experience was marked with a mean value of 4.58 and SD = 0.71. In addition, the perceived level of usability of the DARS Traffic Plus application was marked with a mean value of 4.79, SD = 0.49. Results for user experience and usability of the application gathered from concluding interviews are in correlation with results derived from validated questionnaires.
Drivers expressed an interest in using the DARS Traffic Plus app in the future. Future use of the application was marked with a mean value of 3.91, SD = 1.01.
In conclusion, we provide some quotes from the drivers:

Positive:
“It really is better!”
“I didn't know that the DARS Traffic Plus application also has this functionality. I like it.”
“Great improvement of the application.”

Neutral:
“Maybe I’ll use application in the future.”

Negative:
“I don't feel safe using my phone in the car.”

Conclusions

Based on the results of validated questionnaires and concluding interviews with drivers, we conclude that the DARS Traffic Plus application offers a good user experience. We gained results with the same conclusion from two different validated questionnaires (UEQ and meCUE 2.0). Results show that driving with the DARS Traffic Plus application provided a better user experience than driving without the application. Visual notifications were accepted as positive; they were ranked even more positive when combined with sound notifications, like a beep or voice. However, in order for notifications to be effective, the number of notifications must remain reasonable; excessive notifications are defined as driver distractions. Results also indicated that the application was easy to get familiar with and learn how to work with. The application offered motivation for future use of the application. Results from questionnaires were confirmed with responses from concluding interviews. The content of the received notifications was marked as positive. It was indicated that the selected icons, text information, and colors used in the notifications were clear and understandable. Perceived levels of user experience and usability were marked as positive. Gathered results show an intent from the drivers to use the DARS Traffic Plus application in the future. The received feedback comments were mostly positive, some were neutral, and some were negative.

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7.4.4. Summary

Opinions of users who experienced the HLN suite of services from Spain varied in how they felt pre and post-test across the regions but in general there was a good acceptance after testing, with a majority in some areas feeling the service improved trip quality.

In Slovenia, results showed that driving with the DARS (the motorway network operator) Traffic Plus smart phone based application provided a better user experience than driving without the service. Further, the results of questions regarding usefulness, satisfaction and safety were very positive in terms of the service and users strongly agreed that the information about SV was useful, increased their overview when approaching the slow vehicle, and helped them feel safer.

The HLN service was used by most drivers and in some areas of Spain around two thirds of participants found it to be useful. Slovenia stated that based on scale scores that the DARS Traffic Plus application offered a good user experience. High scale values indicated that the application was easy to get familiar with to use the application. After testing, Spain's users generally disagreed with the statement that the device distracted them from traffic, this didn't change from their views before testing so that was positive.

Participants from Spain were overall less at ease with HLN warnings compared to RWW but this was a marked increase on their feelings for IVS where only around a quarter of users felt at ease. One region reported that half of the users would like to have the service permanently in their vehicle so overall acceptance was still good.

User acceptance in Czechia was considered positive in terms of C-ITS services. The drivers consistently stated that the information was successfully shown, was useful and it increased an overview of the situation while approaching railway crossings.

Based on results of validated questionnaires and concluding interviews drivers in Slovenia concluded that DARS Traffic Plus application provided a good user experience. Results indicated that application was easy to get familiar with and learn how to use.

One region of Spain reported that half of the users would like to have the service permanently in their vehicle. Most drivers across Spain were also generally unconcerned about the idea of sharing positional data although a fifth of drivers in two of the regions were not in favor.

In Slovenia, based on the results and interviews with drivers it was concluded that DARS Traffic Plus application offered a good user experience. Results show that driving with the DARS Traffic Plus application provides a better user experience than driving without the application. Visual notifications were accepted as positive; they were ranked even more positive when combined with sound notifications like a beep or voice. Results also indicated that the application was easy to get familiar with and learn how to work with. Results from questionnaires were confirmed with responses from concluding interviews.

Where stated, drivers still showed a lack of interest in paying for the service which is in line with a low willingness to pay for other services in this report.

Many users in Spain were influenced by HLN with SISCOGA 40%, Madrid 65%, Catalan 64%, and Andalusia 66% drivers stating they were influenced by the service. Around 50% of Spain's users said that the service also improved their trip quality.

The timing of the messages were deemed very important to drivers although there was great variance in the requirements, as some felt they got the message too early, others about right while some thought the message was too late. Czechia commented *"From these results it can be concluded that various drivers have different needs in terms of C-ITS reception."*

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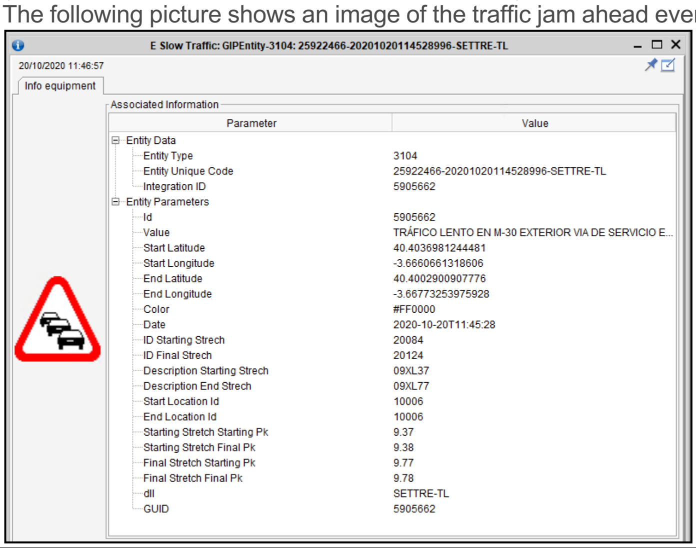
7.5. Functional Evaluation

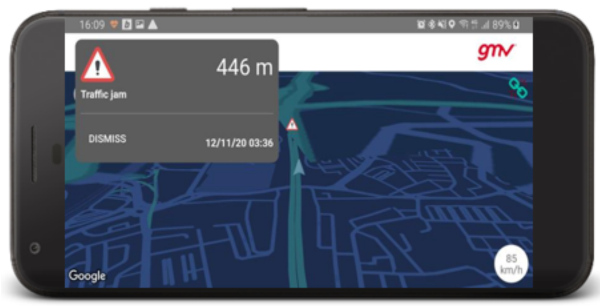
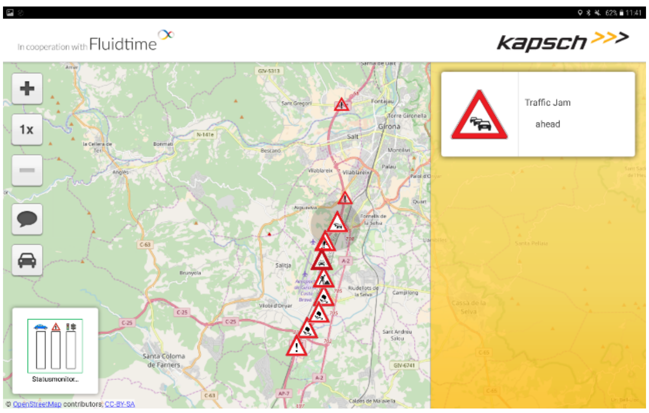
This section provides a list of the hazardous location notification use-cases evaluated from a functional evaluation perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2, Belgium-Flanders, Germany, Czech Republic

7.5.1. Spain

The Spanish pilot evaluated the functional evaluation on most of the services deployed. Table 137 shows the functional evaluation of TJA. Refer to [RD.3] the final evaluation result of Spain to have more information about the rest of services and use cases in every sub-pilot.
Table 137 details the feedback obtained from the implementation in the Spanish pilot (Madrid, Cantabrian and Andalusian sub-pilots).

Table 137 - HLN-TJA Functional evaluation. Spain. Madrid sub-pilot

Service	HLN-TJA
Lessons Learned	[GMV deployment] The service HLN-TJA was implemented in all the OBUs and HMIs agreed on the project. These developments together with the possible logs of HMI and OBU enabled analysis of all the impact areas, technical KPIs and user acceptance. A web application was implemented to store the logs for the analysis. Although initially it was not planned to have Internet in the OBU for the project, later, we needed to have an Internet connection in order to send the logs to the server (HMI and OBU logs about the events received from the RSUs) for the subsequent analysis and also to update the security certificates. It was a challenging challenge. To fulfil these functionalities, the HMI was used as a bridge to provide the Internet connection to the OBU. For this, Wi-Fi zone of the Smartphone was activated and the drivers were advised not to forget to activate this. As lessons learned, include a modem with an integrated SIM or modem with hub connection could simplify the current implementation. Another option would be to manage the certificates through the network itself (send the certificates through the RSUs to the OBUs). [INDRA HUB deployment] Different sources of information for this kind of event had different levels of criticality. Some events changed their state from slow traffic to traffic Jam and generated new events (previous it should be clear the slow traffic event). The following picture shows an image of the traffic jam ahead event registered in the C-ITS hub. 

	[Kapsch deployment] Traffic jams are the most unexpected and frustrating incidents that a driver can face. We learnt that if drivers are warned with enough advance timing, they make better decisions in order to avoid traffic jams. That's finally helping to improve traffic jam itself as less vehicles reach incident zone. Inherent advantages of ITS-G5 communications is to make it possible to inform about those incidents without the need of any DMS infrastructure available. It is important, then to define a large detection zone in order for drivers to be warned with enough advance time for them to adapt driving to expected upstream restrictions. Kapsch deployed this pilot with a full set of field equipment that was key to fulfilling project requirements. At Gateway level, receiving all sets of messages from different services from TMC provided the capability of disseminating to appropriate RSUs in order to reach with HLN-TJA information to all set of OBUs available in the pilot. One challenging issue was properly defining accurate segments to properly inform drivers in real time. ITS-G5 short range communications allowed minimum latency to reach driver with expected information. Full standard compliance for ITS-G5 provided interoperability with future systems deployed. Already detected and managed existing Car2Car systems available in market and deployed in vehicles. During the pilot care was taken not to provide inconsistent information to those users, not involved in pilot scope.
HMI*	The Smartphone as HMI for the GMV deployment in the Madrid pilot was the main device used by the participants to receive feedback about the user acceptance for the HLN-TJA service. The GMV C-ROADS App showed the traffic jam ahead notification and the distance to reach the event. Also, the end date of validity of the event was displayed. These data were appreciated by the participants.  Kapsch deployed in all test vehicles included in this Pilot with an OBU and an HMI with a tablet that was paired through a Bluetooth connection. All tablets had an app devoted to HMI purposes that provided all received information to the driver. For the HLN-TJA service, the next screenshot shows an example of how this information was provided to driver. 
Quality of the Service	If the event had a trace/eventHistory, the event was shown to the user in the HMI when the vehicle entered the zone. If the event did not have trace/eventHistory, it was shown within the relevanceDistancevalue. The user had enough time to react. Some indications could confuse drivers in case of slow traffic transforms to a traffic Jam but generally the events were defined well and clearly

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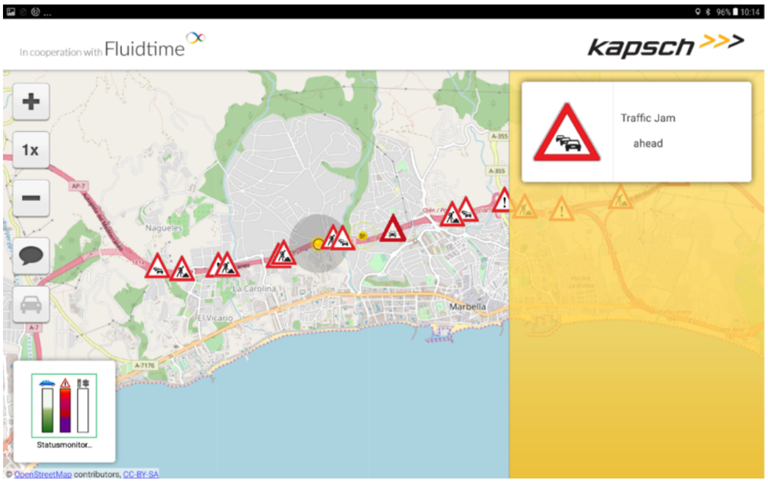
	In general terms, users considered their behavior was affected by this notification as follows: Decreasing the velocity to change the lane before the area of the event Users felt more calm and safe using this service.
Added Value of the Service	Participants of GMV C-ROADS application expressed a common added value for all the services: notifications with text-to-speech could be more beneficial instead of a sound notification. Anyway, the sound alerted the user and the information provided in the HMI was enough to identify the event with a simple glance. As added value of the service, the HMI could show the distance to reach the event. Kapsch HMI provides text-to-speech capabilities. Simply touching selected event or IVS, HMI will read associated text.

Table 138 - HLN-TJA Functional evaluation. Spain. Cantabrian sub-pilot

Service	Traffic Jam Ahead
Lessons Learned	Asturias sub- pilot: The information collected by floating car data proved to be a non-intrusive and reliable data collection system for the generation of a traffic jam ahead services. As the vehicles were connected, the information was even more reliable, but it can be concluded that today it can be complementary to inductive loop systems and with a much lower maintenance cost. Bizkaia sub-pilot: The traffic jam ahead information was merged from different data sources. These data sources are the floating car data from Here, information on traffic loops from the Provincial Council of Bizkaia and also Bluetooth beacons for travel times. Merging the data required the use of a common road mapping. One lesson learned is that the sections that will later be reported on must be harmonized.
HMI*	Asturias sub- pilot: No HMI was developed within this use case. The service developed and the corresponding web services were created so that any third party can use them at their discretion. Bizkaia sub-pilot: The HMI used in all services was the same, the sub-pilot's C-Roads mobile application. A specific app was built that provided alerts about travel times, the purpose of which was very similar to the traffic jam ahead service. The information to be displayed by the HMI must be useful enough for the driver to keep it on while travelling. Therefore, navigation functionality would be recommended, since seeing the position on a map is useful. In the sub-pilot, the decision was made to integrate the HMI with the vehicle's onboard systems, in addition to ensuring the safety that notifications reach the car screen.
Quality of the Service	Asturias & Bizkaia sub- pilots: Technical evaluation determined that the Traffic Jam Ahead service functioned correctly when congestion occurred. The maximum delay time in the generation of alert was one minute from its publication in the data provider. Bizkaia Sub-pilot: One of the official providers used a category to report that a section of the road was out of data. The Traffic Jam Ahead service did not filter these cases, so numerous notifications were sent in which, in the absence of traffic congestion, an alert was sent with an Unknown Traffic message. Despite the fact that Datex II allows entering traffic status as unknown, it was found that the Traffic Jam Ahead service must previously filter them and only report when there is congestion. The Geomessaging System worked effectively, generating the relevant messages in the environment in which the user was located and limiting the number of events to be displayed.

	It should include trace information in the message, as is recommended in C-ITS messages for minimizing false positives to the driver.
Added Value of the Service	Asturias sub- pilot: The added value of the service is that it is based on a data source based on the information provided by thousands of vehicles. Based on the speed of circulation, the service levels were established and no type of installation or work was necessary to be able to provide the data. Another added value is that the service can be created for any point of the network, it is not limited by the physical characteristics of the road or by administrative boundaries. Bizkaia sub-pilot: Users felt they had increased situational awareness and of the current road information which increased a feeling of comfort. By integrating the information into the on-board system, the perception of security was greater and greater comfort was also appreciated by having the possibility of listening to the message.

Table 139 - HLN-TJA Functional evaluation. Spain. Andalusian sub-pilot

Service	HLN-TJA
Lessons Learned	Nature of the messages: In this case, and unlike the RWW use case, we did not have the opportunity to test the service with real events, so we have created "fake" events that have been sent to the vehicles on different situation. We must take into account that the ultimate goal of the pilot is to test the link between a back office and an OBU (via RSU in this specific sub-pilot) and then it is not needed to use a traffic information system in real time modus. The rest of the lessons learned from the use case RWW-LC apply to this use case.
HMI*	The same functions, issues and thoughts gathered for the RWW-LC use case in previous sections are applicable to the current use case. Below, a couple of screen captures for this specific use case are shown. Pre-warning message:  Warning Message:

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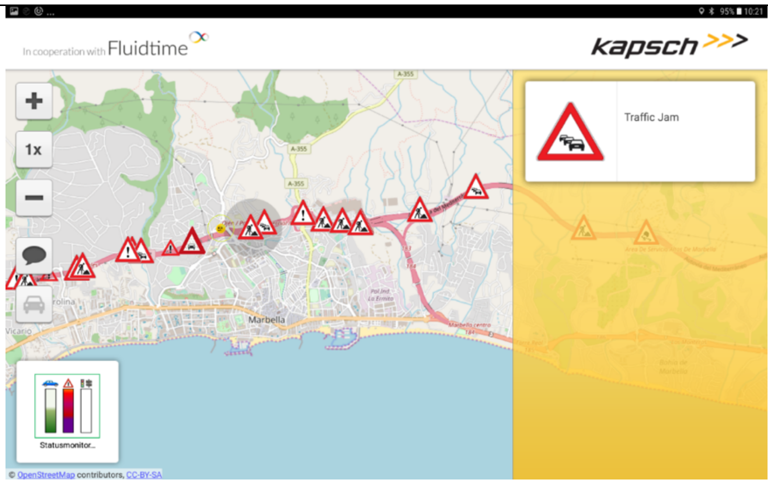
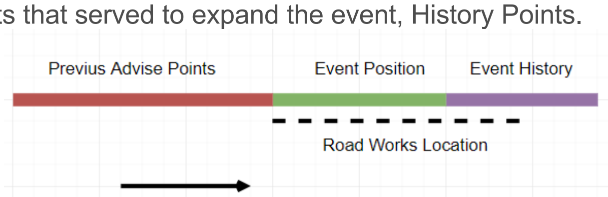
<tr><td></td><td>
</td></tr>
<tr><td>Quality of the Service</td><td>The pre-warning and warning messages just appeared on the screen of the app on the moment as loaded in the C-ITS platform. The information is available during a variable time slot that is adjusted to the length of the pre-warning and warning zones. The accuracy of the distances is the accuracy of GPS, in a radius of 15m.

Positioning and Time: The position of the vehicle and time synchronization of the system relied on the GNSS-systems, using the GPS system as the time base. The OBU includes an internal multi-constellation GNSS receiver which supported GPS, Glonass and Galileo GNSS systems. The current position, with corresponding timestamp, of the vehicle is stored in the “Facility Layer DataBase” where it could be extracted and used by both the communication stack and applications that were interfacing the facility layer of the communication stack.

Event Location: All events, and specifically each Situation Record, needed a location where the messages were active. These fields were very sensitive, and the coordinates needed to be indicated in the correct order. It is recommended to prepare and review the coordinates for an event before creating the message.
First of all, it was necessary to identify the areas where the message will be active. Including some previous warning points for drivers, known as Previous Advise, and some historical end points that served to expand the event, History Points.


The definition of each area is as follows:
Previous Advice Points: Notification points prior to the event. It was mandatory to indicate only one start and one end, but optionally, in the intermediate field, up to 22 more warning points could be indicated to drivers. The maximum distance between two coordinate points of 1.8kms and the minimum distance of 25 meters. This area was also known as “Trace”.
Event Position: It was a single point and it was used to indicate where the event was located (it doesn’t have start and end).
Event History: This last section was used to extend the position of the event or the information to the drivers. For example, as the maximum distance between two location points was 1.8kms, if the event takes place over a greater distance, as usually happens with RWW, with the History we could be extend. It had two mandatory points, one initial and one final, as well as an intermediate one that worked in the same way as in the previous notice points. If you did not want to extend the event, it waws recommended to place these points at a distance of 50 meters respectively from the end of the event position.</td></tr>
</table>

	How Event is Displayed: when a message was received, a small icon (in this use case a traffic sign) was shown on the map at the event position. If the vehicle current position was approaching the event, a window on the right side showed the information: “Roadworks ahead”. If the vehicle’s current position was inside the event the information, then it switched from “Roadworks ahead” to “Roadworks”. The window on the right side just showed if the following conditions of the message were fulfilled: The OBU calculated the heading based on the difference of the trace point that was most far away of the event position (last trace point in the list of the trace in the MESSAGE) and the event position. When the vehicle passed the trace point that was furthest away from the event position it compared the own heading with the calculated heading. If the own heading was inside a tolerance angle of +/- 25°, compared to the calculated heading, the event was shown in the right menu. Event Validity: the event remained active from the StartDateTime (when the event started) until EndDateTime (when the event ended). The validity of the message could be extended more than 24 hours. Message ID: All messages had a unique numeric identifier (ID Situation Record), which could be used to change the parameters of the message. If a message was sent with an existing ID, if the previous message with the same ID was active, then the new message replaced the first one, making the parameters of the latter effective. This functionality was very useful when reducing, extending or cancelling messages. This programming of the start and end date and time was very useful in the RWW use case since generally this type of event could be scheduled in advance. Likewise, the service as designed allowed total flexibility to shorten or extend the duration of the event according to its evolution. It also allowed the cancellation of the event. Impact - Restricted Lanes: it was possible to indicate the number of lanes affected by the incident, but it was an ineffective feature since the distance between lanes is below the error allowed by the GPS positioning (15m). Message with speed management: the operator had the option of reporting a road works with speed management, i.e. with a recommended or mandatory speed. The affected area coincides with the coordinates of the event, which limited the flexibility with which the area can be signaled, and it was proven more effective to combine it with a Dynamic Speed Limit Information (IVS-DSLI) message that allowed a greater division of the affected section.
Added Value of the Service	The HLN-TJA use case was found to be particularly useful to drivers. It allowed them to prepare for the coming events, adapting speeds and lane changing well in advance of the event. This definitively improved traffic flow and efficiency, increased safety and thus reduced fuel consumption and emissions. Most participants reported that they found the messages to be helpful as they gave the driver more time to think and increased awareness of the road conditions.

7.5.2. Czech Republic

Railway Level Crossing

There was consensus between the drivers not to inform about the crossing after it was crossed. Some of the drivers would also like to have information about recommended speed of the vehicle while approaching the crossing when the driver was informed there was a train approaching the crossing. Drivers also considered it necessary to better distinguish between crossing conditions (approaching train, open condition, etc.) Some drivers would welcome information about the surface quality of the level crossing (degree of damage). The drivers were generally satisfied with the information from the HMI. Some of them would like to omit the bottom bar with additional information.

Slow Vehicle

There were no general issues with this use-case however some drivers wanted to have a better map of the situation and also more information about stationary vehicle like color and type. The drivers also wanted to know the lane and the speed of the slow vehicle. They were also interested in the time when they came across the slow vehicle.
On one evaluation site, evaluation was performed on the highway with three lanes, with the slow vehicle driving in the slowest right lane. When overtaking a slow vehicle by the test drivers, the drivers were usually in the fastest left line and did not care what was going on in the first (slow) lane.

Emergency Vehicle Approaching

The drivers generally reacted to sirens of the emergency vehicle, the information on the HMI was the secondary source. On the other hand, this use-case was evaluated in the city. The benefits in the rural areas are even higher because the driver will see the emergency vehicle on the HMI sooner than he or she will hear the sirens.
One of the main benefits of EVA for users was the fact that on the HMI they could see exactly where the emergency vehicle is and how far it is. This was especially useful in urban areas, where the sound of the siren is often reflected from nearby houses and drivers do not know where the ambulance is and whether they should even start an evasive maneuver before seeing it.
The key factor of this use-case was to have the information on the passage of the emergency vehicle to warn the driver and to create a space for the passage.
The primary goal was to inform a driver about emergency vehicle approaching in order to increase their attention, look around and possibly create a space for the emergency vehicle.

Public Transport Vehicle Crossing

The evaluation was carried out at the place where a tram came out of the forest. Therefore, there is one big issue related to the pilot location. A DENM message arrived at an OBU in the evaluation vehicle mostly late. It was because of obstacles between the tram and the vehicle.
Drivers would like to be informed about the remaining time, until the tram crosses the tram crossing and also about the tram speed. Some drivers would welcome a larger sign of this use-case. Furthermore, drivers certainly wanted to omit the word “Now” at the moment of waiting for the tram to pass.

Public Transport Vehicle at Stop

All drivers agreed that they would like to know the remaining time for the public transport vehicle departure. There was also one issue related to the location of the public transport vehicle. The driver passed the public transport vehicle and then turned around. At one point the driver received the information about PTVS again, though he or she turned in the opposite direction. This fact seems logical, with the HMI not knowing which side the vehicle intends to drive on. No other issues were found during the PTVS evaluation.

The drivers were generally satisfied with the information from HMI. Some drivers would welcome the larger sign of this use-case. Furthermore, they do not need to display the word "Now" on the HMI while the vehicle is in bus stop.

7.5.3. Belgium/Flanders

Summary	A road operator detects a traffic jam, and sends the information to the road user (mentioning the position, the length of the traffic jam and the section/ lanes concerned if the information is available).
Desired behavior :	Well informed drivers adapting their driving behavior (e.g. reduce their approaching speed, before arriving at the end point of the traffic jam and while passing it). Precisely and correctly informed drivers also drive more cautiously or concentrated nearby the end of traffic jam area. The constant speed adaptation of single vehicles when approaching the end of queue area has also an impact on the overall traffic flow.
Display/Alert principle:	The in-vehicle information should be adapted to the relative position between the vehicle and the TJA warning positions. The display could be different according the position of the receiving vehicles or not even happen if the other vehicle is too close to the end of queue. The in-vehicle information could inform the driver that TCC-ACC is active and working according to the driver's set of preferences. The user is provided with related information, displayed on the dashboard. Layout and sequence of presentation is left to specific implementation
Functional constraints/dependencies:	The precision of the information of the end of queue from the road operator can be low depending on the systems to update them and the available information sources used by the road operator, e.g. if these are single sensor networks like loop detectors, the highest precision will be the road section length between two installed loop detectors, which would mean low quality of localization of the end of the queue. The equipped vehicles as probe data (or source of information) could enhance the quality of localization and improve awareness of drivers that are approaching the traffic jam zone. For high accuracy of this use case, a high percentage of equipped vehicles generating messages at the end of traffic jams is necessary.

Lessons Learned

The objective of this service was to warn of traffic jams ahead. The driver could then reduce their speed. This message is of high interest. Today information on traffic jams across the whole network is received via radio. This is not precise, and the driver must listen very carefully to find out if the route they are driving on is of relevance. Traffic jam information is also available via RDS-TMC, but again this is not very precise.
In the HERE app there is already a function indicating the LOS of traffic (yellow line for slow traffic and red line for congested traffic).
A basic question is when should a driver get a message. It is clear when a driver is approaching at high speed the end of a standing queue they must be warned. On the other hand when the driver approaches slow traffic and shock waves it is unclear at which point the driver should be warned.

HMI

The app provided the message traffic jam ahead. The message was given in time (1000m before the end of queue).
As already explained above the app also provided information about the LOS. It means that as a driver, from the moment you receive the warning you look at the device to see if the congestion is heavy (yellow or red) and to find out the length of the queue.

Quality of the Service

The quality of the service depends on when you receive the message (information zone) and assurance that you are warned for all events.
The information zone was 1000m before the event. In cases when the congestion is a shock wave, it was quite difficult to find out the position of the event. It also happened when driving in a shock wave that new messages for ((Traffic Jam ahead' were produced. This is of course was irrelevant. A more important problem was the detection and location of traffic jams. The end of queue is a moving stream upwards. In case of blockage of the road the speed can be up to 16km/h stream upwards. The HERE app gets info from the traffic center (using loops) and at the same time the app uses floating car data for LOS messages. The information from both services did not match quite often.

Added Value of the Service

The potential added value of this service is very high. There are in Flanders more than 70 accidents per year with trucks that drive into the back of a queue with more than 50 people killed per year.
The service could prevent these accidents.
The quality of the service must be better. The OBU knows the speed of the car. In the case the driver does not react on the warning a second message can be produced.
On this topic more research and testing is needed.

7.6. Socio-economics

The explicit assessment of socio-economic impact with respect to the individual Use Case was developed by Italy (HLN-SV and HLN-WCW), based on the impacts estimated on the KPIs on mobility. The economic values considered for this operation are reported in Table 140. Further details are available in [RD.5].

Table 140 - Monetary value of KPIs considered

KPI	Value	Unit of measure
Accidents resulting in injured or fatality	0,011	M€
Injured	0,042	M€
Fatality	1,504	M€
Value of time	20	€/hour
Cost of CO_2 Emitted	100	€/ton

Table 141 and 136 summarise the impacts on the KPI on mobility and their economic conversion for HLN-SV and HLN-WCW respectively.

Table 141 - HLN-SV - Estimated socioeconomic impacts

	KPI	Economic Impact [M€ saved]
Direct Safety Impact	-146 accidents	1,60
	-279 Injured	11,76
	-20 fatalities	30,79
Indirect Traffic Efficiency Impact	-659.471 hours in congestion	13,19
Indirect Environmental	-906 CO_2 ton	0,09
	Total	**57,44**

Table 142 - HLN-WCW - Estimated socioeconomic impacts

	KPI	Economic Impact [M€ saved]
Direct Safety Impact	-56 accidents	0,61
	-117 Injured	4,94
	-3 fatalities	4,51
Indirect Traffic Efficiency Impact	-251.613 hours in congestion	5,03
Indirect Environmental	-346 CO_2 ton	0,03
	Total	**15,12**

Furthermore, the socio-economic impact was addressed with qualitative assessment summarising the findings with respect to factors affecting safety, efficiency and environment and whether these changes are positive or negative from socio-economics viewpoint.

Impact area	Indicator	Effect	Socio-economic impact
Safety	Change in nr of accidents	Decrease for WCW	+
	Change in nr of accidents with injuries	Decrease for TJA and WCW	+
	Change in speed adaptation	Inconsistent	?
	Change in speed standard deviation	Increase for TJA Decrease for WCM	- +
	Change in average speed	Decrease for TJA, WCM	?

	Instantaneous accelerations	Inconsistent for SV Decrease for TJA Slight increase for AZ	? + 0
	Instantaneous decelerations	Inconsistent for AZ Decrease for TJA Increase for SV Decrease for WCM, EBL, APR, EVA (controlled tests)	? + - +
	Nr of lane changes	Decrease for TJA, SV, WCW	+
	Amount of time vehicles exceed speed limit	Decrease for WCW, SV	+
Efficiency	Change event time	Decrease for EVA, EBL (controlled tests) Slight increase for AZ Increase for APR	+ - -
	Travel time	Increase for WCW Inconsistent for TJA, SV Decrease for EBL	- ? +
	Number of stops and duration	Inconsistent	?
	Traffic flow	Slight decrease for SV	+
	Speed	Positive for TJA Inconsistent for WCW	+ ?
Environment	Fuel consumption and CO_2 emissions	Inconsistent Decrease for SV / WCM (indirect estimated impact based on hours saved)	?
	NO_X emissions	Decrease for WCM Increase for TJA Inconsistent for SV	+ - ?
	Pollutant emissions PM2.5	Reduction for TJA Significant reduction for WCW	+ +

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8. Signalized Intersection

8.1. Safety

This section provides a list of the signalized intersection use-cases evaluated from a safety perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, UK, Austria, Portugal, NW2, Germany, Czech Republic

8.1.1. Spain

Use Cases considered

- SI-SPTI: Signalized Intersection - Signal Phase Timing Information
- SI-ISVW: Signalized Intersection - Imminent Signal Violation Warning
- SI-EVP: Signalized Intersection - Emergency Vehicle Priority

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is safety affected by changes in driver behavior due to SI use case?

Sub Research Questions:

- How does the SI service affect the number of accidents in the use case?
- How does the SI service affect the accidents severity in the use case?
- How does the SI affect to the (safety) conduction in the use case?
- How does the SI service affect the sense of security of drivers/passengers and the workforce in the use case?

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS SI v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation have been obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 156, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 156, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 143 - SI Safety. Spain.

KPI	Service	Use Case	Pilot	Summary
Change in average speed	SI	EVP	SISCOGA Extended	Controlled tests: 11%
		SPTI	DGT 3.0 SISCOGA	-5%
			SISCOGA Extended	Naturalistic study: -12% (red-green) -21% (Green-red)
		ISVW	DGT 3.0 SISCOGA	-12%
			SISCOGA Extended	-32%
Change in instantaneous accelerations	SI	EVP	SISCOGA Extended	Controlled tests: 27%
		SPTI	DGT 3.0 SISCOGA	0%
			SISCOGA Extended	Naturalistic study: -65% (red-green) -6% (Green-red)
		ISVW	DGT 3.0 SISCOGA	-40%
			SISCOGA Extended	Naturalistic study: -98%
Change in instantaneous decelerations	SI	EVP	SISCOGA Extended	Controlled tests: -52%
		SPTI	DGT 3.0 SISCOGA	-6%
			SISCOGA Extended	Naturalistic study: -23% (red-green) -4% (Green-red)
		ISVW	DGT 3.0 SISCOGA	19%
			SISCOGA Extended	Naturalistic study: 21%

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8.1.2. UK

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

In developing the objective impact methodology within InterCor, the following key indicators were considered:

- Change in speed as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior (detailed in User Acceptance).

Area	Priority	Research questions	KPIs
Safety	+ Secondary Impact	Are drivers smoothing their passage through a junction in response to GLOSA? Also See User Acceptance RQs.	• Speed adaptation • Fewer accidents at junctions (not measured during UK Pilot)

In the UK Pilot, use of extensive subjective impact from user surveys and individual interviews and matching of individual driver objective OBU common log data measurements to subjective feedback given enabled targeted reviews of objective data for individual drivers. Based on this approach we then plotted vehicle speed before and after receiving the HMI warning around these specific events to validate the driver subjective data.
An objective impact assessment of GLOSA was carried out, analyzing objective data from individual driver data and guided by subjective impact data from User Acceptance, where specific drivers indicated a change in their driving behavior due to the information provided on the HMI.
Although this was not statistically significant, a number of drivers in their interviews indicated a change in their behavior (speed adaptation) either by following the speed advice or slowing earlier than they usually would. The evaluation team then looked at their test data from the dates and times from their controlled test events to see if a match could be found between their claimed subjective impact of the service and an objective change measured from the common log data; CAM data for speed/location, SPAT message data, and the HMI application log data to determine when the driver received the warnings and what their speed was at the point in time, and their distance to the stop line.
Note: See 0 for more details on UK Impact methodology looking at Traffic Efficiency aspects.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

Overall, more than half of the participants (61%) expressed intentions to reduce speed, with actual speed reduction after receiving Time-to-green information.
Although the main benefits of GLOSA are assumed to come from traffic efficiency (increased junction throughout) and environmental benefits (less stop/starting at junctions), there was an inherent safety benefit from drivers following the speed advice

and reducing their speed earlier on approach to a signalized intersection. Examples of objective impact examples of this claimed behavior are described below that besides having a Traffic Efficiency impact could also benefit safety, particularly with the case measured of drivers slowing earlier for red lights.
Sub Use Case: Time to Green 1 (approach Green staying Red, then Green)
Table 144 shows the speed-time-distance profile of a driver (OBU23 Experiment 9) in the Kent (Rural) GLOSA section with FTE4 data. For this section of the road the HMI was configured with a speed limit of 80 km/h, and the HMI only displayed time advice during this experiment.

Evaluation results – KPIs on Mobility

There are three observations for this experiment in terms of apparent driver behavior change;

EARLY STOP EXAMPLE (SAFETY RELATED)
Observation 1: (Secondary Safety and Environmental Impact)
The first notification was given at 232.48m from the stop line, when HMI displayed 8 seconds to turn to red. Then, it was observed in the Figure 36 that the speed behavior changed (10:05:55 – 10:06:01) after receiving a time advice during the green phase at 195m distance to the stop line. So, the approach to a red signal was smoothed during the countdown (8 seconds - GLOSA Time to Red), since there was a smaller reduction in speed. This result matched with the participant’s feedback gathered during the interviews after the pilot sessions.
“I had 7 seconds to the red, my instinct was to slow down a bit and then catch the red.”

Observation 2: (Secondary Safety and Environmental Impact)
From the transition of the phases until 7.6 seconds after the red phase started (10:06:02 - 10:06:13), the driver was reducing speed until stop at 17.55m distance before approach to the junction. It seems that there was a queue of traffic (approx. 3-4 cars) leading to this junction. Although, GLOSA Time to Green advice was less useful as the other vehicles were a constraint, the driver was decreasing speed gradually and preparing to stop.

Observation 3: (Traffic Efficiency and Safety Impact)
When the red phase finished (GLOSA Time to Green) after 24 seconds, there was a strong acceleration to regain speed after passing the junction. In addition, the participant mentioned during the interviews, that there was a possibility to accelerate to arrive at the intersection before the end of the green phase. However, this seems unlikely because the required speed to pass on green would had been 119km/h, which is beyond the legal speed limit, so the advice was useful to influence the driver stopping in this case.
“I could've put my foot down'. Chose to wait on the red- 'if I was in a hurry, I might have put my foot down”.

Table 144 - Distance to stop line GLOSA

GLOSA Service	Range distance to stop line (m)
Green phase 1	232.5 – 105.3
Red phase	92.8-17.4
Green phase 2	16.94 -10.6 (last message)

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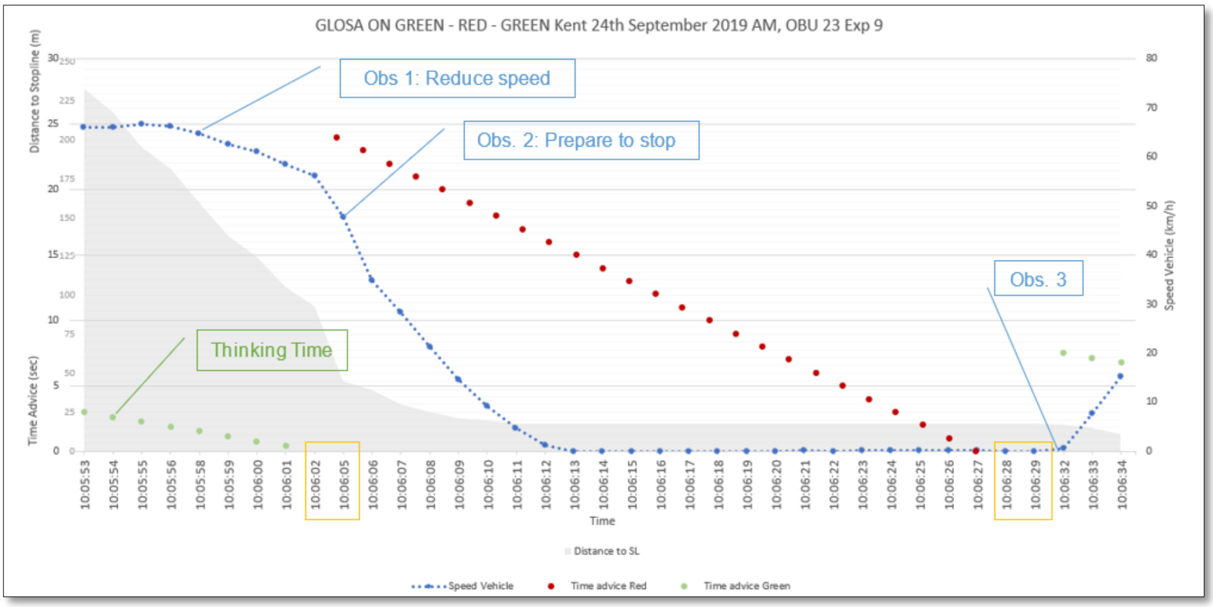


Figure 36 - Speed-time-distance profile of a driver (OBU23 Experiment 9) in the Kent (Rural) GLOSA section in FTE 4

A larger set of results would be needed from drivers following speed/countdown advice to observe if there was less was less chasing of Green signals to fully answer the sub RQs: The following safety behavioral changes were observed:

- Reduced chasing of green signals
- Reduced rapid acceleration or deceleration – more gentle decelerations / less frequent rapid accelerations / decelerations
- Less aggressive driving (increased driver comfort)

8.1.3. Czech Republic

Use Cases considered

- SI-ISV: Signalized Intersection - Imminent Signal Violation

Evaluation method

The main consideration was on the following key indicators:

- Change in speed and acceleration as per the table below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Area	**Priority**	**Research questions**	**KPIs**
Safety	++ (primary evaluation area for the pilot)	1. Do drivers slow at an earlier point after receiving road works warnings? 2. Do drivers drive in a less erratic way after receiving RWW? 3. Do the drivers comply with the advice given by the service?	• Speed adaptation • Speed standard deviation • Instantaneous acceleration and deceleration • Objective Data linked to User Acceptance Driver Interviews

The organization of the ISV use case and the preparation of the tests were very difficult. As it was a real simulation of the vehicle going red at a closed intersection in the city of Brno, there was a need for cooperation with police forces and other authorities during closures. For these reasons, it was not possible to carry out the evaluation on a larger scale and with a larger number of drivers. The comparison method of two-vehicle passes with and without C-ITS was impossible to perform due to time and organizational constraints. For this reason, great emphasis was also placed on the user acceptance part of the evaluation, where drivers expressed their subjective feedback on the execution and display of the report and whether its impact is rather positive or negative.
In assessing the effect of C-ITS on the driver's behavior, the driver's behavior before receiving the message and then his behavior after the message was displayed were taken into account. In this way, it was compared whether the driver changed their behavior after receiving the message and whether they adjusted their speed to adapt to the situation.

Data collected

The data used for the impact assessment was gathered with a logging device capturing communication between vehicle and infrastructure. One logging device (OBU Comsignia ITS OB4) was placed inside the testing vehicle during the testing, logging real-time communication simultaneously. The route was also logged via GPS data logger in case of data loss as a backup option. This situation did not occur and the data from the OBU communication was used for reasons of better sampling frequency. An OBD2 can bus logging device was also used to record the data from the vehicle. However, the data from this recording unit was not used due to the incompatibility of the protocols with the car.

Evaluation results – Field tests

The Impact assessment was evaluated for the Safety impact area of the ISV use-case. The evaluation was performed in one pass of the vehicle and the impact of the DENM message on the driver was evaluated. The evaluation of the ISV in terms of speed reduction was not found to be the expected result. The average speed and maximum drivers were higher after receiving and displaying the ISV message (28,98 Km/h vs 31.36 Km/h), while the minimum speed remained the same. This may be due to the evasive maneuver of the vehicle that received the ISV warning message or even the driver's estimate that the vehicles will not cross each other. The average acceleration recorded during the evaluation was generally closer to zero (0.98 m/s^2 vs 0.57 m/s^2) after the driver received and displayed the ISV message, as well as with the minimum and maximum acceleration in the measured section. After receiving the message, drivers had a greater tendency to brake.

8.1.4. Germany

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

The Use Case was evaluated in a field test study at the pilot site Hessen in the city of Heusenstamm.
Effects on driver distraction with real GLOSA information visible on an HMI during a test drive were analyzed. The study was based on a user acceptance questionnaire (subjective) and an eye-tracking device (objective).

Data collected

A questionnaire was used to capture the thoughts and impressions of the pilot participants. The glance directions and durations were captured by a special eye-tracking device. A video camera was used to support the evaluation. The driving speeds were measured based on a GPS logger.

Evaluation results – Field tests

An additional focus of the study was to analyze the effects and experience of using the GLOSA service. For this purpose, two groups of test participants were chosen. One group was familiar with the service and one group used the service for the first time.
It could be evaluated that the GLOSA service did not have a significant distraction level that could lead to safety issues while driving. While the number and duration of glances on the GLOSA service, compared to a navigation service, was significantly higher for the inexperienced user group, the group familiar with the service had almost equal values for these indicators. The subjective responses of the testers could be compared to the objectively evaluated glances for a better understanding of the testers' impressions.
The evaluation of the driving speed can be further improved as a clear lesson learned from this project. The overall evaluation showed that driving speeds could be reduced by using the GLOSA service, which is a positive result for safe driving on urban roads. But in some cases, also a recommendation for speeding up to the allowed speed limit was provided to approach the green traffic lights in time. To better evaluate these effects, a further differentiation in the analysis and evaluation of the speed logging would be helpful to distinguish between desired decelerations and accelerations and the corresponding speed levels.

Evaluation results – KPIs on Mobility

No dedicated KPIs on Mobility were computed.

8.1.5. Summary

Evaluation results – Field tests

The main results regarding the impact area Safety related to the Service RWW are referred to the analysis of speed and accelerations/decelerations, elements considered by all the Countries.

The **Spanish pilot** considered a wide range of KPIs, reporting different observations across the Use Cases considered:

- There was a reduction in the average speed during the implementation in SPTI benefit: -21% in the best case) and ISVW (Benefit: -32% best case). On the other hand, there was an increase in the service EVP (Benefit: 11%). The hypothesis for this last service has been edited in order to adapt its meaning to the emergency situation. An increase was expected.
- Change in instantaneous accelerations: The number of times that the vehicles accelerated harshly was reduced in the service SI-SPTI (Benefit: -65% best case) and SI-ISVW (Benefit -98% best case). There was an increase in EVP use case
- Change in instantaneous decelerations: the number of times that the vehicles braked harshly was reduced in the services EVP (Benefit: -52%) and SPTI (benefit: -23% best case). There was an increase in the service ISVW as expected (Benefit: 21% best case). The service asks the drivers to stop because the traffic light is in red, the hypothesis is edited in this sense.

In the **UK** an objective impact assessment of GLOSA was carried out, analyzing objective data from individual driver data. Key results for GLOSA showed examples of drivers slowing following advice on Time to Red and also maintaining speed based on the speed advice given .

In the **CZ** the evaluation of the ISV in terms of speed reduction was not found to be the expected result. The average and maximum speed were higher after receiving and displaying the ISV message, while the minimum speed remained the same.

In the **UK** feedback about safety impacts of the SI service were also collected through interviews to the users. Specific drivers indicated a change in their driving behavior due to the information provided on the HMI. Although this is not statistically significant, a number of drivers in their interviews indicated a change in their behavior (speed adaptation) either by following the speed advice or slowing earlier than they usually would. The evaluation team then validated the test data from the dates and times from their controlled test events to see if a match could be found between their claimed subjective impact of the service and an objective change measured from the common log data.

8.2. Traffic Efficiency

This section provides a list of the signalized intersection use-cases evaluated from a traffic efficiency perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: France, Spain, UK, Austria, Portugal, NW2

8.2.1. Spain

Use Cases considered

- SI-SPTI: Signalized Intersection - Signal Phase Timing Information
- SI-ISVW: Signalized Intersection - Imminent Signal Violation Warning
- SI-EVP: Signalized Intersection - Emergency Vehicle Priority

Evaluation method

Depending on the use case, the mentioned impact investigation safety area led to different questions/sub-questions:
Main Research Question:

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

Sub Research Questions:

- How does the SI service affect to the journey time in the use case?
- How does the SI service affect to the traffic flow in the use case?
- How does the SI service affect to the speed in the use case?
- How does the SI service affect the traffic light approaching in the use case?

Refer to Final Report of Spain [RD.3] for more details of evaluation methods and the list of KPIs. There is a summary table in Annex 2 - C-Roads Spain FESTA Methodology_v1.6.

Data collected

Refer to chapter 5.1.1.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS SI v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Results from the evaluation of signalized intersection use-cases are summarized in Table 145.

Table 145 - SI Traffic Efficiency. Spain.

KPI	Area	Service	Use Case	Pilot	Summary
Change in the event time		SI	EVP	SISCOGA Extended	Controlled tests: 9%
			SPTI	DGT 3.0 SISCOGA	-8%
				SISCOGA Extended	Naturalistic study: -6% (red-green) 1% (green-red)
			ISVW	DGT 3.0 SISCOGA	99%
				SISCOGA Extended	41%
Change in the number of stops	Traffic Efficiency	SI	ISVW	DGT 3.0 SISCOGA	109%
				SISCOGA Extended	Naturalistic study: 54%

8.2.2. UK

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

Evaluation	Impact Evaluation
Service	GLOSA
Research Question(s) or Use Cases evaluated.	GLOSA use case 1: Time to Green / Time to Red, was evaluated according to the following in line with the agreed Common Methodology.: Indicator Description: • Difference in speed profile between triggering the GLOSA notification and stopping or passing the stop-line [i.e. GLOSA Drivers adapt their speed approaching a red or green light] • Change in speed profile moving off from a red light [i.e. GLOSA vehicles should be closer to their intended final speed in a shorter time] • Smoother driving - adapted driving as a result of the advice. Measurement method: *Comparison of subjective impact from user acceptance with any objective impact for specific drivers from Controlled Tests (FTEs).*

An objective impact assessment of GLOSA was carried out, analyzing objective data from individual driver data and guided by subjective impact data from User Acceptance, where specific drivers indicated a change in their driving behavior due to the information provided on the HMI.
Although this is not statistically significant, a number of drivers in their interviews indicated a change in their behavior (speed adaptation) either by following the speed advice or slowing earlier than they usually would. The evaluation team then looked at their test data from the dates and times from their controlled test events to see if a match could be found between their claimed subjective impact of the service and an objective change measured from the common log data; CAM data for speed/location, SPAT message data, and the HMI application log data to determine when the driver received the warnings and what their speed was at the point in time, and their distance to the stop line.

Data collected

This was fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

A significant percentage of drivers armed with advanced information about traffic lights say they will adjust their speed accordingly; they feel more at ease driving and be more likely to take a smoother passage through the junction.

Many participants found it useful to have the knowledge about when the light will change, especially when you are joining a queue. This prepares you more as a driver and you are more ready to go when the light changes (i.e. having your foot on the pedal at the right time). This is a traffic efficiency benefit to aid more vehicles getting through on a green, especially for shorter green cycles.
The majority of participants suggested that GLOSA can be useful in improving traffic flow and junction capacity as it keeps the momentum of the traffic and prevents the chance of tailbacks.
The majority of participants agreed that GLOSA would be particularly useful and readily accepted by HGV drivers as it would help them avoid stopping at junctions.

Evaluation results – KPIs on Mobility

Following speed advice given could increase junction throughput and this is discussed further in section this section for measured effects of the GLOSA service.

Sub Use Case: Time to Red

Time to Red 1 (approach Green staying Green)

Figure 37 shows the speed-time-distance profile of a participant (OBU23 Experiment 15) in the Kent (Rural) GLOSA section with FTE4 data. For this section of the road the HMI was configured with a speed limit of 80 km/h. During the whole experiment, GLOSA Time to Red, HMI displayed time advice and speed advice.

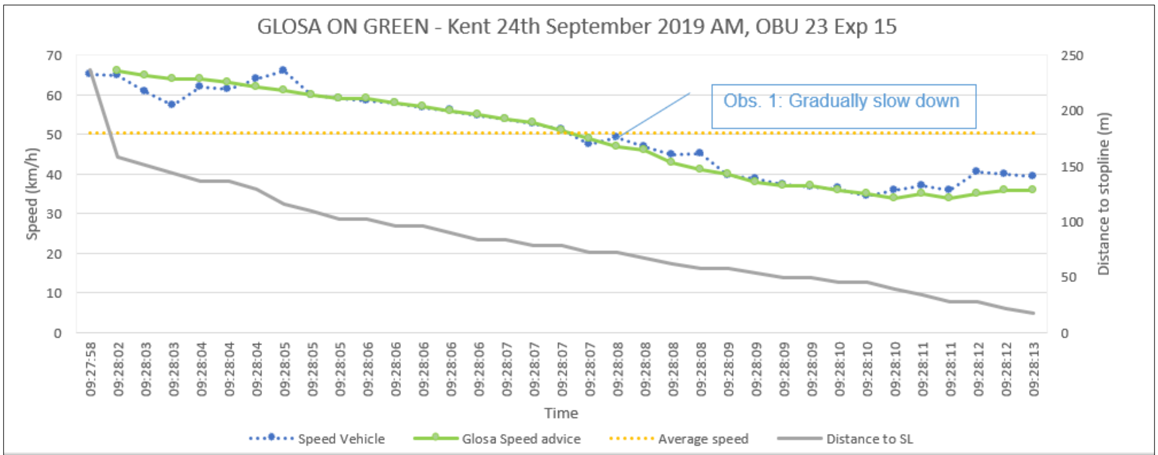


Figure 37 - Speed-time-distance profile of a participant (OBU23 Experiment 15) in the Kent (Rural) GLOSA section in FTE 4

Observation 1: (Traffic Efficiency with Secondary Safety and Environmental Impact)
As it can be seen the speed wasn't maintained on approach to a green signal, so there was a change in the behavior of this participant. The speed of the vehicle was gradually decreased, and the vehicle arrived at the intersection 9 seconds before the signal turned to red. So, following the logic of the speed advice service (i.e. programmed system behavior), it can be observed that the HMI was replicating the speed of the vehicle. Therefore, no actual speed advice was given, but the participant smoothed their passage through this junction, likely in response to a GLOSA time to Red countdown, **feeling secure they didn't need to speed to make the green.**

Time to Red 2 (approach Green staying Green)

Figure 38 below, shows the speed-time-distance profile of a driver (OBU19 Experiment 6) in the Kent (Rural) GLOSA section with FTE4 data. For this section of the road the HMI was configured with a speed limit of 80 km/h. During the whole experiment, GLOSA time to Red, HMI displayed time advice and speed advice.

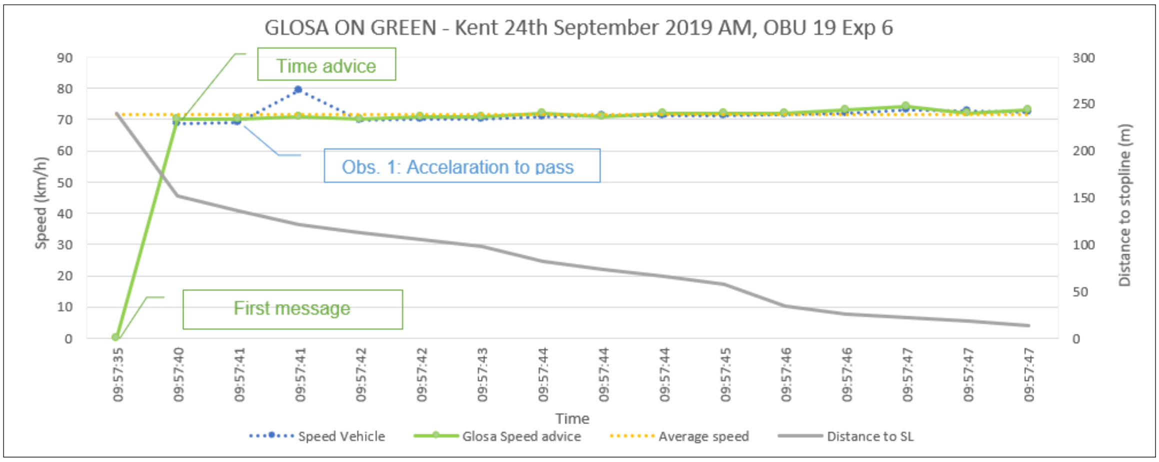


Figure 38 - Speed-time-distance profile of a driver (OBU19 Experiment 6) in the Kent (Rural) GLOSA section in FTE 4

Observation 1 (Traffic efficiency):

It can be observed that the speed behavior changed (09:57:40.7 – 09:57:41.9) after receiving a time advice during the green phase at 151m distance to the stop line. So, the vehicle slightly increased the current speed at its approach to a red signal during the countdown (20 secs).

In this case, speed advice was replicating the speed of the vehicle.

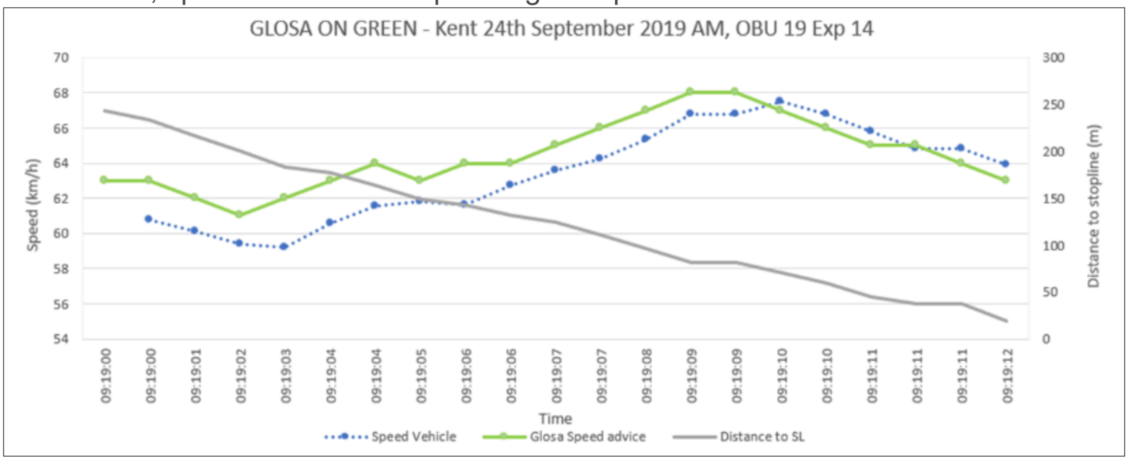


Figure 39 - Speed profiles from experiment 10 and 14 in FTE 4

This participant arrived at the intersection before the end of the green phase. In Figure 38, two other examples have been illustrated (Experiments 10 and 14) the same behavior (speeding up) was observed, Figure 39. The participant followed the speed advice as it was indicated, but never beyond the legal speed limit.

This result matched with participant's feedback gathered during the interviews after the pilot sessions with respect to speed advice.

"I would say it influenced it a little bit… 'when I knew it was on green, I did speed up to try and get there'- speed up a couple of times 'not manically..."

Although maintaining / following speed advice has the potential to increase traffic efficiency, a larger set of results would be needed from drivers following speed advice to

observe if there the following sub RQs are consistently met through modified driver behavior.
The following traffic efficiency benefits could be achieved:

- Smoother vehicle flow through the signalized junction
- Secondary benefits from links to Traffic Signal Optimization (i.e. optimization to maximize throughput for vehicles using GLOSA) where this optimization is implemented (traffic modelling required using GLOSA behavioral parameters as inputs).

8.2.3. Hungary

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Data collected

The control case and the GLOSA test case were compared based on five performance indicators:

- Total Travel Time: the total time elapsed from reaching the start of the test road segment to the end
- Average Speed: the total length of the test road segment divided by the Total Travel Time
- Number of Stops: the number of times when the vehicle stopped during a run (with the recorded speed indicating 0)
- Total Waiting Time: the total time elapsed while the vehicle's speed was 0 during a run
- Average Waiting Time: the average duration of one stop

All of these measures were in connection with traffic efficiency. None should be viewed as a sole indicator of how efficient GLOSA services are, the results have to be evaluated as a whole.

Evaluation results – Field tests

Apart from the average speed, all indicators are desirable to have a lower value whilst receiving GLOSA messages. The environmental aspects appear indirectly in the number of stops and the total travel time. Although a direct measurement of emissions and fuel consumption was not carried out, as the general results are in line with other similar studies, the following impacts can be assumed using GLOSA services:

- 3-7% fuel reduction when approaching an intersection
- 5% reduction in CO_2 emissions
- 2% reduction in HC emissions
- 2% reduction in NO_x emissions

The evaluation results for each measured performance indicator are depicted in Table 146. The average values are shown for the control vehicle (without GLOSA) and the test vehicle (with GLOSA). The difference in measurements using GLOSA services can be found in the last column in percentage.

Table 146 - Average test results with/without GLOSA (Hungary)

Performance indicators	w/wo GLOSA	Average	Difference with GLOSA
Total Travel Time (sec)	with	314.67	0.39%
	without	313.44	
Average Speed (km/h)	with	32.26	-0.39%
	without	32.39	
Number of Stops	with	2.11	-20.83%
	without	2.67	
Total Waiting Time (sec)	with	57.22	-10.43%
	without	63.89	
Average Waiting Time (sec)	with	27.11	13.14%
	without	23.96	

Receiving GLOSA messages did not have a substantial effect on the total travel time and the average speed, which can be a result of the traffic conditions, constraining the application of the advised speed. However, there was a considerable improvement in the number of stops (more than 20% reduction) and the total waiting time (more than 10% reduction). The average waiting time increased by 13%, which alone is a less desirable outcome. Although, taking into consideration the decrease in the total waiting time and the number of stops, the explanation is that the vehicle using GLOSA services only stops when it is unavoidable (often when arriving at an intersection at the beginning of a red phase). In this way, the duration of an average stop increases without effecting the efficiency of the journey.

Despite the test results showing the basic traffic efficiency measures (total travel time and average speed) to stagnate, the GLOSA services clearly contribute to a smoother traffic flow and also have a positive impact on the environment. The positive effects derive mainly from a decrease in the number of stops, resulting in a reduced need for braking and acceleration.

To present the possibilities of the GLOSA services, Figure 40depicts the trajectories of the test and control vehicles inserted into the signal schedule of the 10-intersection test road segment. This specific measurement was recorded during peak hours. Following the tracks of the vehicles, 2 more stops can be noticed in the control case: at the 2nd and 8th intersection (and one after the last intersection, but within the measurement boundaries). Moreover, in the middle of the test road segment, just before 6th intersection, the trajectory of the vehicle using GLOSA services is much smoother than that of the control vehicle, resulting in decreased waiting time.

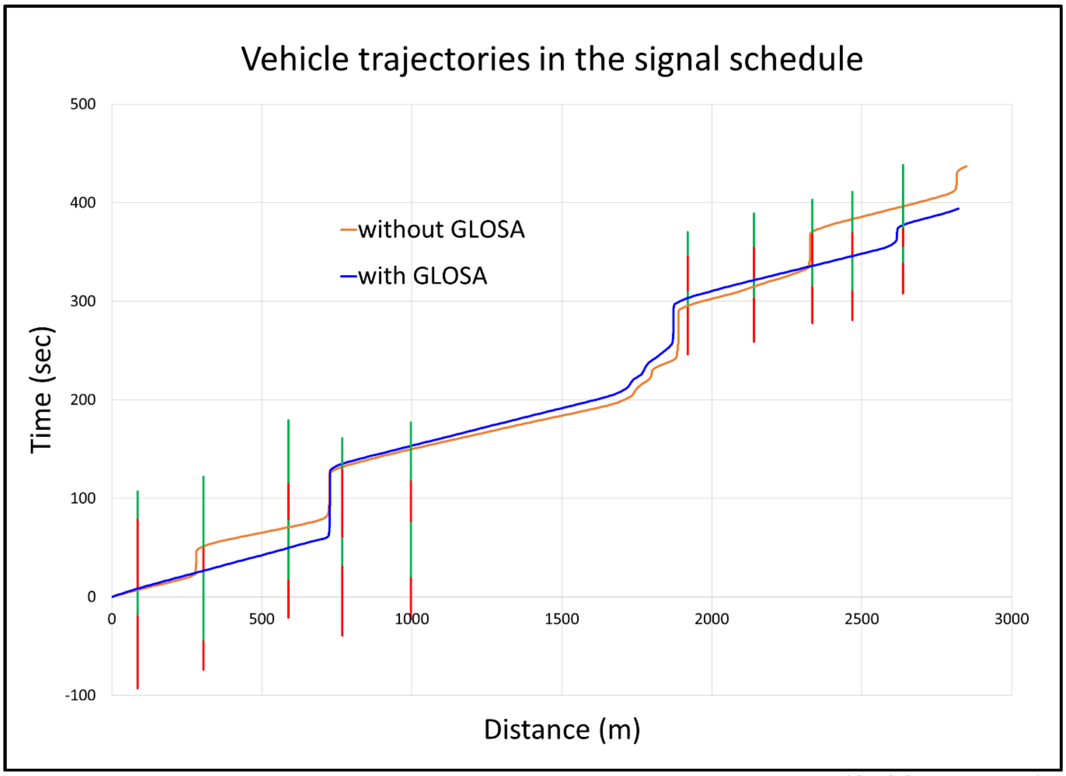


Figure 40 - Vehicle trajectories and signal schedule in a time-space diagram (GLOSA, Hungary)

8.2.4. Italy

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor
- SI-SPTI: Signalized Intersection - Signal Phase Timing Information

Evaluation method

The evaluation was performed using modelling tools (micro-simulation models), aimed at simulating the operation of GLOSA on the real case studies of the implementations foreseen in C-Roads Italy 2.
All the single approaches of intersections present in the cities involved in the Project and affected by the implementation of the GLOSA/SPTI services were characterized and classified/clustered according to the following attributes:

- number of lanes and presence (or not) of lanes dedicated to specific maneuvers
- presence of unique or dedicated traffic light phases
- level of traffic, traffic flow composition and presence (or not) of flows in opposition to the approach
- duration of the traffic light cycle and green ratio
- activation zone length of GLOSA
- different potential market penetrations of C-ITS-equipped vehicles

Specific simulations were performed for each of the different types of approaches previously determined and potential GLOSA impacts were estimated for each type.
The effect of GLOSA was simulated by creating a special category of vehicles able to adapt their speed based on a recommended speed calculated by an algorithm embedded in the simulation program.
The used algorithm calculates the optimal speeds without considering the presence of queues and/or stopped vehicles between the vehicle receiving the message and the traffic light: it can be a realistic scenario of GLOSA operation in a short and medium-term horizon, when there will still be no integration of functionalities to allow vehicles to receive a precise estimate of the number of other vehicles between its position and the intersection.
In the simulations, all users traveling in GLOSA-equipped vehicles adapt their speed to the recommended speed calculated by the algorithm.
Finally, the results obtained through the simulations for each individual intersection approach were re-aggregated by whole intersection and by entire city, assessing the effects of GLOSA for all planned implementations.

Data collected

For each simulation carried out, the following types of output results were defined and obtained:

- *Queue length*: average length of the queue upstream of the signal during the simulation period
- *Maximum queue length*: maximum length reached by the queue upstream of the signal during the simulation period
- *Average delay*: average delay experienced by vehicles to cross the intersection. The area considered for the intersection began 300 meters before the signal and extended for 50 meters beyond the end of the intersection, to consider also any time lost to return to the desired speed after crossing the intersection

* *Stopped average delay*: it was a subpart of the average delay, represented by the accumulated delay in stationary or semi-stationary conditions (into the queue)
* *Average number of stops*: average number of times vehicles stop while crossing the intersection area
* *Average fuel consumption*: the average fuel consumption to cross the intersection area

Evaluation results – Field tests

Two main types of results were obtained:

* the first type of results consisted of a set of theoretical results, which highlighted how the impacts and consequent benefits of GLOSA are a function of additional attributes that characterize the approaches to traffic light intersections. Examples of these attributes are the vehicular flow, the distance of reception of the messages, the duration of the traffic light cycle and the market penetration
* the second category reports the results referring to the GLOSA/SPTI implementations planned in the cities involved in the C-Roads Italy 2 project, providing an assessment of the impacts for the intersections that will be equipped with the service and for the overall installations planned in the cities

Theoretical results: sensitivity of the impacts with respect to the main attributes

This method allowed a sensitivity analysis of the results with respect to the variation of the attribute considered.
The most significant result emerged in the evaluation of the Influence of GLOSA, tested for one- and two-lane approaches.
The geometric and functional attributes considered in the two evaluated scenarios are described in the following table:

Table 147 - Geometric and functional attributes considered for GLOSA and SPTI

Parameters	1-lane scenario	2-lanes scenario
traffic light phase	non-differentiated	
flows in opposition	no	
market penetration	25%	
flow	500 veh/h	1.000 veh/h
cycle duration	100 sec	
green/cycle ratio	0,5	
receiving distance	50 m, 100 m, 200 m, 300 m, 400 m	

The following table reports the percentage variation of the main traffic efficiency performance indicators for different reception distances. The changes are presented with respect to the NO GLOSA scenario (Market Penetration = 0%).

Table 148 - Percentage variations of KPIs for different reception distances - 1 lane scenario

Distance (m)	Total		Single Vehicle (average)		
	Queue length	Queue length Max	Stops	Vehicle Delay	Stop Delay

Co-financed by the Connecting Europe Facility of the European Union

50	-1,3%	-5,7%	1,8%	0,6%	-1,7%
100	-4,1%	-4,6%	8,8%	-3,3%	-5,6%
200	-42,8%	-7,4%	-10,5%	-13,4%	-53,7%
300	-43,6%	-4,5%	-14%	-14,4%	-55,3%
400	-43,7%	-5,4%	-14%	-17,2%	-63%

Table 149 - Percentage variations of KPIs for different reception distances - 2 lane scenario

Distance (m)	Total		Single Vehicle (average)		
	Queue length	Queue length Max	Stops	Vehicle Delay	Stop Delay
50	-8,0%	-13,8%	-3,4%	-3,2%	-3%
100	-6,9%	-13,1%	1,7%	-6,8%	-6,7%
200	-27,3%	-13,6%	-10,3%	-15,9%	-37,7%
300	-28,8%	-13,4%	-12,1%	-16,6%	-38,3%
400	-30,6%	-12%	-12,1%	-18,4%	-40,2%

In both scenarios the greatest benefits were obtained from 200 meters upwards, while reception distances of 50 and 100 meters do not provide meaningful benefits, as the space available for vehicles to adapt the speed was rather small. Above 200 meters, the benefits increase slightly with the increasing distance.

Impact of GLOSA implementations planned in C-Roads Italy 2

Thanks to the application of the evaluation methodology, it was possible to estimate the overall impacts of the planned implementations of the GLOSA/SPTI services in the different cities involved in the C-Roads Italy 2 project.
For each individual intersection (and for the collection of all intersections of the city) the values of two main traffic efficiency indicators were obtained:

- the **average length of the queue** upstream of the traffic lights recorded during the simulation period, multiplied by the value of the traffic flow that uses the intersection. This value represents the total amount of queuing meters experienced by all users as a whole passing through the intersection
- the **average delay** experienced by the vehicles to cross the intersection, multiplied by the value of the traffic flow that uses the intersection itself. This value represented the total amount of seconds of delay experienced by all users as a whole passing through the intersection

Below are the results obtained for the city of Trento. For this city, the 12 intersections involved by the planned implementation of GLOSA/SPTI applications were all located along one of the main access roads to the urban center.
Nine of the twelve traffic light systems were dedicated exclusively to pedestrian and/or bicycle crossings along the above-mentioned road axis (and therefore are not located at real intersections).
For the scenario without GLOSA the absolute values of these indicators are presented, while for the different simulated market penetrations (MP) the percentage variation with respect to the NO GLOSA scenario is reported, both in absolute terms and in percentage terms.

Queue length

		Queue lenght (meters) * number of users							
		abs. value	var. % (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	2.893	-5,5%	-11,0%	-17,9%	-35,2%	-51,7%	-74,5%	-95,9%
B - 42	Via Bolzano - bivio Spini	77.724	-7,3%	-9,0%	-24,7%	-38,6%	-51,3%	-62,6%	-69,5%
C - 41	Via Bolzano - bivio Meano	7.844	-1,5%	-16,2%	-23,8%	-36,5%	-65,9%	-78,1%	-95,6%
D - 133	Gardolo - via Bolzano - via Noce	5.679	-5,4%	-9,0%	-19,7%	-34,7%	-55,7%	-73,8%	-92,6%
E - 132	Gardolo - via Bolzano (case Itea)	5.678	-5,4%	-9,0%	-19,5%	-34,3%	-55,7%	-73,6%	-92,5%
F - 37	Via Brennero - Bren Center	4.619	-3,7%	-7,3%	-16,5%	-32,2%	-40,6%	-49,3%	-72,4%
G - 100	Via Brennero - Mediaworld	4.652	-6,4%	-10,0%	-16,0%	-31,7%	-54,8%	-72,2%	-92,7%
H - 111	Via Brennero - Tridente	2.876	-2,5%	-7,1%	-7,9%	-15,6%	-18,3%	-13,4%	-37,4%
I - 31	Via Brennero - via Marconi	51.888	-6,9%	-6,9%	-6,7%	-4,1%	-8,9%	-9,5%	-16,2%
L - 35	Via Brennero - Fornaci	3.413	-15,8%	-23,3%	-34,3%	-44,3%	-53,2%	-58,6%	-64,2%
M - 1	Via Ambrosi - via Brennero	2.272	-13,0%	-15,9%	-24,3%	-32,0%	-38,1%	-43,4%	-49,3%
N - 126	Via Ambrosi - Piazza Centa	2.027	-2,9%	-10,0%	-11,8%	-21,2%	-27,5%	-46,5%	-55,8%
Total		**171.565**	**-6,7%**	**-9,1%**	**-18,1%**	**-26,8%**	**-38,3%**	**-46,7%**	**-56,2%**

		Queue lenght (meters) * number of users							
		abs. value	var. % (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	2.893	-5,5%	-11,0%	-17,9%	-35,2%	-51,7%	-74,5%	-95,9%
B - 42	Via Bolzano - bivio Spini	77.724	-7,3%	-9,0%	-24,7%	-38,6%	-51,3%	-62,6%	-69,5%
C - 41	Via Bolzano - bivio Meano	7.844	-1,5%	-16,2%	-23,8%	-36,5%	-65,9%	-78,1%	-95,6%
D - 133	Gardolo - via Bolzano - via Noce	5.679	-5,4%	-9,0%	-19,7%	-34,7%	-55,7%	-73,8%	-92,6%
E - 132	Gardolo - via Bolzano (case Itea)	5.678	-5,4%	-9,0%	-19,5%	-34,3%	-55,7%	-73,6%	-92,5%
F - 37	Via Brennero - Bren Center	4.619	-3,7%	-7,3%	-16,5%	-32,2%	-40,6%	-49,3%	-72,4%
G - 100	Via Brennero - Mediaworld	4.652	-6,4%	-10,0%	-16,0%	-31,7%	-54,8%	-72,2%	-92,7%
H - 111	Via Brennero - Tridente	2.876	-2,5%	-7,1%	-7,9%	-15,6%	-18,3%	-13,4%	-37,4%
I - 31	Via Brennero - via Marconi	51.888	-6,9%	-6,9%	-6,7%	-4,1%	-8,9%	-9,5%	-16,2%
L - 35	Via Brennero - Fornaci	3.413	-15,8%	-23,3%	-34,3%	-44,3%	-53,2%	-58,6%	-64,2%
M - 1	Via Ambrosi - via Brennero	2.272	-13,0%	-15,9%	-24,3%	-32,0%	-38,1%	-43,4%	-49,3%
N - 126	Via Ambrosi - Piazza Centa	2.027	-2,9%	-10,0%	-11,8%	-21,2%	-27,5%	-46,5%	-55,8%
Total		**171.565**	**-6,7%**	**-9,1%**	**-18,1%**	**-26,8%**	**-38,3%**	**-46,7%**	**-56,2%**

In all simulated scenarios there was an overall decrease in queue length between -6.7% (in case of MP = 5%) and -56.2% (in case of MP = 100%). In absolute terms, the benefit was more evident for the real traffic light intersections (Via Bolzano - Bivio Spini and via Brennero - via Marconi) compared to the traffic lights serving pedestrian and cycle crossings.

Delay

		Average vehicle delay (sec.) * number of users							
		abs. value	abs. variation (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	3.580	-60	-120	-339	-758	-1.237	-1.716	-1.217
B - 42	Via Bolzano - bivio Spini	66.228	-2.511	-2.760	-7.011	-11.958	-17.581	-26.928	-35.600
C - 41	Via Bolzano - bivio Meano	6.690	-30	-525	-854	-1.214	-2.324	-2.784	-3.994
D - 133	Gardolo - via Bolzano - via Noce	5.700	-251	-368	-721	-1.088	-1.858	-2.462	-3.063
E - 132	Gardolo - via Bolzano (case Itea)	5.700	-246	-364	-713	-1.078	-1.859	-2.455	-3.054
F - 37	Via Brennero - Bren Center	4.998	-252	-335	-556	-862	-1.152	-1.373	-2.109
G - 100	Via Brennero - Mediaworld	4.903	-186	-307	-515	-902	-1.604	-2.137	-2.742
H - 111	Via Brennero - Tridente	3.648	-116	-208	-189	-369	-442	-404	-873
I - 31	Via Brennero - via Marconi	51.251	-3.418	-3.509	-2.518	-4.989	-8.539	-10.948	-15.334
L - 35	Via Brennero - Fornaci	3.824	-33	-144	-261	-286	-447	-629	-782
M - 1	Via Ambrosi - via Brennero	2.888	-91	-55	-92	10	-98	-292	-372
N - 126	Via Ambrosi - Piazza Centa	9.736	-39	-277	-371	-519	-599	-998	-1.155
Total		**169.144**	**-7.233**	**-8.973**	**-14.141**	**-24.013**	**-37.741**	**-53.125**	**-70.295**

		Average vehicle delay (sec.) * number of users							
		abs. value	var. % (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	3.580	-1,7%	-3,3%	-9,5%	-21,2%	-34,6%	-47,9%	-34,0%
B - 42	Via Bolzano - bivio Spini	66.228	-3,8%	-4,2%	-10,6%	-18,1%	-26,5%	-40,7%	-53,8%
C - 41	Via Bolzano - bivio Meano	6.690	-0,4%	-7,8%	-12,8%	-18,1%	-34,7%	-41,6%	-59,7%
D - 133	Gardolo - via Bolzano - via Noce	5.700	-4,4%	-6,5%	-12,7%	-19,1%	-32,6%	-43,2%	-53,7%
E - 132	Gardolo - via Bolzano (case Itea)	5.700	-4,3%	-6,4%	-12,5%	-18,9%	-32,6%	-43,1%	-53,6%
F - 37	Via Brennero - Bren Center	4.998	-5,0%	-6,7%	-11,1%	-17,3%	-23,1%	-27,5%	-42,2%
G - 100	Via Brennero - Mediaworld	4.903	-3,8%	-6,3%	-10,5%	-18,4%	-32,7%	-43,6%	-55,9%
H - 111	Via Brennero - Tridente	3.648	-3,2%	-5,7%	-5,2%	-10,1%	-12,1%	-11,1%	-23,9%
I - 31	Via Brennero - via Marconi	51.251	-6,7%	-6,8%	-4,9%	-9,7%	-16,7%	-21,4%	-29,9%
L - 35	Via Brennero - Fornaci	3.824	-0,9%	-3,8%	-6,8%	-7,5%	-11,7%	-16,4%	-20,4%
M - 1	Via Ambrosi - via Brennero	2.888	-3,1%	-1,9%	-3,2%	0,4%	-3,4%	-10,1%	-12,9%
N - 126	Via Ambrosi - Piazza Centa	9.736	-0,4%	-2,8%	-3,8%	-5,3%	-6,2%	-10,2%	-11,9%
Total		**169.144**	**-4,3%**	**-5,3%**	**-8,4%**	**-14,2%**	**-22,3%**	**-31,4%**	**-41,6%**

In all the simulated scenarios there was an overall decrease in the delay accumulated by the vehicles between -4.3% (in case of MP = 5%) and -41.6% (in case of MP = 100%). Also in this case the benefit in absolute terms was more evident for the real traffic light intersections (Via Bolzano - Bivio Spini and via Brennero - via Marconi) compared to the traffic lights serving pedestrian and cycle crossings.

8.2.5. France

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

The key research questions identified for the GLOSA use case were the following:

- What is the impact on traffic and environmental efficiency due to C-ITS services in the vicinity of an urban intersection?
- How does the driving behavior change after reception of a message?
- Does the C-ITS service affect the number of stops?
- Does the impact improve with increasing market penetration of C-ITS services?
- What is the minimum required market penetration rate required to significantly affect KPI?
- What is the optimal (recommended) notification distance?

The database has been generated from European project, C-TheDifference, and the Coopits smartphone application from C-ROADS project, thanks to several Field Operational Tests (FOT) covering the metropolitan area of Bordeaux. The database was analyzed to obtain the response behavior (response rate, response time, speed compliance, etc.) of the connected driver. The observed behavior was then incorporated in an integrated traffic and telecom simulator (SUMO + ARTERY), where a similar GLOSA logic was incorporated and scaling-up was done to observe the impacts for different scenarios of market penetrations of connected vehicles, traffic, signal and road geometry. A full-factorial experiment was designed to investigate the effect of different factors, that included:

- traffic factors, viz., demand (in terms of degree of saturation): [0.50; 0.75; 0.90],
- market penetration rate (%): [0; 10; 30; 50; 75; 100],
- road and control factors, viz.:
  - – number of lanes: [1; 2],
  - – cycle length (s): [60; 90],
- a factor related to operation of GLOSA, viz., activation distance (m): [300; 500; 1000].

The key performance indicators selected for the analysis included average stopped delay and average number of stops per vehicle (traffic efficiency), and average CO_2 and NO_x emissions per vehicle-km travelled (environmental efficiency).

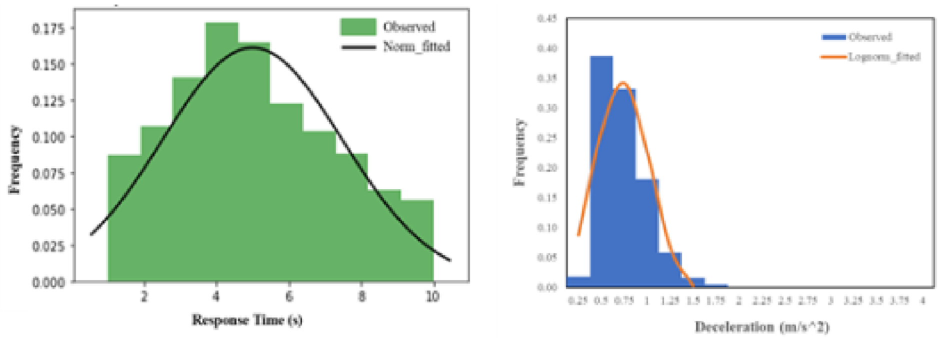
Data collected

For the SI-GLOSA use-case, the C-The-Difference database collected for eight months on the metropolitan area of Bordeaux (France), where 580 intersections were managed via 4G, while 546 of them were mapped for GLOSA use case. It resulted in 600 drivers (MPR around 0.1%) who generated around 3 Mns of position during the experiment.
The Coopits database was generated on five months since February 2021 and involved 78 drivers.
The database was refined and after filtering, 1328 eligible trajectories were obtained from the C-The-Difference database and 130 eligible trajectories were obtained from the Coopits database.

Evaluation results – Field tests

The findings related to the driver response behavior with respect to the *SI-GLOSA* use-case are summarized here (see also Figure 41).

- Analysis of the C-TheDifference and Coopits datasets revealed that about 70% of the eligible use-cases displayed a response to the GLOSA speed advice in both the cases. Out of the eligible use-cases, 933 and 91 users for C-TheDifference and Coopits respectively displayed a response. This showed a consistent attitude by the connected drivers to both the smartphone applications in terms of response rate when conditions enable to apply the recommendations.
- The response time, which was defined as the time elapsed, in seconds, from the time of display of the first speed advice to the time when the driver began to reduce speed, was observed to follow a normal distribution. The deceleration, expressed as the average deceleration (m/s^2) that the driver performed while continuously and gradually reducing the speed after receiving the first speed advice, indicated closer resemblance to a lognormal distribution with an average value of $0.61 m/s^2$. Speed compliance matches with the difference in the final speed (after continuous speed reduction) and recommended speed expressed as a fraction of the difference in the initial speed and recommended speed and a speed compliance value of 0.75 was observed among the connected drivers.



a b

Figure 41 - (a) Response Time, and (b) Deceleration rate of the connected drivers

- A deeper investigation revealed that the response behavior changes with respect to different factors. Therefore, statistical models were adopted to explore the effect of different factors on each aspect of the response behavior. The most relevant findings are as follows:
  – Significant impacts on driver response were observed with respect to several factors, the most important of which include the activation distance, the difference of the advised
  speed with the instantaneous speed of the driver and whether the driver was accelerating when the speed advice was displayed on the HMI.
  – The response rate was observed to generally decline and the response time was observed to increase with increase in activation distance. On the other hand, the speed compliance was improved, and the drivers performed gradual deceleration rather than strong deceleration. This suggests that the activation distance should be neither too close nor too far from the stop-line.
  – If there is a high difference between the instantaneous and the advised speed, then there are less chances of drivers showing a response or adhering to the speed instructions. Therefore, the speed of the driver should be taken into account before offering a speed advice. In cases where the difference is too high (e.g., higher than 20kmph), a speed advice should not be provided.

– The drivers who were accelerating at the instant when the speed instruction was provided were more likely to show a response in terms of speed reduction, but the response time will be naturally higher in such cases.

Evaluation results – KPIs on Mobility

Most relevant findings related to traffic efficiency are summarized here as follows (see also Figure 42):

- **Impact of Market Penetration Rate**: Both the performances of connected vehicles and overall traffic stream generally improves with increase in market penetrations of connected vehicles (CV). However, at low traffic demands, there were significantly higher number of stops made by non-connected vehicles in lieu of the CVs at a market penetration of 30% or below. This showed that, under such conditions, the CVs are unable to influence the traffic stream, as a whole.
- **Impact of Cycle Length and Activation Distance**: With long signal cycles (e.g., 90s), a 300m activation distance is too short to generate a positive impact even at high MPR. It is recommended to provide 500m activation distance in such cases; for a 90s traffic cycle and at 0.75 degree of saturation on a single lane road, an activation distance of 300m provides only 3% improvement in stops at 30% MPR while, in comparison, about 60% improvement is observed for activation distance of 500m under similar conditions. In cases where it was not possible to provide enough activation distance, the cycle length of the traffic signal could be shortened to achieve a meaningful impact from GLOSA. An activation distance of more than 500m generally does not provide any substantial improvement.
- **Impact of Available Lanes in the Direction of Travel**: At low degrees of saturation and low market penetration of CVs, an increase in the number of lanes provides higher opportunity for the unequipped vehicles to overtake the GLOSA-equipped vehicles and hence the impact will be reduced. For example, for a 60s cycle, at 0.5 degree of saturation, 500m activation distance and at 10% MPR, the reduction in number of stops is more than 30% for single-lane roads, while the same drops to less than 10% for two-lane roads.

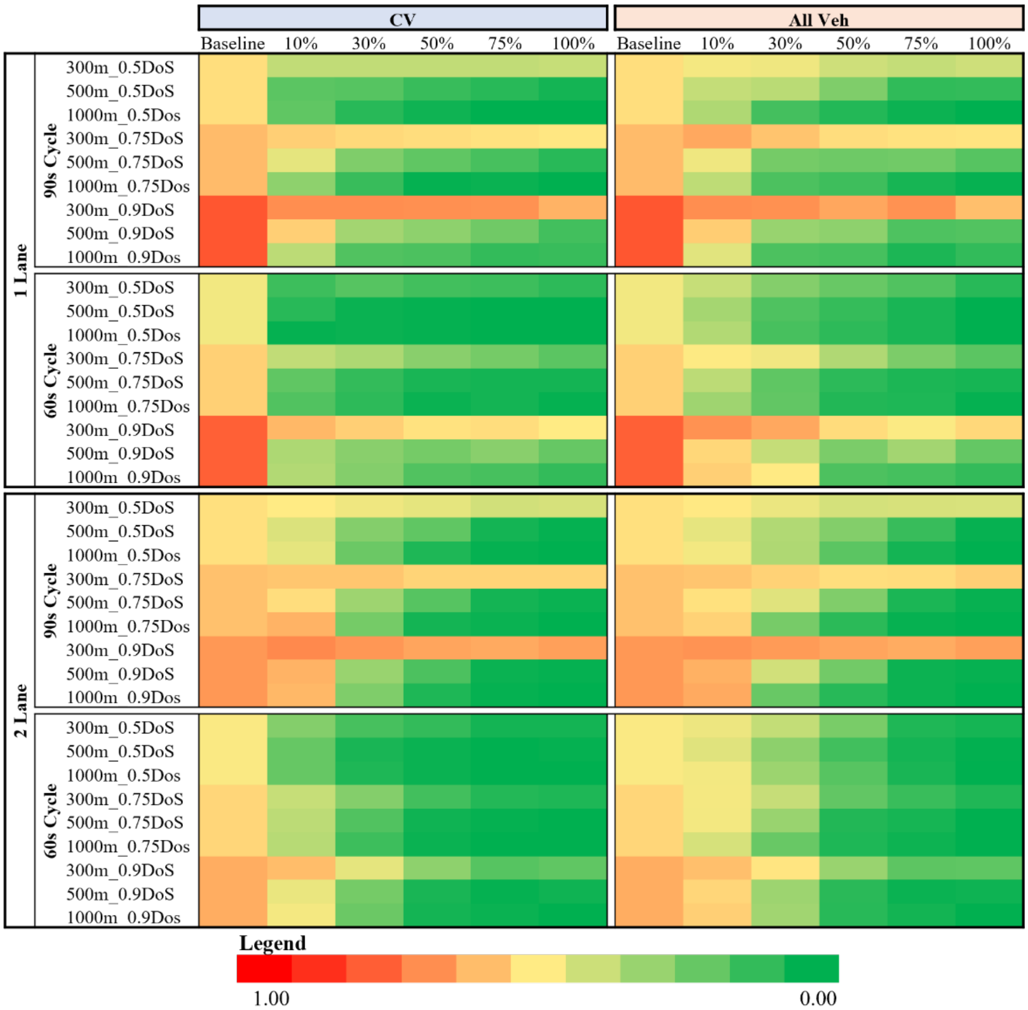


Figure 42 - Impact of SI-GLOSA on average number of Stops per vehicle

8.2.6. Summary

Evaluation results – Field tests

Several use cases with reference to Signalized Intersection have been investigated by different countries that include Signal Phase and Timing Information (Spain, Italy), Imminent Signal Violation Warning (Spain), Emergency Vehicle Priority (Spain), and Green Light Optimal Speed Advisory (UK, Hungary, Italy).

The impacts on traffic efficiency in terms of different KPIs are summarized below:

- Change in number of stops, stopped delay and queue length: With the implementation of the GLOSA use case, Hungary reported a significant reduction in the number of stops (more than 20%) and total stopped delay (more than 10%). An increase of about 13% was observed in the delay for stopped vehicles which is an indication of the fact that a vehicle using GLOSA services only stops when it is unavoidable i.e., at the beginning of the red interval. Such finding is also reported in the French report. The simulation-based experiments conducted in Italy and in France also provided a positive combined effect of GLOSA and SPTI in the reduction of queue length and total delay and the benefits were observed to improve with increased market penetration rate of equipped vehicles. Some other factors such as the number of lanes, the activation distance and the cycle length as illustrated by French and Italian simulations have an impact on the evaluation. For instance, with a cycle of 90s and an MPR=30%, an activation distance of 300m will provide only 3% of improvement, while it reaches 60% for 500m. GLOSA performs better when no overtaking option is possible, i.e. no more than one lane. On the other hand, pilot studies conducted in Spain indicated that, ISVW showed a considerable increment in the number of stops in front of the traffic light during red.
- Change in travel time and speed: No significant impact was observed in terms of travel time and speed with the GLOSA use case. The change in the travel time has negative values in SPTI use case for DGT3.0 sub-pilot and SICOGA Extended for the transition from red to green. On the other hand, this KPI has positive values for the use cases EVP, ISVW and SPTI for the transition from green to red.
- Change in traffic flow: The tests conducted in the UK revealed that the drivers equipped with GLOSA are more prepared for the signal to turn green which can, therefore, potentially improve traffic flow and junction capacity. Hungary also provided evidence of smoother traffic flow for GLOSA equipped vehicles.

Evaluation results – KPIs on Mobility

This table summarizes and reflects the main trends in the findings over the various tests and analysis drawn by country. The color describes the positive/neutral/negative evolution of the KPI under consideration. When some quantitative values / windows (percentage) of benefits are available, it is written within the cell in addition to the color indicator.

Please pay attention to the fact that negative effects on some KPI might be expected and completely explainable. For instance, Dynamic Speed Limit voluntary reduces the speed upstream to avoid congestion propagation and capacity drop due to traffic heterogeneities.

	KPI	Travel Time	Congestion	Capacity	User acceptance
Use cases	Market Penetration Rate level	Average Travel Time [TT] / Average Speed [S] / change in Delays [D]	Number of stops [SN] / stops or queuing duration [SD] / Queue Length [QL]/ etc	Traffic Throughput	Rate of users intending to response or strongly compliant (safer behaviour)
SI-GLOSA	low	**Hu:** ▲ +0,39% [TT]; ▼ -0,39% [S] **It:** ▼[+0,6%; -18,4%] [D]	**UK:** ▼[SN] **Hu:** ▼-20,83% [SN] ; ▼ -10,43% [Total SD] ; ▲ +13,14% [Average SD] **It:** ▼ [-14%; +8,8%] [SN] ; ▼ [-1,7%; -63%] [Average SD]; ▼ [-1,3%; -43%] [QL]; **Fr:** ▼ [SN]; ▼ [Total SD] ; ▲ [Average SD]	**UK:** ▲(+smoother flow)	**Fr:** ~75% speed compliance / ~5s response delay
	high		**Fr:** ▼ [SN]; ▼ [Total SD] ; ▲ [Average SD]		
SI-SPTI	low		It: ▼ [-4,3%; -14,2%] [Average SD]; ▼ [-6,7%; -26,8%] [QL]		
	high		It: ▼ [-22,3%; -41,6%] [Average SD]; ▼ [-38,3%; -56,2%] [QL]		
SI-ISVW	low		**Sp:** ▲ [+54%; + 109%] [SN]		
	high				

Legend

- Colors:

Not Concerned	Variable benefits	Positive benefits	No significant changes	Negative Benefits

- Countries under consideration: Spain (Sp) / United Kingdom (UK) / Hungary (Hu), Italy (It), France (Fr).

8.3. Environment

This section provides a list of the signalized intersection use-cases evaluated from an environmental perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: France, Spain, UK, NW2.

8.3.1. Spain

Use Cases considered

- SI-SPTI: Signalized Intersection - Signal Phase Timing Information
- SI-ISVW: Signalized Intersection - Imminent Signal Violation Warning
- SI-EVP: Signalized Intersection - Emergency Vehicle Priority

Evaluation method

Questions about what the Pilot investigated are presented hereunder:
Main Research Question:

- Is environment affected by changes in driver behavior due to SI use case?

Sub Research Questions:

- How does the SI service affect the fuel consumption in the use case?

Data collected

The data collected used to evaluate the different impact areas are the same for all of them. Refer to Chapter 5.1.1 to check the data collected in the Spanish pilot.

Evaluation results – Field tests

Refer to Annex 2 - C-Roads Spain Impact KPIS SI v1.0 and Annex 2 - C-Roads Spain FESTA Methodology_v1.6 of [RD.3] to check the list of KPIs considered to be evaluated in the Spanish pilot.
These annexes include the main research questions and the research hypotheses about the sub research questions.
Global results of impact evaluation have been obtained. The KPIs that are calculated in each of the sub-pilots are presented in Table 160, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 160, the results presented with an asterisk (*) were extracted from a simulated environment and correspond to a technological penetration rate of 100% (understood as the maximum benefit or impact theoretically achievable with the implementation of the service).

Table 150 - SI Environment. Spain.

KPI	Service	Use Case	Pilot	Summary
Change on fuel consumption and CO_2 emissions	SI	EVP	SISCOGA Extended	Controlled tests: -2%
		SPTI	DGT 3.0 SISCOGA	-52%
			SISCOGA Extended	Naturalistic study: -77% (Red-green) -16% (green-red)
		ISVW	DGT 3.0 SISCOGA	-19%

8.3.2. UK

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

See Sections 0 and 0 that describe the approach taken for evaluating GLOSA.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as our data collection approach was consistent for all services evaluated.

Evaluation results – Field tests

Note: GLOSA also had observed Environmental benefits due to drivers slowing earlier and smoother driving to a red or passing on a green signal more easily due to the HMI GLOSA advice given.
The objective impact aspects are covered in 0 and 0 as the evaluation analysis covered all three impact aspects as part of a single analysis of the GLOSA service during the focused test events (FTE) carried out during the UK Pilot.

Evaluation results – KPIs on Mobility

Subjective Impact observations:
A significant percentage of drivers armed with advanced information about traffic lights said they will adjust their speed accordingly; they felt more at ease driving were more likely to take a smoother passage through the junction.
Following speed advice given could increase junction throughput, reducing queuing stop/starts at traffic lights. This can then have a positive environmental impact, particularly for HGVs.
Drivers interviewed felt this service would be particularly beneficial for HGV drivers who would be keen to reduce gear changes. Smoother driving is known to reduce congestion, which should provide better junction throughput and reduce the production of harmful emissions from vehicles. It was also suggested that the service may be particularly well accepted by drivers who are environmentally conscious. The majority of participants suggested that GLOSA could be useful in improving traffic flow and junction capacity as it keeps the momentum of the traffic and prevents the chance of tailbacks.
The majority of participants agreed that GLOSA would be particularly useful and perhaps more importantly readily accepted by HGV drivers as it would help them avoid stopping at junctions which aids driver comfort. Not stopping and starting, especially for larger HGVs will have a direct environmental benefit at busy intersections.
Although not statistically significant, a number of drivers in their interviews also indicated a change in their behavior (speed adaptation) either by following the speed advice or slowing earlier than they usually would. As described in the safety section, drivers were reporting being less anxious/stressed which will often contribute to less aggressive driving, and a lighter right foot so less emissions with smoother driving.
Drivers reported GLOSA as especially useful while waiting at red lights/Useful for decreasing fuel consumption e.g. start/stop technology; not restart engine too early or manually turn engine off, put handbrake on, ensure engine off or at idle only.
Subjective data and individual objective results in section 6.3.2 shows the service having an impact, such as smoother braking on the approach to traffic signals resulting from GLOSA Time-to-red service information. Smoother driving should reduce the production of harmful emissions from vehicles

8.3.3. Italy

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor
- SI-SPTI: Signalized Intersection - Signal Phase Timing Information

Evaluation method

See Section 8.2.4 that describes the approach taken for evaluating GLOSA.

Data collected

See Section 8.2.4 that describes the data collected in the evaluating process of GLOSA.

Evaluation results – Field tests

Two main types of results were obtained:

- the first type of results consists of a set of theoretical results, which highlight how the impacts and consequent benefits of GLOSA are a function of additional attributes that characterize the approaches to traffic light intersections. Examples of these attributes are the vehicular flow, the distance of reception of the messages, the duration of the traffic light cycle and the market penetration
- the second category reports the results referring to the GLOSA/SPTI implementations planned in the cities involved in the C-Roads Italy 2 project, providing an assessment of the impacts for the intersections that will be equipped with the service and for the overall installations planned in the cities

Theoretical results: sensitivity of the impacts with respect to the main attributes

This method allowed a sensitivity analysis of the results with respect to the variation of the attribute considered.

The most significant result emerged in the evaluation of the Influence of GLOSA, tested for one- and two-lane approaches.

The geometric and functional attributes considered in the two evaluated scenarios are described in the following table:

Table 151 - Geometric and functional attributes considered for GLOSA and SPTI

Parameters	1-lane scenario	2-lanes scenario
traffic light phase	non-differentiated	
flows in opposition	no	
market penetration	25%	
flow	500 veh/h	1.000 veh/h
cycle duration	100 sec	
green/cycle ratio	0,5	
receiving distance	50 m, 100 m, 200 m, 300 m, 400 m	

The following table reports the percentage variation of the fuel consumption for different reception distances. The changes are presented with respect to the NO GLOSA scenario (Market Penetration = 0%).

Table 152 - Percentage variations of fuel consumption for different reception distances - 1 lane scenario

Distance (m)	Fuel Consumption
50	0,2%
100	0,9%
200	-5,6%
300	-6,5%
400	-7,4%

Table 153 - Percentage variations of fuel consumption for different reception distances - 2 lanes scenario

Distance (m)	Fuel Consumption
50	-1,3%
100	-1,2%
200	-5,8%
300	-6,3%
400	-6,9%

In both scenarios the greatest benefits were obtained from 200 meters upwards, while reception distances of 50 and 100 meters did not provide meaningful benefits, as the space available for vehicles to adapt their speed was rather small. Above 200 meters, the benefits increased slightly with increasing distance.

Impact of GLOSA implementations planned in C-Roads Italy 2

Thanks to the application of the evaluation methodology, it was possible to estimate the overall impacts of the planned implementations of the GLOSA/SPTI services in the different cities involved in the C-Roads Italy 2 project.
For each individual intersection (and for the collection of all intersections of the city) the values of the following indicator were obtained:

- the **average fuel consumption** of vehicles required to cross the intersection, multiplied by the value of the traffic flow that used the intersection itself. This value represented the total amount of fuel consumed by all users as a whole passing through the intersection

Below are the results obtained for the city of Trento. For this city the 12 intersections involved by the planned implementation of GLOSA/SPTI applications are all located along one of the main access roads to the urban center.
Nine of the twelve traffic light systems were dedicated exclusively to pedestrian and/or bicycle crossings along the above-mentioned road axis (and therefore are not located at real intersections).
For the scenario without GLOSA the absolute values of these indicators are presented, while for the different simulated market penetrations (MP) the percentage variation with respect to the NO GLOSA scenario is reported, both in absolute terms and in percentage terms.

		Average fuel consumption (liters) * number of users							
		abs. value	abs. variation (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	74,22	-0,10	-0,38	-0,66	-1,66	-2,85	-4,30	-0,21
B - 42	Via Bolzano - bivio Spini	195,65	-2,45	-1,54	-4,45	-10,42	-17,58	-30,59	-42,24
C - 41	Via Bolzano - bivio Meano	140,27	0,07	-0,61	-1,13	-2,31	-5,86	-7,81	-9,78
D - 133	Gardolo - via Bolzano - via Noce	112,61	-0,69	-0,93	-2,13	-3,40	-5,23	-7,50	-9,15
E - 132	Gardolo - via Bolzano (case Itea)	112,61	-0,68	-0,93	-2,11	-3,35	-5,22	-7,47	-9,14
F - 37	Via Brennero - Bren Center	102,68	-0,49	-0,64	-1,42	-2,43	-3,01	-4,09	-5,57
G - 100	Via Brennero - Mediaworld	102,72	-0,51	-0,79	-1,47	-2,78	-4,61	-6,50	-8,18
H - 111	Via Brennero - Tridente	83,31	-0,06	-0,30	-0,26	-0,61	-0,65	-0,68	-1,59
I - 31	Via Brennero - via Marconi	144,80	-4,27	-4,23	-2,52	-1,74	-5,20	-6,70	-11,66
L - 35	Via Brennero - Fornaci	61,05	-0,68	-1,08	-1,65	-2,35	-2,79	-3,15	-3,93
M - 1	Via Ambrosi - via Brennero	46,09	-0,64	-0,62	-1,02	-1,06	-1,42	-1,82	-2,24
N - 126	Via Ambrosi - Piazza Centa	48,97	-0,10	-0,56	-0,64	-1,24	-1,52	-2,48	-3,07
Total		**1.224,99**	**-10,59**	**-12,61**	**-19,44**	**-33,35**	**-55,94**	**-83,09**	**-106,75**

		Average fuel consumption (liters) * number of users							
		abs. value	var. % (from MP 0%)						
Int. code	Intersection name	MP 0%	MP 5%	MP 10%	MP 20%	MP 35%	MP 50%	MP 75%	MP 100%
A - 113	Lamar	74,22	-0,1%	-0,5%	-0,9%	-2,2%	-3,8%	-5,8%	-0,3%
B - 42	Via Bolzano - bivio Spini	195,65	-1,3%	-0,8%	-2,3%	-5,3%	-9,0%	-15,6%	-21,6%
C - 41	Via Bolzano - bivio Meano	140,27	0,1%	-0,4%	-0,8%	-1,6%	-4,2%	-5,6%	-7,0%
D - 133	Gardolo - via Bolzano - via Noce	112,61	-0,6%	-0,8%	-1,9%	-3,0%	-4,6%	-6,7%	-8,1%
E - 132	Gardolo - via Bolzano (case Itea)	112,61	-0,6%	-0,8%	-1,9%	-3,0%	-4,6%	-6,6%	-8,1%
F - 37	Via Brennero - Bren Center	102,68	-0,5%	-0,6%	-1,4%	-2,4%	-2,9%	-4,0%	-5,4%
G - 100	Via Brennero - Mediaworld	102,72	-0,5%	-0,8%	-1,4%	-2,7%	-4,5%	-6,3%	-8,0%
H - 111	Via Brennero - Tridente	83,31	-0,1%	-0,4%	-0,3%	-0,7%	-0,8%	-0,8%	-1,9%
I - 31	Via Brennero - via Marconi	144,80	-2,9%	-2,9%	-1,7%	-1,2%	-3,6%	-4,6%	-8,1%
L - 35	Via Brennero - Fornaci	61,05	-1,1%	-1,8%	-2,7%	-3,8%	-4,6%	-5,2%	-6,4%
M - 1	Via Ambrosi - via Brennero	46,09	-1,4%	-1,4%	-2,2%	-2,3%	-3,1%	-4,0%	-4,9%
N - 126	Via Ambrosi - Piazza Centa	48,97	-0,2%	-1,1%	-1,3%	-2,5%	-3,1%	-5,1%	-6,3%
Total		**1.224,99**	**-0,9%**	**-1,0%**	**-1,6%**	**-2,7%**	**-4,6%**	**-6,8%**	**-8,7%**

The total fuel saving in percentage terms is between -0.9% (in case of MP = 5%) and -8.7% (in case of MP = 100%).

8.3.4. France

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method

Please refer to Section 8.2.5.

Data collected

Please refer to Section 8.2.5.

Evaluation results – Field tests

Evaluation results – KPIs on Mobility

The PHEMlite emission model integrated with SUMO was used to obtain the emission outputs. Results with reference to SI-GLOSA use-case are summarized below (see also Figure 43):

- Although the environmental efficiency of CVs improved at all levels of market penetration, a significant benefit in terms of environmental efficiency for the entire traffic stream is observed only when the MPR exceeds 30%. For example, up to an MPR of 30%, the environmental benefits in terms of CO_2 emissions were in the range of 3-5% which goes up to 10% at 50% MPR and more than 15% in a fully connected environment. The unequipped vehicles were likely to contribute to high traffic oscillations at low MPR, causing more frequent speed change and higher emissions.
- While a more-or-less linear reduction in emissions was observed with respect to increasing MPR for 90s cycle time, there was a visible non-linear effect with 60s cycle lengths.
- There was a stronger reduction in the emissions with increase in MPR for single lane roads.
- While the general trend was similar for CO_2 and NO_x emissions, the improvement is higher for the latter. For example, while there was a reduction of up to 5% in CO_2 emissions at 30% market penetrations of CV, the same was more than 15% in terms of NO_x emissions. With reference to increasing activation distance, the improvement in NO_x emission gain was also higher when compared to CO_2.

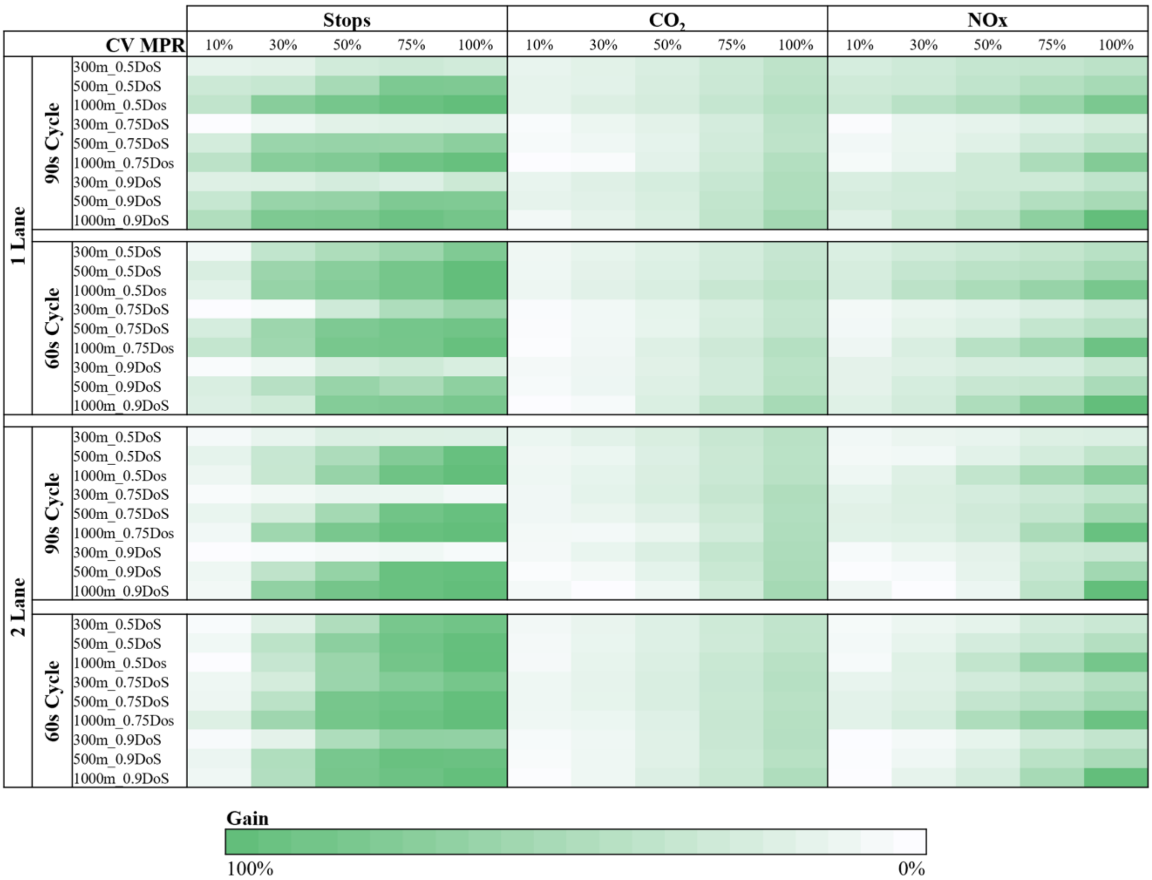


Figure 43 - Summary of Impact of SI-GLOSA use-case on traffic and environment performance

8.3.5. Summary

Evaluation results – Field tests

Several use cases with reference to Signalized Intersection have been investigated by different countries, which include Signal Phase and Timing Information (Spain, Italy), Imminent Signal Violation Warning (Spain), Emergency Vehicle Priority (Spain), and Green Light Optimal Speed Advisory (Italy, UK, France).

The impacts on environment in terms of different KPIs can be summarized as follows:

- Concerning Signal Phase and Timing Information, evaluation in **Spain** showed a significant decrease of -52% in the DGT3.0 area, and of -16, resp. -77% in the SISCOGA area.
- Concerning Green Light Optimal Speed Advisory, **Italy's** evaluation (in combination with SPAT) obtained two main types of results:

    - The first type of results consisted of a set of attributes that characterize the approaches to traffic light intersections, such as the vehicular flow, the distance of reception of the messages, the duration of the traffic light cycle and the market penetration
    - The second type reported the results referring to the GLOSA/SPTI implementations planned in selected cities, providing an impact assessment of the equipped intersections.
    - Summarizing all results, the total fuel saving is between -0.9% (in case of a penetration rate of 5%) and -8.7% (with MP = 100%).

Also, the **UK** reported that GLOSA had observed Environmental benefits due to drivers slowing earlier and smoother driving to a red or passing on a green signal more easily due to the HMI GLOSA advice given. Additionally, drivers felt this service would be particularly beneficial for HGV drivers, who will be keen to reduce gear changes, and the consequent smoother driving is known to reduce congestion, which then provides better junction throughput and finally reduce harmful emissions. Finally, drivers were reporting being less stressed - which will often contribute to less aggressive driving, which also results in fewer emissions due to smoother driving.

Finally, France evaluated the emission output using the PHEMlite emission model (integrated with SUMO). It can be stated that significant benefit in terms of environmental efficiency for the entire traffic stream was observed only when the MPR exceeded 30%. There was a benefit of 3-5%, with even higher values of up to 15% with a MPR of 100%. Moreover, there was a stronger effect with increases in MPR for single lane roads. In addition, the general trend was similar for CO_2 and NO_x emissions, where there was a reduction of up to 5% in CO_2 emissions at 30% market penetrations of CV, and more than 15% in terms of NO_x emissions. This improvement in NO_x emission gain was also higher when compared to CO_2.

It is worth to mention, that specifically the **Spanish pilot** considered a large number of KPIs and their evaluation.

So, taking into account the summary results of Spain, the following main conclusions at the Spanish level were obtained**:**

Change of fuel consumption and CO_2 emissions: the result of this KPI indicated a reduction for all the use cases where this KPI was evaluated (EVP, SPTI and ISVW). It was highly reduced in the naturalistic study of SISCOGA Extended with a value of -77% for SI-SPTI (red-green case).

8.4. User Acceptance

This section provides a list of the signalized intersection use-cases evaluated from a user acceptance perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NL, UK, Portugal, NW2, Czech Republic

8.4.1. Spain

Use Cases considered

- SI-SPTI: Signalized Intersection - Signal Phase and Timing Information
- SI-ISVW: Signalized Intersection - Imminent Signal Violation Warning

Quantitative Test Results (Surveys)

The initial questionnaire issued to pilot participants at the beginning of the trial collected information on: gender, age, level of completed schooling, occupation, monthly net incomes, profile as driver (if they have an own car, how many km/year they drive, if they are professional drivers, if they share transport and, finally, what is their level of knowledge about CT-ITS and their thoughts about how they think they might change their driving behavior in response to the use-case.

After several weeks testing this system, participants provided feedback about the use of the C-ITS service. The structure of the questionnaire was as follows:

- General Service information (and expectation). The variables to analyze in this section are the next:
  - Perceived Efficiency taking into consideration a general perspective, environment, safety and traffic efficiency.
  - Perceived usability. This was analyzed using a system usability scale.
  - Workload. In this case the Rating Scale Mental Effort (RSME) was used.
  - Perceived usefulness and satisfaction through Van der Laan Scale.
  - Equity.
  - Willingness to pay.

Please, refer to Annex 3 – “User Acceptance Questionnaire” of the report from Spain [RD.3] for more information regarding the complete questionnaire used in the Spanish Pilot as well as the KPIs list that can be extracted from.

Together with the questions related to general driver and service information explained before, the participants could also provide feedback about HLN service in particular, in two different phases:

- Before testing started (pre-test HLN specific questions)
  - HLN will contribute to feeling at ease whilst driving
  - With HLN service in my car I would feel more secure whilst driving
  - With HLN service in my car I would distract my attention from traffic
  - I am comfortable providing my position data as part of the HLN service
  - I would like to have HLN service permanently in my vehicle
  - I would be willing to pay to have access to HLN information

- After several weeks testing this system (post-test HLN specific questionnaire)
  - Perceived effectiveness: Scores between 1 and 10 on the following:
    - Availability (Was the service available when the service was needed?)
    - Correctness (Was the information correct when the service was active?)
    - Completeness (Was the information complete when the service was active?)

- Consistency (Was the service consistent and easy to understand when the service was active?)
- Accuracy (Was the service accurate (geographical accuracy)?)
- Up-to-dateness (Was the service up-to-date? Was the service available right on time?)

Moreover, participants would identify the reasons if the effectiveness issues are lower than 5 points:

- Why service was not available? (Availability score < 5)
- Why service was not correct? (Correctness score < 5)
- Why service was not complete? (Completeness score < 5)
- Why service was not consistent? (Consistency score < 5)
- Why service was not accurate? (Accuracy score < 5)
- Why service was not up to date? (Up-to-dateness score< 5)

Other specific questions for the HLN service will have into account the next issues:

- Percentage of participants who notice the icon on the screen
- Perception frequency & usage frequency
- Perceived HLN acceptance

Qualitative Test Results (Interviews)

Some questions are asked to the participants to analyze the influence of the service on behavior and trip quality and to know the proposed improvements to the service.

- I feel using the service, it influenced in my behavior. If so, how?
- I think the services improved my overall trip quality. If so, how?
- What improvements would you introduce in the service?

Conclusions

Several specific questions have been asked to the participants during pre-tests and post-tests in the different sub-pilots. The following tables summarize the result of them.

Table 154 - SI User Acceptance. SISCOGA Extended sub-pilot

KPI		Estimated Value of KPI (%)
SI acceptability (pre-test)	SI will contribute to feeling at ease whilst driving	Around 63% of drivers totally agreed with this sentence.
	With SI service in my car I would feel more secure whilst driving	Around 63% of drivers agreed or totally agreed with this affirmation.
	With SI service in my car I distract my attention from traffic	Around 70% of the drivers felt that their attention was not distracted from traffic while around 19% presented a neutral answer for this statement, and 11% of drivers considered that it could distract their attention.
	I am comfortable providing my position data as part of the SI service	About the idea to reveal their position data while using SI service, 15% were not satisfied with sharing their location, around one third expressed a neutral opinion and 52% did not mind.
	I would like to have SI service permanently in my vehicle	Most drivers would like to have this service always in their vehicle (22% of them said that they are agree with it and 52% are totally agree). 12% of drivers provided a neutral answer and same percentage, 12%, were disagreed.
	I would be willing to pay to have access to SI information	Although around 40% were not in agreement to pay for it, around half of the sample (47%) were neutral to this question. Only 13% is totally agree with the idea of charge for the service.
SI acceptance (post-test)	SI will contribute to feeling at ease whilst driving	Having in consideration the SI acceptance, 63% of sample was agreed with the next statement: "Thanks to the SI information I felt more at ease while driving". Only 10% of them expressed that they

		were not agreeable with that. Furthermore, 27% replied with a neutral answer.
	With SI service in my car I would feel more secure whilst driving	40% of drivers agreed with this sentence and 17% totally agreed. It is necessary to indicate that around 26% of drivers provided a neutral answer. Only 15% were opposed with this idea.
	With SI service in my car I distract my attention from traffic	19% considered that this service could distract their attention from the traffic, but 44% disagreed with this affirmation. Around 11% was neutral for this statement after testing the service. Around one quarter of respondents was totally opposed.
	I am comfortable providing my position data as part of the SI service	Over half of the sample believed that there was no problem for sharing their position. Around 40% provided a neutral answer.
	I would like to have SI service permanently in my vehicle	Around 30% totally agreed that they would like to have SI information permanently in their vehicle. Over half of the sample agreed with that. Only 12% of sample was neutral.
	I would be willing to pay to have access to SI information	15% of the sample expressed themselves negatively and around 30% said that they totally disagree. 28% answered “neutral”. Over one quarter of them considered to pay for having access to this service.
Users that noticed the SI icon on the screen		Most of participants (92%) saw the icon on the screen. A very low percentage (2%) was not sure if they noticed it and only 6% stated not perceive it.
SI perceived frequency during the test		Considering the test period, 26% of drivers noticed the SI sometimes while 40% saw it very often and even, 30% of drivers always observed the icon.
SI perceived usage during the test		The information about SI was used for the drivers in the treatment phase, 30% used it always, 50% utilized it very often and 21% sometimes.
SI influence in driver behavior		Only a low percentage of participants (13%) judged that using the service had not influenced in their behavior. 32% of users felt neutral, and over half of the sample answered positively.
SI improvement in overall trip quality		Regarding the idea if the SI service increased the quality of the trip, only 5% of them disagreed but most of the sample considered the influence of the service on the trip (45% agreed and 7% totally agreed). Around 41% had a neutral opinion.
HLN perceived effectiveness	Availability	65% of drivers provided a score over 6 points.
	Correctness	Most of the scores were over 4 points, the highest score was 8 (32%)
	Completeness	Most of scores are over 5. Highest percentage was for the value 8 (one quarter) and 10 (20% of them).
	Consistency	Scores were over 6 points, even around 28% provided a score of 8 and other 28% the maximum value.
	Accuracy	The scores are very positive, around 60% of sample provide a score over 7 points. One third gave a score of 8 points.
	Up to dateness	Around one third gave a score of 7 points. 20% provided a punctuation of 8 points and other 20% the maximum score.
	General score	The score is of 77 points therefore the value is over to the medium point

8.4.2. UK

Use Cases considered

Evaluation	User Acceptance
Service	GLOSA
Research Question(s) or Use Cases evaluated.	GLOSA Use Case: Time to Green / Time to Red. How do end users rate this service and its influence on them? Quantitative Evaluation: Common set of User Acceptance used as agreed within InterCor Activity 4.4 using online survey (pre and post-test questionnaires to measure acceptability vs acceptance). Qualitative Evaluation InterCor Activity 4.4. following testing.

Quantitative Test Results (Surveys)

Service	Road Safety	Traffic Efficiency	Environment
GLOSA	60% felt it wasn't distracting 30% were more aware of their speed	61% reduced their speed to avoid stopping 30% increased their speed to avoid stopping	Not measured. Pollution levels may improve if GLOSA encourages smoother and less aggressive driving.

Qualitative Test Results (Interviews)

Service	Road Safety	Traffic Efficiency	Environment
GLOSA	Opinions about the impact of the technology on the driving task were divided. Participants found that GLOSA had an effect on their preparedness/ awareness, especially when they were stationary and waiting at red lights. About half of the participants reported that GLOSA had a positive effect on their behavior as they adjusted their speed after receiving the message.	The majority of participants suggested that GLOSA can be useful in improving traffic flow and junction capacity as it keeps the momentum of the traffic and prevents the chance of tailbacks.	It was suggested that the service may be particularly well accepted by drivers who are environmentally conscious. Reduction of stopping for HGV drivers could also reduce emissions.

Attitudinal Test Results

N/A

Conclusions

GLOSA provided a service to inform drivers of traffic signal status, coupled with time to green/time red countdown information and speed advice when appropriate to pass on a green phase. The key impacts of the service were gleaned from both subjective impact and objective results summarized below (see Table 155).

Table 155 - GLOSA Impact Summary

Safety	Traffic Efficiency	Environment
GLOSA had observed Safety benefits due to drivers slowing earlier on approach to a red signal or a green with a short period to reaching red. The majority of participants also agreed that GLOSA would be particularly useful and readily accepted by HGV drivers as it would allow for more stopping distance.	A significant percentage of drivers armed with advanced information about traffic lights said they will adjust their speed accordingly and were more likely to take a smoother passage through the junction. Following speed advice could increase junction throughput as was validated during sample testing during controlled test events.	Reducing stopping at red lights will reduce emissions, particularly for Heavy Goods Vehicles, allowing them to 'roll through' junctions more often, particularly when combined with Green Light Prioritization.

All drivers armed with advance information regarding traffic light status and lane guidance, will be encouraged to adopt appropriate speed choices and early lane selection therefore reducing the risk of collision with pedestrians and other road users.
Based on the preliminary survey findings, a significant percentage of drivers armed with advanced information about traffic lights say they will adjust their speed, accordingly, feel more at ease driving and be more likely to take a smoother passage through the junction. This is especially true for HGV drivers who will be keen to reduce gear changes. Smoother driving is known to reduce congestion, which should provide better junction throughput.
Confusion can arise from the presentation of too much information, for instance presenting speed advice and a countdown timer together. Care must be taken in how the information is presented as two sets of numbers may lead to an incorrect decision.
Some drivers found the information distracting and preferred to concentrate on their driving at busy intersections.
In interviews with drivers after testing it was felt that GLOSA Time-to-red could encourage risky behaviors (i.e. speeding). Although the GLOSA Time-to-green was found to be particularly useful to drivers. It allowed them to prepare for the lights to change. This should improve traffic flow and efficiency, thus reducing pollution and junctions.
With over half the drivers reporting that they adjusted their behavior positively, i.e. reducing speed when they knew that the lights were against them, smoother driving will result in other benefits besides a reduction in gaseous and noise pollution. Calmer driving reduces feelings of anxiety and anger which in turn can reduce road rage and other health issues.

8.4.3. Netherlands

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Technically the GLOSA service works in Helmond, the Netherlands. GLOSA was deployed as a hybrid service and the in-vehicle devices use ITS-G5 and cellular communication in parallel to present time and speed advice for all turn directions. The InterCor standards ensure interoperability. Vehicles equipped with an OBU provided by different manufacturers received and processed the data in the GLOSA (SPAT and MAP) messages. GLOSA therefore was able to function correctly; however, both the delivery of information and the reliability of the information was not at a desired level. This issue may be related to the highly adaptive traffic regulation infrastructure on the one hand and the intuitiveness of the User Interface of the GLOSA assistant on the other hand.
The reliability and predictability of GLOSA advice varied considerably per intersection and turn direction. The reason for these performance issues relates to fluctuations of SPAT timing information generated by the adaptive traffic light controllers. In 26-43% of intersection passes, no advice can be generated. If a time or speed advice is presented, then only during the last 78-87% of the approach, while the prediction error of time advice fluctuates with a spread as large as the duration of a green or red phase. Derived speed advice show proportionally large variations.

Evaluation	User Acceptance
Service	GLOSA
Research Question(s) or Use Cases evaluated.	GLOSA Use Case: Time to Green / Time to Red. How do end users rate this service and its influence on them? Quantitative Evaluation: Common set of User Acceptance used as agreed within InterCor Activity 4.4 using online survey (pre and post-test questionnaires to measure acceptability vs acceptance). Qualitative Evaluation InterCor Activity 4.4. following testing.

Quantitative Test Results (Surveys)

The acceptance of the GLOSA service was assessed after the driving test where the participants' vehicles were equipped with the GLOSA system. The important topics concerning the acceptance are addressed below.
The GLOSA system was not considered predictable and stable from the perspective of the driver. As a consequence, the GLOSA end-user service was inadequate as an in-car assistance service and GLOSA could not reach (in this deployment) its potential as a traffic management instrument. The public road authorities in the Netherlands have invested a lot in the optimization of regulated traffic intersections over the recent years. In order to achieve the necessary optimizations a lot of use was made of adaptive traffic regulation systems which give priority to certain directions on the basis of the volume of traffic on offer. It is a common view by experts in the field that vehicles will become more and more connected the coming decennium. Connected vehicles can share their position and intentions with intelligent road infrastructure. As such, it is highly plausible that the need for more intelligent intersections will increase and more EU member states will apply this

principle in the future. Based on the results from both the quantitative and qualitative evaluations it seems apparent that the choice for highly adaptive regulations interferes with the reliability of the information presented to drivers through the GLOSA assistant. It is therefore highly recommended to launch subsequent development and assessment addressing the need for specification of the requirements imposed on the stability/predictability of the GLOSA data.

Furthermore, because information on time to green or time to red is able to change in a matter of seconds the end-user may experience a great variation in the stability of the information delivery.

When considering the intuitiveness of the User Interface it has to be noted that a large number of participants seemed to be confused about the way the system works. This may not necessarily be a flaw of the User Interface with regard to the information delivery, it does however add to the lacklustre User Experience of the participants. It is important to learn more about the best way to inform users about the reliability of the service as well as the density of the information being presented.

In addition, the InterCor experience in relation to the GLOSA service provider learned that there is a large interest for a European approach on the standardization of the presentation of traffic management information (such as GLOSA to large extent is) in-car. It is noted that this standardization should respect the commercial interest for innovation and differentiation of how services appear to end-users.

It was also learned that the value of the GLOSA service can benefit importantly from information from the vehicle which is fed into the data-ecosystem accessed by the intersection controllers. In other words, a GLOSA service that is aware of traffic turning left or right and that is aware of traffic queues before the lights, is much more relevant to a car driver than one that is not. Standardization of the CAM message is insufficient for this, also standardization of how such data is fed into the different national data-ecosystems is crucial. It is noted that a hybrid approach is essential. Service providers that make use of the cellular chain should provide data on moving vehicles in a similar manner as vehicles that communicate over ITS-G5 with the intersection controllers. And all data should come consistently together, near real-time.

8.4.4. Czech Republic

Intersection signal violation

The overall results of the user acceptance are considerably positive in terms of C-ITS. The drivers always said that the information was successfully shown, was useful, satisfactory, and clear. The results were mostly between 3 – neutral attitude to 5 – strongly agree. There was also a slight change in a willingness to pay for the ISV service (from 0% to 11%).

The issue of this message is when to send the warning to the driver. The drivers responded differently (22% notice the warning in intersection, 45% before intersection, 33% not filled the questionnaire). The drivers are more inclined to believe that the information was useful, but the variance is relatively high.

Furthermore, drivers' opinions that "Information about dangerous vehicles makes the dangerous situation more clear" are very different (each answer from 1 to 5 was chosen at least once).

8.4.5. Summary

The Signalized Intersection service across multiple pilots suffered from some technical and presentation difficulties but despite these problems, it was very well used by most participants (over 55% in Spain over an extended period).

In Spain there was little change in user acceptance after testing, although more users (20%) were prepared to pay for the service after experiencing the service which is a positive change.

A significant proportion of UK drivers armed with advanced information say they will adjust their speed. They also stated that they felt more at ease driving. 61% of UK participants reduced their speed to avoid stopping, while 30% increased their speed for the same reason.Nearly two thirds of Spain's users said they felt at ease because of the service.

Czechia users said that the information was useful, satisfactory, and clear. In the attitude survey most drivers marked the service for usefulness as neutral to strongly agree.

Unfortunately, due to widespread use of adaptive-traffic light controllers the Netherlands drivers felt that the information was less than valuable for a high proportion of the testing, but results were more positive for fixed time signals.

While 19% of Spain's users post-test said that the service could distract, in general, participants considered that the SI information did not distract their attention from traffic before and after having this kind of information. In comparison, 60% of UK users felt it wasn't distracting at all.

Most of Spain's participants stated that the service was effective with the general score of 77 points across all areas.

Over 80% of Spain's participants would like to have the service permanently. All users in Spain's tests found the service useful, with over half stating that they were influenced by the information and 91% in the UK stating that it influenced their driving.

Participants found that GLOSA had an effect on their preparedness/ awareness, especially when they were stationary and waiting at red lights. About half of the participants reported that GLOSA had a positive effect on their behavior as they adjusted their speed after receiving the message.

Around 20% of Spain's users would be willing to pay after having used the service this up from 13% pre-tests. After using the service Czechia participant's willingness to pay increased in favor from 0% to 11%.Half of Spain's participants said that it improved the trip quality. Based on the UK survey findings, a significant percentage of drivers armed with advanced information about traffic lights say they will adjust their speed, accordingly, feel more at ease driving and be more likely to take a smoother passage through the junction.

Confusion can arise from the presentation of too much information, for instance presenting speed advice and a countdown timer together. Care must be taken in how the information is presented as two sets of numbers may lead to an incorrect decision.

In interviews with drivers after testing it was felt that GLOSA Time-to-red could encourage riskier driving behaviors (i.e. speeding up to make a green).

Finally, in one set of driver interviews, GLOSA was thought to be especially useful for HGV drivers who are perhaps keener to reduce gear changes /stop at red lights and therefore also have a positive effect at reducing emissions. Driver Quotes:

- *"It made me aware that the lights were changing so I could reduce speed from an earlier point."*
- *"Yes, it did change my driving behavior, because I was trying to slow down to see if I could not need to stop."*
- *"I did slow down earlier because I knew I was going to hit a red light."*

8.5. Functional Evaluation

This section provides a list of the signalized intersection use-cases evaluated from a functional evaluation perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, UK.

8.5.1. Spain

The Spanish pilot evaluated the functional evaluation of most of the services deployed. Refer to [RD.3] to check this functional evaluation in every sub-pilot of Spain per use case. The following table details the feedback obtained from the particular implementation in the Spanish pilot (SISCOGA Extended and DGT3.0 sub-pilot).

Table 156 - SI Functional evaluation. Spain. SISCOGA Extended and DGT3.0 Sub-pilot

Service	SI - SPTI
Lessons Learned	The service provided all the traffic light information in the direction of driving regardless of the vehicle's lane position. With a more precise GPS device and a map matching process, it would be possible to filter only the information corresponding to the lane to give more precise information.
HMI*	An improvement suggested by the users was to provide in the same screen the information of the current traffic light and also the upcoming one.
Quality of the Service	The HMI's user receives the current phase of the traffic light and the time in seconds to the change when the vehicle is on the trace. This means that the advance of the first warning depends on the geometry of the road and the number of consecutive traffic lights. The information is available until the vehicle passes the traffic light.
Added Value of the Service	The HMI does not only provide information on the current phase of the traffic light but also on the countdown to the next phase that allows the user to perform an eco-driver behavior.

8.5.2. UK

Service / Use Case	SI (GLOSA)
Lessons Learned	GLOSA was particularly challenging to implement when used in conjunction with existing highly optimized and adaptive traffic signals. The existing traffic control systems may need to be modified to enable the creation suitable data for C-ITS services e.g. a 90% probability time to green/red provided for the next phase. Data quality KPIs will be necessary to develop sustainable services. Innovative solutions may also help, such as the use of machine learning, or inventive HMI design (see HMI section). As such, the value of simulation especially with GLOSA, A-TLCs, etc., and looking at wider network benefits. TfL & Kent CC to consider extending investigation into the impact of GLOSA on the efficiency of junctions in different operational modes. Extend pilot activities to HGVs.
HMI	HMI design to mask jumps in countdown clocks which are caused by interactions with SCOOT and bus priority systems. Existing traffic control systems will need to be modified to enable the creation of nationally deployable C-ITS services. Providing a meaningful GLOSA countdown is a challenge, and GLOSA's acceptance as a reliable source of information for users is dependent on a finding successful way to present the information presented by A-TLCs. Other useful information that could be provided on the device cited by users during interviews includes accident information, congestion and diversion routes (these can be achieved through other C-Roads use cases e.g. HLN use cases). Design considerations for HMI should be explored e.g. more use of icons rather than a number for the countdown for GLOSA.
Quality of the Service	The Kent GLOSA ITS-G5 site worked well. Technical evaluation proved in the rural context that the functionality and behavior of applications were suitable for providing the GLOSA service via ITS-G5. For the cellular solution we saw more challenges in lane accuracy due to the topology of the sites which were close together and had lane filters. Also, the interface with the back-end UTC system in generating reliable time to green/red information due to the extremely dynamic nature of the traffic light controllers and a variable latency of more than 1 second that meant drivers received warnings later than anticipated. It could be argued that the ITS-G5 site evaluated was a simple test for GLOSA, whereas it may perform less well where complex traffic signal algorithms are used as was seen during testing GLOSA via a cellular only communications channel on the A2/A102. The urban deployment was optimized for the final controlled test in November 2019, although technical validation revealed that further optimization could still have been achieved with regards to latency to the UTC back office. However, our testing proved that GLOSA worked well for specific traffic signal junction configurations, and when combined with the results of the User Perception aspect of the User Acceptance evaluation, showed that the technology is seen as beneficial, which included driver's views of both the ITSG5 and the Cellular only implementations. Presentation of Warnings: The testing and interviews showed that early warnings in rural settings are very helpful to allow the driver to prepare for the lights. For instance if GLOSA indicates that the signal will be red the driver can adjust their speed to arrive when the light is green. Conversely within an urban setting, drivers could be confused if warnings were sent too early and they should be given GLOSA advice within a tighter relevance zone. Varying the relevance zone depending on the situation can provide greater informational relevancy. Technical summary: The average coverage was 99.66% and the accuracy of the application with respect of the time and speed advice was 96%.

	When advice was calculated to be beneficial by the OBU software, advice was displayed for 100% of the ingress road. Where speed advice was available it was accurate within a few percent. The RSU had a radio coverage of around 800m which was ample for coverage of the junction. There were no False displays negative or positive.
Added Value of the Service	Although the GLOSA Time-to-green was found to be particularly useful to drivers. It allowed them to prepare for the lights to change. This should improve traffic flow and efficiency, thus reducing pollution and junctions. Additionally, participants reported that GLOSA would help them make a decision to let someone out of a junction in cases when they had sufficient time before the lights change; and thus, the service could improve the flow of traffic. Based on the survey findings, a significant percentage of drivers armed with advanced information about traffic lights said they would adjust their speed, accordingly, would feel more at ease driving and be more likely to take a smoother passage through the junction. This was felt by drivers interviewed to be especially true for HGV drivers who will be keen to reduce gear changes / stopping at junctions, which came out of our qualitative user acceptance driver interviews.

8.5.1. Czech Republic

Lessons learned

The objective of this use-case was to warn drivers passing an intersection about "a dangerous driver" driving through a red traffic light from the other directions of the intersection. Without any traffic limitations, this use-case was hard to simulate in real-time conditions. It has several specifics:

- DENM message is broadcasted from OBU based on its calculations of a vehicle speed, location and based on SPAT/MAP messages containing information about a shape of an intersection and traffic light phases.
- DENM message begins to broadcast when a "dangerous vehicle" evaluates that it will not be able to pass the green light.

During the evaluation tests of the ISV use-case, it became clear that the accuracy and timing of the DENM message were key factors influencing the usability and driver's opinion on this use-case.

There was also a suggestion to evaluate the location and the speed of a dangerous vehicle in RSU and then broadcast DENM to make the calculation more accurate. However, there are several issues with this approach, mainly the latency caused by sending a message to RSU.

It is important to send this message only when it is true. If a driver obtains a DENM message about a dangerous vehicle and there is no vehicle in an intersection, the driver may be confused, and the service is not beneficial but dangerous.

Quality of service

The key parameters in terms of the level of quality are latency and location accuracy. The crucial questions in this case are:

- Who/what should determine whether the vehicle is dangerous or not? Should it be the RSU or OBU? This determination may differ based on intersection parameters (shape, the field of view etc.)
- Which values of parameters (distance to the stop line, current speed) are already behind the threshold and which are not?

The correctly selected evaluator and the correct values of the parameters will lead to a better quality of the service.

At this moment, the opinions of showing the message in the correct time differs. Subjectively, someone got the message too late, someone on time.

During the evaluation of this use-case, there were no issues related to the key parameters.

HMI

There is only one main comment to this use-case regarding HMI. At the moment of displaying ISV message, the dangerous and evaluation vehicles were already near each other (max. 40m). The driver would need the information a little bit sooner to adequately react to that situation. The other comments regarding HMI are mostly general and not related to the particular use-case.

8.6. Socio-economics

The socio-economic impact was addressed with qualitative assessment summarising the findings with respect to factors affecting safety, efficiency and environment and whether these changes are positive or negative from socio-economics viewpoint.

Impact area	Indicator	Effect	Socio-economic impact
Safety	Average speed	Reduction for SPTI and ISVW Increase for EVP and ISV	+ -
	Instantaneous accelerations	Reduction for SPTI and ISVW Increase for EVP	+ -
	Instantaneous decelerations	Reduction for EVP and SPTI Increase for ISVW	+ -
	Adoption of speed in line with advice	Yes for GLOSA	+
	Instantaneous speed	No impact for ISV	0
Efficiency	Number of stops	Reduction for GLOSA Increase for ISVW	+ -
	Stopped delay	Reduction for total delay with GLOSA and SPTI Increase for stopped vehicles with GLOSA	+ -
	Queue length	Reduction for GLOSA and SPTI	+
	Total delay	Reduction for GLOSA	+
	Total travel time	No impact for GLOSA Reduction in travel time for SPTI Increase for transition from green to red with EVP, ISVW and SPTI	0 + -
	Traffic flow	Improvement for GLOSA	+
	Junction capacity	Increase for GLOSA	+
Environment	Fuel consumption	Reduction for EVP, SPTI and ISVW	+
	CO2 emissions	Reduction for EVP, SPTI, ISVW and GLOSA	+
	Start of slowing down before intersection	Earlier for GLOSA	+
	Smooth driving	Result depends on penetration rate and cycle length for GLOSA	?
	NOX emissions	Reduction for GLOSA	+

9. C-ITS services as a bundle

9.1. Safety

9.1.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Evaluation method

The safety assessment was carried out according to the methodology described by Kulmala (2010). The assessment begins by selecting the relevant safety mechanisms of the service from the following list (originally from Draskoczy et al. 1998):

(1) Direct in-vehicle modification of the driving task
(2) Direct influence by roadside systems
(3) Indirect modification of user behavior
(4) Indirect modification of non-user behavior
(5) Modification of interaction between users and non-users
(6) Modification of exposure
(7) Modification of modal choice
(8) Modification of route choice
(9) Modification of accident consequences only

The safety assessment investigated first the direct, then indirect, effects of the NordicWay 2 C-ITS services selected. Concerning the direct impacts (mechanisms M1 and M2), it was necessary to determine the accident types affected by the direct effects. Additionally, the accidents were classified according to normal and adverse weather conditions.
In order to estimate the direct safety effects, we needed to determine the effectiveness of the services with regard to the target accidents. The effectiveness of a service was expressed as the percentage (%) of prevented target accidents due to the driver being informed/warned by the C-ITS service. It can also be regarded as the proportion of target accidents that would have occurred if the driver had not received the C-ITS warning/information. With these estimates it was possible to calculate the direct safety effects of the services for a 100% use situation.

Data collected

Safety impact assessment was based on national accident statistics, findings from literature and expertise of the evaluation partners.

Evaluation results – KPIs on Mobility (Extended)

Safety impacts were calculated for all networks studied for 2030 for the low and high effectiveness scenarios (see Table 157) in percentages for the Nordic countries. Road safety was assessed to be improved with fatal accidents dropping by 1.2–4.8% in the low and 1.7–6.3 % in the high scenario. The corresponding changes for less severe accidents were assessed to be 0.9–2.0 % and 1.5–3.5%, respectively. These effects are shown in terms of reduced numbers of accidents in Table 158. The effects were assessed lowest in Finland, where a large part of the networks consists of rural main roads with low levels of service and event coverage.

Table 157 - Impacts on accidents in terms of percentages in 2030

Low effectiveness scenario	Denmark	Finland	Norway	Sweden
Fatal accidents (number/year)	-3.3%	-1.2%	-4.8%	-3.9%
Non-fatal injury accidents (number/year)	-1.6%	-0.9%	-2.0%	-1.7%
Property damage only accidents (number/year)	-1.6%	-1.0%	-2.0%	-1.7%
High effectiveness scenario	**Denmark**	**Finland**	**Norway**	**Sweden**
Fatal accidents (number/year)	-4.5%	-1.7%	-6.3%	-5.2%
Non-fatal injury accidents (number/year)	-2.7%	-1.5%	-3.5%	-2.9%
Property damage-only accidents (number/year)	-2.7%	-1.6%	-3.5%	-2.9%

Table 158 - Impacts on numbers of accidents in 2030

Low effectiveness scenario	Denmark	Finland	Norway	Sweden
Fatal accidents (number/year)	-1.86	-1.02	-3.46	-2.48
Non-fatal injury accidents (number/year)	-7.6	-11.6	-47.2	-46.0
Property damage-only accidents (number/year)	-26.6	-51.3	-236.2	-334.7
Low effectiveness scenario	**Denmark**	**Finland**	**Norway**	**Sweden**
Fatal accidents (number/year)	-2.48	-1.40	-4.55	-3.29
Non-fatal injury accidents (number/year)	-13.03	-19.26	-82.21	-80.60
Property damage only accidents (number/year)	-45.94	-84.92	-411.06	-586.19

For full methodology and more detailed results, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

9.2. Traffic Efficiency

9.2.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Evaluation method (Brief)

The assessment focused on the impact on average travel times. The travel times can be affected via the following mechanisms:

- Traffic flow is harmonized through speed advice locally, improving the throughput of a road section or intersection
- Warnings of problems ahead prepare drivers to slow down, reducing the emergence of shock waves which would cause congestion
- Traffic is diverted from roads suffering an event or incident to an alternative route
- Traffic is distributed smartly on the road network to maximize the throughput of the network
- Safety improvement due to the service is reducing accident-related congestion

In the impact assessment, the travel time impacts needed to be estimated for the whole transport system as, for instance, at signalized intersections reductions in travel time on one street can be associated with an increase on the crossing street, and rerouting to an alternative route can be longer than the originally chosen route and result in increased travel time.

Data collected (Brief)

Efficiency impact assessment was based on national statistics, findings from literature and expertise of the evaluation partners.

Evaluation results – KPIs on Mobility (Extended)

Table 159 shows the efficient impacts for the high and low effectiveness scenarios in percentages for the Nordic countries. Travel times were assessed to be reduced by 0.01–0.04% in the low and 0.02–0.10% in the high scenario. Table 160 shows the same benefits in terms of vehicle hours driven and vehicles hours spent in congestion.

Table 159 - Impacts in terms of percentages in 2030

LOW EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
Vehicle hours driven (million/year)	-0.04%	-0.01%	-0.04%	-0.02%
Vehicle hours spent in congestion (M/year)	-0.004%	-0.002%	-0.003%	-0.0002%
HIGH EFFECTIVENESS SCENARIO	**DENMARK**	**FINLAND**	**NORWAY**	**SWEDEN**
Vehicle hours driven (million/year)	-0.10%	-0.02%	-0.10%	-0.02%
Vehicle hours spent in congestion (M/year)	-0.9%	-0.02%	-0.5%	-1.8%

Table 160 - Impacts in terms of vehicle hours driven and vehicle hours spent in congestion in 2030

Low effectiveness scenario	Denmark	Finland	Norway	Sweden
Vehicle hours driven (million/year)	-0.17	-0.05	-0.35	-0.09
Vehicle hours spent in congestion (M/year)	-0.0008	-0.0002	-0.0009	0.00
High effectiveness scenario	**Denmark**	**Finland**	**Norway**	**Sweden**
Vehicle hours driven (million/year)	-0.37	-0.06	-0.47	-0.12
Vehicle hours spent in congestion (M/year)	-0.17	-0.003	-0.16	-0.23

For full methodology and more detailed results, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

9.2.2. France

The connected vehicle is seen as a solution for several issues concerning road traffic and especially road accidents. We suppose that connecting vehicles between them and with the infrastructure can help to reduce the number of accidents or improve traffic flow. To measure and compare benefits and investments, we use a common public decision support tool: socioeconomic assessment.
This kind of analysis allows us to take into account social benefits, which are not explicitly monetized. In our case, we can compare the investments needed to develop connected vehicle, with the benefits produced particularly by the lives saved in road accidents. The conversion between lives saved and euros uses the notion of value of statistical life, we consider that this value matches with the cost for the society of a dead in road accidents. On the same basis, we can use a socioeconomic framework to convert time gained, or emissions reduction into euros. All these values are available in several documents such as the European handbook of the external cost of transportation[13], or sometimes a transportation projects evaluation national framework (France for us[14]).
To process a socioeconomic assessment, first we need to define a common global evolution (macroeconomics, road traffic, accidental rate, …). Then we can calculate benefits depending on several variables, such as the year of deployment, the penetration rate of connected vehicle in the fleet or the road network coverage.

	Reference	1	2	3	4	5	6
Connected vehicles	No	Only cellular	ITS-G5 only	ITS-G5 and 4G	LTE-V2X	LTE-V2X and 4G	5G long and short range
Interconnection between infrastructure and cellular network	No	No	No	Yes	No	Yes	Yes
Year of deployment	2022	2022	2023	2023	2025	2025	2026

In the table above, we consider as connected vehicles, a vehicle equipped which can send automatically messages to other vehicles or to a specific network. Driving with a smartphone is taken into account, but we consider that the driver only receives information.
In the tested scenarios, differences are essentially contained in the year of deployment and the interconnection with the cellular network. This means that the information collected by the infrastructure, can be forwarded to drivers with a smartphone, increasing the penetration rate and the network coverage.

13 https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1
14 https://www.ecologie.gouv.fr/evaluation-des-projets-transport

	1	2	3	4	5	6
Infrastructure	*0 M€*	*422 M€*	*422 M€*	*422 M€*	*422 M€*	*422 M€*
Vehicles	*7 732 M€*	*7 732 M€*	*8 123 M€*	*6 087 M€*	*8 041 M€*	*8 249M€*
Deaths avoided (during 2022-2052)	*863*	*2527*	*3913*	*2005*	*3446*	*3306*
Road safety benefits	*3 301 M€*	*8 338 M€*	*13 619 M€*	*6 243 M€*	*11 804 M€*	*11 298 M€*
Congestion benefits	*8 M€*	*174 M€*	*385 M€*	*132 M€*	*315 M€*	*292 M€*
Total	*- 4 419 M€*	*360 M€*	*5 464 M€*	*-132 M€*	*3 660 M€*	*2 925 M€*

We made the assessment during 30 years from 2022 to 2052 and the table above presents the main results. During this period, we see that scenarios involving a specific network (scenarios 2 to 6), are the only profitable scenarios from a socioeconomic point a view.

We can say about these results that in every cases lives are saved, but the different scenarios allow us to highlight some points. First, the investment needed to equip the vehicle fleet is much more important than those needed to create a specific network (ITS-G5, LTE-V2X or 5G short range). However, the system is fully effective when the vehicles and the network work together, so it is better to invest in a specific network.

We see also that the road safety benefits drives the global socioeconomic results, so any measure that saves more lives (such as interconnection with the cellular network, or basically, an earlier deployment), improve the social benefits of the project.

The results of our socioeconomic assessment is quite clear, and shows that connecting the vehicle fleet with the infrastructure can save lives and be profitable for the entire society. However, these findings are related to the drivers' behavior toward the instructions given by the vehicle, even if we chose reasonable hypothesis.

The connected vehicle is a step towards automated vehicle, so even if the figures are not accurate, we can reasonably say that connected vehicle will have a positive impact on road safety. When the automated vehicles will be deployed, a specific network will already be in place, reducing the required investments for a general use.

9.3. Environment

9.3.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Evaluation method (Brief)

The environmental impact assessment focused on CO_2 emissions, which are closely linked to the fuel consumption of the vehicles, which are in turn related to changes in amount of travel (vehicle kilometers driven), as well as changes in speed and congestion. Hence, the main inputs to the environmental assessment came from the mobility and efficiency impacts.
The fuel efficiency of vehicles will likely improve during the period 2020–2040. Electrification of vehicle fleets will also affect the CO_2 emissions from an average vehicle. Therefore, the assessment took these trends into account.

Data collected (Brief)

Environmental impact assessment was based on national statistics, findings from literature and expertise of the evaluation partners.

Evaluation results – KPIs on Mobility (Extended)

Table 161 shows the environmental impacts for the high and low effectiveness scenarios in percentages and in terms of million tons of CO_2 for the Nordic countries. The changes in CO_2 emissions range from 0.01% to 0.07% in the low and from 0.03% to 0.10% in the high scenario.

Table 161 - Impacts in terms of percentages in 2030

LOW EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
CO_2 emissions (million tons/year)	-0.05%	-0.01%	-0.07%	-0.02%
HIGH EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
CO_2 emissions (million tons/year)	-0.07%	-0.07%	-0.10%	-0.03%

Table 162 - Impacts in terms of vehicle hours driven and vehicle hours spent in congestion in 2030

LOW EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
CO_2 emissions (million tons/year)	-0.0024	-0.0005	-0.0032	-0.0018
HIGH EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
CO2 emissions	-0.135	-0.049	-0.662	-0.102

For full methodology and more detailed results, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

9.4. User Acceptance

9.4.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Evaluation method

In NordicWay 2, the user acceptance of C-ITS services was evaluated via a common survey in all four countries to address the following aspects:

- Which C-ITS services/messages are relevant in Nordic conditions?
- Which C-ITS services/messages are feasible to deploy in Nordic conditions? (User viewpoint)
- What is the willingness to use?
- What is the acceptance of the systems?

The survey was designed for the general public, targeting 1,000 driver's license holders per country.

The questions were the same for all the countries, enabling pooling of data and comparison of country-specific results. Survey was published as Annex of NordicWay 2 Evaluation results report (Innamaa et al. 2020).

Quantitative Test Results (Surveys)

Four high-level research questions set above summarize the more detailed research questions set for the user acceptance study in NordicWay 2. Based on the survey results, all of the C-ITS service contents were considered important or relevant in Nordic conditions. The most important information contents for trips made on motorways or main roads were all of the type indicating some kind of road blockage — either accident, obstacle, closure or large animals on the road. For trips made on urban streets, emergency vehicle approaching, accident ahead, road or lane closure and warning about potential red-light running were considered the most important.

Feasibility of deployments in Nordic conditions was addressed in the user study by willingness to share data with the data provider and willingness to pay. Willingness to share data was quite high, and 75–82% of respondents considered for all data types (manually sent warnings and weather or road conditions, emergency braking, speed and location of the vehicle) that they would be willing or might be willing to share these data with the service provider. Willingness to pay for C-ITS services may become a barrier to deployment, as the share of respondents willing to pay (selected 5 or higher on the 7-point scale) was only 15% and an additional 15% were unsure (selected 4, the neutral alternative, on the 7-point scale).

Respondents considered the information content important for both motorways and main roads, as well as for urban environments. They also perceived the services to have safety, fluency and comfort benefits and did not expect the services to distract them.

Willingness to use was high for the C-ITS services. In total, 84% of respondents considered that they would use these services either on all trips or on selected trips, especially on long trips or on unfamiliar routes. Having the C-ITS services available also in other Nordic counties and in Central Europe was considered important by those who drive abroad.

For more detailed results, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

Conclusions

In conclusion, C-ITS services were considered relevant, and the acceptance was high. It must be borne in mind, though, that most of the drivers (54–66%) had never heard of C-ITS services and only 3–6% had used these services themselves. Thus, even if there is acceptance for those who know or are informed about these services, the overall awareness is still rather low. In addition to lack of awareness, also lack of willingness to pay may become a barrier to deployment of the services, and later when the services become more widely known and used, issues such as HMI may become more relevant for acceptance and willingness to use.

9.4.2. Hungary

An online survey was carried out by Hungarian Public Roads in which the general awareness and the potential acceptance of C-ITS services were examined. 629 people participated in the survey. The evaluation of the survey helps answer questions about the deployment and operation of C-ITS services.
The awareness of C-ITS services was surveyed as well as the general attitude toward them. Around 2/3 of the people who answered these questions were familiar with C-ITS services to some extent. 62% of the respondents found it very important to be able to use the same platform and receive the same messages and warnings as in Hungary, and 83% claimed it is important to some degree. The most frequent answers to what other regions would they prefer for C-ITS services to be available is Central and Western Europe, followed by Eastern Europe.
The key services mentioned in the survey could be divided into three groups regarding the assumed effects on traffic performance.

- Safety related warnings and information
- Traffic efficiency related warnings and information
- Environmental impact related services and information

The questions were asked regarding each type of service (e.g. How useful would you find receiving C-ITS information about lane closures?). During the evaluation, the individual services were sorted into the aforementioned groups. The answers were divided according to urban and inter-urban driving environments as well (i.e. city driving vs. country roads and motorways). The percentage of people are shown who attributed considerable importance to C-ITS services that were later grouped into potential positive effects on traffic conditions.
Only 77% of people who mostly drove within a city found safety related services important to some extent as opposed to the 92% of inter-urban drivers. This can be explained by the reduced speed and severity of accidents in an urban environment contrary to the more dangerous speeds and higher risk of fatal accidents on country roads and motorways.
In another section of the questionnaire, other assumed benefits of C-ITS services were involved in the questions (asking respondents if thought using C-ITS services would result in these benefits):

- increase traffic safety,
- improve traffic flow,
- decrease traffic congestion,
- increase driving comfort.

It was also recorded whether the respondents would generally use C-ITS services and to what extent would they be willing to pay for them.
Based on the perceived benefits, there was a general positive attitude toward C-ITS services. 80-90% of the respondents thought that receiving C-ITS messages comes with these advantages. 90% answered that they would use C-ITS services in the future, and a quarter of the respondents said that they would be willing to pay for them, which is definitely a promising start.
In the last section, the willingness to share travel and sensor data was recorded. Sharing with the transport authorities was anonymous and serves the improvement of the quality of service. Five different types of data were mentioned in the survey:

- current position of the vehicle,
- current speed of the vehicle,
- emergency braking of the vehicle,

- data collected by the vehicle sensors (weather, road conditions, etc.),
- warnings recorded by the driver in application (object on the road, accident, etc.).

All the questions had four possible answers: 'yes', 'no', 'maybe' and 'I don't know'. Based on the number of 'yes' answers, four categories were created:

- willing to share all data: 5 'yes' answers,
- willing to share most data: 3-4 'yes' answers,
- willing to share some data: 1-2 'yes' answers,
- would not share data / uncertain: 0 'yes' answers.

Figure 45 depicts the proportions of respondents concerning their willingness to share travel data.

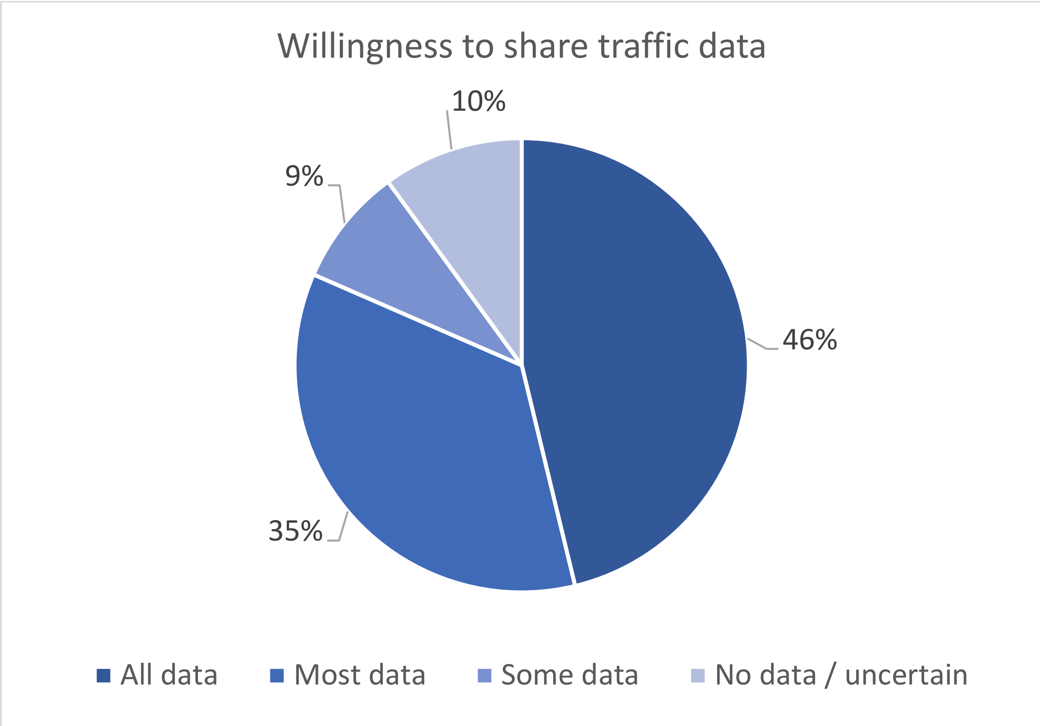


Figure 45 - Willingness to share traffic data (Hungary)

Almost half of the participants would share all their data and another third is willing to share most of the travel information. An overall of 90% would share some of their data with only 10% of those that would not or are uncertain.

Generally speaking, there is a considerable awareness and positive attitude toward C-ITS services. The respondents know about the concept and they think that it could have a positive effect on safety and traffic flow. Also, 9 people out of 10 would generally use C-ITS services in the future, and would be willing to share some or all of the travel data they generate throughout their journey.

9.4.3. France

On-board traffic managers application

C-ITS allow vehicles to communicate with each other (V2V), but also with the infrastructure (V2I or I2V). While some of these information exchanges are automated, others require the use of a human-machine interface (HMI). This is the case for traffic managers who have an "on-board traffic managers application" (OBTM APP) integrated in tablets installed in their intervention vehicles. A study was conducted to evaluate the HMI of this application.

Use cases considered

The use cases referred to in our study are those provided by the OBTM APP in the framework of the C-Roads France project.

Evaluation method

Prior to the general deployment of the OBTM APP on the entire site of the Interdepartmental Directorate of Roads in the West of France (IDRW; Direction Interdépartementale des Routes Ouest in France), the Maintenance and Intervention Center (MIC ; Centre d'Entretien et d'Intervention in France) of Pleumeleuc was selected to test the OBTM APP between June and September 2021. Each week, a group of three users (1 supervisor and 2 operators) were invited to test the application. After one week of use, these professionals were interviewed on the usability of the OBTM APP.

The OBTM APP proposed by DIRO differed from that of the other test sites because, in addition to the C-ITS interface, it included an embedded handrail application (EHA) that allowed professionals to enter information about the events they encountered. Therefore, in this application, there are events that belong only to the C-ITS universe and that allow sending information to other vehicles (*e.g.*, intervention in progress), events that belong only to the EHA universe (*e.g.*, crushed animal on the road).

Population. 22 of the 27 MIC professionals (81.5%) were interviewed, including 7 supervisors and 15 operations staff.

Materials. The interview grid consisted of four sections designed to: (1) reconstruct the agents' initial experiences with the tablet (*e.g.,* frequency of use, conditions of use, or technical problems encountered); (2) simulate a patrol or intervention activity during a fictitious scenario but similar to the professionals' real-life activity; (3) assess their ability to perform some specific manipulations that they would not have performed during the simulation (*e.g.*, edit or terminating events); and (4) assess expectations regarding expected developments of the OBTM APP.

Main results

Use of the OBTM APP

First, the interviews showed that most professionals used the OBTM APP under the conditions intended by the experiment: during patrols for responders and during interventions for their superiors. They indicated that they reported most of the events they encountered, unless they were overwhelmed or the events were minor (*e.g.*, picking up trash on the side of the road) that they do not usually report.

First experience and expected evolution

Overall, users were satisfied with their first experience with OBTM APP and felt that it is compatible with their way of working. In particular, they saw it as a way to track events more efficiently, even if it means daily monitoring by managers to avoid being overwhelmed by events. Nevertheless, the teams encountered some difficulties at different levels.

First of all, regarding the driving position. The position of the tablet in the vehicles was not quite satisfactory, because depending on where it is located, it is difficult to use either for the passenger or for the driver in some vehicles. Recharging the battery was also a problem for users, as the tablet must be perfectly positioned on its holder, which requires great attention to each manipulation, otherwise it is no longer connected and ends up shutting down. Teams also encountered numerous premature shutdowns of the application, with significant difficulties in restarting when the engine was turned off with the vehicle start and stop system. This made users disable this feature in the vehicle. In addition, some users felt distracted by the many tools available to them in addition to the tablet and reported errors in use (*e.g.*, not removing the panel on the roof of the vehicle after the intervention).

Second, at the OBTM APP level. The system launch and authentication process is considered too time consuming, leading users to rush to authenticate on the way to the event (*i.e.*, while driving or when stopped by a stop sign or traffic lights) or after the event has been resolved. In addition, significant latency issues have been noted. These cause a lot of confusion for users when creating, editing, or closing events. They also found connection issues that weaken confidence in the system, especially when it comes to using the tablet outside of the vehicle as they should be able to (intervention too far from the vehicle).

Finally, the event forms in the EHA application. The vast majority of users felt that too much information is requested in the event forms and that they therefore take too long to complete. They ask that they be simplified and that input aids be integrated to save time.

<u>Mastery of the system</u>

The evaluation also showed that they are quite comfortable with the OBTM APP. Almost all professionals were able to turn on the tablet, authenticate to the system, report events, and, if possible, complete event records. However, there were a few errors when reporting some events, where the correct symbol was not used (*e.g.*, vehicle blocked instead of vehicle broken down or vice versa). It was also common for events to be reported in the wrong activity (*e.g.*, a dead animal on the hard shoulder was reported as an obstacle in the response activity rather than the patrol activity). In addition, professionals reported many more events related to the EHA to record events (*i.e.*, EHA events or EHA and C-ITS events; *e.g.*, obstacle on the tracks) than events that would allow them to inform the user (*i.e.*, C-ITS only; *e.g.*, patrol in progress or stop in protection). They indicate that they do not know what these events are for, that they do not consider these events useful because they do not allow for the completion of an event form (EHA), or because they believe that the number of users connected with C-ITS is too small. Finally, few of the professionals interviewed knew exactly how geolocation works within the system. A significant proportion of these professionals thought that they were likely to be tracked as soon as the system was in operation, that is, as soon as the vehicle was started.

<u>Conclusion</u>

In conclusion, the OBTM APP was generally well evaluated and mastered by the users. However, many adjustments to the workstation and the application appear to be necessary to guarantee a completely satisfactory user experience. The training of professionals should also be reinforced so that they are able to report events corresponding to the situations they encounter. In this logic, it seems essential to communicate more on the functioning and the usefulness of C-ITS events, which allows them to protect themselves by warning users of their presence on the tracks. Eventually, it would be useful to interconnect the OBTM APP with the other tools used by the agents so that the C-ITS events are triggered automatically in order to reduce the number of manipulations while driving. Finally, and although it was explained during the training sessions, the detailed operation of geolocation should also be studied in depth, as it is a major lever of acceptability.

Smart Phone Application

In order for users who do not have a connected vehicle to participate in this information exchange, a smartphone application (SP APP) has been developed. The SP APP has been pre-tested in the Bordeaux area. On this occasion, a study to assess its acceptability was conducted. It also allowed to pre-test the methodological procedure that will be used during the future deployment of the SP APP on a national scale.

Use cases considered

The use cases concerned by our study are those made available by the SP APP within the framework of the C-Roads France project.

Evaluation method

The SP APP was released on a download platform on January 5, 2021. When the app was first launched by users, they were invited to participate in its evaluation by filling in their email address. About a week later, an email was sent to them with a link to complete an online questionnaire. As a reminder, a new email was sent to participants one week after the first one.

Population. Of a total of 3,022 users surveyed over the period January 5 to August 28, 2021, 262 users responded (8.67%), of which 170 completed the survey in full (5.62%). Of these 170 participants, 91 had used the SP APP at least once and 79 had not yet used it. In addition, of the 91 users, 23 were involved in some way with a C-ITS project and were removed from the analyses.

Material. The questionnaire consisted of 86 questions, divided into four sections aimed at: (1) learn about participants' use of the SP APP; (2) assess the acceptability of the SP APP (*i.e.*, measure intention to continue using and determinants of this intention; Lee, 2010); (3) understand the use of the SP APP and its added value compared to other existing applications (*e.g.,* ease of installing the application, use of the application in addition to other applications [overlay function], added value of the application or usefulness of specific services, etc.); (4) knowing the general profile of the participants (*e.g.*, gender, age or driving experience).

Main results

Population Description. There was a large majority of men (55/68, or 80.9% men and 11.8% women; 7.3% missing data). Participants were experienced drivers, with 75.0% having more than 20 years of driving experience.

Download and use the SP APP.

Participants who had not yet used the SP APP (N = 79) said they had not used it because it did not meet their needs for 55.7% of them, or because their region was not covered by the deployment for 12.7%. We also note that 8.9% of people said they did not like the interface, 7.6% said they encountered technical problems and finally 6.3% said they downloaded it only because they were curious.

Among the participants who had used the SP APP, their experience was relatively limited: 85% had used it between 1 and 5 times. The SP APP was used in built-up areas (75%) and in inter-urban areas (expressways, freeways, ring roads; 64.7%).

39.7% found out about the SM APP through a website, 35.3% through social networks, and 13.2% through the press. Installation was considered easy (M = 5.35/6; SD = 1.19) and installation explanations were considered fairly understandable (M = 4.27/6; SD = 1.60).

Users are used to this kind of SP APP (97.1% say they have already used other APPs of the same type; 88.2% have already used Waze, 80.1% Google Maps, 35.3% Mappy, 30.9% ViaMichelin and 20.6% Coyotte).
Almost half of the participants use the SP APP as an overlay (48.5%; preferably with Waze and Google Maps), only 20.6% use it alternately with another APP according to their needs. It can be noted that only 8.8% use only the SP APP evaluated. Finally, 19.1% no longer use the SP APP.
Regarding reports, only 23.5% of users reported an event through the SP APP. The main events reported were: obstacle (50%), blocked road (43.8%) and accident (37.5%). Similarly, only 23.5% of participants were informed of an event via the SP APP (main events received: traffic conditions or accident (56.3%) and construction sites (56.3%)). Finally, 42.6% of users report encountering events that were not reported on the SP APP (main events not reported: traffic conditions or accident (82.1%), construction sites (58.6%), and optimal speeds to get the light green (51.7%)).
Users who received information from the app report having confidence in it (M = 5/6; SD = 1.32) and consider it reliable (M = 4.88/6; SD = 1.46). The information judged as the most useful is "to receive information and alert messages (traffic, accident, etc.)," "to know the optimal speed to get the green light" and "to be able to overlay the SP APP with another application to receive information from both applications simultaneously ("overlay" function) (although only 39.7% of users know about this function). The least popular features are "receiving information about construction sites", "knowing the location of parking lots and the availability of places" and "displaying variable message signs directly in the application".
Evaluation of the SP APP and Lee's determinants (2010).
The results for the determinants of acceptability are shown below (see Table 1). The only exceptions are ease of use (M = 4.17; SD = 1.50) and perceived behavioral control (M = 4.17; SD = 1.50).

Table 163 - Means (standard deviations) of the different dimensions of Lee's model (2010) (for the record, six-point scale)

	Users (N=69)
Usefulness	2,85 (1,30)
Ëase of useFacilité d'usage	4,17 (1,50)
Intention to continue using	3,64 (1,73)
Attitudes	3,37 (1,49)
Subjective norms	3,18 (1,36)
Perceived Behavioral Control	4,00 (1,54)
Confirmation	2,71 (1,41)
Satisfaction	2,72 (1,52)
Pleasure	2,78 (1,15)
Concentration	2,38 (0,95)

The ecological or road safety added value of the SP APP is only slightly perceived by the users.
The reliability of the application's information is judged to be less good than that of other applications and, more generally, the SP APP is judged to be less responsive than other applications.

Lessons from the pre-test.
Convergent validity of Lee's model (2010)
The internal consistency of each of the dimensions in Lee's (2010) model was assessed to verify that the statements in the questionnaire were measuring the dimension to which they related. Out of ten dimensions measured, only three of them would need to be reworked. This is the case for perceived usefulness (α = 0.66), perceived pleasure (α =

0.70), and concentration (α = 0.37). The other seven dimensions are very well represented by their statements with alphas all above 0.80: ease of use (α = 0.86), intention to continue (α = 0.92), attitudes (α = 0.95), subjective norms (α = 0.91), perceived behavioral control (α = 0.91), confirmation (α = 0.81), satisfaction (α = 0.90). Thus, Lee's (2010) model has good convergent validity.

Discriminant validity of Lee's model (2010)

Factor analysis were performed to verify that the dimensions are well discriminated against each other. Of the four models combined by Lee's model (2010), only the Theory of Planned Behavior (TPB; Ajzen, 1991) has acceptable discriminant validity. That is, its four dimensions of "attitudes," "subjective norms," "perceived behavioral control," and "intention" each saturate on a single factor showing no cross-saturation. The TPB model is therefore exploitable to understand, explain, and predict the intention to continue using the SP APP. According to the first analyses, this is not the case for the TAM, ECM and Flow models whose cross-dimensional discrimination is not acceptable.

Testing Lee's (2010) acceptability model, predictive model and structural equation analyses

Convergent and discriminant validity are prerequisites for model testing by structural equation analyses. The measurement equipment should therefore be reworked accordingly in order to achieve discriminant validity for the TAM, ECM and Flow models. The TPB model could be exploited as is by structural equation analyses in a future study with more participants (at least 120). The current sample size is too small to allow us to perform these analyses.

9.4.4. Summary

Nordic Way

C-ITS services were considered relevant, and the acceptance was high. 84% of respondents stated that they would use C-ITS services as part of their travel, whether it was for daily or for less familiar situations.

Respondents considered the information content important for most strategic roads, as well as urban environments. They also perceived the services to have safety, fluency and comfort benefits and did not expect the services to distract them.

Most drivers indicated that they were unwilling to pay for services and only 15% indicated that they would pay.

It is also important to note that since so few drivers had personal experience of the services, the results should be considered indicative.

Hungary

An online survey was carried out by Hungarian Public Roads in which the general awareness and the potential acceptance of C-ITS services were examined. Based on the perceived benefits, there is a general positive attitude toward C-ITS services. 80-90% of the respondents thought that receiving C-ITS messages comes with advantages. 90% answered that they would use C-ITS services in the future and 62% of the respondents found it very important to be able to use the same platform and receive the same messages and warnings as in Hungary.

77% of people who mostly drive within a city found safety related services important to some extent as opposed to the 92% of extra-urban drivers.

An overall of 90% would share some proportion of their data and 25% of the respondents said that they would be willing to pay for the services. Although this is quite low, it is actually slightly higher than seen for other services evaluated in this report.

France

The On-board traffic managers' application was well accepted by most users and they stated that they were able to report most events. However, users felt the app required too much information when reporting events. It was clear that many users required training in reporting the events as many were confused as to which category was correct for the situation. It was also clear that despite having received training in geolocation most users had a poor understanding when applied.

Other lessons learnt included: Position of the HMI is crucial for correct operation; a robust power connection is required to stop complete discharge of the HMI; a long boot time meant users were driving off before the system had fully started; latency

A survey among the participants who had downloaded and used the Smart Phone app, 85% had used it between 1 and 5 times and it was used in built-up areas (75%) and in inter-urban roads (64.7%).

48.5% of users used the app as an overlay; preferably with Waze and Google Maps, 20.6% use it alternately with another app according need. Only 8.8% use the Smart Phone app only and 19.1% no longer use it.

23.5% of users reported an event through the app. Similarly 23.5% of participants were informed of an event via the app. Most users found the information useful and reliable. The most useful features were: incident management; GLOSA; and to overlay the app with another app. The least popular features are RWW, Parking and VMS.

The ecological or road safety added value of the Smart Phone app is only slightly perceived by the users.

The reliability of the application's information is judged to be less than that of other applications.

9.5. Functional Evaluation

9.5.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Lessons Learned

The technical evaluations in NordicWay 2 provided some lessons related to the organization and implementation of the technical testing of the piloted services. The conformance of log files, data logging practices and message processing has to follow common specifications (including a stable and unique message ID), which enables successful analysis of the results from the log files. In addition, the possibility to analyze message latencies from the log files is dependent on the possibility to synchronize the clocks of transmitting and receiving nodes to a time reference. This needs to be verified constantly during the trials. When there are multiple partners or actors involved with the service value chain, the implementation of these testing requirements needs clear communication early enough and follow-up during the trials. The same methods also enable monitoring of the C-ITS services after deployment to provide reassurance as to their proper functionality.

The cross-organizational data sharing in the national NordicWay 2 pilots and data sharing across the interchange system was confirmed. Interoperability between the different countries was tested during the Nordic Tour, and events reported were visible across the Nordic countries. During the Nordic Tour it was discovered that there are issues with GNSS (e.g., consumer grade devices in poor reception areas, GPS jammers and global affairs) and cellular coverage/networks in cross-border situations (e.g., roaming agreements/sim cards, loss of / re-establishing reception, etc.). These technical issues need to be taken into account when deploying the C-ITS services. The (4G) cellular coverage will develop further and can be expected to cover the whole road network soon, as this is required from the mobile network operators (at least in Finland).

HMI

The design of the HMI and the interaction of C-ITS services used while driving needs special attention. In addition, the information content in C-ITS messages needs to support a driver-centric presentation of warning messages in vehicles. There are concerns that displaying a message (for example the emergency vehicle warning) to the driver could, in the worst-case scenario, create a new incident and accident. This topic was not included in the technical evaluation of the services, and further research is recommended.

Quality of Service

The end-to-end latency analyses showed that cellular (4G-LTE) implementation of the piloted C-ITS services and the NordicWay 2 interchange system is able to provide fully functional services, although the implementations in the pilots were not optimized for minimizing latency. The median values of end-to-end latency measured in controlled tests allow successful implementation of many Day-1 C-ITS services such as different types of hazardous location notification. The medians of latency measured between federated nodes are consistent with this outcome. However, the number of events in the controlled test was relatively small, and the measurements were carried out over a short time period. A more detailed analysis of the end-to-end latency, including its distribution, characteristics and contributing factors, would be a relevant topic for future research. In addition, as the technologies evolve, presumably the latency will decrease.

Variability of the latency results in the pilot implementations highlights the need for designing robust solutions during the deployment of services that are also scalable. It also shows the importance of constant monitoring of the KPIs of the complete system to make sure data is usable for end-consumers. The quality of the services depends highly on the quality of the data. During the pilots, it was realized that the quality of data from detection systems needs to be confirmed before implementing the services. There is a risk of sending a false message if the incoming data is not correct or accurate. Other service providers, like traffic network management systems and weather service providers, should be able to be integrated in the NordicWay2 interchange system.

Added Value

The cellular networks can support ITS services on top of all other communication use cases, delivering excellent economy of scale and nationwide road network coverage from the start. Combined with a neutral data sharing platform, such as a federated network of interchange nodes, Nordic and European service continuity can be assured for all NordicWay 2 Day-1 cases.

For full methodology and more detailed results, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020).

9.6. Impact of the exposure of people to electromagnetic waves

The Working Group of the project led by university Gustave Eiffel is dedicated to analysis and evaluation of the exposure of people to electromagnetic waves in the context of the deployment of Cooperative ITS on vehicles, road infrastructure and eventually on vulnerable road users.
In a general exposure assessment method, the main aim is to assess the overall EM exposure of a given population, integrating the field level over a given time and cumulating it over a frequency band. Here, our methodology is adapted to evaluate the exposure due to only the wireless systems introduced by a particular use case of the C-Roads project (I3 use case) where a P2V device based on C-ITS systems is introduced for workers in the field. As a complement to the 2.3.2.2 deliverable, this deliverable focusses on the methodology for assessing the additional exposure due to the introduction of this P2V device.
The P2V device specification has been recently proposed by the project partners and the design of the device and the antenna design were yet to be proposed. In this context, it seemed relevant to propose an exposure management-by-design approach such that the antenna design and the exposure assessment tasks are coupled. The exposure levels are thus ensured to be below the threshold levels recommended by ICNIRP while making sure that the C-ITS P2V communication device preserves good performances.

Use Case considered

During C-ROADS project, we focused on electromagnetic exposure evaluation for the I3 usecase: workers in the field for C-ITS 802.11p systems.

Deliverable ID	Deliverable Name	Validation Date
2.3.2.2 b	Methodology for assessment of RF electromagnetic exposure of P2V device in the I3 use case (workers in the field)	July 2021
2.3.2.3 b	Results and RF electromagnetic exposure assessment of P2V device in the I3 use case (workers in the field)	December 2021

Description of the P2V device proposed

Table 164 is an extract from the Deliverable 2.4.2.5-M: Device P2V Functional specifications – ITS-pedestrian Station P2V which provides the functional specifications of the P2V device.

Table 164 - Basic system profile of the P2V device (extract from Deliverable 2.4.2.5-M)

ID	**2.4.2.5.H- Basic System Profile -1**
Component(s)	Securing the Road worker
Requirement	The minimum broadcast distance of the Device shall be of 300 m to be efficient even with adverse weather conditions. This distance shall be reachable in a linear road profile considering a device positioned at a human average height (maximum 1.5 m).
Acceptance Additional information	This value corresponds to this calculation: Reaction Time is equal to 1 seconds and corresponds to 36 meters at 130 km/h Braking time at 130 km/h is equal to 93 meters. So total stop distance is about 130 m with dry road conditions. Considering wet road conditions, total stop distance is about 260 m.

As per this basic profile, one of the main constraints to ensure the securing of road workers, a distance of 300 m should be considered. Appendix A gives a rough analytical approximation of the minimum gain required by an antenna for the P2V. More accurate and realistic values should be available with propagation modelling results for the three relevant pilot sites chosen.

For comfort and ease of use, wearable antenna needs to be seamlessly integrated with regular clothing.

Figure 46 - Body worn P2V device (antenna integration scenario)

A possible integration scenario which will be considere P2V device is shown in Figure 39. It consists of twc microstrip patch. One antenna element is worn on top le antenna element is worn on the front of the body, which are connected to the electrical device by conductive wires. The placement of the antenna elements has been studied in order to reduce the losses due to coaxial cable length by proposing an integration scenario where EM radiation in the human body can be minimized while ensuring a height as close as possible to the one of the functional specifications.

Exposure assessment methodology

This section provides a brief description of exposure management “by design” proposed for the I3 use case for a P2V device at a proof-of-concept design stage.

The following picture depicts the predominant parameters to be considered for EM exposure assessment in the context of a pedestrian to vehicle scenario (P2V) whereby a road worker can be equipped with an 802.11p broadcasting device.

Figure 47 - The three predominant parameters for exposure assessment, namely: (i) EM sources characteristics, (ii) Propagation environment and system integration (close to the body) and (iii) the population to be considered for the exposure.

The EM sources present are the 802.11p roadside units, vehicular onboard units and the pedestrian body-worn device for P2V communications. All the signals are identical to the ones studied and fully described in the 2.3.2.2 and 2.3.2.3 deliverables of the Scoop project.
Since this methodology focusses on exposure due to the P2V device, the particular configuration of a body-worn 802.11p device will be considered. The device being worn close to the trunk and at a distance of less than 200 mm to the body, specific absorption rate (SAR) has to be evaluated with respect to the standards as described in chapter 5.
The population exposed here are mostly roadworkers. The latter are a subcategory of the population consisting of a priori healthy adults, aware of the risk involved and exposed during a working day. We will thus focus on occupational exposure.
The exposure management by design approach relies on an multi-step assessment as depicted in Figure 48.

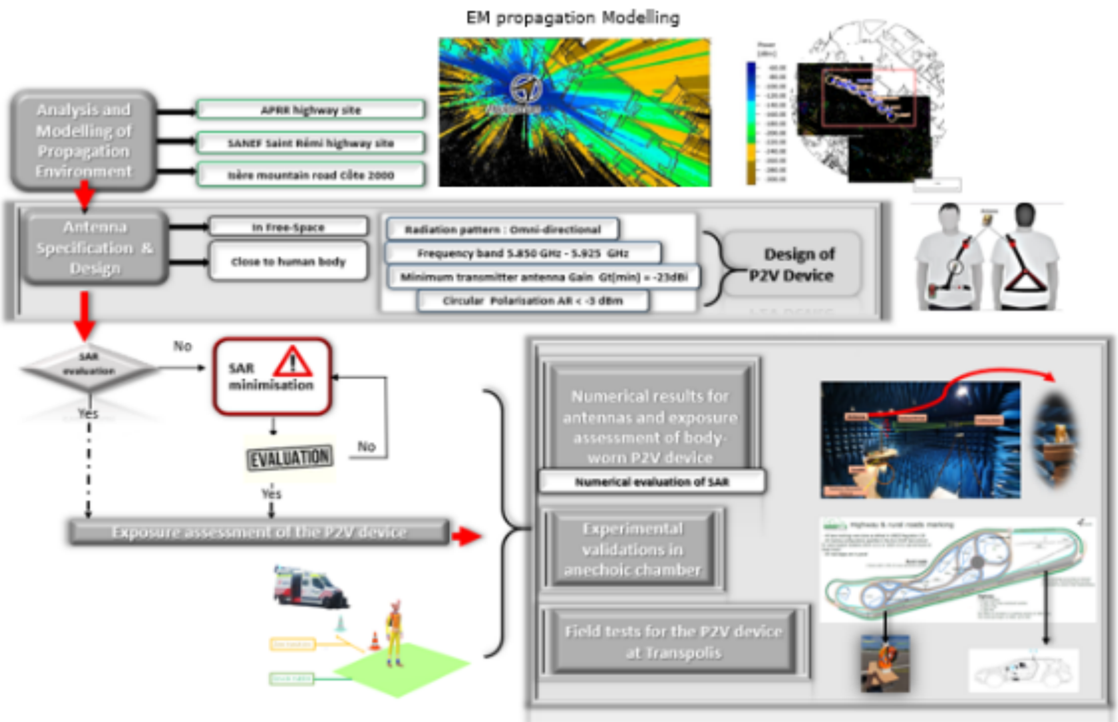


Figure 48 - Overview of the methodology for management of RF electromagnetic exposure “by design” of P2V device prototype (at a proof-of-concept stage)

The three different steps are (i) P2V antenna specifications and design for SAR reduction, (ii) numerical assessment of the antenna in the road scenario through the modelling of the propagation environments of the pilot sites chosen by the C-Roads partners. This step allows for fine-tuning of the antenna parameters such that the functional specifications objectives are reached, (iii) Experimental validation of the prototype both in a controlled laboratory environment (anechoic chamber) and field tests at Transpolis. Numerical SAR (exposure) assessment of the P2V prototype as this proof-of-concept stage.
Experimental SAR evaluation should be planned at a later development stage for a P2V device with a higher level of integration.

Description of the antenna system structure

The antenna system considered in this research work is shown in Figure 49. It consists of a two microstrip-monopole antenna system backed by metasurface reflectors. A circularly polarized monopole antenna integrated is designed and simulate, as shown in the following figures. The operating frequency band of the ITS-G5 antenna system is in the band ranging from 5.875 GHz to 5.905 GHz. Moreover, a metasurface of reflection coefficient with 0° phase based on patch antenna was investigated, as shown in the following Figures, which has the capability of reflecting energy with zero phase shifts. So that the backward energy toward human body will be redirected to opposite direction resulting in increasing the radiation in opposite direction. The gap between the antenna and the MS was chosen to the point where the distance between the human body and the antenna is almost equal to λ/4. The simulated antenna is fabricated within the specified frequency range and tested using vector network analyzer. A top and bottom picture of the antenna is shown in Figure 52.

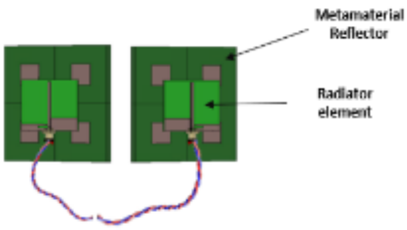


Figure 49 - Antenna system structure

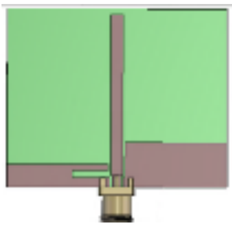


Figure 50 - Antenna design.

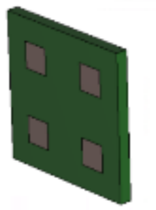


Figure 51 - Metasurfa reflector.

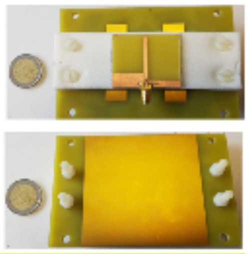


Figure 52 - Fabricated antenna system (Front and Top View)

SAR requirements (Limits in the exposure levels)

The population to be protected is divided in two categories: occupational and public. The category of workers is made up of a priori healthy adults, aware of the risk involved and exposed during a working day. The Public is composed of a greater dispersion of profiles and sensitivities (including the elderly, young children, the sick, etc.) with exposure durations of up to 24 hours and 7 days a week. The values of Table 165, provide a reference level for the SAR aspect of antenna design, according to European Directive 2013/35/EU adopted by French Decree 2016-1074 effective on 1 January 2017. In our scenario, we will only focus on the workers (Road Workers).

Table 165 - SAR standards and limits for the occupational exposure

		Europe
Directive and Decree	EU Council Recommendation 2013/35/CE [Directive 2013/35/EU] Adopted by French decree 2016-1074	
Measurement and computation method (standard)	**Numerical:** IEC 62704-1 [IEC/IEEE 62704-1] **Experimental:** IEC 62209-1528 [IEC/IEEE 62209-1528]	
ELVs related to whole-body heat stress expressed as averaged SAR in the body		0.4 [Wkg^{-1}]
ELVs related to localized heat stress in head and trunk expressed as localized SAR in the body		10 [Wkg^{-1}]
ELVs related to localized heat stress in limbs expressed as localized SAR in the limbs		20 [Wkg^{-1}]
Averaging time		6 [min]
Averaging mass		10 [g]

Antenna performance

The antenna performance, including the S11 and Axial Ration, are displayed respectively, in Figure 53 and Figure 54. The simulated and measured reflection coefficient bandwidth is covered from 5.8 GHz to 5.95 GHz with S11 less than -10 dB. The simulated AR of the antenna backed metasurface is smaller than 3 dB at 5.9 GHz, the antenna shows circular polarization at 3.1 dB. Moreover, by adding the body tissue effect, the AR goes down to 2.6 dB

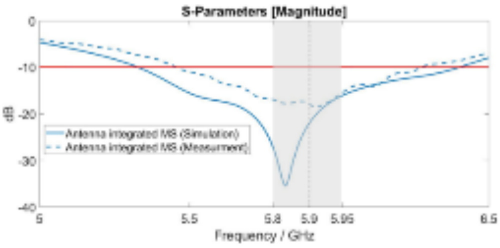


Figure 53 - Simulated Return Loss, validated by experimental.

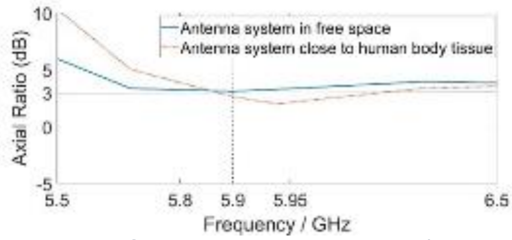


Figure 54 - Simulated Axial Ratio with/without body tissue effect.

The 3D radiation patterns in φ plane of the antenna system back-to-back, at 5.9 GHz, is shows in Figure 55 -. the human body effect was included.
As can be seen from this pattern, the back-to-back antennas are omnidirectional and cover the whole 360° range.

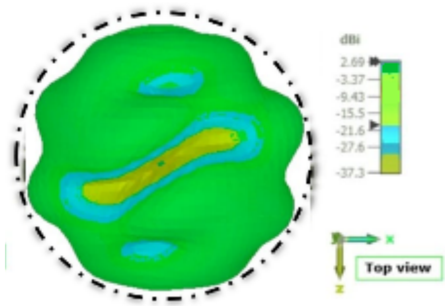


Figure 55 - 3D simulated radiation pattern, for the monopole antenna system - P1 version

The normalized radiation patterns obtained from numerical simulation were validated by the experimental results performed in the anechoic chamber at 5.9 GHz in the E-plane (for φ = 90) and H-plane (φ = 0) Cross polarization and Co polarization cuts respectively, as shown in Figure 56. Generally, the measured results match the simulations well in both the E- and H-planes.

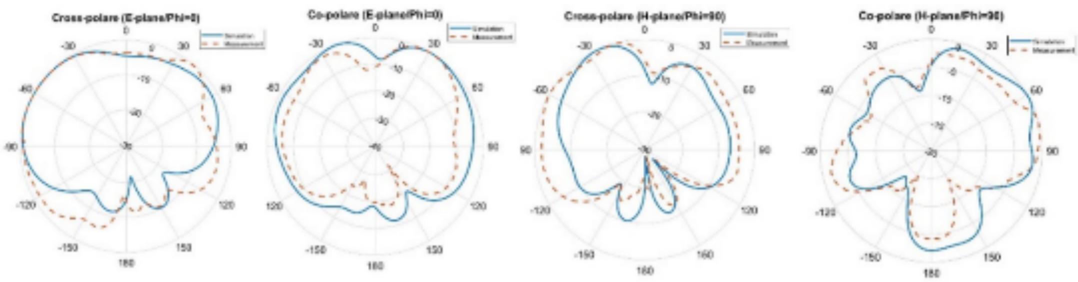


Figure 56 - Simulation validates with experimental measurements in E-plane and H-plane Cross polarization and Co polarization at 5.9 GHz.

Exposure results and field tests

The SAR value was obtained by simulation according to European Directive 2013/35/EU adopted by French Decree 2016-1074 effective on 1 January 2017. and with the averaging method stated in IEEE/IEC 62704-1, for an input power of 23 dBm. The SAR distribution averaged over 10g of inside body tissue at 5.9 GHz, is depicted in Figure 57, when the antenna was put on the body tissue.

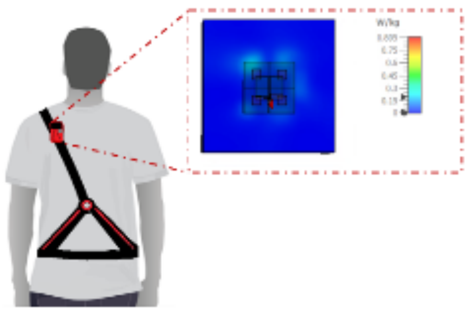


Figure 57 - Distribution of SAR values when the antenna with metasurface was placed on the body tissue at 5.9 GHz.

The maximum SAR value 0.193 W/kg obtained from simulation, shows that it is well within the limits of the safety standards of the ICNIRP and FCC. The results thus confirm that the proposed metasurface antenna system can effectively protect the road workers in the highway environment from the electromagnetic radiation produced by the P2V device.

According to the specifications of the P2V device by the French road operators of the C-Roads and Indid projects, the minimum broadcast distance of the device should be 300 m to be efficient even with adverse weather conditions. An evaluation of the P2V device integrating our antenna was performed the in controlled highway environment of Transpolis test site in Les Fromentaux in France. The received signal strength indicator (RSSI) level by a 802.11p system onboard a vehicle is shown over the a distance of 1 km in Figure 52.

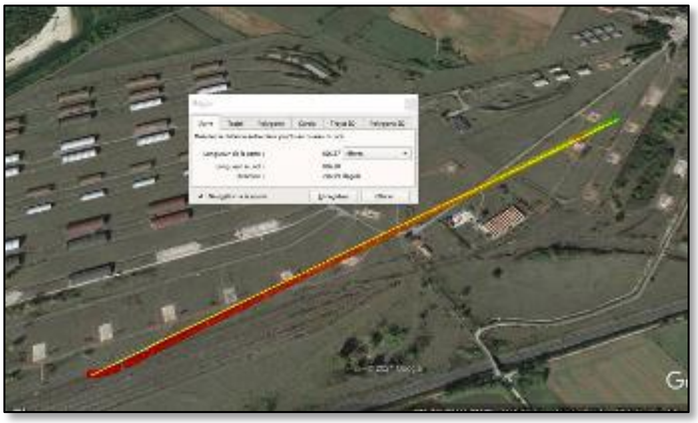


Figure 58 - Received Power Vs. Distance (dBV/Km) test on Transpolis highway road

The P2V antenna system achieved a maximum broadcast distance of 860 m, which is 2.75 times the specified distance of 300 m. Several configurations were also tested to validate our prototyped antenna.

9.7. Socio-economics

NordicWay 2 project (Denmark, Finland, Norway and Sweden) assessed the impacts of C-ITS as a bundle of use cases. In their work (Innamaa et al. 2020), the safety, efficiency and environmental benefits were calculated for all networks studied for 2030 for the low and high effectiveness values concerning the impacts. Table below shows the quantitative benefits of the C-ITS services in 2030 on the networks of the NordicWay countries for the high effectiveness scenario. The benefits are shown as changes in user-related costs. Negative numbers are a reduction in user costs and thereby real benefits. Positive changes indicate higher user costs and thereby disbenefits. More results can be found from NordicWay 2 Evaluation results report by Innamaa et al. (2020).

Table 166 - Benefits or user-cost changes due to the deployment of C-ITS services in 2030 in the high effectiveness scenario (Innamaa et al. 2020)

Benefits in number	**Denmark**	**Finland**	**Norway**	**Sweden**
Vehicle hours driven (million/year)	-0.37	-0.06	-0.47	-0.12
Vehicle hours spent in congestion (M/year)	-0.17	-0.003	-0.16	-0.23
Fatal accidents (number/year)	-2.48	-1.40	-4.55	-3.29
Non-fatal injury accidents (number/year)	-13.03	-19.26	-82.21	-80.60
Property damage only accidents (number/year)	-45.94	-84.92	-411.06	-586.19
Co2 emissions (million tons/year)	-0.0034	-0.0044	-0.0046	-0.0026
Value in million €				
Vehicle hours driven	-10.221	-0.960	-12.872	-3.895
Vehicle hours spent in congestion	-7.046	-0.044	-6.374	-10.855
Fatal accidents	-12.74	-5.03	-16.49	-16.88
Non-fatal injury accidents	-14.38	-9.45	-29.62	-88.96
Property damage only accidents	-0.23	-0.42	-2.06	-2.93
Co2 emissions	-0.193	-0.404	-0.964	-0.145
Total value of changes in user costs	**-44.8**	**-16.3**	**-68.4**	**-123.7**

The merit of carrying out a benefit-cost assessment is doubtful, as there is no definite timing for the investments yet, and the sensitivity analysis showed large variations due to different development scenarios. However, comparison of the benefits in 2030 and the costs is possible. (Innamaa et al. 2020).

Table 167 - Costs and benefits for C-ITS service deployment and provision in the NordicWay 2 countries (Innamaa et al. 2020)

Costs and benefits (€)	Denmark	Finland	Norway	Sweden
Vehicle unit costs				
Investment 2021–2030	118 087 200	141 381 000	133 325 533	352 944 000
Operation & maintenance 2030	10 496 640	12 567 200	11 851 158	31 372 800
Road operator costs				
Investment 2021–2030	5 312 500	3 672 000	34 675 000	73 500 000
Operation & maintenance 2030	486 000	2 062 960	2 653 000	5 900 000
Benefits				
Low effectiveness scenario 2030	22 741 967	10 475 197	41 087 119	68 239 294
High effectiveness scenario 2030	44 806 980	16 318 268	68 377 214	123 663 528

According to NordicWay 2, the comparison of costs and benefits shows that from the road operator perspective, the benefits even in the low effectiveness scenario in 2030 exceed the sum of the annual operating and maintenance costs that year and the investment costs up to that year in all countries. In the high effectiveness scenario, the benefits would cover also the operation and maintenance costs of the in-vehicle units in other countries than Finland. (Innamaa et al. 2020)

NordicWay 2 concluded that concerning the stronger efficiency, safety and CO_2 impacts on high traffic volume and congested roads than on lower volume roads, it is beneficial to focus the operation of C-ITS services on roads with high traffic volumes. Service provision on low traffic volume roads may also be socioeconomically profitable, but this depends on how the service users adapt their speeds and car use to the C-ITS services in the long run. (Innamaa et al. 2020)

France performed socio-economic assessment of C-ITS services as a bundle, too, addressing period 2022-2052. In their scenarios, differences were essentially contained in the year of deployment and the interconnection with the cellular network. They assumed that the information collected by the infrastructure, could be forwarded to drivers with a smartphone, increasing the penetration rate and the network coverage. During this period, it can be seen that scenarios involving a specific network (scenarios 2 to 6), are the only profitable scenarios from a socioeconomic point a view, with exception of scenario 4 for which the costs exceed the benefits.

Table 168 - Benefits and costs for C-ITS service provision in France during 2022-2052

Scenario	1	2	3	4	5	6
Connected vehicles	Only cellular	ITS-G5 only	ITS-G5 and 4G	LTE-V2X	LTE-V2X and 4G	5G long and short range
Interconnection between infrastructure and cellular network	No	No	Yes	No	Yes	Yes
Year of deployment	2022	2023	2023	2025	2025	2026
Infrastructure	0 M€	422 M€	422 M€	422 M€	422 M€	422 M€
Vehicles	7 732 M€	7 732 M€	8 123 M€	6 087 M€	8 041 M€	8 249M€
Deaths avoided (during 2022-2052)	863	2527	3913	2005	3446	3306
Road safety benefits	3 301 M€	8 338 M€	13 619 M€	6 243 M€	11 804 M€	11 298 M€
Congestion benefits	8 M€	174 M€	385 M€	132 M€	315 M€	292 M€
Total	- 4 419 M€	360 M€	5 464 M€	-132 M€	3 660 M€	2 925 M€

France stated that based on these results in every case lives are saved, but the different scenarios allow us to highlight some points. First, the investment needed to equip the vehicle fleet is much more important than those needed to create a specific network (ITS-G5, LTE-V2X or 5G short range). However, the system is fully effective when the vehicles and the network work together, so it is better to invest in a specific network. They saw also that the road safety benefits drives the global socioeconomic results, so any measure that saves more lives (such as interconnection with the cellular network, or basically, an earlier deployment), improve the social benefits of the project.
France made a conclusion was that these results of this socioeconomic assessment were quite clear and showed that connecting the vehicle fleet with the infrastructure can save lives and be profitable for the entire society. However, these findings were related to the drivers' behavior toward the instructions given by the vehicle, even if we chose reasonable hypothesis. The connected vehicle is a step towards automated vehicle, so even if the figures are not accurate, we can reasonably say that connected vehicle will have a positive impact on road safety. When the automated vehicles will be deployed, a specific network will already be in place, reducing the required investments for a general use.

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References

The following documents, amplify or clarify its contents. They are referenced in this document in the form [RD.x]:

Ref.	Title
[RD.1]	C-Roads WG3 Evaluation and Assessment Plan. Version 1.2. November 2020.
[RD.2]	C-Roads WG2-TF2 Common C-ITS Service and Use Case Definitions Version 1.8.0. March 2021.
[RD.3]	C-Roads Spain Final Evaluation Report (M42)_v1.1.zip. Report from Spain. June 2021.
[RD.4]	Innamaa, S., Kulmala, R., Mononen, P., Penttinen, M., Tarkiainen, M., Baid, V., Bergqvist, D., Dörge, L., Hjälmdahl, M., Hökars, F., Kauvo, K., Malin, F., Meland, S., Pedersli, P. E., Rämä, P., Sannholm, M., Schirokoff, A., Simons, M., Ström, M., Sørensen, A. B., Victorsson, C., & Öörni, R. (2020). *NordicWay 2: Evaluation results.* NordicWay 2, 16 Dec 2020, 141 p.
[RD.5]	C-Roads Italy - Evaluation and Assessment Report. Version 1.0. March 2022.