C-Roads Working Group 3 – Evaluation and Assessment

Final Report

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Publication History

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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	Final
1.2	31/12/2023	Inclusion of results and outcomes collected in the years 2022-2024	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 June 2024) 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
Ireland	Final
Italy	Final
NordicWay 2 & 3	Final
Portugal	Final
Slovenia	Final
Spain	Final
The Netherlands	Final
United Kingdom	Final
Greece	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). The value of this Use Case in terms of perceived awareness

and knowing potential hazardous situations in advance was confirmed also in urban contexts, even if with more restrained impacts.
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 Greece it was found out through simulation experiments that for the specific use case of lane closure the number of lane changes was decreased with the provision of the respective C-ITS message. There was also a significant reduction in the number of collisions.

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.
Similar estimation in Portugal showed that with 100% penetration, the C-ITS could contribute to less 40 accidents with victims and to save human lifes, 4 serious injuries and 55 injuries.

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 use cases examined for the Greek pilot included Weather Condition Warning, where the C-ITS message provided the information for slippery road, and Obstacle on the Road with the provision of information for a Slow/ Stationery Vehicle. For the WCW use case, the number of lane changes decreased and the same resulted in the number of collisions. Similar changes were observed for the Obstacle on the Road use case.

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.

Use Case HLN- EPVA - Emergency or Prioritised Vehicle Approaching

The C-ITS message allows to increase the distance of the event detection by 73%, from an average of 370 m (C-ITS OFF) up to an average of 642 m (C-ITS ON).

The lane change maneuver starts and ends far in advance with respect to the C-ITS OFF scenario, with reduced spatial and temporal durations (-28% and - 32% respectively). The maximum steering angle recorded is increased, highlighting a more resolute and quick maneuver, deployed suitably with the surrounding traffic conditions.
The temporal distance between the detection of the simulated emergency vehicle and its maneuver of overtaking by 142%, from an average value of 36 sec (C-ITS OFF) up to 87 sec (C-ITS ON).

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.

In France, on a global scale, results showed that the connected vehicle has an impact on traffic and environment. This impact depends on the Market Penetration Rate (MPR) and the traffic demand. In case of low traffic demand, the emission of pollutant is reduced, as received warnings help reduce speed. On the other hand, in high traffic demand scenarios, even under a high MPR, congestion is unavoidable.

As we saw in the previous research, the activation distance of the C-ITS message can have an impact on traffic and environment but also on safety. In another study, fed with the European partners' findings, the benefits in the 15th percentile Time-to-Collision was observed compared to an MPR of 0%. For most of the use cases under consideration, the performance analysis was drawn according to three categories of modelling scenarios to point out the impact of delays and latencies on the comprehensive performance:

- Scenarios modelling latencies for the event detection and delays for the driver response.
- Scenarios modelling a perfect detection of the event, but delays for the driver response.
- Scenarios modelling a perfect detection of the event and a perfect anticipation of the driver, i.e. without latency.

In fact, the driver's delay can be different according to the person. The connected drivers are assumed to react on average 450 meters upstream of the "obstacle" with a standard deviation set to 20% of the average distance. Furthermore, it is assumed that the connected driver will not react before reaching a distance of 1 km toward the "obstacle", since such a distance is deemed too long for lane-change anticipation.

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.
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. For

the case of Greece, the indicator of average speed showed a slight decrease and as expected travel times were increased.
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 Greece for both use cases, Weather Condition Warning and Obstacle on the Road, average speeds decreased and travel times increased.

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.

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.

Field tests in Italy (C-Roads Italy 2) confirmed the positive impacts of the GLOSA: a general improvement in most of the performance indicators used for evaluation was indeed noticed. Observation on the effectiveness of the Use Case under different conditions were allowed: greater activation distances of the GLOSA upstream of the traffic light bring greater benefit; the system works better in the presence of lower speed limits (50 km/h compared to 70 km/h. GLOSA seems to obtain the greatest benefits in the presence of fixed traffic light cycles or in any case with not excessively dynamic traffic-dependent actuation levels

In Germany, in the Pilot Hamburg, GLOSA has also been tested on pedelecs and eScooters, using a series of test drives and simulations. The following conclusions emerged from the analysis of the speed profiles:

- On the test route in the direction of Baumwall, the average speed increased from 11 km/h to 19 km/h using the signal data from the GLOSA app.
- Using the GLOSA app's signal data, the average speed on the test route towards Landungsbrücken increased from 10 km/h to 15 km/h.
- The significant increase in average speed using signal data (signal phases and timing) is because stopping at the red phase along the road is avoided or minimized as much as possible by the signal data.
- Using signal-specific data on signal phases and times, stops at traffic lights can be avoided, or the number of stops at traffic lights can be reduced as much as possible.
- Minimizing the number of stops behind traffic lights reduces travel times with a higher average speed, which can contribute to a smoother flow of traffic in urban areas.

The Traffic Light Prioritization use case was also tested in Germany, with the introduction of the BiDiMoVe system in Hamburg. In this project, conventional bus prioritisation via R09 telegrams was replaced by a C-ITS-based prioritisation on parts of the Metrobus line M26. Buses equipped with onboard units (OBUs) received strong prioritization in ~42% and normal prioritization in ~58% of bus priority requests. BiDiMoVe buses were on average less delayed than the R09 buses: On average, the BiDiMoVe buses in October had a delay of 24 seconds in direction one (direction Rahlstedt, Amtstraße) and a delay of 42 seconds in direction two (direction Kellinghusenstraße), compared to 36 and 60 seconds respectively of the R09 buses. Considering the delay around 2 pm separately, the BiDiMoVe buses were, on average 90 seconds late at 2 pm in direction one (direction Rahlstedt, Amtstraße) and 66 seconds late in direction two (direction Kellinghusenstraße), compared to 220 seconds and 96 seconds respectively for the R09 buses. Finally, it was observed that the BiDiMoVe buses had a better timetable position on average than the R09 buses. Due to the high prioritisation that could be applied to delayed BiDiMoVe buses, the most extended average delay for BiDiMoVe buses was significantly lower than the most extended delay for R09 buses.

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	+

Navigation Information

Field tests were carried out in Italy, concerning the Use Cases Parking Information and Smart Routing. Considering Parking Information, the presence of the C-ITS which provides information on the occupancy rate of car parks and at the same time guides the driver to the closest available parking space allowed during tests a saving of time between 35% and 53%, comparing to the C-ITS OFF scenario.
The Smart Routing Use Case reduced the time required for the two tests routes in Verona by 10,2 minutes (-32,4% compared to the C-ITS OFF scenario) and by 15,3 minutes (-47,8% compared to the C-ITS OFF scenario).

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.

CO_2 emissions were decreased in the case of providing C-ITS messages for lane closures in the Greek pilot.

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 simulation experiments for the Greek pilot showed a decrease in the number of CO_2 emissions with the provision of C-ITS messages for an obstacle on the road.

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:

Use Case 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.

Co-funded by the European Union

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.
Concerning the answers of the questionees in Greece, most of the participants weren't familiar with the service and only a few participants had already used the service. Many participants considered that RWW could be a useful service for daily driving purposes and agreed strongly to a daily use of the service. However, most of the participants showed a low willingness to pay for the service.

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.

Many of the drivers of the Greek pilot were familiar with the service but have never used it before. Concerning the usefulness of IVS in daily driving, many participants considered the service useful and stated that they would absolutely use IVS regularly. Most of the participants had a neutral opinion on whether they would be willing to pay for IVS.

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.
For the Greek pilot, most of the participants had zero knowledge about the service and only a very low number mentioned that they had used the service. Most of the participants considered the service useful and stated that they agreed strongly with the daily use of it. The highest number of the participants had a neutral opinion about willingness to pay 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 & 3 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.

France has developed an application called Coopits. Several studies have evaluated user acceptance of this application. In fact, there is a perceptible gap between users' initial expectation and reality. Some tracks of improvement have been highlighted through the user acceptance study like improving the ergonomy. In opposition, the reliability of information is a strength that must be highlighted. To have it, a strong collaboration with road operators is mandatory. Another study assessed the acceptance of the use of C-ITS by the managers. The new technology is well welcome due to the well integration of the C-ITS interface and the web interface for managing events entered on the onboard tablet. Fortified by their experience, agents even made some suggestions to improve the device. C-ITS provide a feeling of safety for agents.

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.

For the service RWW, in NordicWay 3, the collected data were not sufficient for any conclusions, but they potentially indicate that drivers responded slightly on getting information from the application. Additionally, the survey results indicate that most of the drivers adapted their speed when driving with the app being active. Interestingly, the participants thought that the application had greater influence on their driving behavior than the vehicle data shows.

Concerning the service IVS, traffic regulations are stored digitally in databases but ensuring these records are up to date is challenging. A study was conducted in Gothenburg to compare speed limit data in the NVDB database with actual road signs using the 3DAI City platform. Results showed a 5.2% mismatch in Gothenburg, a 4.2% mismatch in Stockholm, and a 10.9% mismatch in Helsingborg between the two sources. Reasons for mismatches include road works not updated in the database, signs positioned with additional downstream signs, or outdated information. Discrepancies were reported to authorities for correction. This study highlights the importance of accurately maintaining digital traffic regulation data, especially with the increasing reliance on this data in navigation systems. Future efforts will include comparing data with a true digital representation of traffic regulations.

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 31th May 2024) 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 7

- Signalized Intersections (SI) - see section 8
- Navigation Information - see section 9

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 10).

For each Service, 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 –	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

Acronyms	Use case	Description
	Emergency Vehicle in Intervention	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 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).

Acronyms	Use case	Description
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).
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.

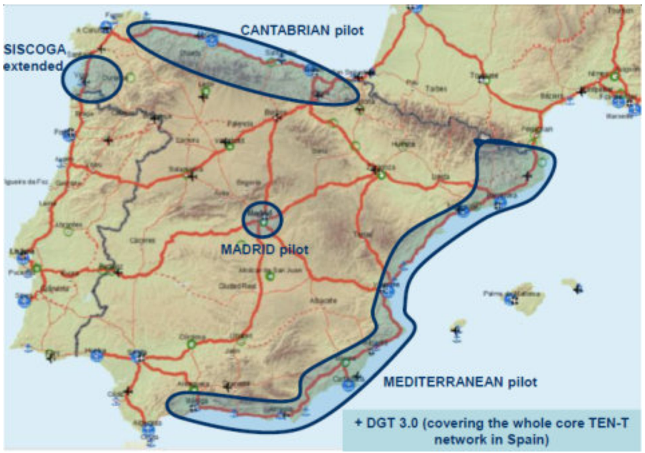


Figure 1 - Spanish Pilots Location

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:
<u>DGT3.0 SISCOGA extension</u>: 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.

Figure 2 - DGT 3.0 pilot location. SISCOGA Extension

<u>DGT3.0 SATELISE</u>: 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.

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

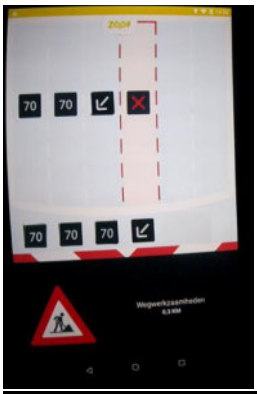
Day-1 service	Use case
Road Works Warning (RWW)	Closure of a lane
In-Vehicle Signage (IVS)	In-Vehicle Signage Dynamic Speed Limit Information
Signalized Intersection (SI)	Green Light Optimal Speed Advisory (GLOSA)d

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 33 describes 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 and NordicWay 3

NordicWay 2 (2017-2020) and NordicWay 3 (2019-2023) were joint activities that included four Nordic Countries; Denmark, Finland, Norway and Sweden. They 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 and 3 projects (see Table 34). However, only few 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 ('2') and NordicWay 3 ('3') 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	2	2	3
	Hazardous location notifications (HLN)	Weather and road condition	2	2	-
		Slow or stationary vehicle	2	2	-
		Emergency vehicle approaching	-	-	2, 3
		Traffic ahead warning	2	2	-
		Emergency brake light	-	2	-
		Cooperative collision warning	-	2	-
	Road works warning (RWW)	Road and lane closure	2	2, 3	3
		Mobile roadworks	-	2, 3	2
	Signalized intersections (SI)	Signal violation / intersection safety	-	2	-
		Time to green	3	3	2, 3
		Green light optimal speed advisory (GLOSA)	3	2, 3	2, 3
		Traffic signal priority request	-	3	2, 3
	PVD	Single vehicle data	2	2	-
Day-1.5 services	Traffic management	Traffic information & smart routing	2	2	-
		On-street parking information and management	-	2	-
		Information on alternative fuel vehicle fueling & charging stations	-	2	-
	CAD	Data collection for mapping of infrastructure readiness	-	2	-
	CCN in and out of the city	Dynamic access control of designated infrastructure	-	-	2
	Dynamically controlled zones	Dynamic environmental zone	-	-	2

The NordicWay 2 and NordicWay 3 evaluations 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. In NordicWay 2, 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, those results in this report are also summarized as a whole. For full methodology, see NordicWay 2 Evaluation Results report (Innamaa et al. 2020). In NordicWay 3, different pilots conducted evaluations for the most important topics related to the implementation and only few topics were selected for joint evaluation. For an overview of applied methods and results, see NordicWay 3 Evaluation Results report (Innamaa 2024).

Table 35 - C-ROADS evaluation areas and their coverage and priority in NordicWay 2 (NW2) and NordicWay 3 (NW3)

Evaluation area	**Priority* in NW2**	**Priority* in NW3**
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.

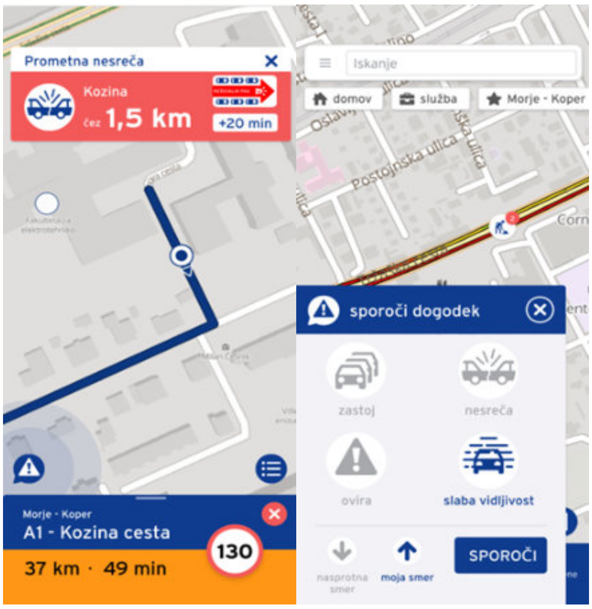


Figure 5 - The DARS Traffic Plus application (left screen: receiving HLN events notifications, right screen: reporting HLN events)

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. In the first phase of C-Roads Italy, 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. Stellantis – CRF was also involved in the C-Roads Italy 2 and C-Roads Italy 3 projects. The impact areas investigated were Safety, Traffic Efficiency and Environment. All the evaluated Services and their respective Use Case are listed in Table 39. All the details concerning the evaluation and assessment activities in Italy can be accessed in [RD.10]. A synthesis of these activities is reported hereby.

Table 39 - Day-1 and Day 1.5 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)
Navigation Information	Parking Information
	Smart Routing

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 and Autostrada Brescia Padova. In C-Roads Italy 2, Use Cases were tested in urban environment, in the cities of Torino, Trento and Verona. 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 were estimated.

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.

KPIs = REACTION x EFFECTIVENESS x 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 636 persons 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 contributes to the C-Roads cooperation with findings from the implementation and operation of several C-ITS use-cases. They are deployed in five different pilot sites, two pilot sites (Hessen and Lower Saxony) in the first C-Roads phase and three pilot sites (Hamburg, Hessen-Kassel and Dresden) in the second C-Roads phase, and they are 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 (C-Roads phase 1)

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

A description of the evaluation activities in the second C-Roads phase is provided below:

Pilot Hamburg

Within the pilot Hamburg, existing C-ITS Day 1 services are extended and further C-ITS services in the Free and Hanseatic City of Hamburg are implemented. It is closely linked to the ITS strategy of the state administration.

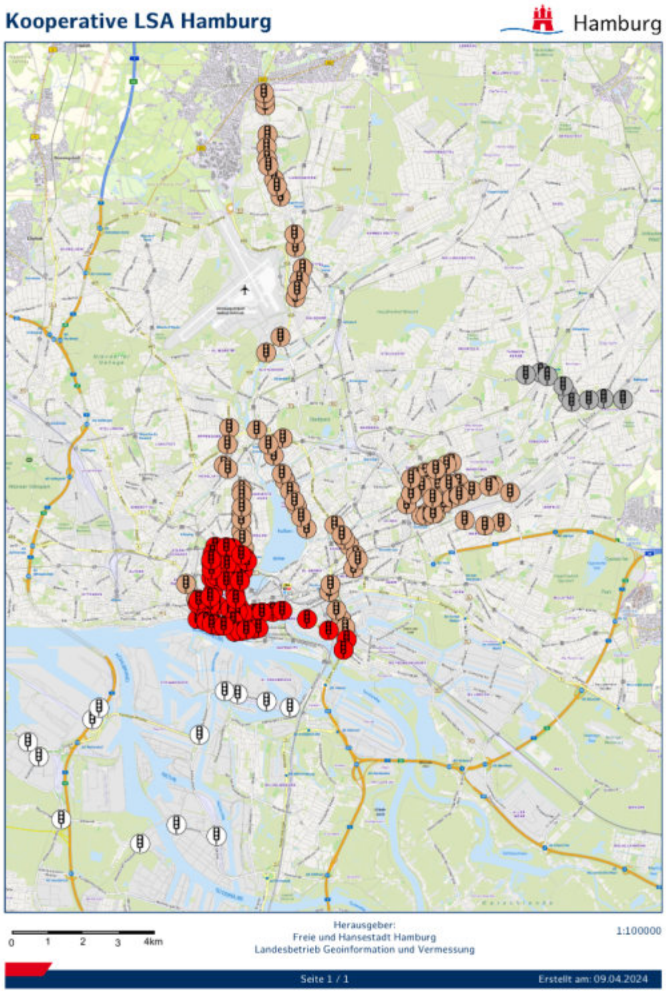


Figure 6 - Overview RSU (Roadside ITS Stations) equipped traffic lights in Hamburg

The pilot Hamburg has successfully implemented the GLOSA Service (Green Light Optimal Speed Advisory) at the test track for automated and connected driving, operational by the end of June 2021. As an open test track, the pilot characteristics allowed for the incorporation of multiple feedbacks to improve the service according to the actual user needs. On a broad spectrum of different intersections, connected cars are supported by the C-ITS messages MAPEM and SPaTEM, including intersection topology as well as actual and prognosis of upcoming traffic light states. By Spring 2024, 180 intersections had been equipped with ITS-G5 technology (Figure 6). The operating status of the RSU can be monitored via the central ITS station. The second Day 1 service implemented in the Hamburg pilot is PVD (Probe Vehicle Data). The service is deployed at the test track for automated and connected driving. The third Day 1 service implemented is TLP (Traffic Light Priority), implemented on the test track of the BiDiMoVe project (Bidirectional multimodal networking). BiDiMoVe uses the message formats (SREM/SSEM), specially

developed for prioritization requirements with multi-criteria prioritization (schedule position, occupancy level, competing requests), with ITS-G5 technology.
Furthermore, VRU (Vulnerable road user protection at intersections) was implemented as a fourth C-ITS service and was operational by the end of March 2024. This service will be evaluated at a later date.

Pilot Hessen-Kassel

The pilot Hessen/Kassel focuses on the development and the improvement of the C-ITS infrastructure in the Federal State of Hessen and the City of Kassel by extending the existing services (Day 1) and by implementing new C-ITS services (Day 1 and Day 1.5). The test site Hessen/Kassel consists of the 'Digital test site for connected driving Kassel' in the northern part of Hessen and the 'Test Field Germany for connected and automated traffic' in the southern part of Hessen around Frankfurt am Main.
In detail, for the transport network in the city of Kassel the services Traffic Light Priority (TLP) for public transport vehicles (operational since 30.09.2023) and Green Light Optimal Speed Advisory (GLOSA, operational since 31.12.2021) were extended. The services Road Works Warning (RWW, operational since 31.12.2022) and Probe Vehicle Data (PVD, operational since 31.12.2022) were newly implemented. The service Connected and cooperative navigation into and out of the city (Route Advice) is also currently being implemented and will be operational by 15.08.2024.
The upgrade and expansion of the infrastructure through ETSI ITS G5 communication (by e.g. deployment with 75 C-ITS capable traffic lights in the test field of Kassel and 10 Roadside ITS Stations in the interurban area of Kassel and the Rhine-Main region), interfaces and system components such as a Public Key Infrastructure (PKI) were necessary in the course of the roll-out of the services within the pilot.
The impacts of the Day 1 and Day 1.5 services in the test site Hessen/Kassel were evaluated after the implementation of the services. The evaluation areas in scope for the pilot were assessed based on the recommendations provided by the C-Roads WG3 "Evaluation and Assessment Plan" (milestone M9, version 1.2). In parts these are impacts that are triggered by the road users' traffic behaviour as response to C-ITS service implementations. As the diffusion of a relevant number of road users driving C-ITS equipped vehicles has not yet been reached, the impact on a macro level cannot be measured. An estimation of the overall impacts based on single vehicles in this pilot is deemed not essential. In absence of larger numbers of C-ITS equipped vehicles that could make e.g. roads safer, traffic smoother and more reliable as well as mobility in general more environmentally friendly (i.e. make an impact on policy measures), the focus of the evaluation is on a functional evaluation and in parts also on quality aspects.

Pilot Dresden

In the Dresden pilot, there exists an established network on the C-ITS topics of connected and automated driving between Fraunhofer IVI and the local stakeholders, including the City of Dresden and the State Office for Roads and Traffic of the Free State of Saxony. In close cooperation with the latter two authorities, Fraunhofer IVI plays currently the key role in the specification, procurement, installation, operation and maintenance of the Dresden pilot's network of Roadside ITS stations. As part of the activities within the C-Roads Germany Urban Nodes initiative, the existing Day 1 use cases are extended and new Day 1.5 use cases are deployed. In detail, these are the applications GLOSA (operational since 30.09.2020), PVD (operational since 31.12.2020), TSP (operational since 31.03.2021), EVA (operational by 30.06.2022), and VRU (operational by 31.12.2021). Furthermore, the

existing corridors are extended by additional Roadside ITS stations (up to 25 ITS-G5 capable intersections planned), two of which are accompanied by additional sensors (e.g. standard and thermal cameras), as well as back end systems.
Fraunhofer IVI is directly involved in the ETSI standardisation work and additionally, implements and tests ETSI standard C-ITS facilities in co-operation with industry partners and develops new and enhanced C-ITS facilities.
As previously assumed, there were not enough C-ITS enabled vehicles available by the end of 2023 to see large scale effects of the implemented services. Therefore, the evaluation activities mainly concern the aspects of functional evaluation as well as user acceptance tests, wherever appropriate. Nonetheless, for example for the GLOSA service some socio-economic impacts can be estimated by using traffic simulation based on real world measurement data, e.g. gained through the PVD service.

An overview of the C-ITS services evaluated in the three pilot sites of the second C-Roads phase is provided in Table 42.

Table 42 - Overview of use cases evaluated in the pilot sites Hamburg, Hessen-Kassel and Dresden (C-Roads phase 2)

Use Case	Pilot Hamburg	Pilot Hessen-Kassel	Pilot Dresden
EVA	---	X	X
GLOSA	X	X	X
PVD	X	X	X
Route Advice	---	X	---
RWW	---	X	---
TLP	X	X	X
VRU	---	---	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 43.

Table 43 - 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 44 - 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 45. 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 45 - 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.

4.13. Greece

The impact assessment and evaluation of the C-ITS services in the Greek pilot was associated with user acceptance, real-life logs collected from the two pilots, and simulation experiments that were conducted for the services.

User acceptance was evaluated through the development and distribution of questionnaires to the users of the C-ITS services, i.e., drivers having access to the services via a mobile application and road operators having access to the services via the TMC emulator software, which was developed by CERTH. The questions included in the questionnaires were related to personal information, to driver profile, to the general expectations of the C-ITS services, such as traffic efficiency, road safety, environment, to expectations of each C-ITS service, and to the usefulness and user friendliness of the software for the road operators. The objective of the questionnaires was to assess the expectations of the users regarding the use of the C-ITS services as the answers were received prior to the launch of the C-ITS services.

Concerning real-life logs, the amount of data for the pilot period was not high enough, to extract evaluation results. For this purpose and to collect more logs, the pilot period was extended after the end of August 2022. This way extra logs were collected, and it was possible to calculate indicators for the services evaluation.

Finally, simulation experiments were conducted to assess the C-ITS services and generate results indicating their impacts. Simulation experiments were conducted for both pilots, Attica Tollway and Egnatia Tollway, and for various demand scenarios (number of vehicles in the network). The resulting indicators included traffic measures, such as average vehicle speed, travel time, safety number, such as collisions, and environmental factors, such as CO_2 emissions.

4.14. Ireland

Transport Infrastructure Ireland (TII) is implementing a European Commission co-funded national pilot across approximately 355km of the trans-European transport network (TEN-T) that connects Dublin with Cork, Limerick and Northern Ireland. The pilot is delivering 14 C-ITS use cases, representing a mix of Infrastructure-to-Vehicle (I2V) and Vehicle-to-Vehicle (V2V) services, including some urban specific applications in Dublin (see Figure 7).

The connected vehicle services are being fully integrated into TII's live traffic management system, being one of only a small number of Member States to achieve this. The pilot is currently in its implementation/data acquisition phase, with numbers of participants growing to a target level of approximately 1,500. The pilot will run until December 2024.

A key objective of Ireland's Cooperative Intelligent Transport Systems (C-ITS) pilot project is to understand how road operators can harness a paradigm shift in traffic management operations through increased vehicle connectivity.

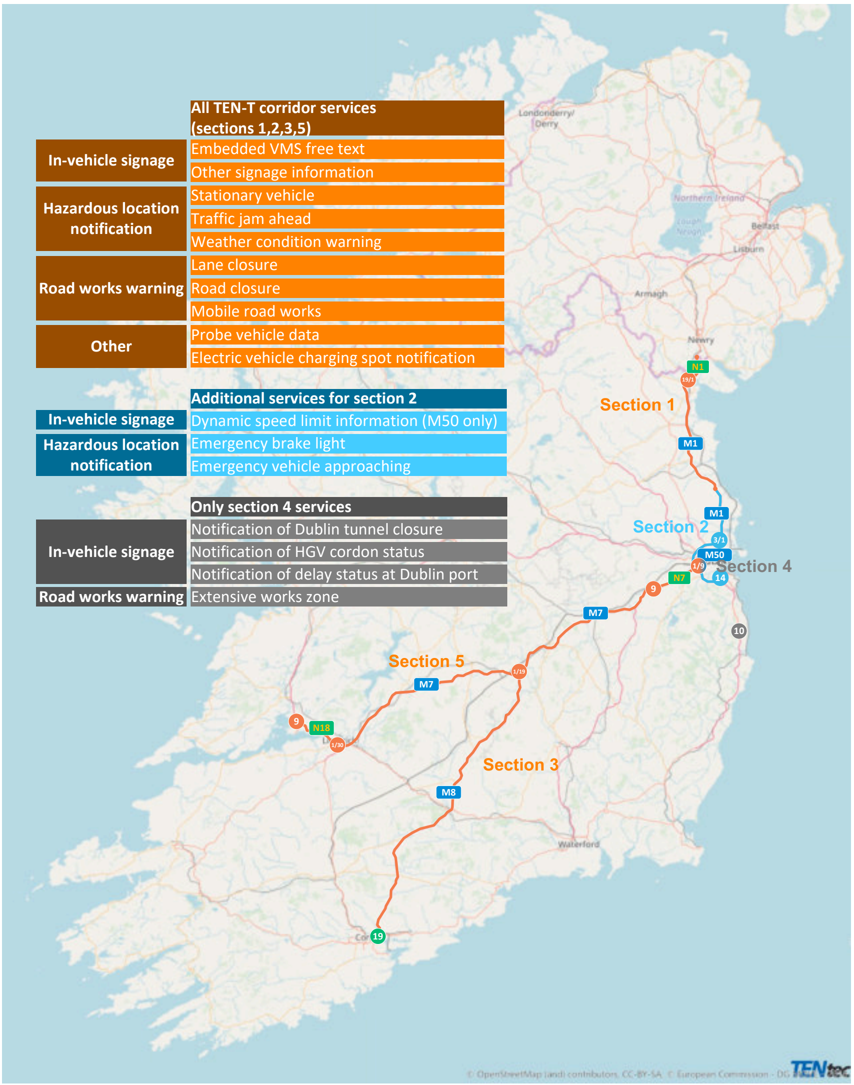


Figure 7 - C-ITS pilot use cases and route sections - Ireland

The C-Roads working group approach to evaluation and assessment was followed and impact areas of safety, traffic efficiency, environment, user acceptance and functional evaluation were assessed. However, given that the project remains in the data acquisition phase (the end date for the pilot is December 2024) only some aspects of the evaluation have been prepared and inserted as interim analysis in to this report.

This report contains the following contribution from Ireland:

- **Traffic efficiency** – output from microsimulation modelling activities to assess the impact of C-ITS at different levels of market penetration. The road works warning – lane closure and hazardous location notification – stationary vehicle uses cases were assessed.
- **Environment** – linked to the microsimulation model, a Bosch instantaneous emissions modelling Vissim add-on was used to assess emissions at fdifferen levels of C-ITS market penetration.
- **User acceptance** – a description of the profile of pilot participants is provided along with an assessment of their expectations of C-ITS services.
- **Functional evaluation** - in the context of this pilot covers a number of distinct aspects based on the real-world performance of the Road works warning – lane closure and Hazardous location notification – traffic jam ahead C-ITS use cases, as delivered into the vehicle.

4.15. Portugal

C-Roads Portugal consists in the deployment of five C-ITS testbed pilot cases in the Atlantic Corridor in Portugal, covering relevant sections of the core and comprehensive networks, two urban nodes and two cross border sections, aiming to contribute to the "C-Roads Platform"' technical specifications development and to demonstrate the potential for swift deployment of a large-scale Portuguese C-ITS network.

Several of C-Roads Portugal pilots target the interoperability and harmonisation of the EU commonly agreed "Day 1" and "Day 1.5" services, to show the maturity and to evaluate the impact and acceptability of these services, by mass deploying them along the Portuguese road network. Other pilots intend to create new use cases and concepts for a better traffic and infrastructure management by means of optimization.

In terms of impact evaluation efforts were concentrated in the **Pilot 2: "Portuguese network for C-ITS"** which comprised the installation of Day 1 and Day 1.5 C-ITS Services across around 460km in length, divided among motorways, borders, tunnels, and entrance in urban nodes. Several interoperability tests, and a total of 116 RUS and 54 OBU and security infrastructure have been deployed. Moreover, C-ITS deployment has been piloted as well as in Túnel da Gardunha (A23) implying the development and installation of technologies and services inside and outside a road tunnel, to collect critical data and events from the tunnel itself and from vehicles, and to disseminate such information in form of alerts for drivers approaching the tunnel.

Day 1 Services tested
1. Slow or stationary vehicle(s)
2. Traffic jam ahead warning
3. Hazardous location notification
4. Road works warning
5. Weather conditions
6. In-vehicle signage
7. In-vehicle speed limits

Day 1.5 Services tested
1. Off-street parking information
2. Traffic information & smart routing

C-Roads PT evaluation & assessment focus covers the following areas

Table 46 - C-ROADS PT evaluation areas and their coverage and priority

Area	Priority
User Acceptance	++
Safety	++
Traffic Efficiency	++
Environment[5]	+
Organizational	
Socio-economy	++
Technical	++

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

4.16. Queensland/Australia

Queensland Department of Transport and Main Roads (TMR) delivered the Ipswich Connected Vehicle Pilot (ICVP) which is the largest Field Operational Trial (FOT) of C-ITS in Australia to date. The pilot tested the performance of C-ITS technologies, produced positive safety results, positive user experience and positive perceptions of the technology. This pilot was delivered by TMR, supported by the Motor Accident Insurance Commission, Queensland University of Technology (QUT), iMOVE Australia, Telstra, Ipswich City Council, and the Department of Infrastructure, Transport, Regional Development and Communications.

To understand the impacts and gather public perspectives of the technology, the ICVP ran between September 2020 and September 2021, involving 355 public participants in Ipswich driving their own vehicles retrofitted with C-ITS technology for a period of nine months. The pilot included a centralised cloud-based service covering 300 square kilometres of road network and 29 TMR-owned signalised intersections in Ipswich, Queensland, Australia.

Safety information was shown on the HMI only when relevant to the driver (except for in-vehicle speed [IVS], which was always shown).
For example, drivers were shown advanced red-light warnings only if they were driving too fast to stop at an upcoming traffic light (see Figure 2). If the driver was driving at a slower speed, they did not receive this safety warning.

ICVP was based on use cases developed prior to the creation of C-Roads and therefore do not map to the C-Roads service/use case conventions. However, an approximation is listed in Table 47. Two (2) use cases were delivered using short-range ITS-G5 communication while four (4) use cases were delivered using long-range 3G/4G cellular connectivity. A simulator was also used to capture driving data for vehicle-to vehicle (V2V) warnings, where the interaction of two connected vehicles could be guaranteed.

For a detailed specification of ICVP's deployment and the use case operation, refer to the Technical Publications ICVP site: https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Ipswich-Connected-Vehicle-Pilot

Table 47 - ICVP Use Cases

ICVP Use Case	C-Roads Equivalent Use Case	Communications Method
Advanced red-light warning (ARLW)	SI-ISV	ITS-G5
Turning warning vulnerable road user (TWVR)	Not aligned yet	ITS-G5
Road works warning (RWW)	RWW service	Long-range 3G/4G cellular
In-vehicle speed (IVS)	IVS-TS (speed signs only) and IVS-DSLI	Long-range 3G/4G cellular
Road hazard warning (RHW)	HLN service	Long-range 3G/4G cellular
Back of Queue warning (BoQ)	HLN-TJA	Long-range 3G/4G cellular
Slow/ stopped vehicle (SSV)	N/A – V2V use case	Simulation
Emergency electronic brake light (EEBL)	N/A - V2V use case	Simulation

The methodology and outcomes for the safety evaluation and user acceptance are detailed in Appendix A. As the simulation study does not include infrastructure use cases, it has not been included in detail here, however, this report can be found at https://imoveaustralia.com/project/project-outcomes/ipswich-connected-vehicle-pilot/

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,the Czech Republic, and Greece.

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/s^2)
- 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 48 - 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 49below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 49 - 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[6], 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[7].

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[6] Note: This adapted method was applied to all use cases evaluated by the UK.
[7] 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.

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 8), 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

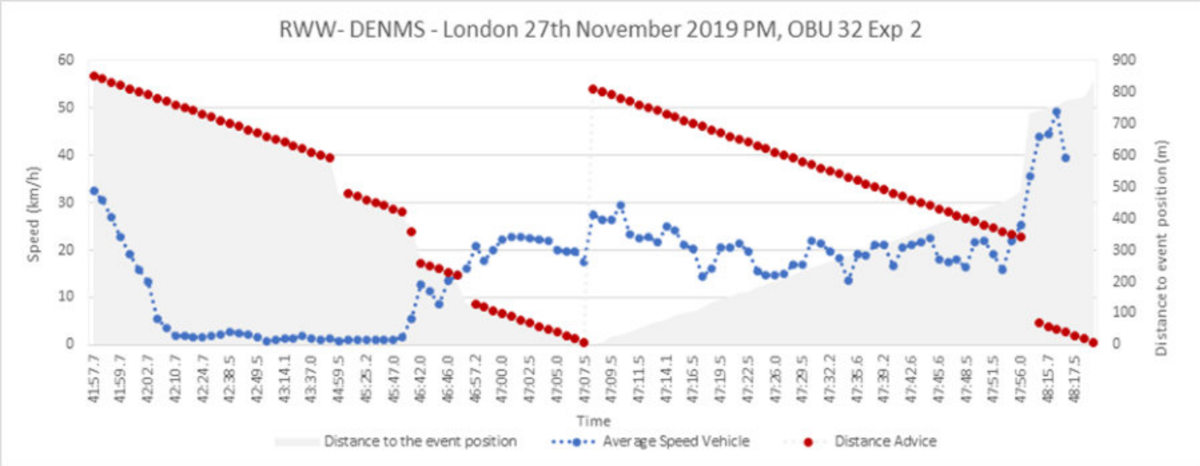


Figure 8 - Comparison of Distance advice and average vehicle speed

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 50 below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 50 - 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 51below was the main KPI;
- Subjective impact data from user surveys on the influence of the service on the driver behavior.

Table 51 - 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.

Co-funded by the European Union

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 – KPIs on Mobility

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

C-Roads Italy evaluated the Use Case Roadworks Warning – Lane Closure in two different context: along the highway and in urban environment. These two cases are described separately.

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure (on Highway)

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

Then, 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 52 - 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/s^2]	0,163	0,111	-0,052	-32%
Max instantaneous deceleration [m/s^2]	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 53 - 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/s^2]	0,442	0,698	+0,257	+58%
Max instantaneous deceleration [m/s^2]	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 54.

Table 54 - 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%

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure (urban environment)

Evaluation method

The objective was to analyze driver behavior in the presence of real roadworks involving lane closures on urban roads. The goal was to compare how drivers respond to lane closure warnings with C-ITS (C-ITS ON) and without C-ITS (C-ITS OFF), focusing on the distance at which lane change maneuvers were initiated. 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.

The test was performed on Via Botticelli, Turin, involving three roadwork sites along 1.5 km road between Piazza Derna and Piazza Sofia.

Data collected

The following data were collected during the testing session:

- vehicular logs of the involved vehicle, containing instantaneous and continuous information on positioning, vehicle dynamics and road information (see paragraph 3.2 for an accurate description of the log contents);
- additional vehicular logs including data specific to the RWW - LC service/use case: in particular, the reception of C-ITS message about the presence of a construction site with a closed lane and the distance between the vehicle and the start of the construction site;
- sheets completed for each experiment, containing annotations for each single repetition regarding the macro-behavior of the vehicle at the traffic light, any technical anomalies experienced, etc.;
- traffic flow data recorded by City of Turin/5T in different sections of Via Botticelli during the day of the test, with a sampling interval of 15 minutes.

Evaluation results – Field tests

With the C-ITS ON configuration and receipt of the RWW - Lane Closure message, the driver seemed able to anticipate the start of the lane change maneuver earlier (-33 meters) while maintaining higher speeds (within limits) and having a shorter travel time, operating with greater situation awareness. This behavior can potentially provide safety and traffic efficiency/fluidity benefits.

Table 55 - RWW-LC - Field test KPIs

C-ITS status	Maneuver start distance [m]	Maneuver start speed [km/h]	Lane closure passage speed [km/h]	Difference maneuver start time – lane closure passage time [sec]
OFF	-129	17	25	40
ON	-161	21	32	29

However, the results should be considered with caution due to:

- Technical issues receiving messages at one construction site and recurrent queues near another site limiting the number of valid experiments and statistical validity.
- High traffic volumes often limited maneuvering spaces and decision-making regardless of prior construction site knowledge, suggesting greater benefits may be seen with less excessive urban traffic levels (though requiring further testing).

Nevertheless, even from driver impressions, the value of this Service/Use Case in terms of perceived awareness and knowing potential hazardous situations in advance was confirmed not only on motorways but also in urban contexts: construction sites were approached more consciously, even when heavy traffic/queues limited the driver's decision space and maneuvering options.

Co-funded by the European Union

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. Greece

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The evaluation of the service included the performance of simulation experiments for the estimation of the safety related KPIs number of lane changes and number of collisions.

The simulation experiments were executed in the SUMO software which is an open source, highly portable, microscopic, and continuous multi-modal traffic simulation package designed to handle large networks.

The methodology for the service simulation relied on the implementation of a traffic management strategy, a Long Term Evolution data communication network to route V2X data communications, and Cooperative Awareness Messages (CAMs) that ensure communications among C-ITS enabled vehicles by exchanging continuously data packets with information such as location, speed, etc. Moreover, the acquired information was integrated to infrastructure through a Traffic Control Server (TCS) that generates proposed messages which are taken over by the infrastructure and transmitted to vehicles via V2I communications. As CAMs indicate abrupt deceleration or sudden stop of the transmission of messages could suggest to the TCS that a crash or a hazardous incident has taken place. Finally, when the TCS detected such a conflict, it distributed the corresponding messages to the vehicles.

A traffic management logic was developed for modelling the Traffic Control Server as well as the drivers' responses to warning messages using the microscopic traffic simulator SUMO. The traffic management strategy is presented in the flowchart of the following figure.

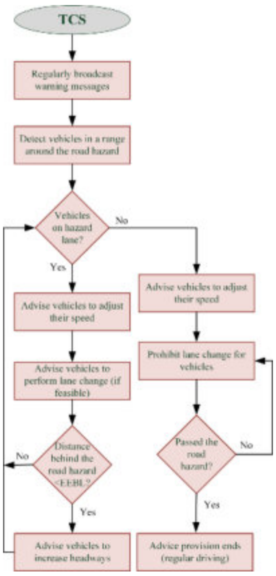


Figure 9 - Flowchart of the traffic management strategy

First, when the TCS detected that a crash had occurred, it regularly sent RHW messages to all vehicles in predefined influence zones through broadcast communication. At this point it is important to highlight that the driver's response to the traffic conflict depends on the type of information that is provided by the TCS, as well as on the location of the C-ITS enabled vehicles regarding the road hazard and the other implicated vehicles of the considered network. Taking the above into consideration, it was assumed that the vehicles were grouped to drive in specific zones, hence the behavior of a vehicle would be defined with respect to the zone or zones in which it belonged.

Figure 10 - Presentation of the network zones

Vehicles which traveled on the hazard lane and entered the dangerous zone received an RHW message to adjust their desired speed as well as to try to change lane at every time step, if feasible. Next, vehicles that drove in the near crash zone received an Emergency Electronic Brake Light (EEBL) warning to inform drivers that a vehicle in front may crash or brake abruptly and therefore the drivers were advised to increase their headways appropriately via a newly developed open-gap function, to avoid a collision. Briefly, this gap control mechanism, facilitated the creation gap between two specific subsequent vehicles and had been modelled to increase the desired time headway of the following vehicle, and determined the minimum space headway that must be maintained between the two vehicles for a predefined duration. Regarding the EEBL, the TCS decided to which vehicles an EEBL warning would be sent.

On the other hand, vehicles that traveled in a lane different than the hazard one pertained to the safe zone. These vehicles were advised to reduce their desired speed with respect to the speed limit of the freeway, whereas they were concurrently restricted from entering the hazard lane. Finally, after passing the conflict area, vehicles' speed and lane change operation were no longer under the control of the TCS. Thus, vehicles that had received no information from the TCS were considered to belong in the standard zone; the behaviour of drivers in this state was entirely determined by the default car-following (Krauss) and lane change (LC2013) model implemented in SUMO.

The abovementioned methodology was applied for all the uses cases of the Greek pilot which were examined.

Data collected

For the purposes of the execution of the simulation experiments, the data considered and introduced in the simulation environment included the following:

- Actual traffic demand (based on collected traffic volumes) in Egnatia Tollway pilot equal to 500 vehicles.
- Attica Tollway pilot maximum capacity equal to 4500 vehicles.
- Assumption of high C-ITS penetration rate in Egantia Tollway pilot equal to 1500 vehicles.
- In the C-ITS Scenario the vehicles' speeds drop down to 0,8 500m upstream and to 0,6 when entering the edge where the event is located (speed decreases smoothly).
- In the manual scenario the vehicles' speeds drop down to 0,6 150m upstream.

Evaluation results - Field tests

Concerning the evaluation results, these rely on the outcomes of the experiments conducted in the simulation environment.

Regarding the experiments executed in the Attica Tollway network, the number of vehicles used in the simulation experiment was around 4500 and is presented in the figure below (throughput).

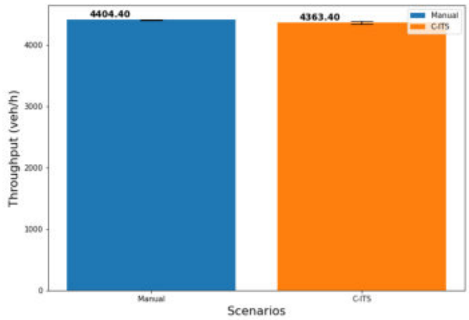


Figure 11 - RWW-LC throughput for manual and C-ITS scenario

The number of lane changes decreased in the C-ITS scenario. This could be justified by the fact that drivers are aware in advance about the closed lane ahead, hence they can adjust their driving behavior timely, and they don't need to perform any sudden changes, such as many lane changes.

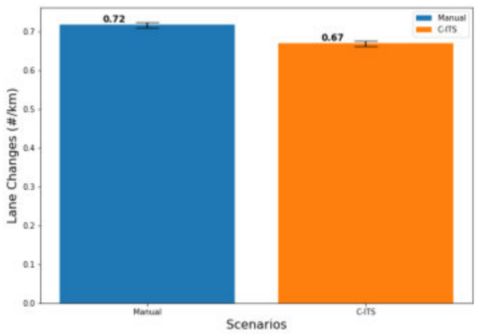


Figure 12 - RWW-LC lane changes for manual and C-ITS scenario

The number of collisions was *reduced significantly at the C-ITS scenario, indicating that drivers have a more attentive driving behavior due to the C-ITS message provision, contributing this way to road safety increase.*

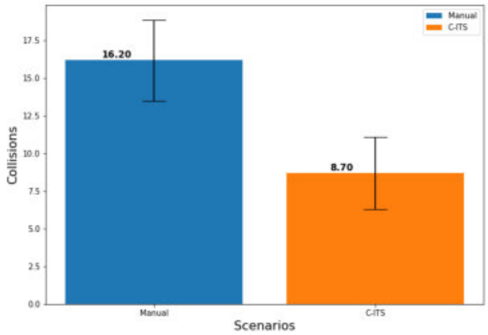


Figure 13 - RWW-LC collisions for manual and C-ITS scenario

The same use case was tested for Egnatia Odos Tollways. In the C-ITS scenario the vehicles' speeds drop down to 0,8 500m upstream and to 0,6 when entering the edge where the event is located (speed decreases smoothly). In the Manual scenario there are no interventions. The number of vehicles used in the simulation was around 500 for the baseline scenario, both for C-ITS and manual scenario, and around 1200 for the high C-ITS penetration scenario respectively, both for C-ITS and manual scenario. The throughput is presented in the figure below.

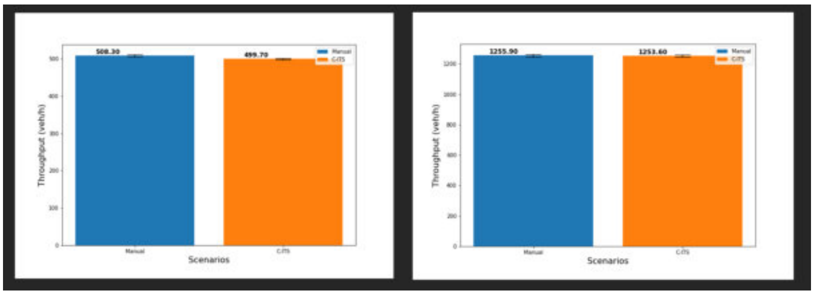


Figure 14 - RWW-LC throughput for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

The number of lane changes has increased in both scenarios (500 and 1200 vehicles) in the case of the C-ITS scenario. However, the increase is very low for the high C-ITS penetration rate scenario (1200 vehicles). The significant increase in lane changes in the case of the baseline scenario could be justified by the fact that in the C-ITS scenario vehicles are advised timelier about the lane closure compared to vehicles in the manual scenario, hence drivers are aware in advance about the event and try to avoid it earlier by performing more lane changes.

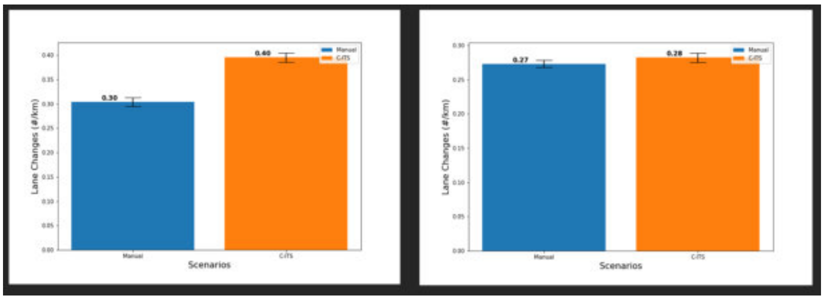


Figure 15 - RWW-LC lane changes for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

5.1.9. Portugal

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Tests were performed in November 2021 in IC17 (CRIL) from Algés to Expo'98 site in an extension of 18,5 km. Round trip, Hybrid services.
Random selection, all vehicles equipped with C-ITS, half with the system on , the other half with the system off. Users were not aware of such situation.
Tests started around 23h and last until around 2 am. There were no issues regarding road conditions, apart from the planned roadworks that imposed the selection of the day to perform tests in real situation,
Road works occurring before the entrance to the Grilo tunnel. The tests were conducted at night to benefit from the planned road works. Along this road traffic is more or less constant across the different periods of the day and night.
During the tests roadworks were planned. This included the closing of a lane. Decreased speed limit is not imposed.
The following data was collected during the tests:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data (m/s2 – resolution 1Hz)
- Time between the reception of the C-ITS message in the vehicle (T0, the presentation on the HMI is in most relevant cases directly linked to it) and the arrival at hazardous location position (T1) – source: C-ITS device, Can Bus data or GPS data (s)
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device

Data collected

20 cars involved in tests with regular drivers. All drivers have received guidance to drive normally, respecting the speed limits of the road and were not aware if their vehicle was equipped with the C-ITS on or off.
RWW-LC and HLN-SV were tested under real conditions, with effective works occurring close to "Tunel do Grilo" (between km 14.7 and km 17,1) closing one lane.

Evaluation results – Field tests

Given the small number of OBUs, the impact of the connected vehicles was low and therefore difficult to detect and evaluate. In order to estimate the potential impact of the connected vehicle for different degrees of penetration, a simulation / modelling environment with VISIM has been performed. Starting from the observed results as baseline, penetration rates of 10%, 25%, 50%, 80% and 100% have been modelled, upon which the main conclusions are taken.

The analysis of data collected is sometimes inconclusive, the on/off difference do not change significantly, and it is difficult to understand if results are affected by other contextual factors. In general, for most of the drivers (particularly test group) there were cases where driver was already in deceleration before the RWW message but with the message increases its deceleration rates; other cases where the driver was accelerating and in face of the messages, decelerates. For RWW-LC, such inconsistencies were not so accentuated as for other services tested, with soft deceleration and early start of manoeuvres.

With C-ITS ON the maneuver starts earlier and the vehicle can change lane due to a lance closure with an improved safety margin. With lower penetration rates, and particularly when those rates are at 10% and 25%, the speed is substantially reduced compared with the speed limit, creating queue that in average for the section is 70 meters.

5.1.10. 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 use case RWW-LC in the highway environment 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%).

The value of this Use Case in terms of perceived awareness and knowing potential hazardous situations in advance was confirmed also in urban contexts, even if with more restrained impacts.

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 56.

Table 56 - 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%

Similar estimation in **Portugal** showed that with 100% penetration, the C-ITS could contribute to less 40 accidents with victims and to save human lifes, 4 serious injuries and 55 injuries.

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 57, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

Note that in Table 57, 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 57 - 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 58 - 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.

5.2.3. Italy

C-Roads Italy evaluated the Use Case Roadworks Warning – Lane Closure in two widely different context: along the highway and in urban environment. These two cases are described separately.

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure (on highway)

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)

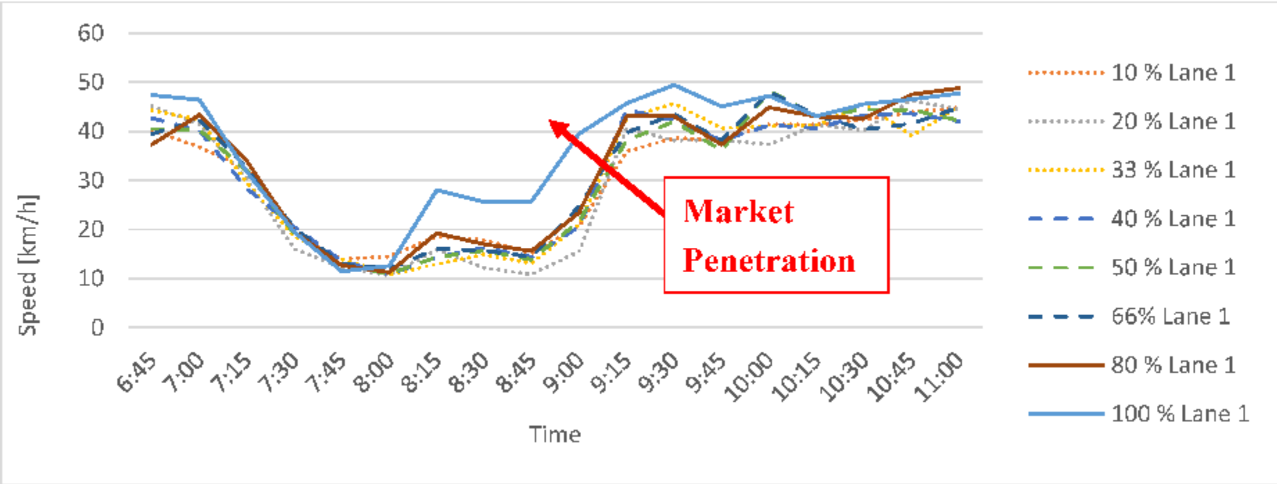
- the traffic volumes on the downstream segment of the Friday in March.

Evaluation results – Field tests

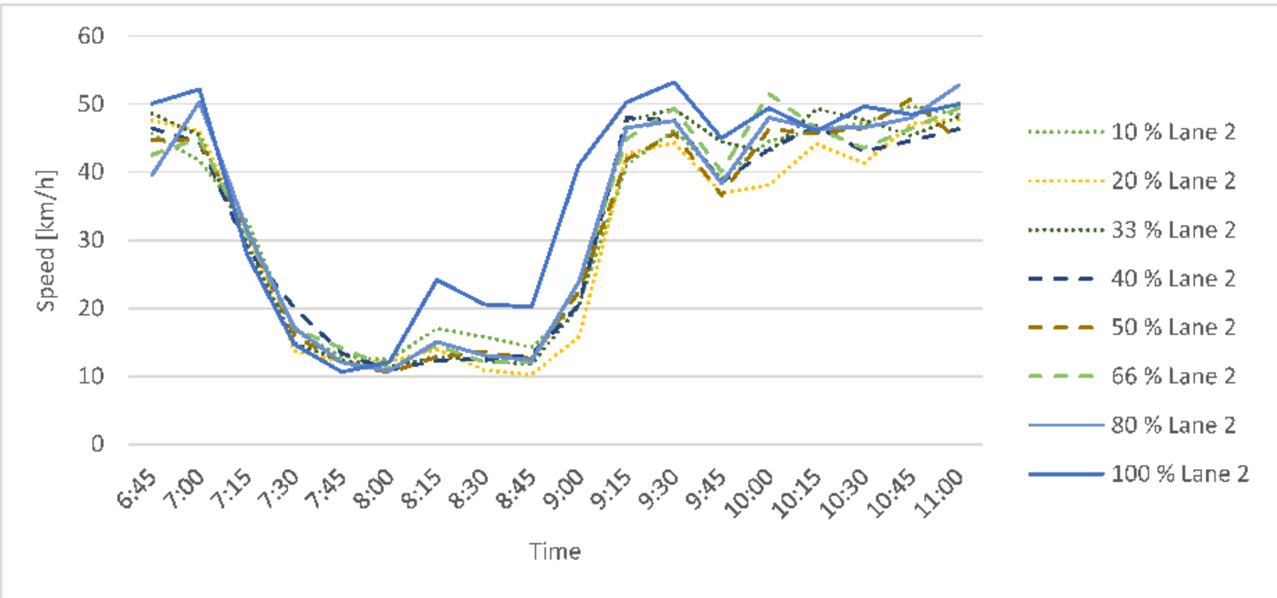
The aim of this analysis was to evaluate the possible impacts arising from the implementation of the use case roadworks warning - closure of a lane on the Italian highways through microsimulations.

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.

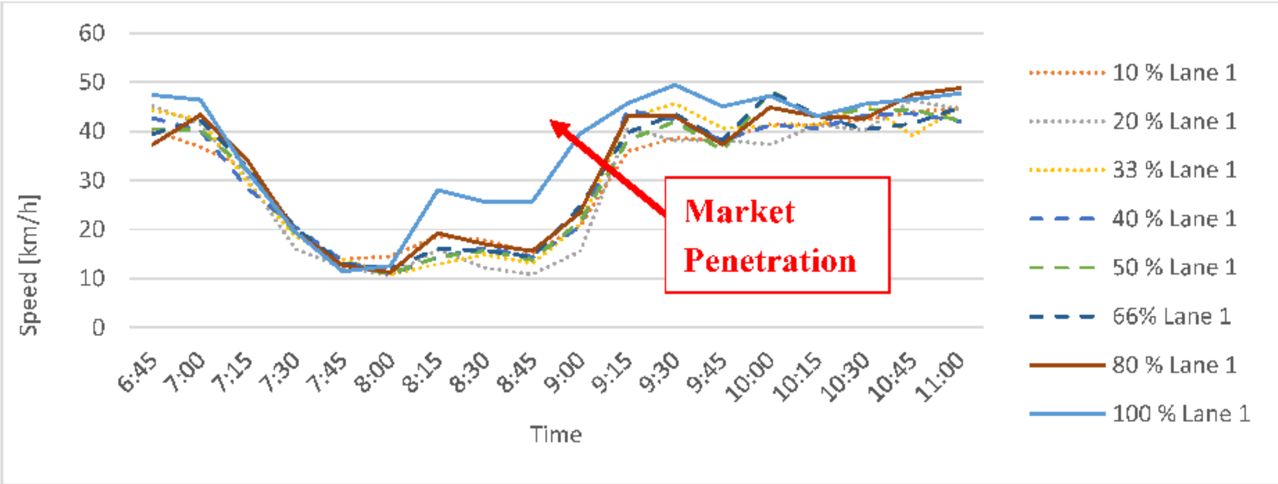
By comparing Figure 16 a and b, it was interesting to note how, on lane 1 (the closed lane), a positive trend arises with the increase of market penetration. In this case, in fact, for an increasing number of connected vehicles among the traffic flow, the speed for most of the simulation time increased 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.


60
50
40
30
20
10
0
Speed [km/h]
6:45
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
Time
Market Penetration
10 % Lane 1
20 % Lane 1
33 % Lane 1
40 % Lane 1
50 % Lane 1
66% Lane 1
80 % Lane 1
100 % Lane 1

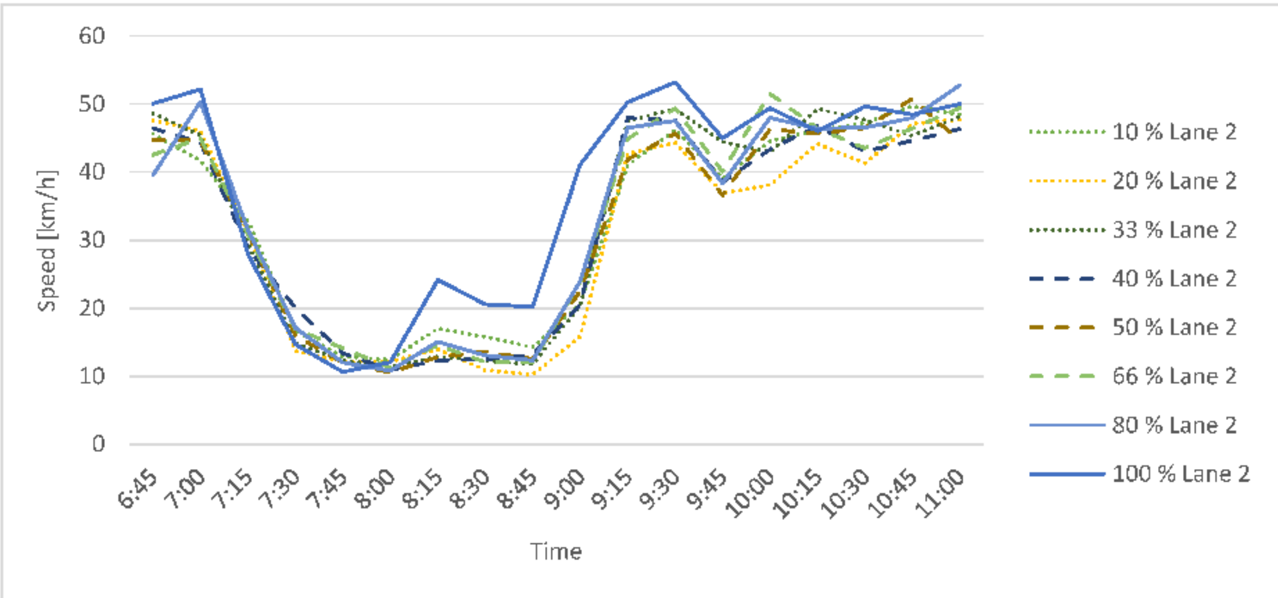
(a)


60
50
40
30
20
10
0
Speed [km/h]
6:45
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
10:15
10:30
10:45
11:00
Time
10 % Lane 2
20 % Lane 2
33 % Lane 2
40 % Lane 2
50 % Lane 2
66 % Lane 2
80 % Lane 2
100 % Lane 2

(b)



(a)



(b)

Figure 16 - Driving speed 200 m upstream the lane closure: (a) slow lane and (b) fast lane.

Figure 17, 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.

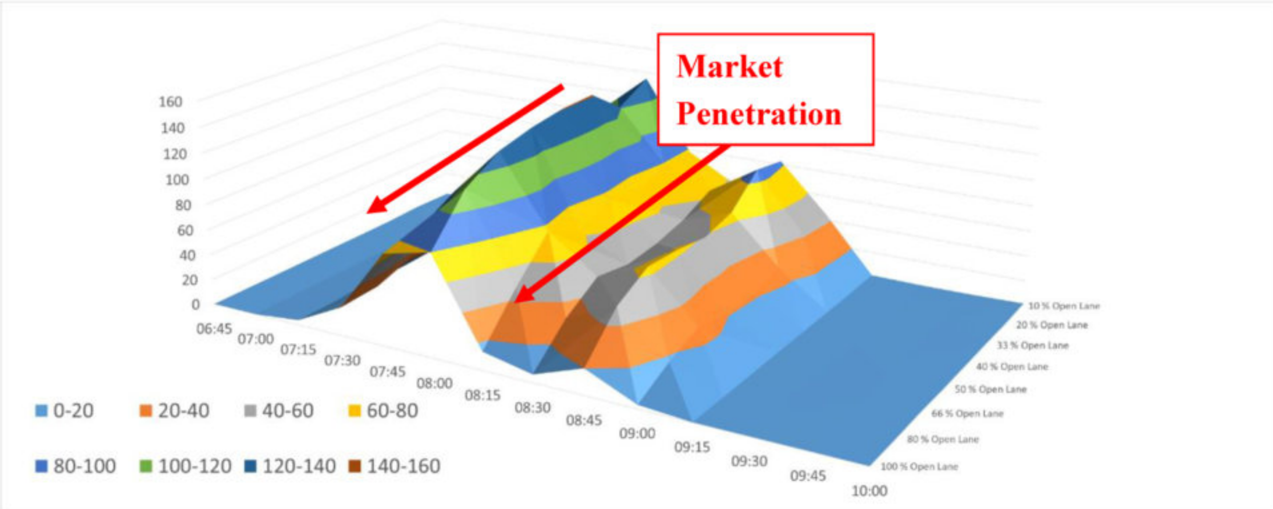


Figure 17 - Time in queue (s) on the open lane.

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 18.

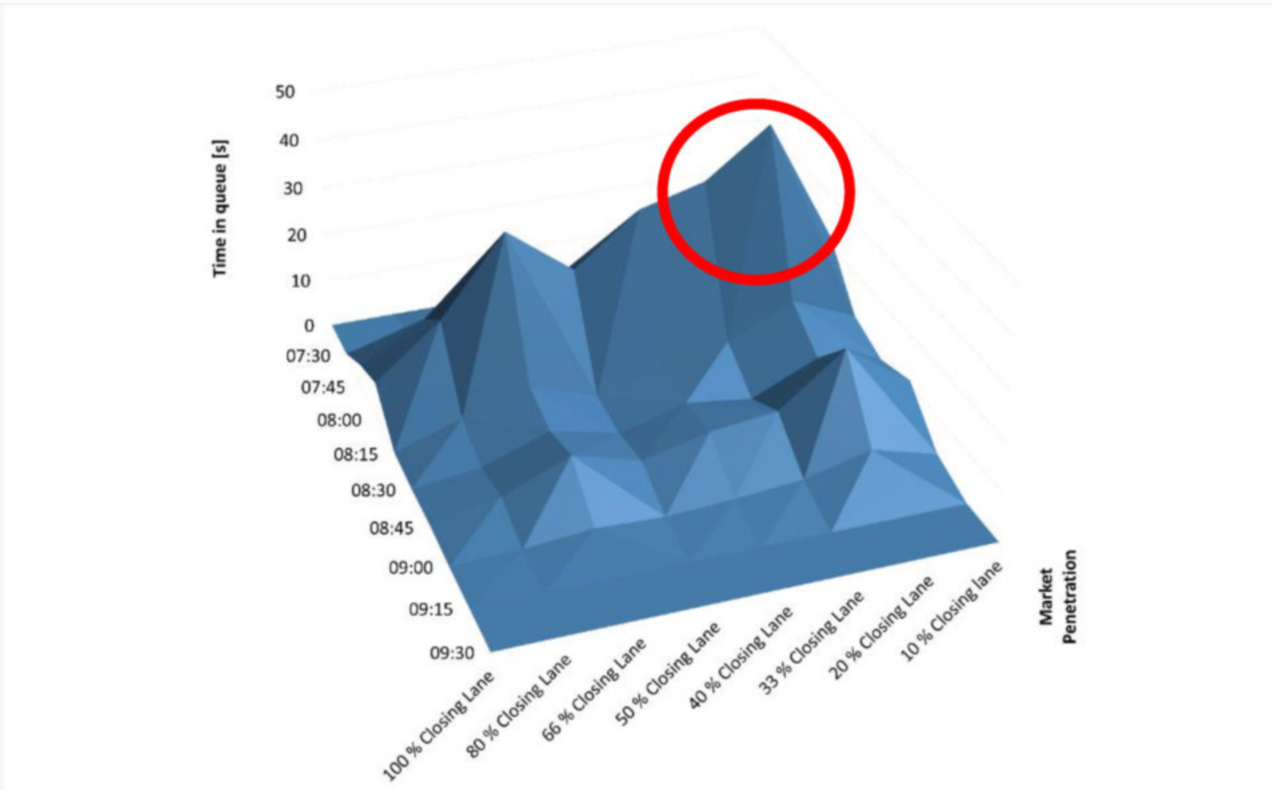
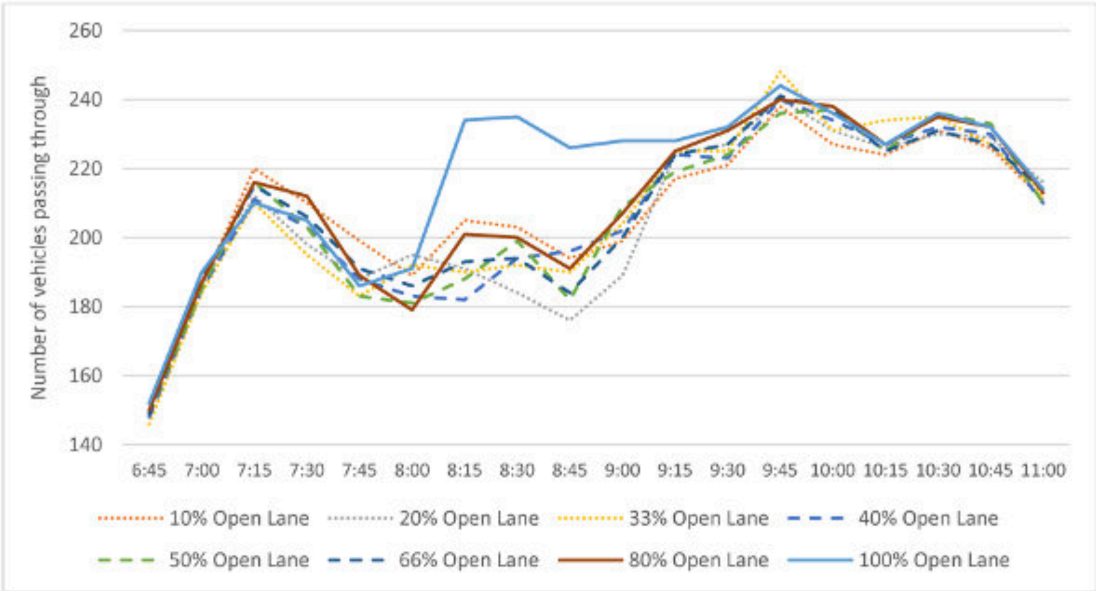


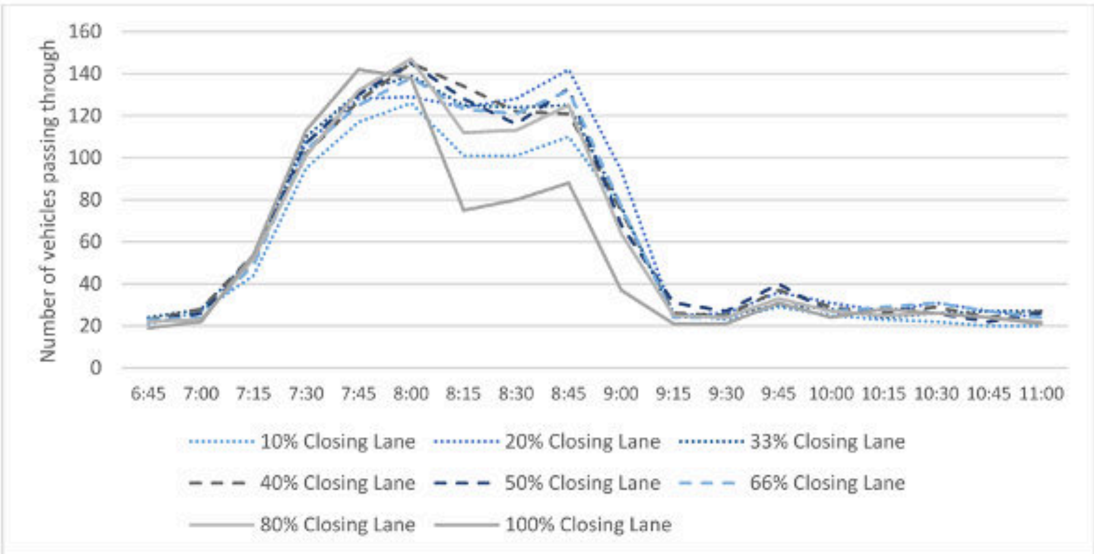
Figure 18 - Time in queue on the closing lane.

In fact, as it can be noticed from Figure 18 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.

The analysis of Figure 19 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.



(a)



(b)

Figure 19 - 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 20). 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.

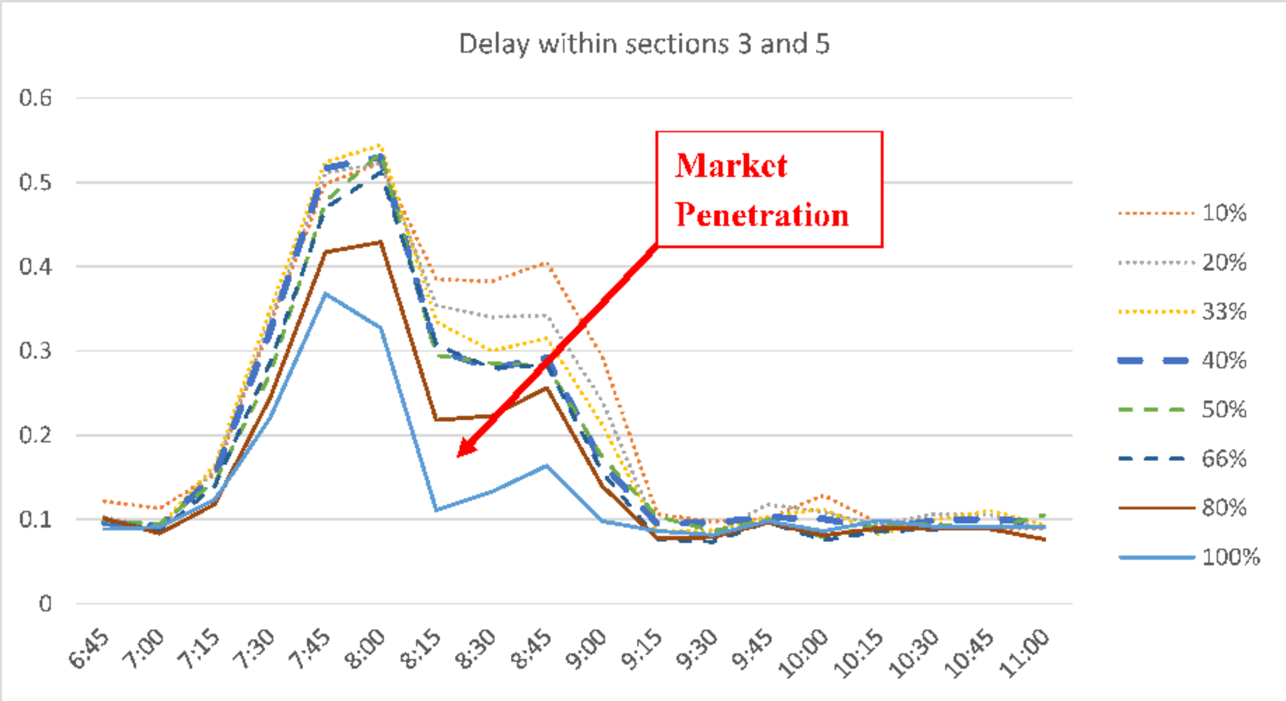


Figure 20 - Percentage of delay - comparison between desired speed and actual speed.

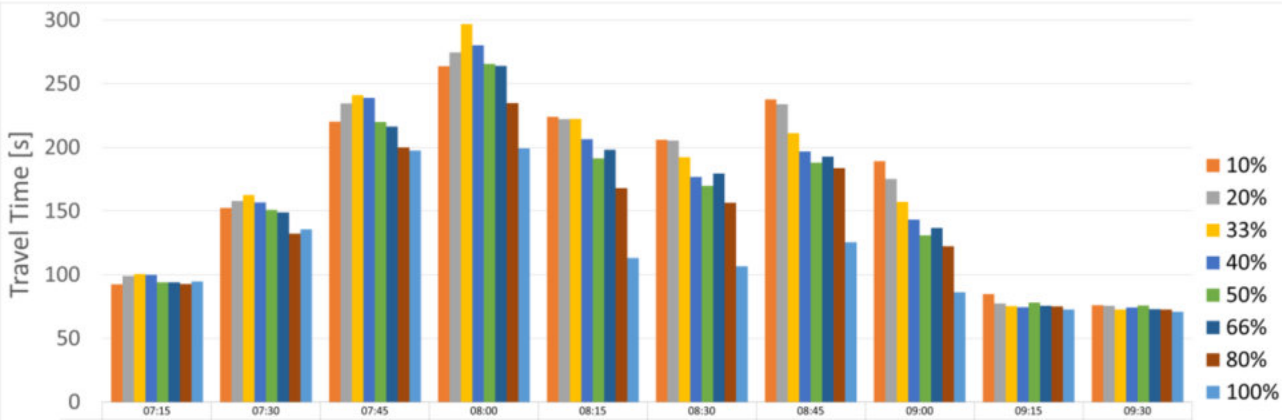
This last result shows that possible disruptions arise between 10% and 30% MP but from 30% MP up, the benefits upstream were much more linear. During the morning peak hour (07:00–08:00 a.m.), no strong benefit was identified for market penetrations lower than 80%, but, at the second peak (08:15–09:15 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 126.

Table 59 - 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 59, 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 21, the travel times from certain sections are reported; it should be highlighted how they cannot be directly related with Table 59, 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 21 - 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 21, 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 22.

Figure 22 - 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).

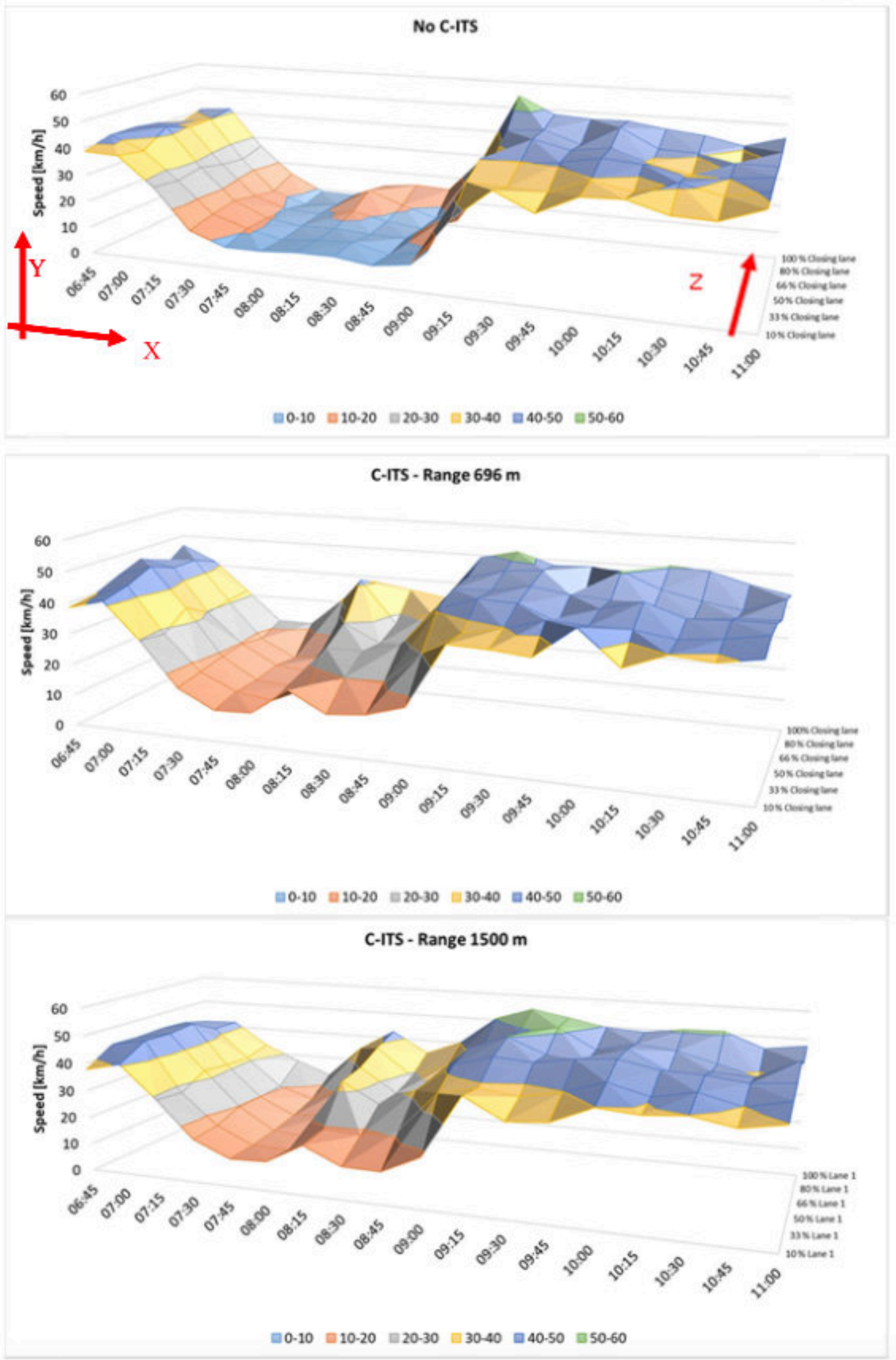


Figure 23 - Scenario comparison; speed on the closed lane

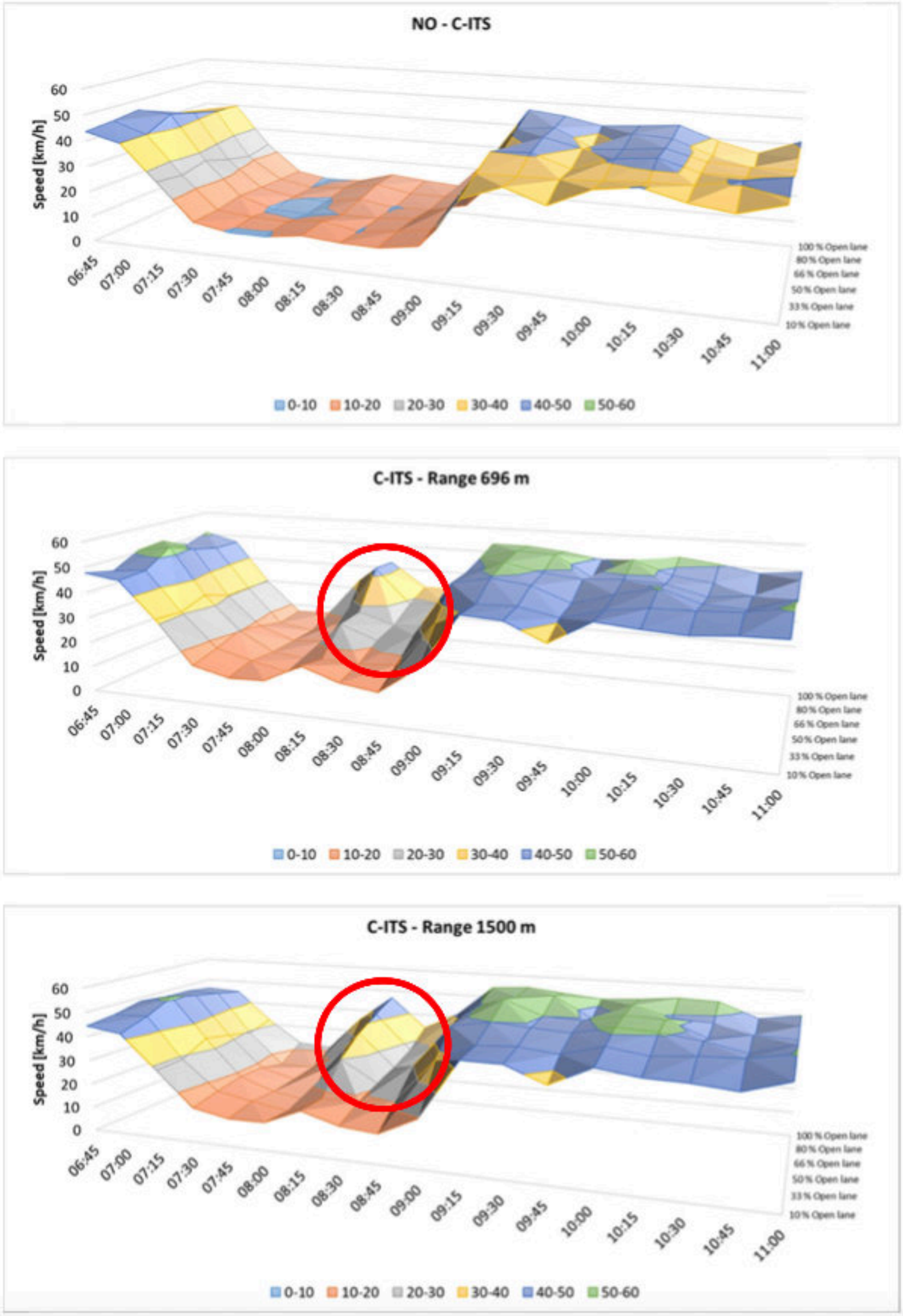


Figure 24 - Scenario comparison; speed on the open lane

Table 60 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 60 - 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 59).
According to the approach adopted, the assessment detailed in Table 61 were provided.

Table 61 - 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 62.

Table 62 - 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

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure (urban environment)

Evaluation method

Refer to Section **Errore. L'origine riferimento non è stata trovata.**. (Safety – Italy)

Data collected

Refer to Section **Errore. L'origine riferimento non è stata trovata.**. (Safety – Italy)

Evaluation results – Field tests

Road Works Warning has the potential to produce traffic efficiency impacts from earlier speed and lane change maneuvers.

Refer to Section **Errore. L'origine riferimento non è stata trovata.**. (Safety – Italy)

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 roadworks, 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. Greece

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.8 (Safety – Greece).

Data collected

Refer to Section 5.1.8 (Safety – Greece).

Evaluation results – Field tests

For the Attica Tollways the indicator of average vehicle speed is lower in the C-ITS scenario. This is an anticipated result are drivers are timely informed about the lane closure and they tend to decelerate and drive at lower speeds.

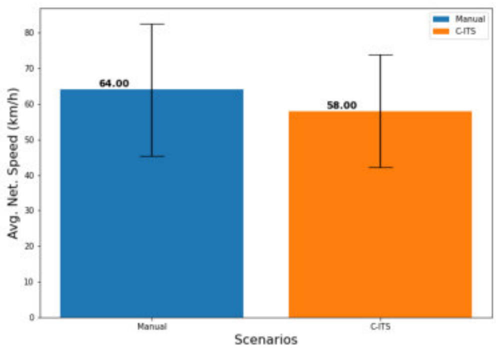


Figure 25 - RWW-LC average vehicle speed for manual and C-ITS scenario

Regarding travel time, this indicator shows an increase, which is something logical considering the speed decrease.

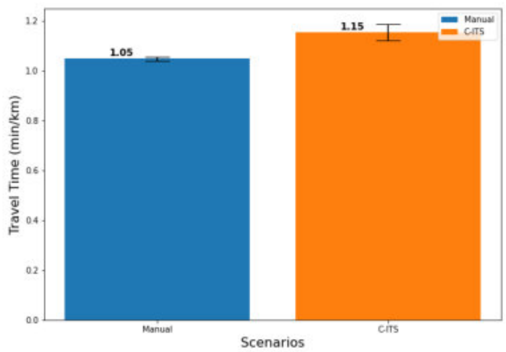


Figure 26 - RWW-LC travel time for manual and C-ITS scenario

In the Egnatia Odos Tollways the average vehicle speed shows a decrease in the C-ITS scenario in both cases (500 and 1200 vehicles). This could be due to the earlier provision of information in the case of the C-ITS messages provision where drivers start slowing down earlier and more smoothly as they are aware of the lane closure in advance.

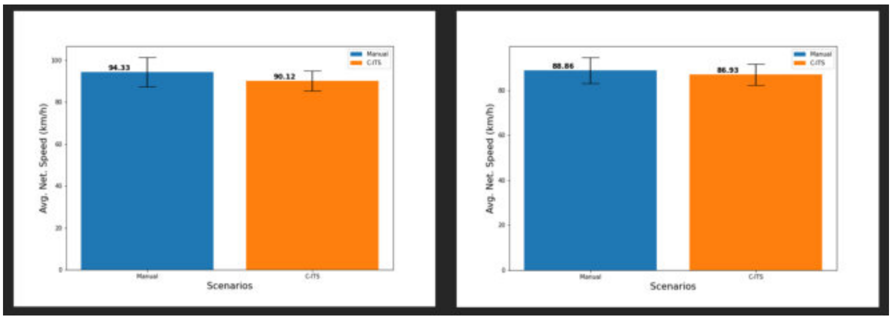


Figure 27 - RWW-LC average vehicle speed for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

Travel time is increased in the C-ITS scenario in both cases, baseline and high C-ITS penetration rate. This is logical as the decrease in vehicle speed could lead to higher travel time.

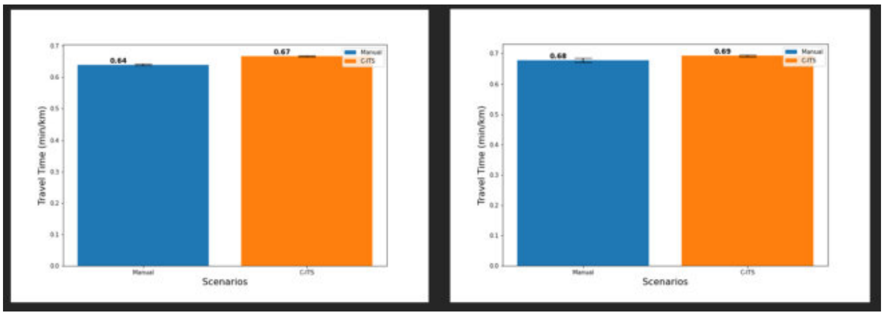


Figure 28 - RWW-LC travel time for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

5.2.6. Ireland

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Microsimulation traffic modelling was used to assess the following traffic efficiency related evaluation questions for the Road Works Warning – Lane Closure use case:

- How does this use case affect journey time at different levels of C-ITS vehicle penetration?
- How does this use case affect traffic flow at different levels of C-ITS vehicle penetration?
- How does this use case affect traffic speeds at different levels of C-ITS vehicle penetration?

A two-stage approach was proposed, initially using default (theoretical) driver behaviour values, and updated where possible using field data. The first stage is documented below, with an overview of the methodology undertaken provided in Figure 29.

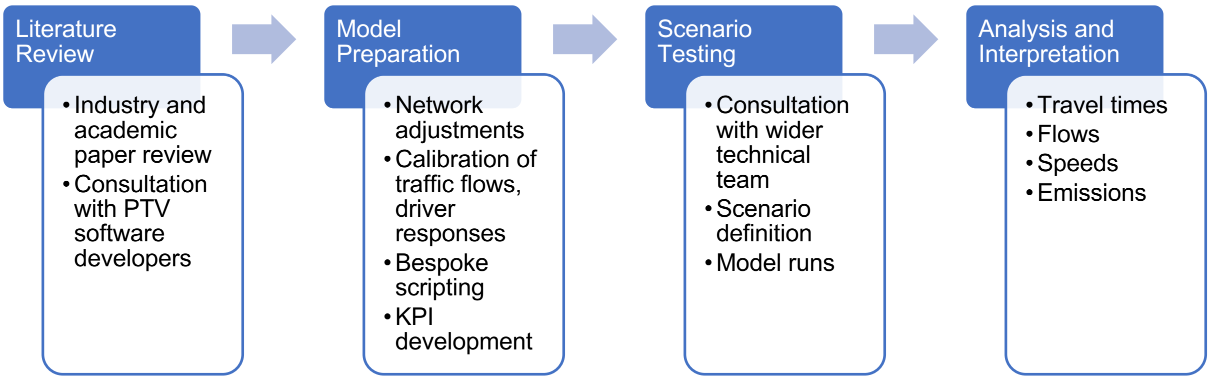


Figure 29 - Road Works Warning – Lane Closure methodology overview

Table 63 shows the set of 11 scenarios that were run. A 'no road works' scenario was run where no hazard was placed on the network. This provided a baseline against which all other scenarios were compared.

Two locations for the roadworks were tested in the model. Location 1 is a northbound two-lane section of motorway with a theoretical flow demand of 2100 vehicles / hour, and location 2 is a southbound three-lane section with a theoretical flow demand of 4600 / hour. This demand was set in order to represent scenarios where the traffic link would be approaching capacity.

Connected vehicle penetration was increased from 0% to 100% in 25% increments. Each scenario was run for 20 random seeds and all results are an average of these runs. It is common practice to run multiple random seeds to replicate day-to-day variations in arrival profiles.

Table 63 - Road works warning – lane closure modelling scenario summary

Use Case	Hazard Location	Connected Vehicle %	Number of Scenarios
None (no road works)	n.a.	0%	1
RWW - lane closure	Location 1	0%, 25%, 50%, 75%, 100%	5
RWW - lane closure	Location 2	0%, 25%, 50%, 75%, 100%	5

Key performance indicators collected as part of the modelling assessment are:

- Journey times
- Traffic throughput
- Average speeds

Traffic throughput was measured directly downstream of the roadworks exit taper with outputs provided of the total number of vehicles that pass that point per minute.

Journey times were measured for each vehicle that passed the start and the end of the 5km long labelled journey time routes. The model outputs included the total number of vehicles that pass the start and end points and the average time taken per minute, aggregated by the time the vehicle completes the route.

Average speed data was collected for every 50m segments shown as a blue model link, aggregated into 5-minute periods. These were analysed from 2km prior to the roadworks to 400m downstream from the end of roadworks.

The road works were represented in the model for the entire simulation period. There was a 15-minute warm-up period which allowed traffic to populate the model before results evaluation began.

Key model operation parameters are provided in Figure 30 below.

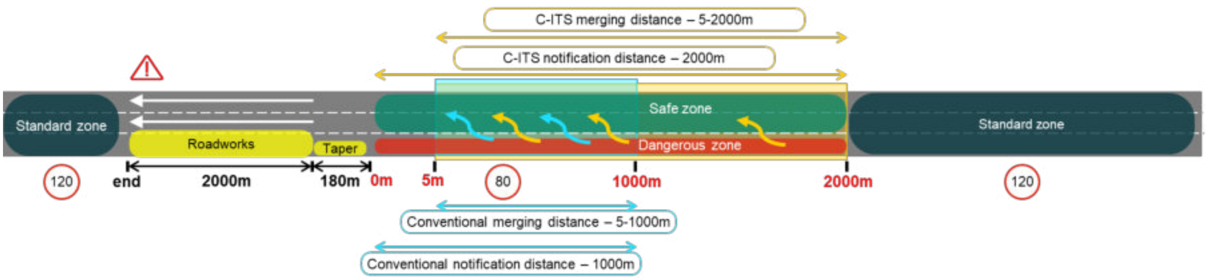


Figure 30 - RWW model operation schematic

Vehicle routes were set before the simulation to reflect the lane reduction adjacent to the roadworks. During the simulation, the connected vehicle types were changed as vehicles moved into the notification zone to simulate a driver response to the notification received.

Connected and conventional vehicles were assigned different lane change distributions. It was assumed that connected vehicle drivers were notified of the lane closure two kilometres in advance of the roadworks. These vehicles were then assigned a desired lane change distribution range of 5 to 2000m. This did not represent the range over which they are notified of the roadworks – as this was two kilometres for all connected vehicles – but rather the point at which they decide to act on the notification and change lane. The distribution of lane-change distances between the minimum and maximum is not linear, but in fact is based on data from a driving simulator study carried out by Hess et al on when users change lane on approach to roadworks .

Connected vehicles adjusted their driving behaviour in the notification zone with an increased propensity to merge.
The roadworks model also featured a speed limit reduction from 120kph to 80kph, from 1km before the start of the roadworks until 45m after the end.

Evaluation results

The microsimulation modelling results are shown in Figure 31 for each KPI (journey time, traffic flow and speed) for both locations 1 and 2 (representing 2 and 3 lane motorway sections.

The results suggest that the impact of the Road Works Warning – Lane Closure use case at different levels of C-ITS vehicle penetration is likely to vary depending on factors such as the roadworks location characteristics and traffic volumes however trends are different to those seen in the HLN use case. The results indicate that the flow breakdown patterns differ when there is a 2-to-1 lane merge compared with a 3-to-2 lane merge.

Overall, in both locations there is an overall traffic efficiency benefit with 100% penetration rate.

A comparison of the 100% penetration scenario versus the 0% penetration rate shows a 20% and 30% reduction in average journey times over a 5km section in Location 1 and 2 respectively but trends with connected penetration vary to those seen in the HLN use case. Traffic flow patterns reflect those seen in the journey time analysis, with deterioration in performance for penetration rates up to 75% in Location 2 whilst Location 1 shows similar trends to the HLN use case but peaking at 25% connected.

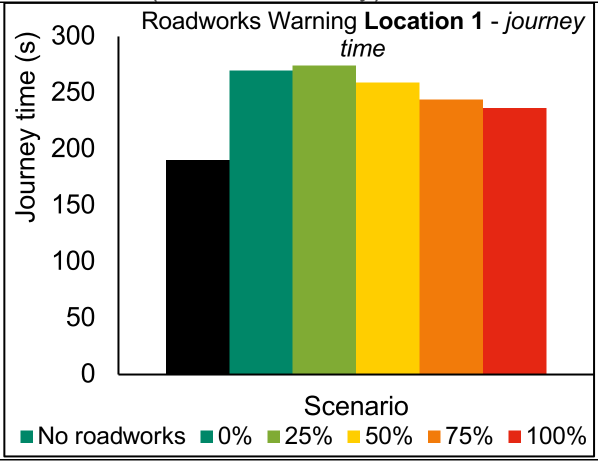
Speed analysis shows that, in both locations, speeds are constant through the roadworks but vary on the approach with levels of queueing. These results reflect the trends seen in journey time results whereby speeds are slower with increasing penetration until 100% when speeds increase again.

The different trends seen in this use case to the HLN use case highlight the effect that lane-change distances have on model operation.

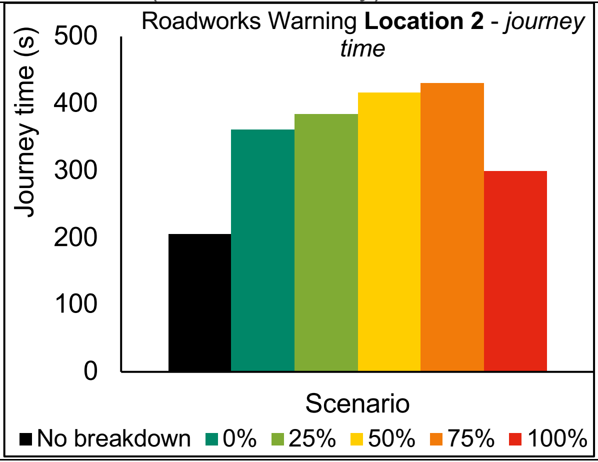
All model outputs are dependent upon the modelling assumptions made regarding the Road Works Warning – Lane Closure use case implementation and driver behavioural response. The variability of traffic efficiency impacts in different circumstances has been illustrated by the two scenarios selected for analysis. It is clear that a multitude of factors including, but not limited to, number of lanes, traffic flow demand, breakdown duration, notification distance, and the driver behaviour response to the notification, will all impact on if and when operational benefits of the use case will occur.

Journey time

Location 1 (2 lane motorway)

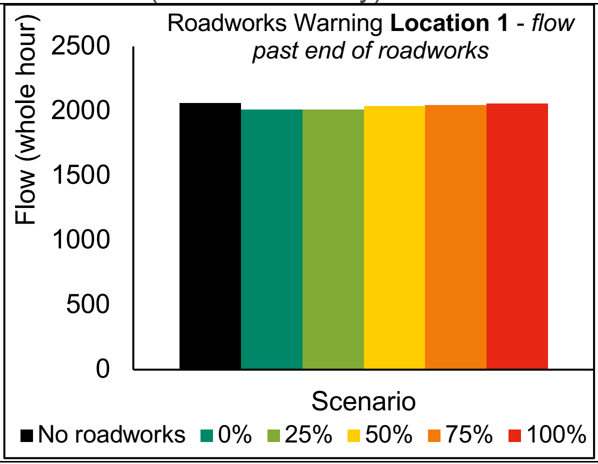


Location 2 (3 lane motorway)



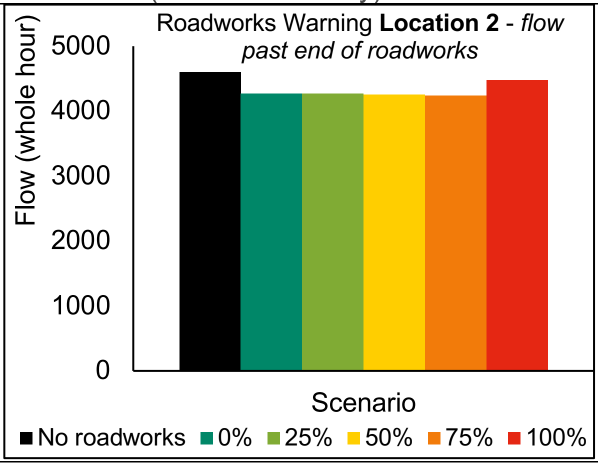
Traffic flow

Location 1 (2 lane motorway)



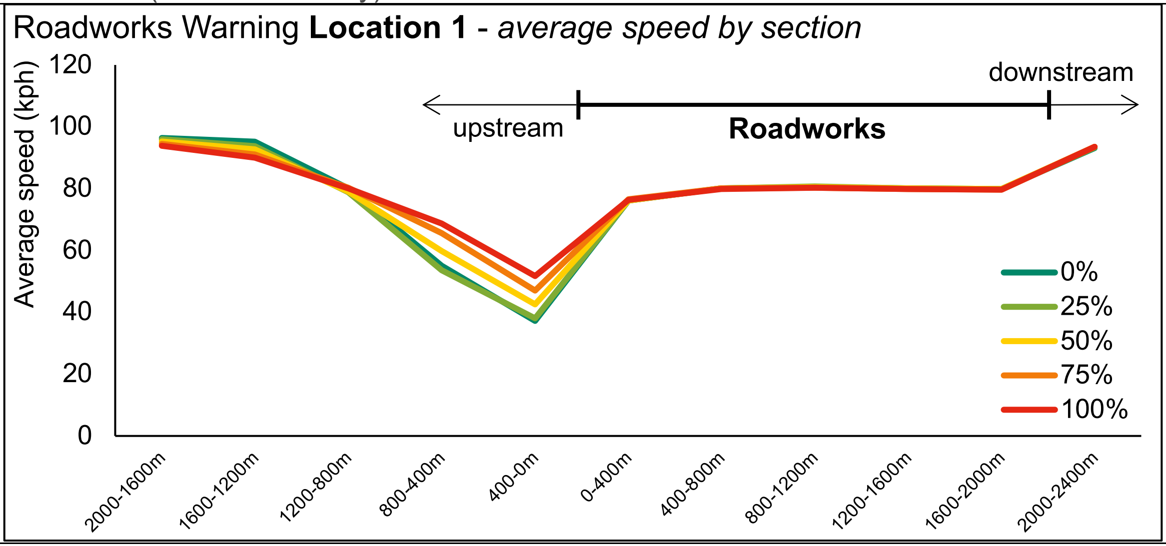
Traffic flow

Location 2 (3 lane motorway)



Speed

Location 1 (2 lane motorway)



Speed
Location 2 (3 lane motorway)

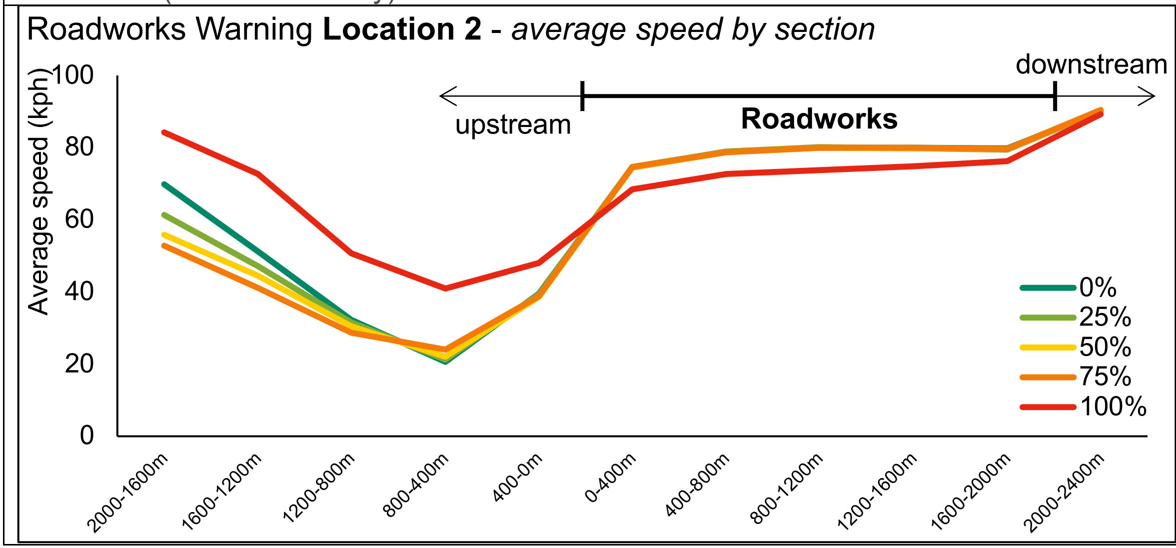


Figure 31 - RWW-LC modelling results

5.2.7. Portugal

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.9 (Safety – Portugal).

Data collected

Refer to Section 5.1.9 (Safety – Portugal).

Evaluation results – Field tests

In free flow, the journey time in the analysed section is 48'. With the closure of the lane for works, the time required to run the section duplicates and the the average speed reduces significantly with the consequent delays in queus. These delays are supposed to be avoided by the deployment of the Use Cases. Up to reaching 50% penetration rates, the C-ITS effects are not visible. The lane closure effect on speed and journey times is still high.

Above 50% C-ITS vehicle, the anticipated information on the closure allows vehicles to be prepared, changing lane in time and not causing unnecessary stops and delays. Model results show that average speed even with the road works can be slight above the speed limit. Overall, with 100% penetration rates, travel time is reduced in 49% compared to the situation of lane closure without C-ITS.

Evaluation results – KPIs on Mobility

Assuming that similar delays to the ones tested occur in the remaining C-Roads PT network due to road works, the hours saved in congestion for a 100% penetration rate could reach 715 000 hours, not considering additional time lost in result of accidents requiring to close roads.

5.2.8. Summary

Evaluation results – Field tests

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

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

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 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 64, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 64, 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 64 - 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[8]	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[8]	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[8]	-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)

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

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5.3.2. UK

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.2 (Safety – UK).

Table 65 - 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 5.4.2 for 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.

5.3.3. Italy

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section **Errore. L'origine riferimento non è stata trovata.** (Safety - Italy)

Data collected

Refer to Section **Errore. L'origine riferimento non è stata trovata.** (Safety - Italy)

Evaluation results – Field tests

Refer to Section **Errore. L'origine riferimento non è stata trovata.** (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 66.

Table 66 - 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 67 - 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 68.

Table 68 - 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, CO_2 (and other)-emissions are constantly low.
This is equally applicable for noise emissions.

5.3.5. Greece

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.8 (Safety – Greece)

Data collected

Refer to Section 5.1.8 (Safety – Greece)

Evaluation results – Field tests

For the case of Attica Tollways there was a significant reduction to CO_2 emissions in the C-ITS scenario, leading to the conclusion that RWW-LC could have a positive impact to the environment as pollutant emissions show a reduction due to smoother driving (smoother speed fluctuations).

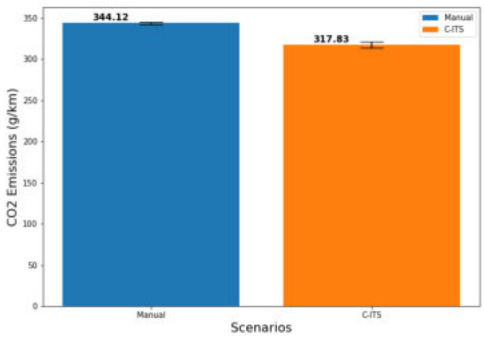


Figure 32 - RWW-LC CO_2 emissions for manual and C-ITS scenario

In the Egnatia Odos Tollways network the CO_2 emissions are decreased in the C-ITS scenario in both cases, 500 and 1200 vehicles, but not at a significant level.

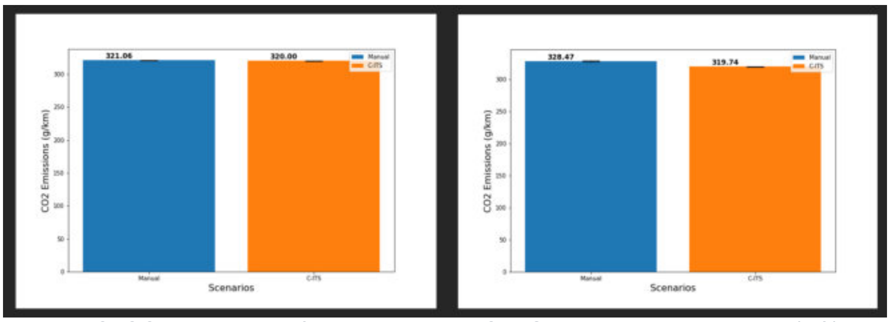


Figure 33 - RWW-LC CO_2 emissions for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

5.3.6. Ireland

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

The Bosch instantaneous emissions modelling (IEM) Vissim add-on was used to assess tailpipe emissions for the Road Works Warning – Lane Closure use case. The emissions model is provided by Vissim with second-by-second speed, acceleration and deceleration profiles within the selected link segments for every vehicle which it uses to estimate emissions for each link segment.

The model was used to answer the following evaluation question:

- How does this use-case affect emissions at different levels of C-ITS vehicle penetration?

The methodology described in section 5.2.6 is relevant to this section.

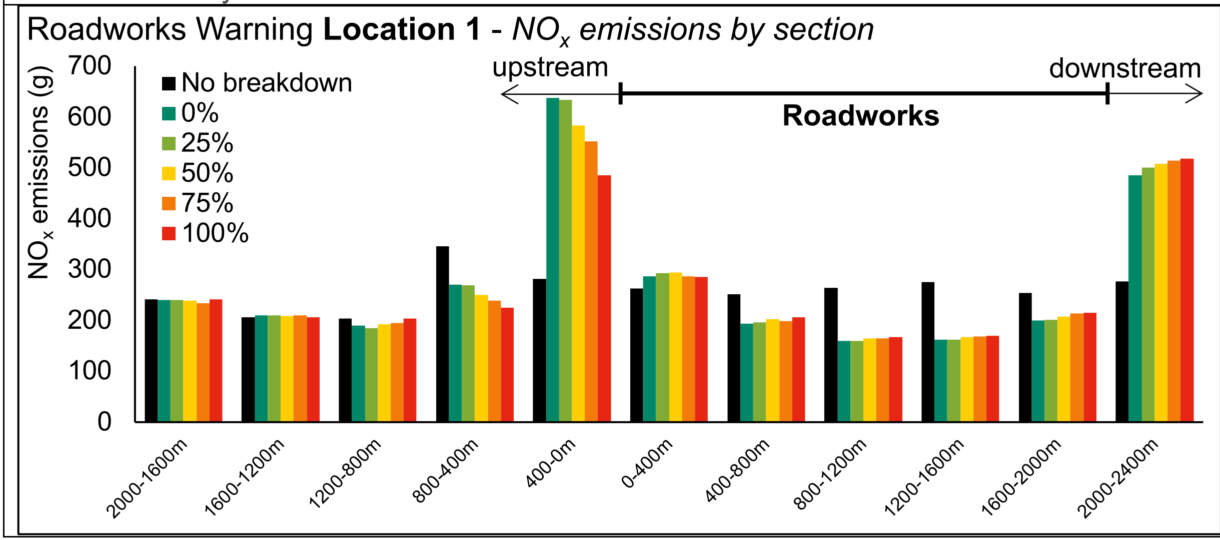
Evaluation results

Results presented are NOx emissions (Nitrogen oxides). CO_2 emissions were also calculated but they show very similar trends to NOx emissions results, so have not been included to avoid repetition.

Results are aggregated across the same sections that were used for the average speed data and the average speed graphs presented in section 5.2.6 are provided alongside the emissions data for context and comparison.

Figure 34 shows total NOx emissions per section for Location 1 and 2.

Location 1
2-lane motorway site



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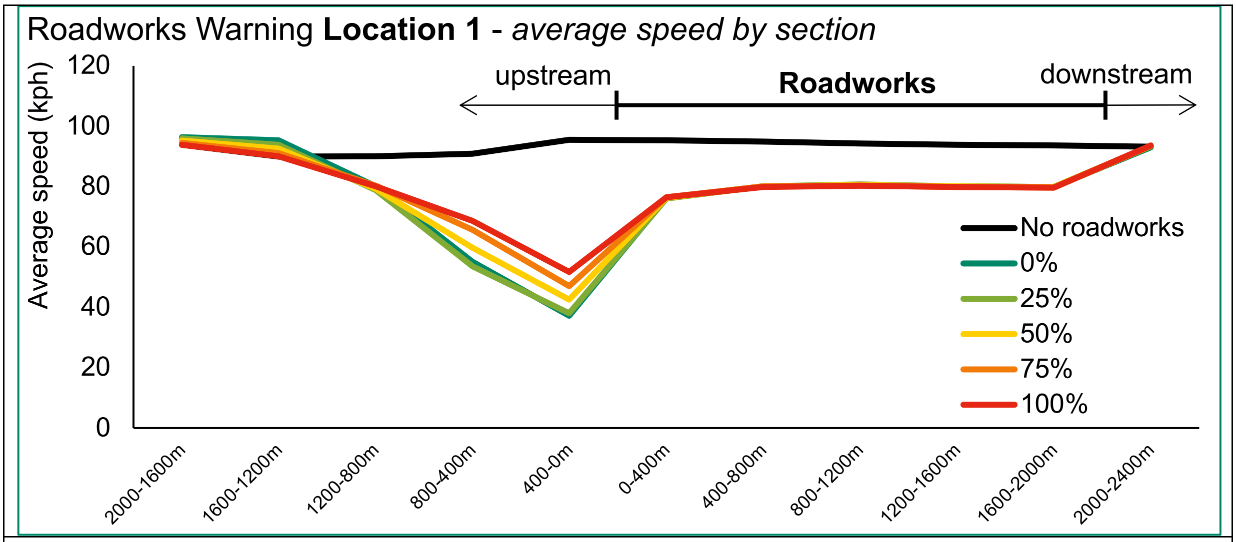
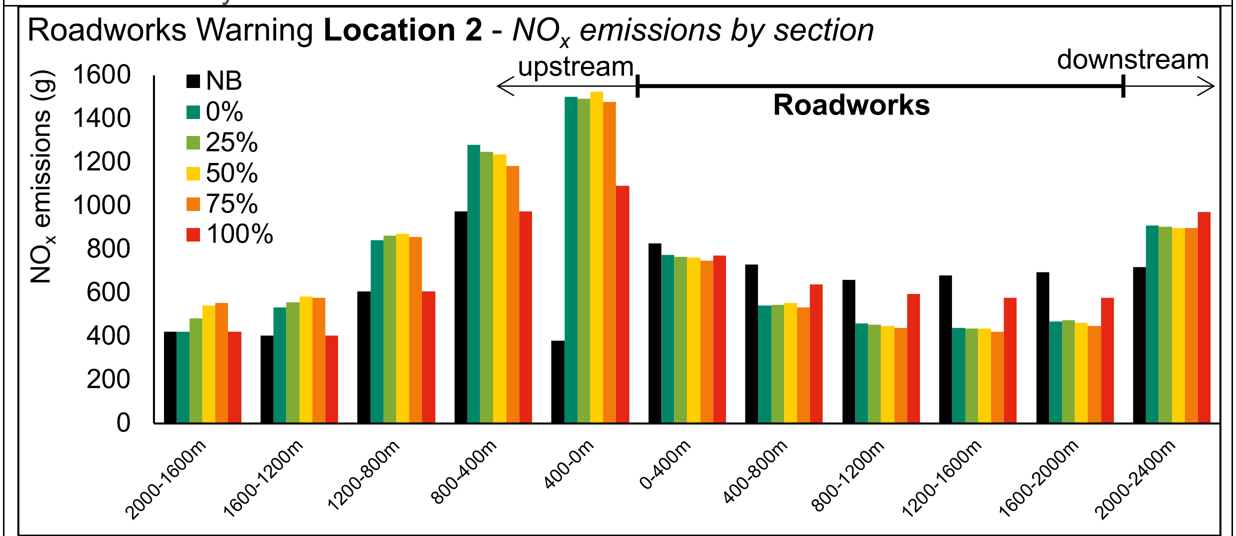


Location 2

3-lane motorway site



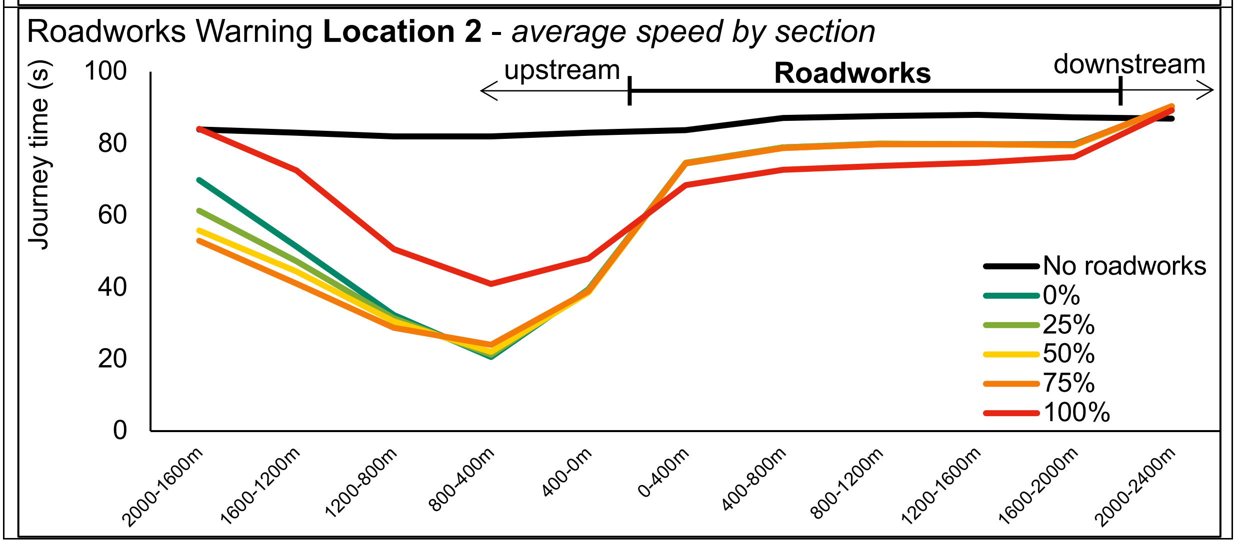


Figure 34 - NOx emissions/section (top) and average speed per section (bottom) for each scenario

At Location 1, it is evident that with reduced average speeds through the roadworks comes reduces emissions. This reduction in emissions is not related to stop-start behaviour but in fact to the other contributor to exhaust emissions: speed. There is an optimum speed at which emissions/km are lowest and above and below this speed, the vehicle creates more emissions. This speed is roughly 80kph so in this case, reducing the speed reduces the emissions. Since the speed is independent of connected penetration, emissions are constant in the roadworks across scenarios. On the approach to the roadworks, as average speeds drop due to increased congestion, emissions spike. Emissions reduce with increasing connected penetration in this section due to smoother flow. Emissions spike after the roadworks as they accelerate out of the end of the speed limit reduction zone.

At Location 2, during the roadworks, emissions are higher for the 100% penetration rate scenario than all the others due to the shockwave queueing that we have explored above. Conversely, in the 100% penetration rate scenario, improved flow efficiency results in reduced emissions as well as increased speeds upstream of the roadworks. Excluding this scenario, the general trend on the approach to the roadworks is that increasing connected penetration reduces emissions.

Figure 35 shows the total emissions aggregated across all sections for both locations.

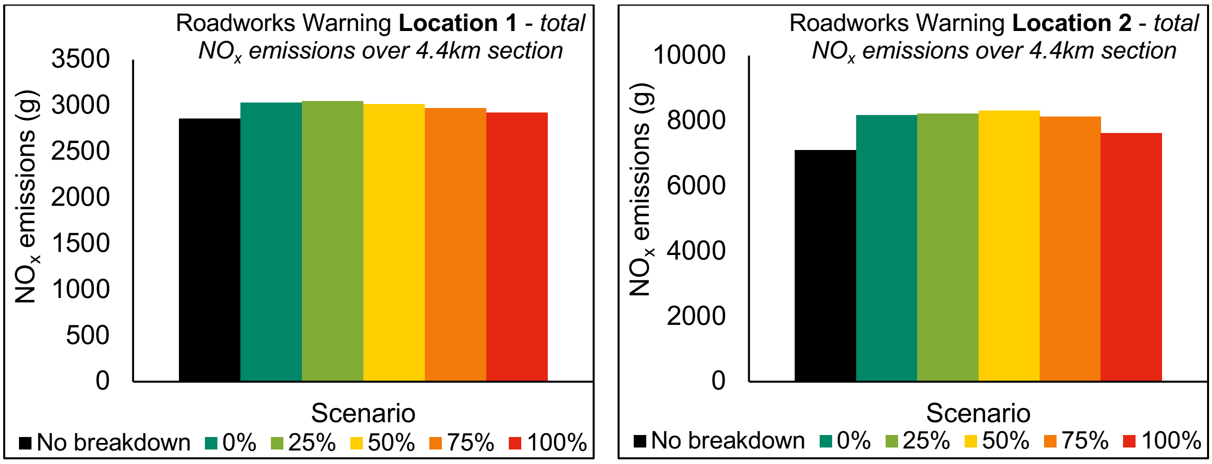


Figure 35 - Total emissions across all sections

Overall, we see a similar trend to that seen in the HLN use case, where emissions increase slightly with low connected penetration but decrease at higher penetrations in both locations. As in the HLN use case (see 7.3.4), total emissions are reduced in the 100% penetration rate scenario compared to the 0% penetration rate.

In general, emissions show trends that are consistent with the traffic efficiency results. The balance of both contributors to exhaust emissions – average speed and stop-start behaviour – can be seen in the results. Emissions tend to increase on the approach to roadworks but are reduced as increasing connected penetration creates smoother entry flow. While in Location 2, increasing connected penetration reduces average speed, it also reduces emissions.

5.3.7. Portugal

Use Cases considered

- RWW-LC: Roadworks Warning - Lane Closure

Evaluation method

Refer to Section 5.1.9 (Safety – Portugal).

Data collected

Refer to Section 5.1.9 (Safety – Portugal).

Evaluation results – Field tests

The reduced congestion leads also to environmental benefits (i.e. reduced fuel consumptions and CO_2 and NO_x emissions). Adopting consumptions and emissions factors, the estimation of environmental impacts can be provided.

The results from tests and simulation exercise shows that with the 100% MP rates, environmental benefit is high. With the lane closure, the travel time and congestion as well as the effect of accelerations / decelerations results in more fuel consumption and higher emissions. In what concerns environmental impacts it is worth noting that from 25% penetration rates the effects appear though its reduction is particularly visible from 80% penetration rates.

Overall, the joint effect of fuel and emissions can go up to -79% when comparing the 100% MP with the baseline, that is with the closure of a lane.

Evaluation results – KPIs on Mobility

Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency, resulting directly from the Visim modelling exercise. It is worth noting that this reflects still a predominance of fuel engine vehicles. With the expected change of fleets and entrance of newer cars in the market, environmental impact will be lower but not congestion.

5.3.8. 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.

Similar findings have been obtained from the Portuguese pilot test. Environmental impacts have been assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency, From 25% penetration rates the effects appear though its reduction is particularly visible from 80% penetration rates.The joint effect of fuel and emissions can go up to -79% when comparing the 100% penetration with the baseline, that is with the closure of a lane.

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, Greece.

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 69 - 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 70 - 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 71 - 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 72 - 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 73 - 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 74 - 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 75 - 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 76 - 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[9] (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

[9] 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.

	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
	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 77 - 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 78 - 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:

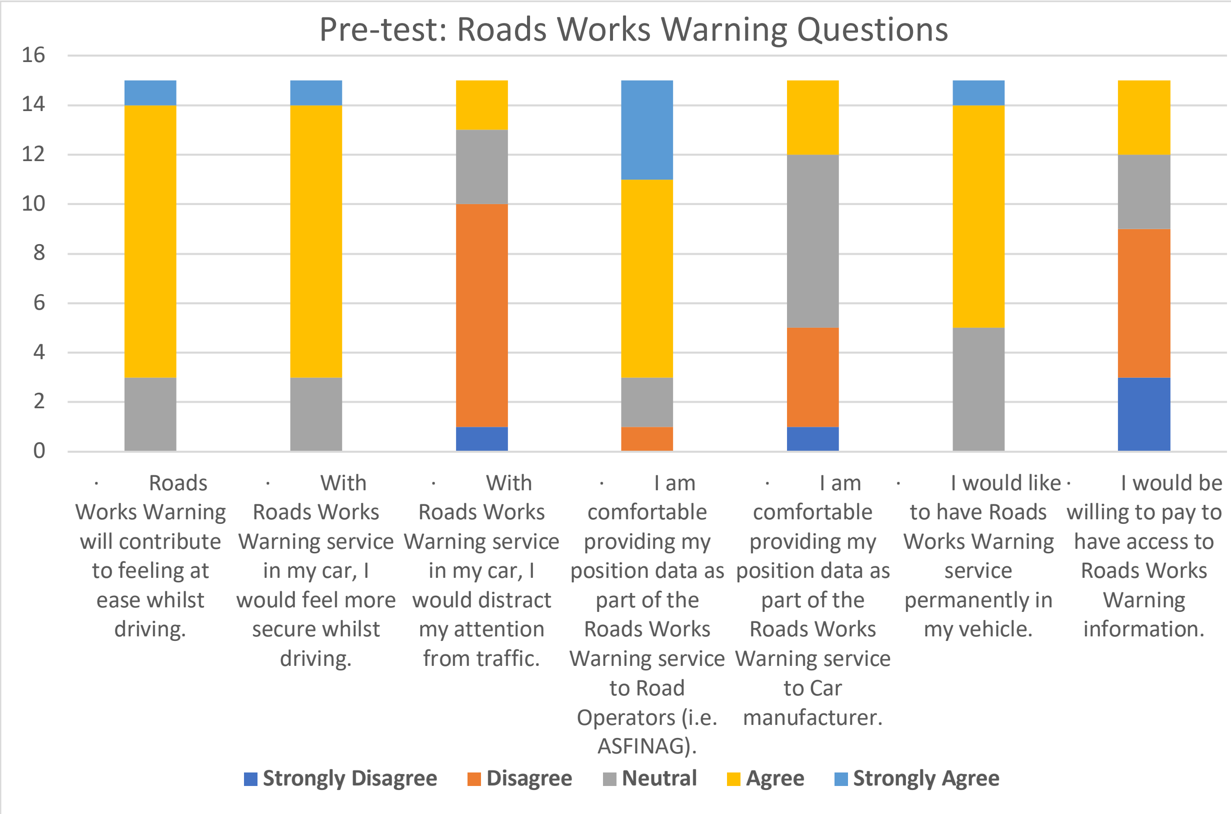


Figure 36 - Pre-test: Roads Works Warning Questions

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

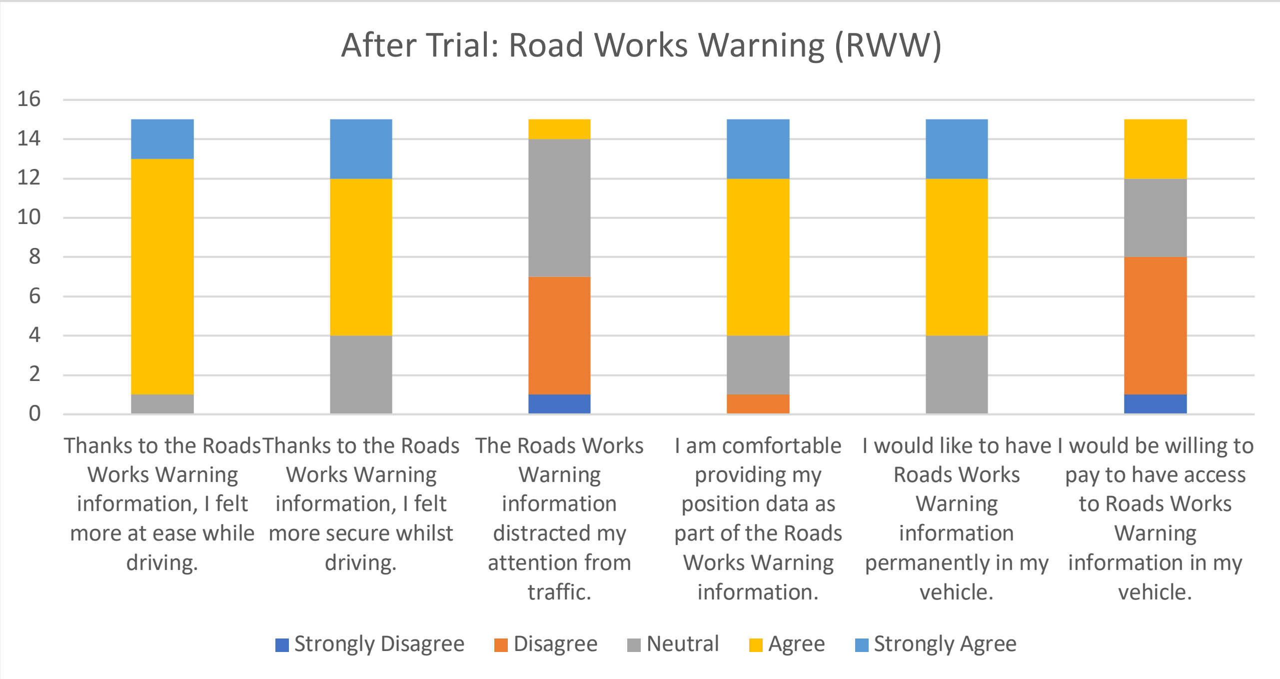


Figure 37 - Answers after Trial: Average score of Roads Works Warning Questions

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 38 - 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 79 - 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. Greece

Use Cases considered

The services that were assessed through subjective evaluation included all the services implemented in the Greek Pilot, covering all the respective use cases:

- RWW-LC: Roadworks Warning - Lane Closure
- IVS-EVFT: In Vehicle Signage - Embedded VMS “Free Text”
- IVS-SWD: In Vehicle Signage - Shock Wave Damping
- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-WCW: Hazardous Location Notification - Weather Condition Warning
- HLN-OR: Hazardous Location Notification - Obstacle on the Road
- Traffic Information: Smart Routing

Quantitative test results (Surveys)

In the context of subjective evaluation, two separate questionnaires were created and distributed online to the users of the C-ITS services. The questionnaires targeted the road operators of the Greek pilot and the actual users of the services, i.e., drivers in the Greek pilot with access to the services. The two questionnaires constitute part of the a priori acceptability (insights in expectations, knowledge of services, to realize if/ if not users are already in favor of using C-ITS solutions). Results were collected during February 2022. The language used in the questionnaires was Greek as all participants were native Greek speakers. Questions regarding the specific services use cases were included in the drivers’ questionnaire.

The questionnaire had the purpose of evaluating whether drivers are in favor of using the C-ITS services that will be provided via a mobile application along the Attica Tollway and Egnatia Odos Tollway networks. The questionnaire included questions related to the following thematic sections:

- Personal information – demographics
- Driver profile
- General expectations about C-ITS services
- Expectations about the RWW service
- Expectations about the IVS service
- Expectations about the HLN service
- Expectations about the Traffic Information & Smart Routing service

In total 59 answers were received. The answers were analyzed and processed to generate charts demonstrating the results. Most of the participants were male, 81%, and the rest 19% were female. Regarding the participants’ education level, 41,4% of them had a Master/ PhD degree, 36,2% had a university degree, and the rest, 22,4%, had attended senior high school. Most of the participants, 96,6%, were professional drivers.

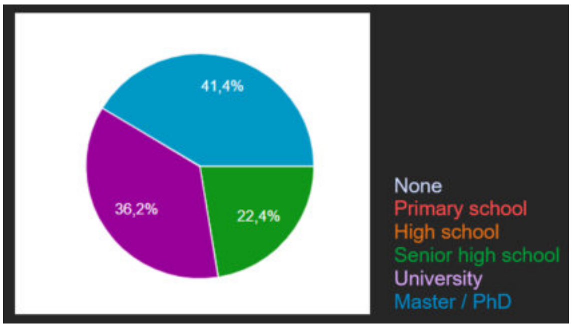


Figure 39 - Participants' level of education

The following chart presents the answers of the participants regarding the number of kilometers they drove last year. As it can be observed, most of the participants drove either 10.000 kms or 15.000 kms or 20.000 kms, while the rest of them drove under that numbers, among them, or above them.

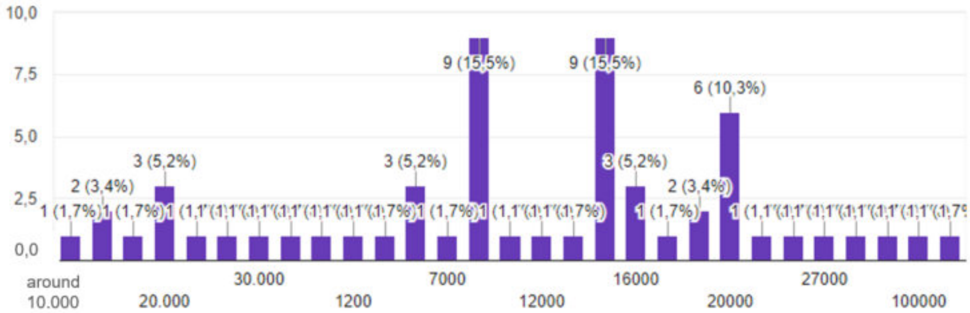


Figure 40 - number of kilometers driven by the participants over last year

With regards to the use of any information system while driving, 44,8% of the participants mentioned that they often do so, 37,9% use such systems sometimes, a small percent uses information systems rarely, while only very few of the participants use such systems either always (5,2%) or never (1,7%).

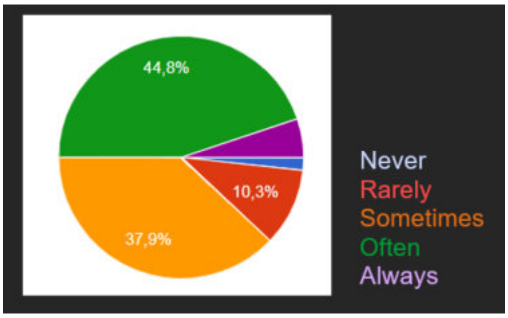


Figure 41 - Frequency of using information systems while driving

Concerning the question about using any safety/ assistance systems provided by their vehicles (e.g., adaptive cruise control, lane keep assist, speed limiter), most of the participants (41,4%) never use such systems, 22,4% of them uses these systems rarely, 17,2% sometimes, 12,1% often, and only 6,9% uses such technologies always.

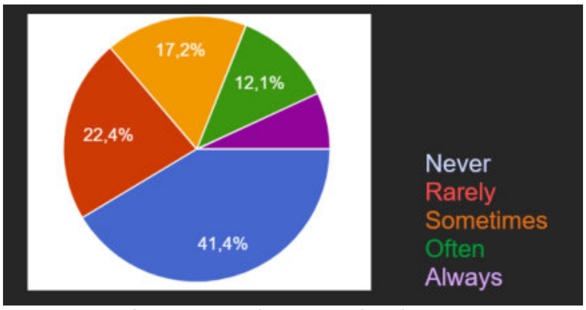


Figure 42 - Chart about the frequency of using safety/ assistance systems while driving

The chart below presents the driving behaviors that participants indicated that characterize them. Most of the participants (67,2%) stated that they adhere to the speed limits. The next driving behaviors with the largest frequency, but with low percentages, were the ones of exceeding the speed limit (29,3%) and of being influenced by the behavior of other drivers (22,4%). Rather low percentages related to the rest of the driving behaviors such as changing lanes frequently (8,6%), frustration due to risky situations (6,9%), sudden braking (5,2%), and easy distraction (3,4%).

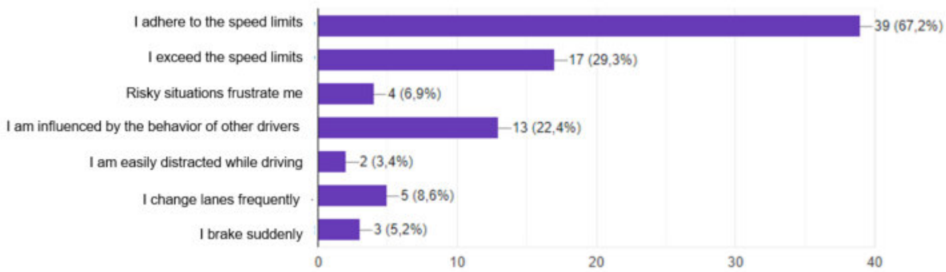


Figure 43 - Participants' driving behaviors

Most of the participants showed a strong preference in using a private vehicle for most activities, such as work, business trips, leisure, and errands. A rather low number of participants use different modes of transport for these activities, except for pedestrian movement for the case of errands. Participants' answers are presented in the table below and the following chart.

Table 80 - Activity-based use of transport modes

	Private vehicle	Public transport	Motorcycle	Bicycle	Pedestrian	I don't do this activity
Work	57	0	1	0	0	0
Business trip	49	3	1	0	0	5
Leisure	49	4	2	1	2	0
Errands	31	1	3	1	22	0

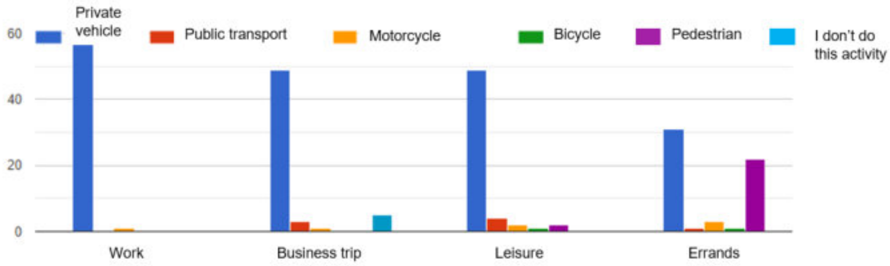


Figure 44 - frequency of use of transport modes for various activites

Concerning the potential contributions of C-ITS to various factors, the largest number of the participants, 89,7%, stated that C-ITS would improve road safety, while 55,2% considered that the services could reduce travel times, and a lower number of participants, 34,5%, considers that there could be a contribution to environmental impacts reduction.

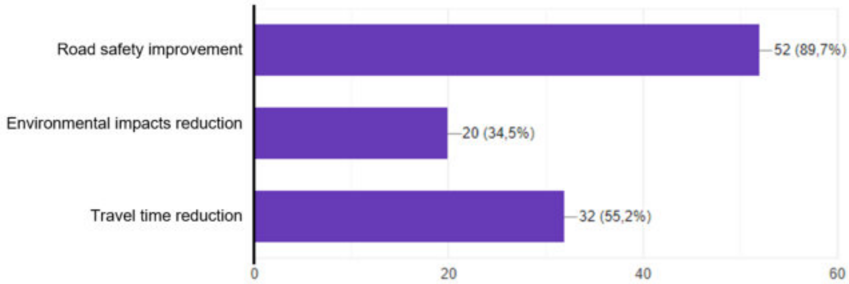


Figure 45 - Perception of the participants regarding the C-ITS contributions to transportation factors

Regarding the importance of road safety while driving, the majority of the participants (81%) considered it as an extremely important factor and 19% rated road safety as very important.

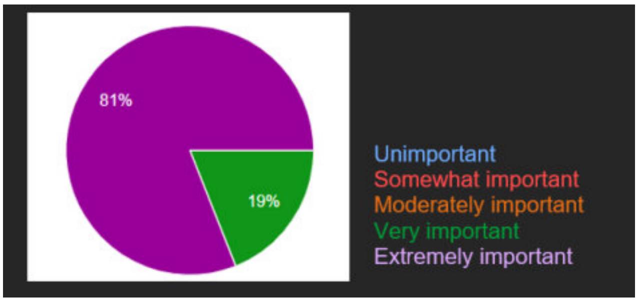


Figure 46 - Perception of the importance of road safety

Concerning the negative impacts of driving to the environment, most of the participants (43,1%) considered them as extremely important and a lower, but still high number, considered them as very important (36,2%) and moderately important (17,2%). Only 2 participants stated that the impact of driving on the environment is somewhat important or unimportant.

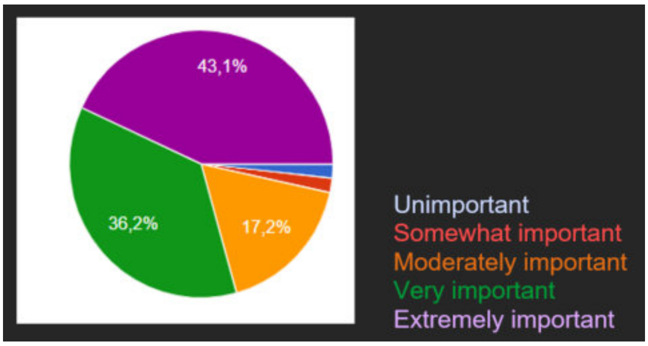


Figure 47 - Perception of the negative impacts of driving to the environment

The parameter of travel time for reaching the destination was considered by almost half of the participants very important, 37,9% of the participants rated it as extremely important, and lower numbers of the participants considered travel time to destination as moderately important (8,6%) and somewhat important (1,7%).

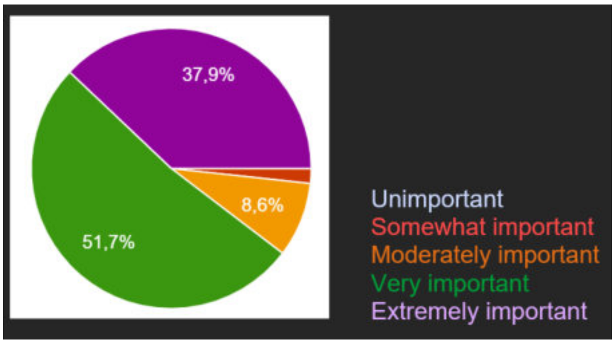


Figure 48 - Perception of the importance of travel time

Regarding the question about a potential positive impact of information provision while driving, the largest percentage of the participants agreed to it (67,2% strongly agreed and 24,1% agreed), while a rather low number had a neutral (6,9%) or negative opinion (disagreed).

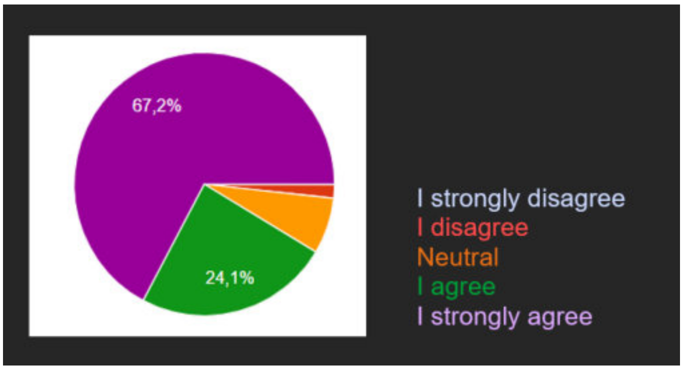


Figure 49 - Perception of a potential positive impact of information provision while driving

Concerning the question whether information provision while driving could cause driver distraction, quite many the participants (39,7%) agreed to the statement and 29,3% of them had a neutral opinion, while a rather low number either agreed strongly (6,9%) or disagreed strongly (6,9%).

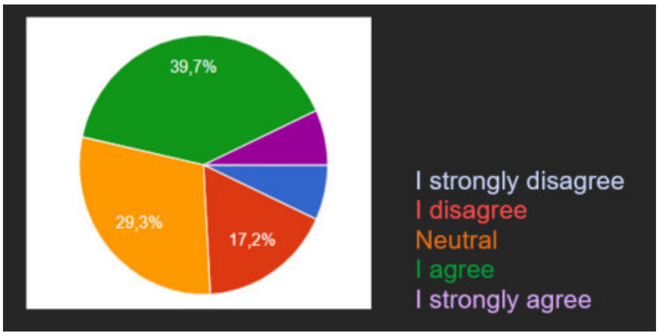


Figure 50 - Perception of distraction due to information provision while driving

Almost half of the participants (48,3%) considered that C-ITS could contribute to fuel consumption reduction, 32,8% had a neutral opinion, and only a low number (5,2%) disagreed.

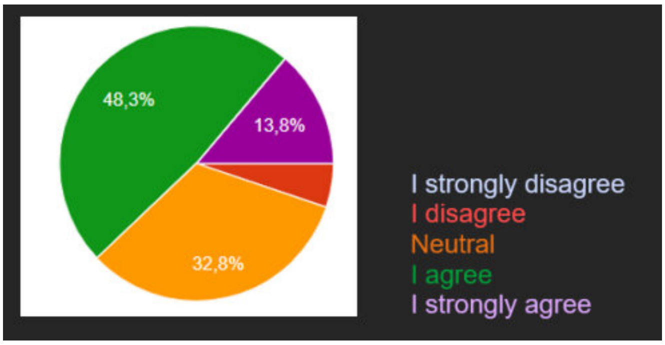


Figure 51 - Potential contribution of C-ITS to fuel consumption reduction

Regarding the factor of traffic efficiency, 58,6% of the participants agreed strongly with the possibility for improvement by using C-ITS and 37,9% agreed as well. A very low number, 3,4%, had a neutral opinion.

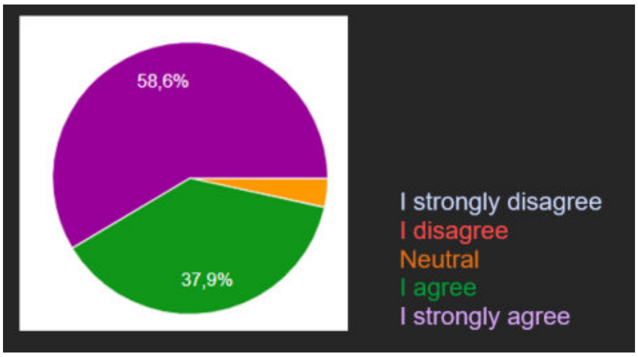


Figure 52 - Potential contribution of C-ITS to traffic efficiency improvement

Concerning the factor of road safety, 60,3% of the participants agreed strongly with the fact that C-ITS could increase it and 29,3% agreed also. Very low numbers of the participants had neutral opinion (8,6%) or disagreed (1,7%).

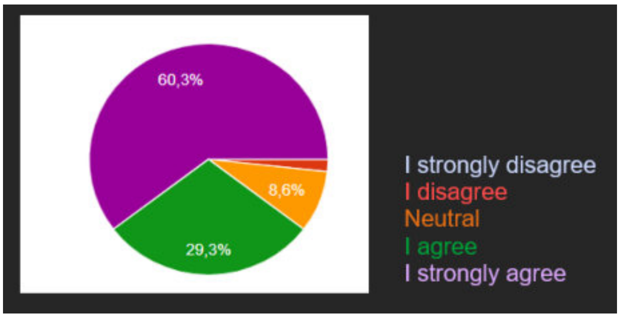


Figure 53 - Potential contribution of C-ITS to road safety increase

Most of the participants agreed to an increase in driver's attention with the use of C-ITS and 15,5% of them agreed strongly with that as well. 27,6% had a neutral opinion and a few participants disagreed (8,6%) or disagreed strongly.

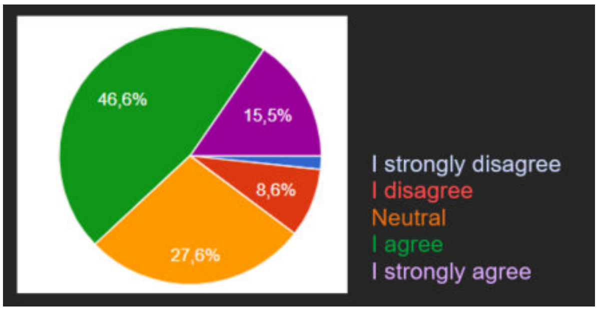


Figure 54 - Potential contribution of C-ITS to driver's attention increase

Half of the participants agreed to the possibility for C-ITS to increase driver comfort, 22,4% of them agreed strongly with that, and 20,7% had a neutral opinion. A rather low number of participants (5,2%) disagreed.

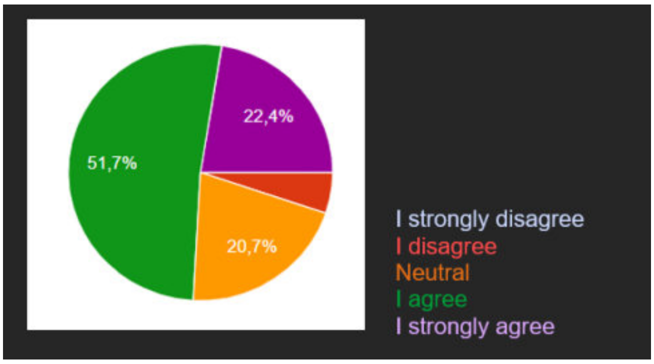


Figure 55 - Potential contribution of C-ITS to driver comfort increase

Similar numbers of participants agreed to the fact that C-ITS could outclass other information provision services, such as radio, Variable Message Signs, navigators, Google, Waze, or had a neutral opinion about that (36,2% and 32,8% respectively). 24,1% agreed strongly to such a possibility and only 6,9% of the participants had a negative opinion.

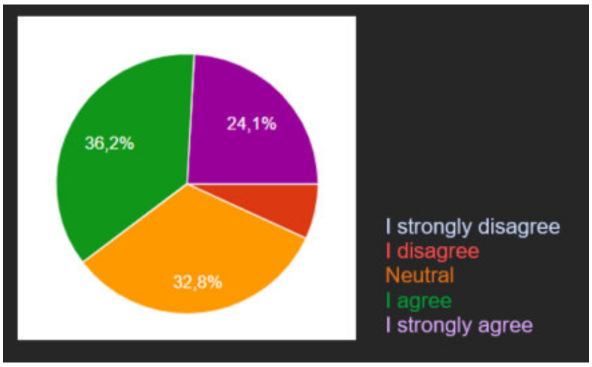


Figure 56 - Perception that C-ITS could outclass other information provision services

Almost half of the participants considered that the C-ITS user interface will be user friendly, 25,9% of them agree strongly, and 20,7% had a neutral opinion. Only a few participants (6,9%) disagreed to that.

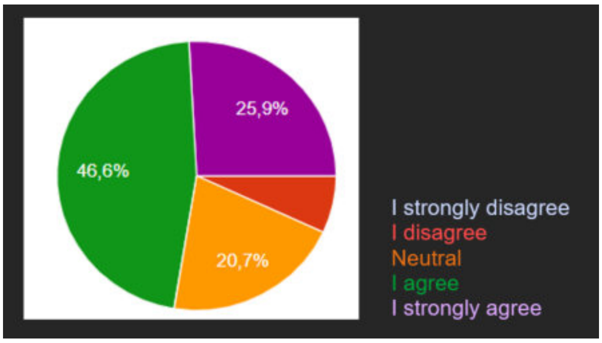


Figure 57 - Perception on the user-friendliness of the C-ITS user interface

Concerning the aspect of data privacy and security, most of the participants (37,9%) had a neutral opinion with regards to the possibility that personal data could be at risk when using C-ITS services and 25,9% agreed with that concern. Lower numbers of the participants disagreed (19%), disagreed strongly (15,5%), or agreed strongly (1,7%).

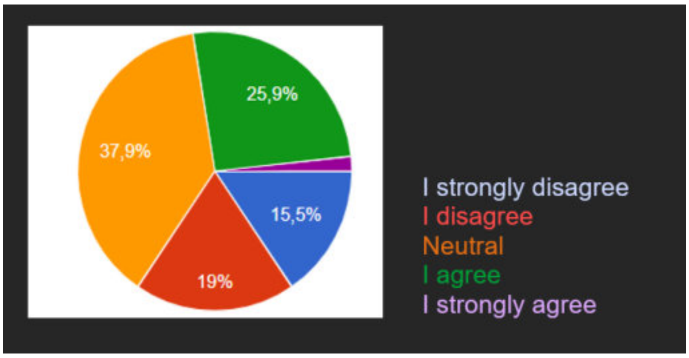


Figure 58 - Perception on data privacy and security when using C-ITS

With regards to the willingness to pay for C-ITS services, most of the participants (37,9%) had a neutral opinion about it, while 32,8% disagreed strongly. Only a few participants were positive about paying to use C-ITS services (15,5% agreed and 3,4% agreed strongly).

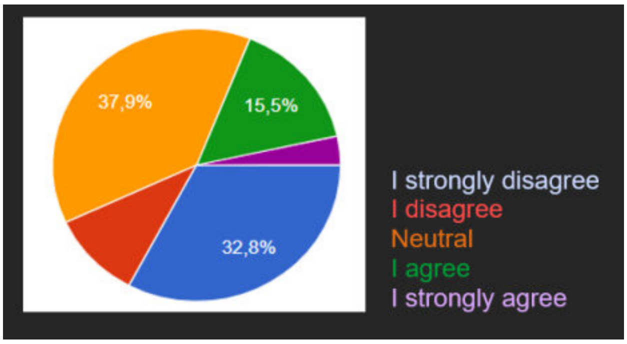


Figure 59 - Willingness to pay for C-ITS

Concerning Road Works Warning (RWW), most of the participants weren't familiar with the service and only a few participants had already used the service a few times in the past (6,9%) or had used it regularly (1,7%). Almost half of the participants (44,8%) considered that RWW could be a useful service for daily driving purposes, 27,6% had a neutral opinion, and 20,7% agreed strongly. Similarly, 48,3% agreed strongly to a daily use of RWW if possible, while the rest half of the participants had a neutral opinion or agreed with that, and only a very low number (5,1%) was negative towards that possibility. However, most of the participants (39,7%) showed a low willingness to pay for the use of the service as they strongly disagreed to such an option or had a neutral opinion about it (32,8%), while only a few were positive (8,6% agreed and 6,9% agreed strongly). The results are presented in the following figures.

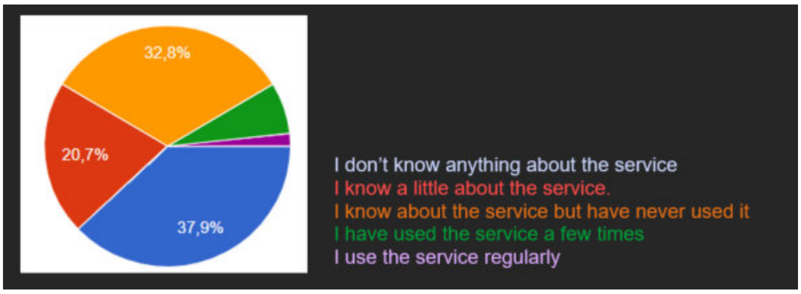


Figure 60 - Knowledge of RWW

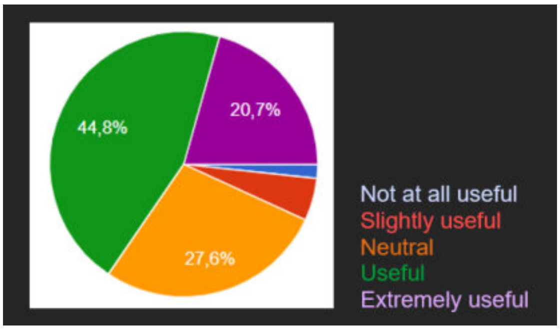


Figure 61 - Perception on the usefulness of RWW in daily driving

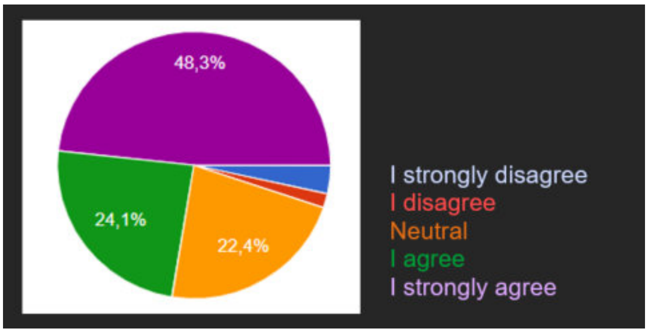


Figure 62 - Willingness to use RWW frequently

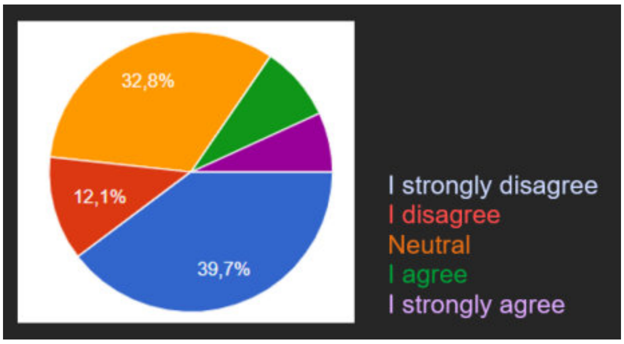


Figure 63 - Willingness to pay for RWW

Conclusions

In summary most of the participants were positive towards the use of the C-ITS services and expected the services to contribute in a positive manner in the various impact areas. The factor that received the least positive answers was the willingness of the participants to pay for the use of the services.

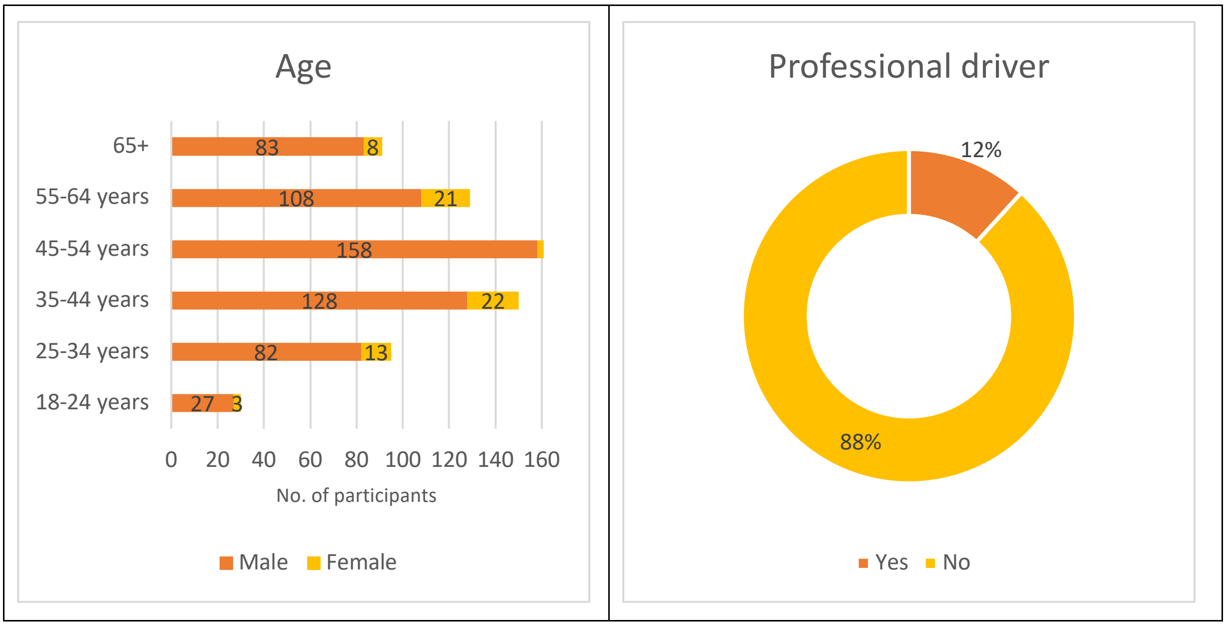
5.4.8. Ireland

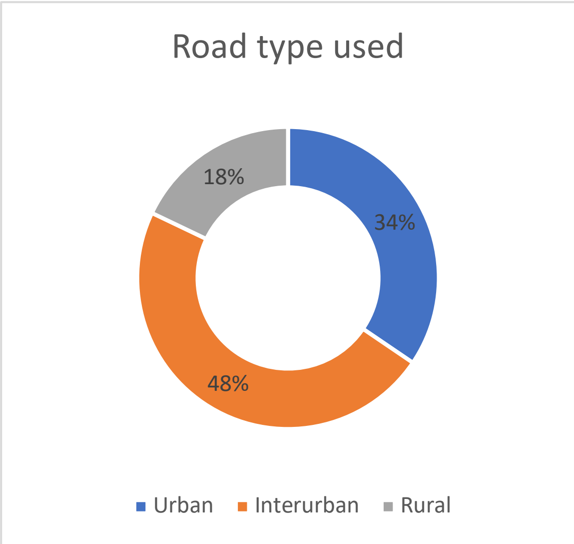
At the time of preparing this interim analysis, only pilot participants' expectations of C-ITS have been assessed. Since the pilot was launched in February 2024, some 680 members of the public have completed both the participant selection questionnaire (including driver profile related questions) and the pre-pilot user acceptability questionnaire (containing commonly asked C-Roads questions from other C-ITS pilots).

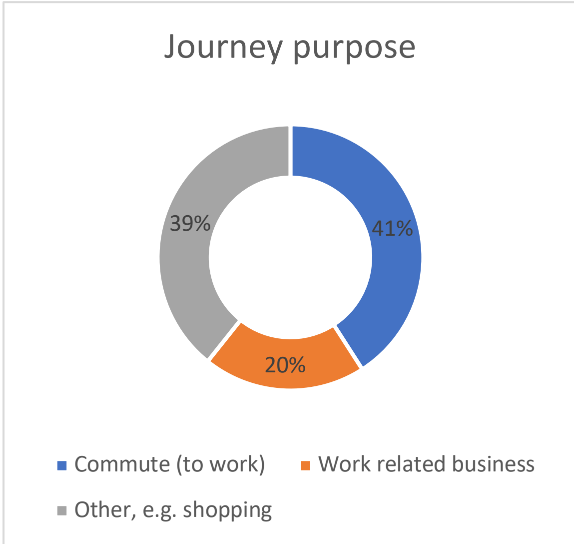
Further analysis will be undertaken towards the end of the pilot programme to 1) update this analysis with additional pilot participant responses and 2) ascertain to what extent C-ITS services have met expectations and specifically to answer the following evaluation questions:

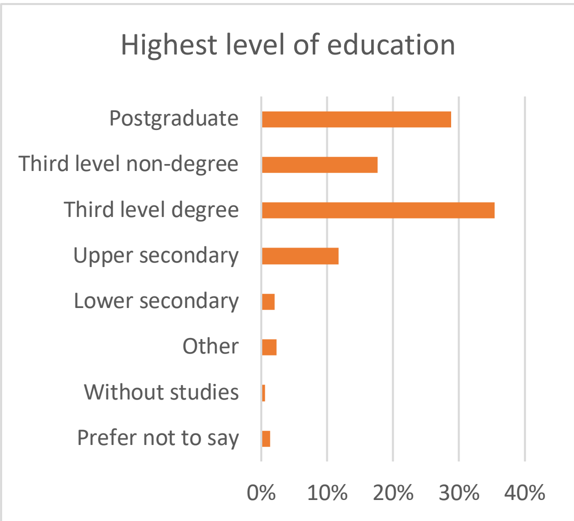
- What information was provided, how often, over what time period, etc.?
- In which way will C-ITS be relevant to the user's driving (behaviour)?
- Does the user understand how and when the system works?
- Does the C-ITS service support the user in driving when using it? Or does it distract the user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

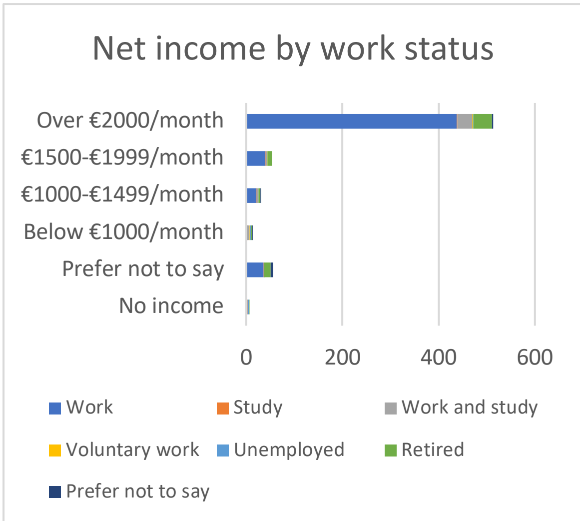
Analysis of the participant selection questionnaire is shown in Figure 64.

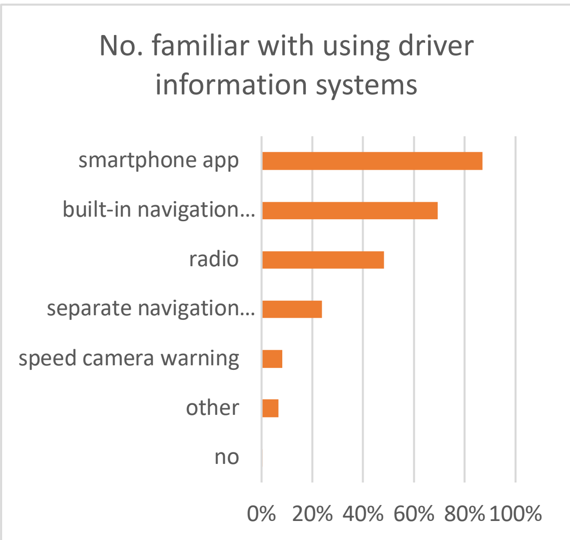



Road type used
18%
34%
48%
Urban
Interurban
Rural


Journey purpose
39%
41%
20%
Commute (to work)
Work related business
Other, e.g. shopping


Highest level of education
Postgraduate
Third level non-degree
Third level degree
Upper secondary
Lower secondary
Other
Without studies
Prefer not to say
0%
10%
20%
30%
40%


Net income by work status
Over €2000/month
€1500-€1999/month
€1000-€1499/month
Below €1000/month
Prefer not to say
No income
0
200
400
600
Work
Study
Work and study
Voluntary work
Unemployed
Retired
Prefer not to say


No. familiar with using driver information systems
smartphone app
built-in navigation...
radio
separate navigation...
speed camera warning
other
no
0%
20%
40%
60%
80%
100%

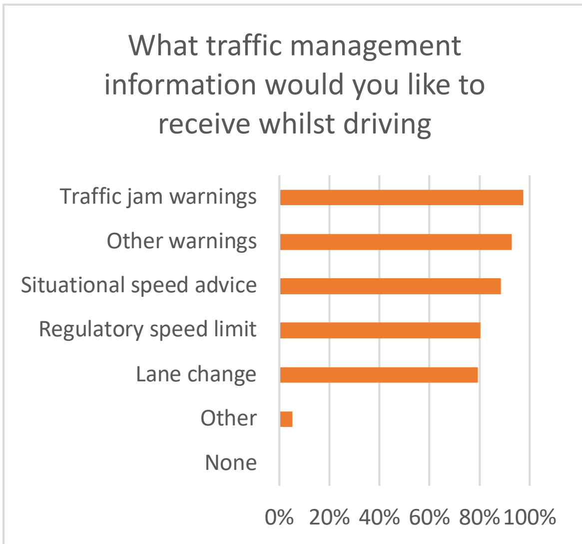

What traffic management information would you like to receive whilst driving
Traffic jam warnings
Other warnings
Situational speed advice
Regulatory speed limit
Lane change
Other
None
0%
20%
40%
60%
80%
100%

Figure 64 - Key driver profile statistics of pilot participant

It is important to understand the demographics of pilot participants to provide context to the user acceptance analysis as well as more broader impact evaluation analyses. A recruitment target was set to achieve a representative sample of road users. It is clear that with nearly 90% male participants, female drivers are underrepresented in this sample group. Further marketing and recruitment activities may help to balance the demographic of users. In any event, the project team has developed an understanding of who is participating in the pilot that will be considered when drawing conclusions on user acceptance.

Prior to experiencing the C-ITS services, participants were a series of C-Roads defined questions. The responses to these questions are shown in a series of graphs shown in Figure 65 and discussed below.

It should be noted that this assessment has grouped all service categories (i.e. road works warning, hazardous location notification and in-vehicle signage). Cross references to this section have been inserted from the relevant sub-section of in-vehicle signage (section 6) and hazardous location notification (section 7) sections.

For all service categories, between 82-94% either agree or strongly agree that C-ITS will make them feel at ease and more secure whilst driving. Of the different services, hazardous location notification appears to be of most interest and potential to participants in this regard.

Approximately 3 out of 4 participants either disagreed or strongly disagreed with the view that C-ITS would be a source of distraction. Noting that approximately 16% of participants could neither agree nor disagree, suggesting that participants could be reserving judgement until experiencing the service for themselves. User acceptance (post exposure to services) will show whether providing this service was a source of distraction.

Over 92% of participants were comfortable providing position data as part of the service, which is fundamental to the C-ITS concept of providing relevant traffic information to you based on where you are.

More than 3 out of 4 participants, across all services would like to have C-ITS services permanently in their car. However, approximately 53% of participants either disagreed or strongly disagreed with the notion of paying for these services. Nearly a third of participants neither agreed nor disagreed with this notion, suggesting that if the service is good enough, e.g. accurate, reliable and of real value to participants, they may be prepared to pay for it – again this will be key to find out in subsequent surveys. It is worth noting that part of the C-Roads vision is to provide a subscription (payment) free service to benefit users that are capable of receiving C-ITS messages. This vision resonates with the findings presented here resonate and more commonly across other C-Roads member states.

Figure 65 - Pre-pilot acceptability responses

5.4.9. Portugal

Users' acceptance in C-Roads PT considered two different surveys:

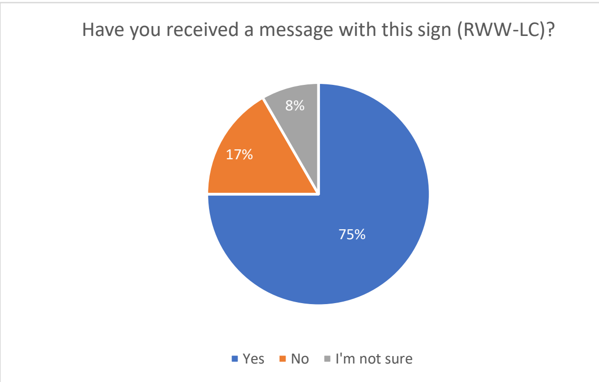
- A general survey to users in motorways aiming at obtaining broad perspectives on the knowledge and general perception on the usefulness of C-ITS services, notably on whether C-ITS services will contribute to feeling at ease whilst driving, make them feel more secure whilst driving, distract their attention from traffic and acceptance in relation to privacy or willingness to pay.
- A targeted survey to participants in the pilot tests, aiming to obtain a better understanding on the users' perceived experiences with the system, or in other words how drivers noticed and reacted to the information provided as well as the perceived impacts and acceptance of C-ITS.

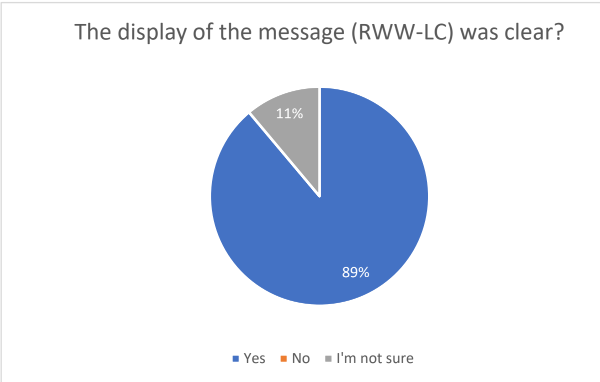
Of the drivers that noticed the RWW information during testing it was found by the majority to be useful.

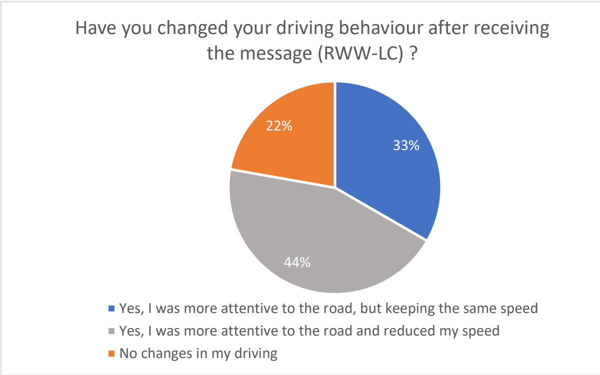
Nearly three quarters of the participants states that have received the message and in its large majority considers the display of the message clear. It is worth noting that two different solutions and displays were available during tests.

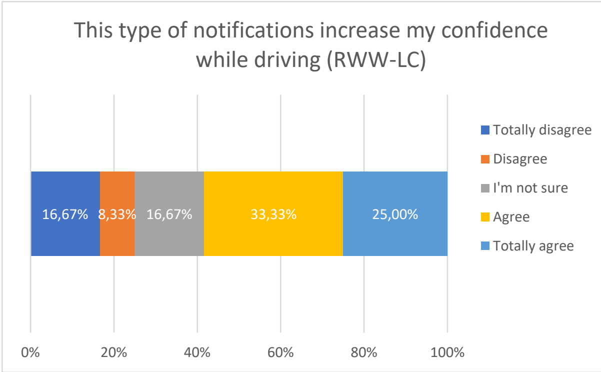
Almost 8 in 10 participants, acknowledge that receiving the RWW message in advance enabled them to be more attentive to the road, some reducing speed (44%), others keeping the same speed as before.

Overall, more than half of the participants refers that such type of notifications increase their confidence while driving. However, nearly a quarter of the participants disagrees and 16% is not yet sure.






Have you changed your driving behaviour after receiving the message (RWW-LC) ?
22%
33%
44%
Yes, I was more attentive to the road, but keeping the same speed
Yes, I was more attentive to the road and reduced my speed
No changes in my driving


This type of notifications increase my confidence while driving (RWW-LC)
16,67%
8,33%
16,67%
33,33%
25,00%
0%
20%
40%
60%
80%
100%
Totally disagree
Disagree
I'm not sure
Agree
Totally agree

5.4.10. France

Use Cases considered

- RWW-WM: Roadworks Warning - Winter Maintenance
- RWW-RM: Roadworks Warning - Roadworks Mobile

Context and evaluation methods

Two tools have been deployed in the Centre d'Entretien et d'Intervention (CEI) of the Direction Interdépartementale des Routes Ouest (DIR Ouest): a touch-sensitive tablet integrating an on-board application with a shared C-ITS/MCE interface, and a web interface for managing events entered on the tablet. Professionals' experience of using the tablet was assessed by means of questionnaires and interviews. The first evaluation phase took place in a first ILC for a test period in real-life conditions (questionnaires N = 22; interviews N = 22). The second evaluation phase took place in a second ILC (questionnaires N = 20; interviews N = 20). The third evaluation phase took place during the gradual roll-out to all DIR Ouest IECs (questionnaires distributed prior to training, at 2 months and then 6 months after roll-out, N = 301; interviews N = 89).

Qualitative Test Results (Interviews)

The particularity of the pilot site studied lies in the technology deployed, since it corresponds to a tablet incorporating both C-ITS and an on-board handrail system (MCE). The deployment of this tablet was accompanied by a web interface that could be consulted on a computer. This particularity led us to carry out a cross-assessment between C-ITS and MCE tools. Despite some technical difficulties (e.g. connection problems), the deployment of this combined tool proved to be a real asset for the deployment of C-ITS, which, if deployed alone, would probably have been less widely adopted and used. All the more so as, without this shared interface, two tablets would have been deployed, which would have led to major difficulties of acceptance, given the already busy workstations. MCE-related functions were, at the outset, those most eagerly awaited by agents. The C-ITS tools made available to operations therefore benefited from the attraction and expectations of MCE teams. However, many agents expressed their support for C-ITS and asked for the information entered on their tablets to be distributed to users. It is also interesting to note that C-ITS functions have been used internally by CEIs, so that teams arriving at an event can more easily locate their colleagues already on site. In the light of the results of this study, and for future rollouts, we recommend continuing the work begun on the interconnection between tools within vehicles, to facilitate the reporting of events and the presence of managers on the tracks, so as to maximize the safety of both agents and users. Consideration will also need to be given to how to integrate CIGT into this system, including C-ITS/MCE tools.

Attitudinal Test Results (Extended)

Perceptions of Automated Driving Vehicles (ADV). Participants spontaneously evoked elements related to ADV operation, mentioning terms such as "autonomous", "artificial intelligence" and "electric", as well as perceived consequences, mostly negative, such as "danger", "driverless", "risk" and "freedom". The results reveal two main trends: a negative attitude associated with a lack of prior involvement or experience, marked by terms such as "distraction" and "disempowerment", and a positive attitude associated with familiarity with the subject, characterized by terms such as "connected" and "progress". These results suggest the existence of two opposing perceptions of ADVs.

Perceptions of the Autonomous vehicle (AV). Participants spontaneously associated the AV with the notions of "safety", "danger" and "driverless", reflecting a questioning of its safety. Terms such as "automatic" and "electric" were also evoked, possibly forming the core of the AV's social representation among road managers (Di Giacomo, 1980; Lo Monaco et al., 2017). The results also revealed a link between distance from the object and perception of the AV: a negative opinion was more common among those less involved, while those with experience evoked accident-related concerns but also potential benefits such as accessibility and reliability, testifying to nuanced perceptions of the AV.
Comparison of perceptions between AV and ADV. The results of the analyses show nuances between the terms AV and ADV, requiring further investigation. The diversity of terms suggests greater variety in the case of ADV, with a lexical field emphasizing technology. On the other hand, AV is often associated with high cost, but perceived as easy to use. Lack of previous experience with ADV seems to influence perceptions less than with AV, probably due to a lower level of knowledge of ADV terminology.
Object distance. After the free association task, participants expressed a generally neutral attitude towards ADV/AV, with a majority expressing no clear opinion. Assessment of participants' knowledge revealed significant differences from expected responses, underlining the need for further clarification and education in this area. Participants' personal involvement in the subject appeared to be moderately low overall, with a majority having no prior experience with ADVs or AV.
Impact of ADV/AV for professionals. Most participants expect the arrival of ADVs/AVs to necessitate adaptations to road infrastructure, particularly in terms of intelligent transport systems, traffic information and signage. They also anticipate repercussions on their work, their service and the structure as a whole.

5.4.11. 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 81 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 81 details the feedback obtained from the implementation in the Madrid and Andalusian sub-pilots.

Table 81 - 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

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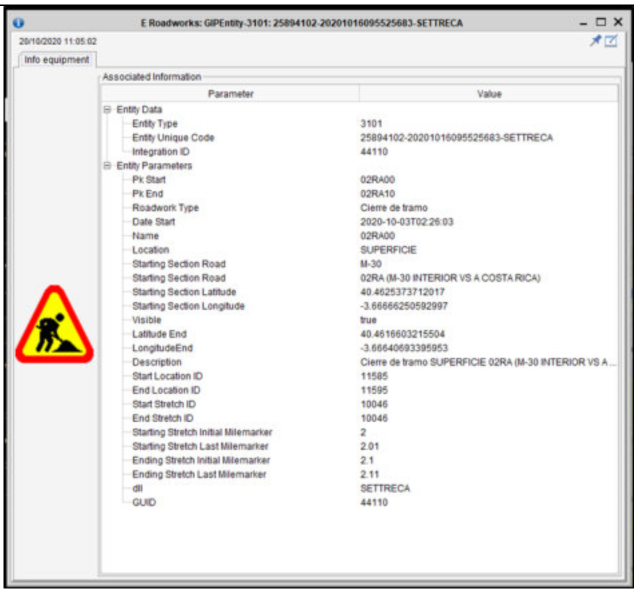

[Kapsch deployment]
RWW is a specific service that is quite sensitive for drivers. One of the project goals was to demonstrate that once the driver received this information, they became immediately aware and cautious about the restrictions they were about to find in front of them. Inherent advantages 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.
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<tr>
<td>HMI*</td>
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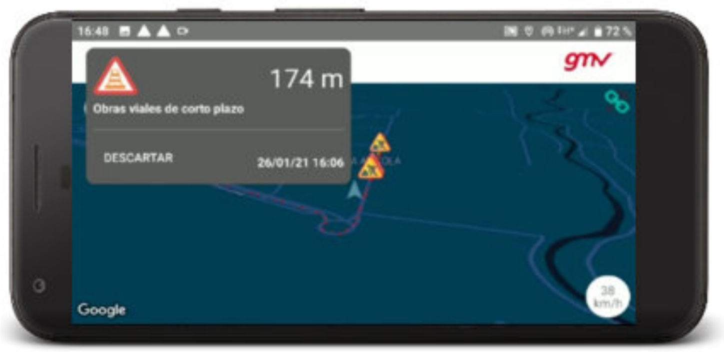
The Smartphone as HMI for the GMV deployment in the Madrid pilot was the main device used by the participants to receive feedback about the user acceptance for the RWW-LC service. The GMV C-ROADS App showed the road works warning, lane closure notification and the distance to reach the event. Also, the 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
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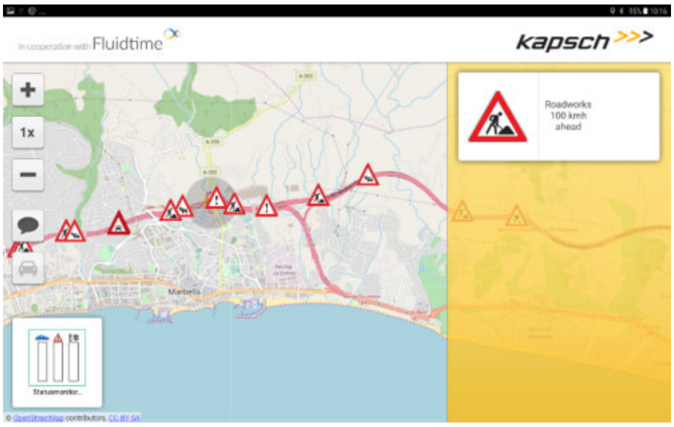
	provided all received info to the driver. For RWW service, the next screenshot shows an example of how this information was provided to the driver. 
Quality of the Service	If the event has a trace/eventHistory, the event was shown to the user in the HMI when the vehicle entered the zone. If the event 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 82 - 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

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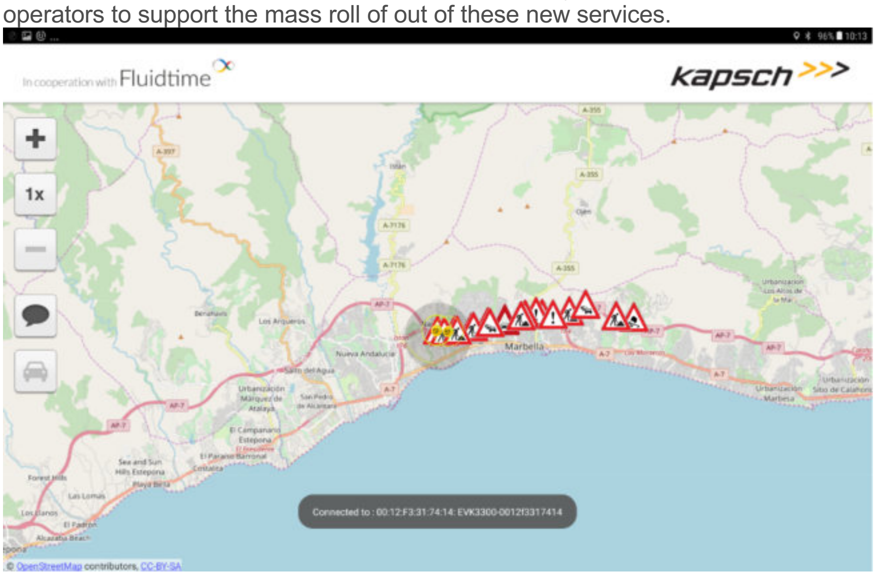
of travel of the vehicle. Driver distraction was a key issue and an important safety concern for road operators to support the mass roll of out of these new services.



<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.
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<tr>
<td>HMI*</td>
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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>:
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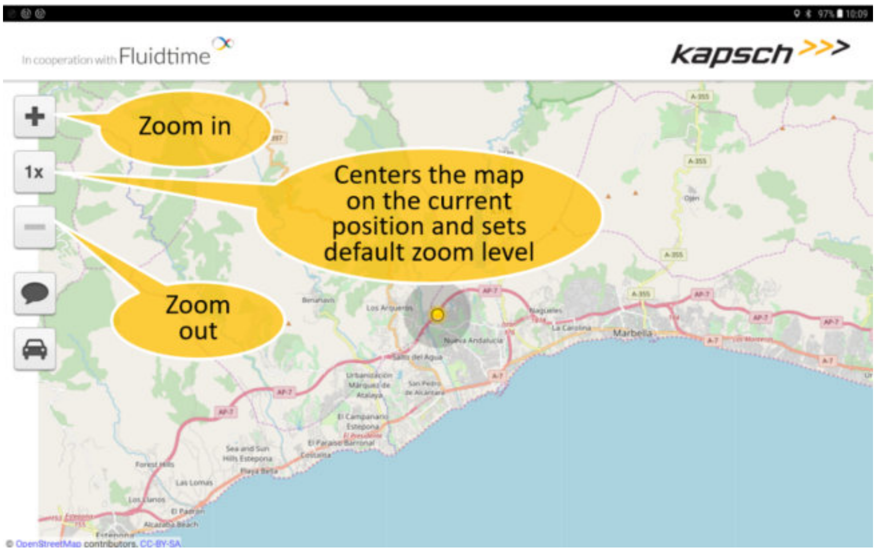
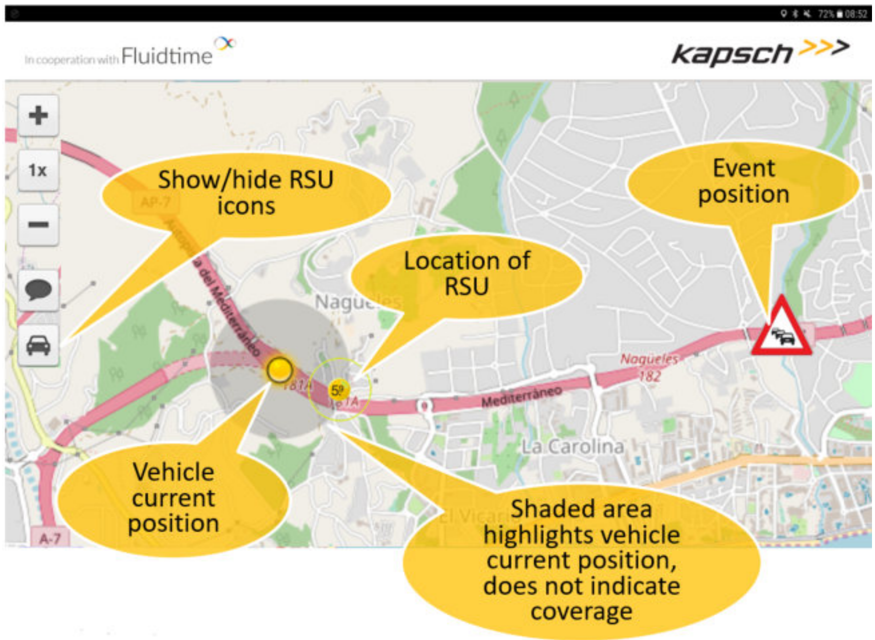
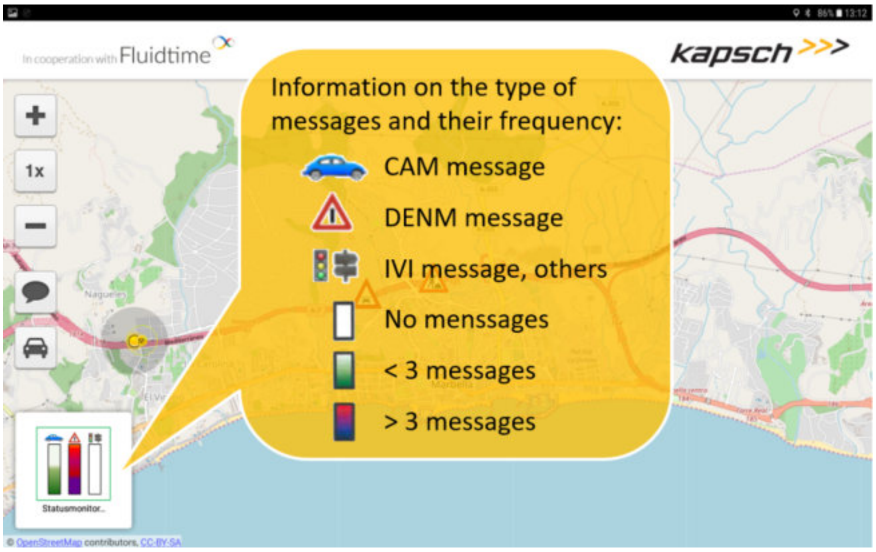
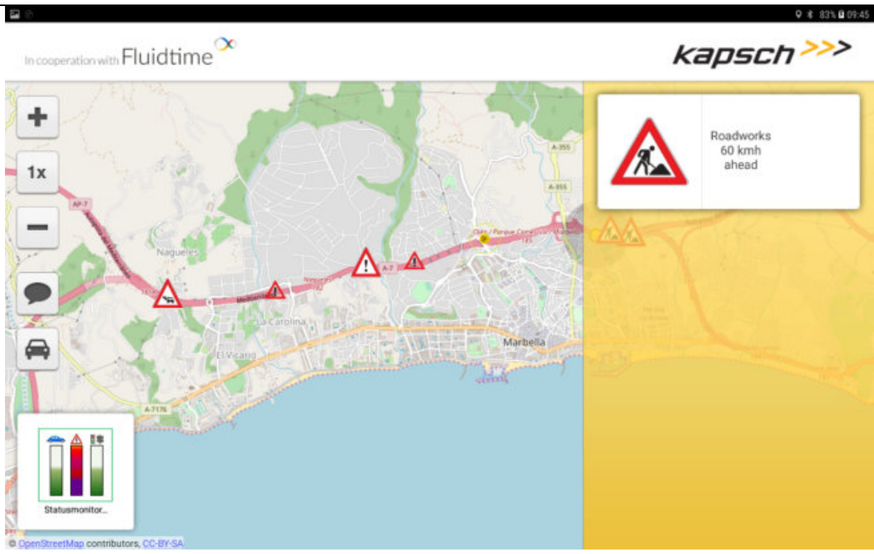
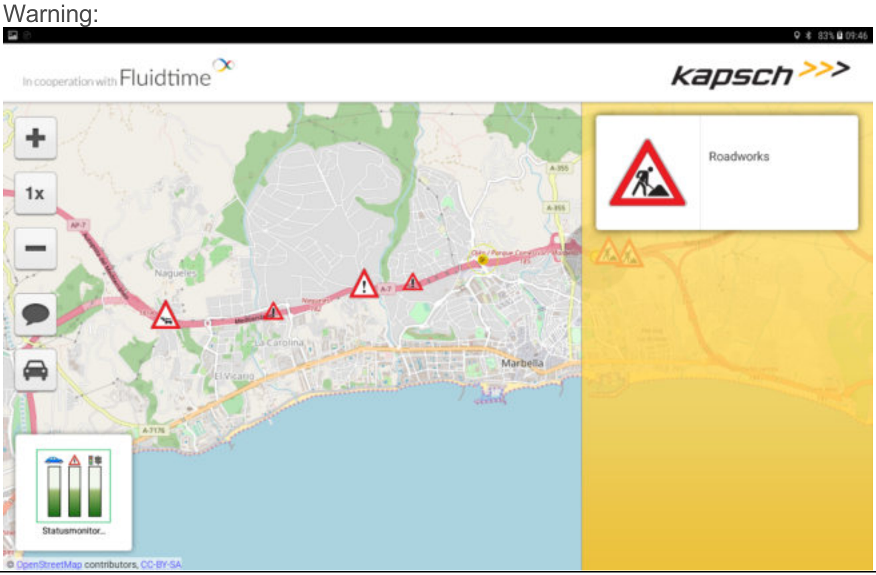
	Zoom Controls  RSU Locations:  Events and information display:

Status Monitor:



<u>Examples</u>:
Pre-warning:

	 Warning: 
Quality of the Service	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. 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 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. 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 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.

5.5.4. Ireland

Interim functional evaluation analysis for the Road works warning lane closure use case is provided below. The project team will continue to capture feedback from pilot participants for the rest of 2024 and the analysis will be completed in the national evaluation and assessment report.

Table 83 - Functional evaluation - Service implementation lessons learned: lane closure

Theme	**What were the lessons learned during the implementation of the service in general?**
Operator error	As per the current implementation, the lane closure information comes from the traffic management system to the C-ITS CMCC (C-ITS central station) system which then disseminates the messages via physical and virtual Roadside Units for the participants to receive the messages on their HMI/ Smartphone application. Hence, the accuracy of data entered by the traffic management system operator is the key to overall correctness of the information that C-ITS participants receive. This has created a dependency such that when the NIMS system is down or has incorrect information, the C-ITS system will also be affected. The current C-ITS implementation requires the traffic management system operator to clear messages on the platform for the messages to get removed from the CMCC. This has room for operator error

Ground truth	The CMCC transmits the lane closure information as received from the traffic management system. Hence there is no means of validating the accuracy (ground truth) of the information
European standards	Since Ireland does not follow any common European standards for lane numbering, mapping exercise was required

Table 84 - Functional evaluation - HMI implementation lessons learned: lane closure

Theme	**What were the lessons learned specifically in relation to the implementation of the HMI?**
HMI limitations	Although C-ITS messages can transmit additional information such as temporary speed restrictions at road works, these were not passed to the participants as the HMI limits displaying temporary speed restrictions from the DENM RW container Countdown of distance to RWW LC was not possible due to the OBU/HMI limitation and not a C-ITS message constraint
Left hand drive/ right hand drive configuration	Since the HMI software was developed in the EU and used in Ireland, minor issues were observed in terms of configuring the direction of travel i.e., Left Hand Drive/ Right Hand Drive. This has also highlighted the importance of configuring the OBU/HMI for cross border usage

Table 85 - Functional evaluation - Technical performance of messages and warnings: lane closure

Theme	**What observations were there in relation to the technical performance of how messages/warnings were displayed in the vehicle?**
Up-stream notification distance (trace length)	The current implementation notifies RWW only 600m upstream. So far there was no complaints of being not enough notice
Aural alerts	Feedback from participants highlighted that message notification sounds were distracting and is the same as what is shown on the screen. In-app option was provided to turn it off.
Length of message display	Some messages displayed for too long at the bottom of the HMI were seen as a distraction
Information overload	Too much information/notifications on the HMI caused some distraction/confusion to drivers

Table 86 - Functional evaluation - Added value summary (general)

Theme	**What observations were there on the added value especially in relation to existing ITS road signage?**

Configurable up and downstream notification distances	C-ITS messages can be provided at configurable distances in advance and beyond physical message signs as long as they are relevant
C-ITS supplements physical signs	C-ITS messages can provide additional information to road users to what is displayed on physical message signs
Virtual VMS	C-ITS messages can be used in areas where there are no physical message signs to fill gaps in message coverage.
Improved situational awareness	Advance notifications and distances to events is seen as highly beneficial, improving situational awareness
Service potential	Feedback from the participants highlighted that there is more potential than just showing the information that was already shown on the motorway signs e.g., if a warning is no longer valid up ahead

5.5.5. NordicWay 3

Using an application which provided a RWW service, several test drives were performed in a live traffic setting in the city of Trondheim over a period of two months in the summer of 2023. In total, 15 participants completed test drives without and with the application activated. Afterwards they filled a survey with questions like if they adjusted their speed towards roadworks based on the information they received. The roadworks area was outside the driven route, thus, the reaction to this functionality should therefore be conceived more on a conceptual and expectational level, more than as experience from an actual test. (Blomkvist et al. 2024.)

The collected data was not sufficient for any conclusions, but it potentially indicates that drivers responded slightly on getting information from the application. Additionally, the survey results indicate that most of the drivers adapted their speed when driving towards the intersection with the app being active. Interestingly, the participants thought that the application had greater influence on their driving behavior than the vehicle data shows. (Blomkvist et al. 2024.)

5.5.6. Germany

The interurban service RWW was assessed by its functional aspects in the pilot Hessen/Kassel. The functional evaluation was carried out by the test of receiving the DENM via V-ITS-S.

Figure 66 shows the implemented system architecture for the RWW service in the city of Kassel with the sub-systems involved. While using the harmonized interoperability specifications from C-Roads, the detailed specifications of the system integration is described in the pilot Hessen/Kassel M43 specification (CRG-UN M43, 2020).

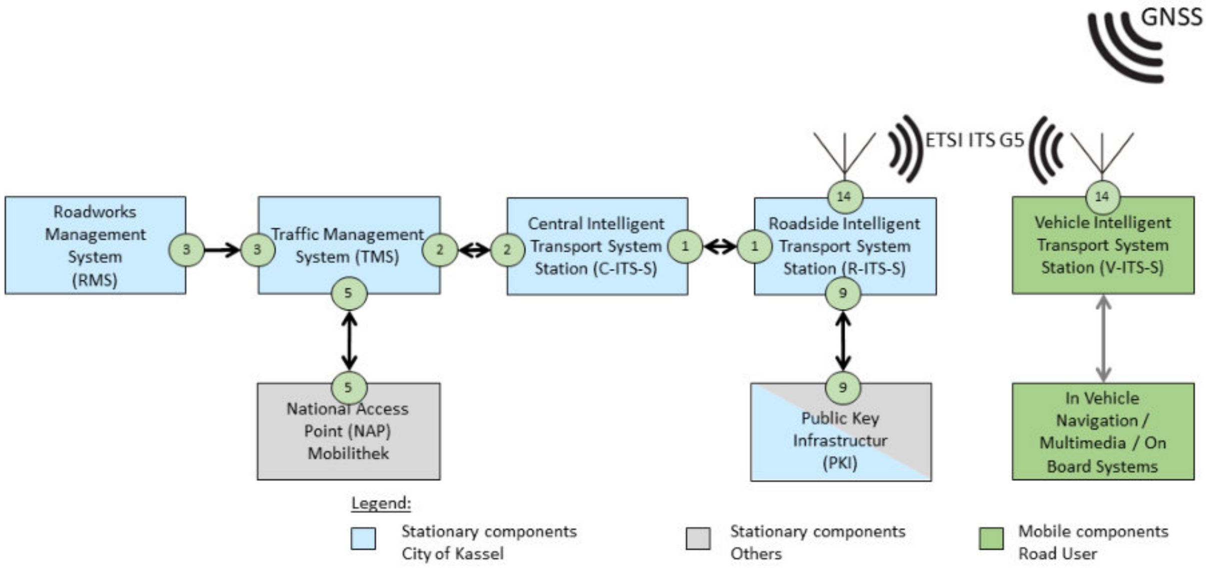


Figure 66 - System architecture of the RWW service in the city of Kassel

The functionalities of the RWW service are implemented at 15 C-ITS equipped traffic lights. The map of the city of Kassel illustrates these C-ITS equipped traffic lights (see Figure 67) (within the CRG-UN project, the service is rolled out in the test field at 75 traffic lights along the main routes of the city of Kassel).

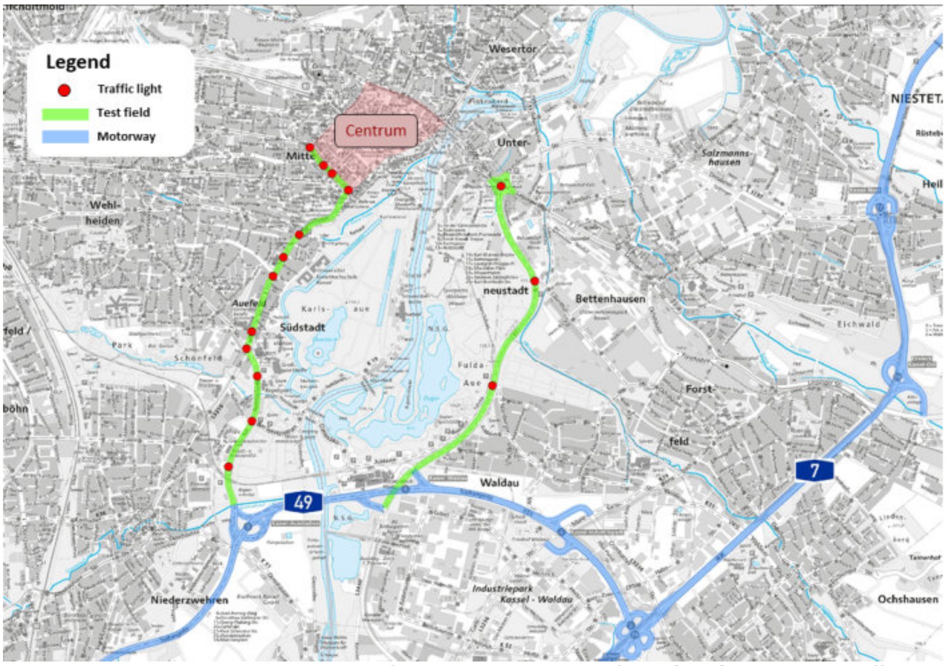


Figure 67 - RWW service in the city of Kassel – overview of the C-ITS equipped traffic lights

Along the routes of the traffic signals equipped for RWW, road closures were generated in the TMS and released for the RWW service. A V-ITS-S with ETSI ITS G5 equipment (see Figure 68) was used to receive the transmitted DENM from the equipped traffic lights (see Figure 69). The received DENM at the traffic light signal systems show the function of the RWW service.

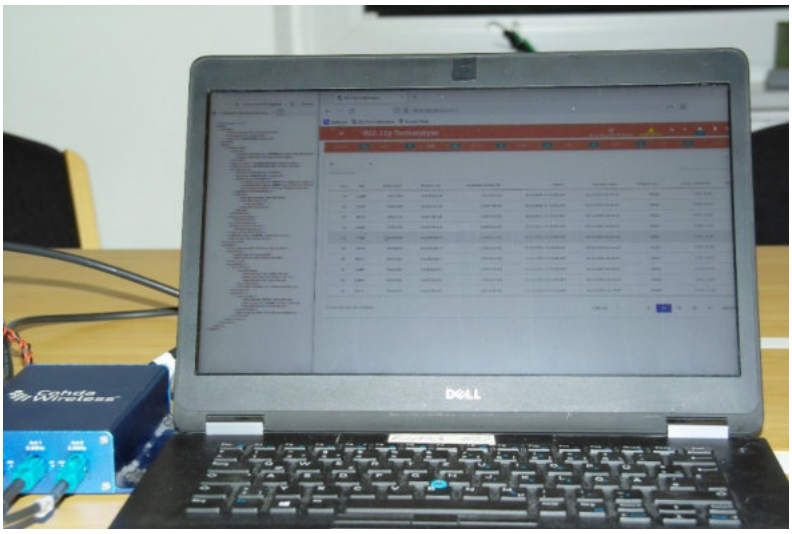


Figure 68 - RWW with ETSI ITS G5 communication test system – V-ITS-S equipment for the receiving of DENM

Figure 69 - R-ITS-S at traffic light

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 87. Further details are available in [RD.10].

Table 87 - 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 88 summarises the impacts on the KPI on mobility and their economic conversion.

Table 88 - 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	+
	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	?

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. (Safety – Spain)

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 89, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 89, 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 89 - 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[10].

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."

[10] 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.

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 90 - 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 91 - 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 92.

Table 92 - 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

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.

C-ROADS

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. Portugal

Use Cases considered

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

Evaluation method

The service IVI-DSLI - In Vehicle Signage - Dynamic Speed Limit Information, was foreseen to be assessed in tests with users.

Unlikely as the service was displayed prior to the entrance to the tunnel, several of the vehicles lost the connection and data could not be retrieved for most of the vehicles in test. Indeed, in the trials in Gardunha tunnel, it was necessary to implement a solution with Beacons, which was not the case for the night tests in Lisboa.

This service will be evaluated in the context of Cooperative Streets.

6.1.7. 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.
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 93.

Table 93- 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%

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. (Safety - Spain)

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 94, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 94, 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 94 - 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 5.1.2 (Safety – UK).

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as the 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.

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 70). 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.

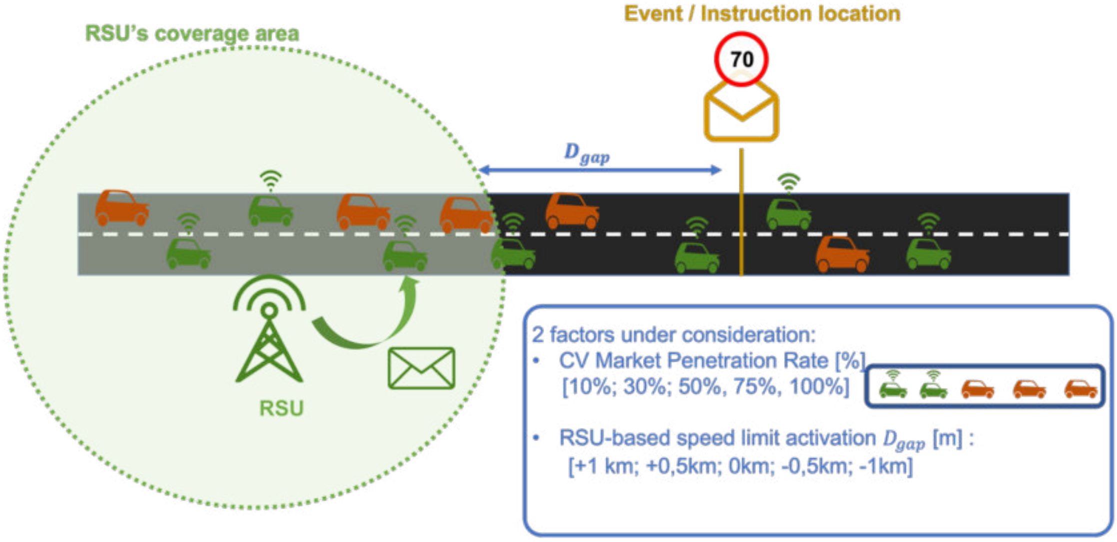


Figure 70 - Design of experiment for C2 use-case

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 71).

- **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.

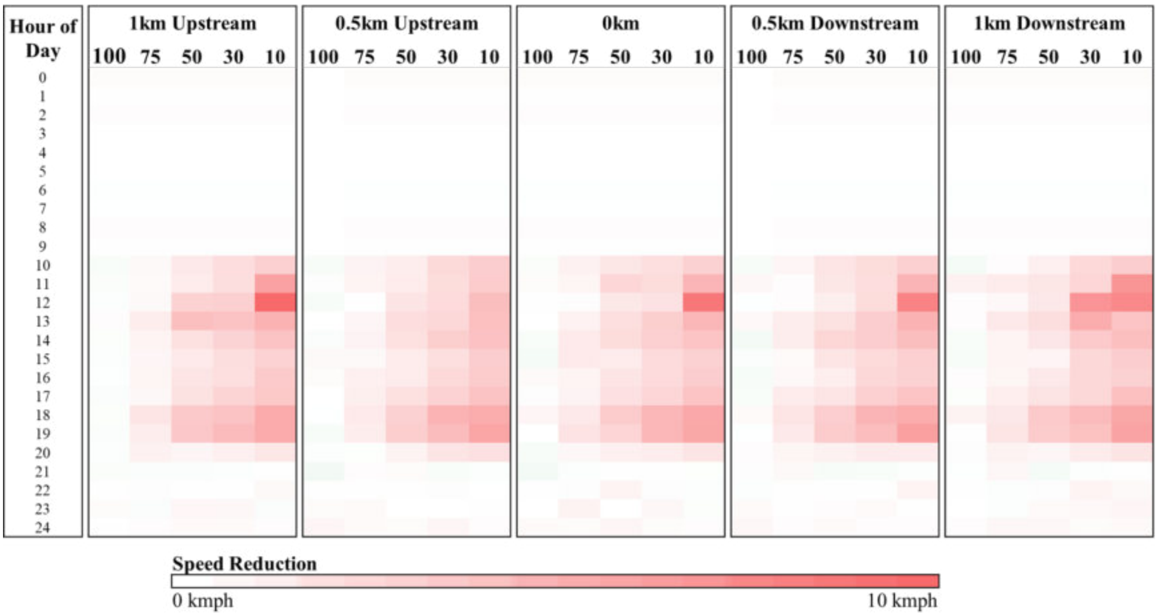


Figure 71 - Change in hourly average speeds for different scenarios (MPR and D_{gap}) of IVS in comparison to VMS for DSLI

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 95.

Table 95 - 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 CO_2 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 96, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 96, 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 96 - 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 5.1.2 (Safety – UK).

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as the 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 (Traffic Efficiency – France).

Evaluation method

Please refer to Section 6.2.3 (Traffic Efficiency – France).

Data collected

Please refer to Section 6.2.3 (Traffic Efficiency – France).

Evaluation results – Field tests

Please refer to Section 6.2.3 (Traffic Efficiency – France).

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 72:

- 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.

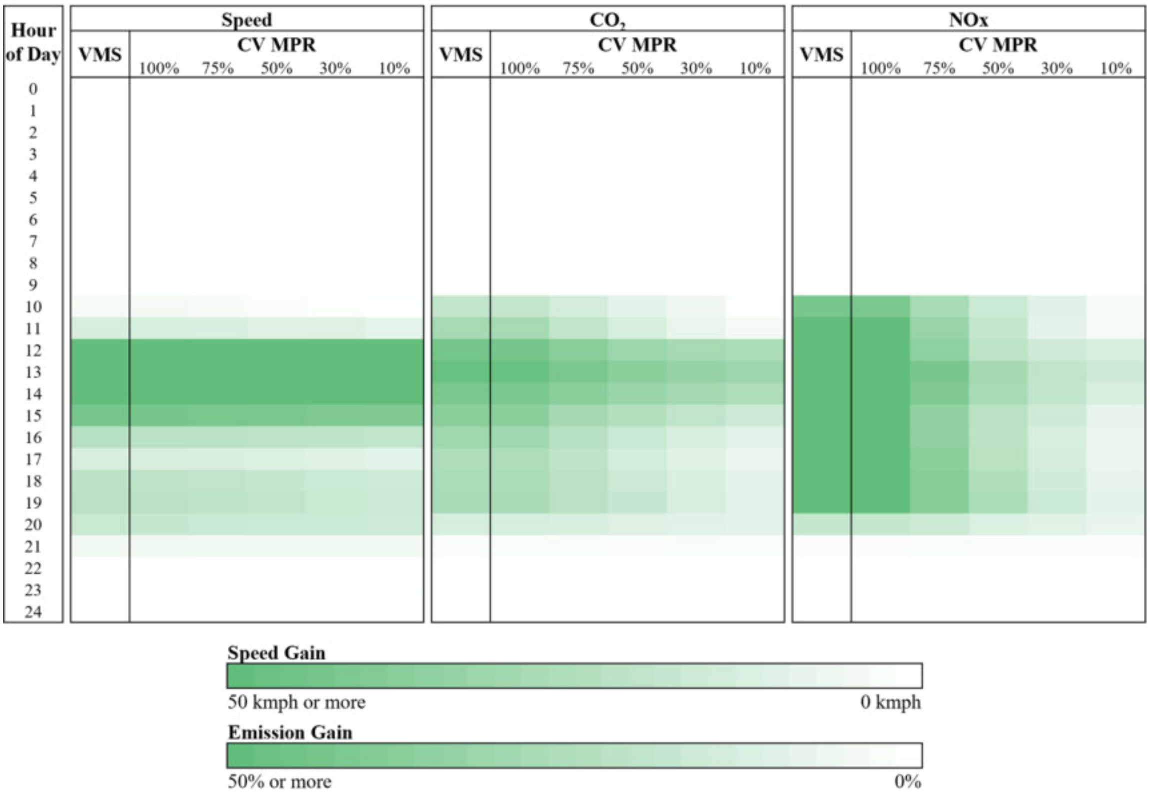


Figure 72 - Summary of Impact of C2 use-case on traffic and environment performance

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 97.

Table 97 - 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 98.

Table 98 - 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 99 - 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 100 - 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 101 - 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 102 - 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 103 - 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[11] 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:

[11] 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.

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.
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 104 - 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 105 - 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 106 - 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.

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 distracted my attention from traffic.	2,53	2,53	0

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. Ireland

Preliminary findings across all service groups were grouped together and are provided in section 5.4.8.

6.4.6. Greece

Use Cases considered

- IVS – EVFT: In Vehicle Signage – Embedded VMS "Free Text"
- IVS – SWD: In Vehicle Signage – Shock Wave Damping

Quantitative Test Results (Surveys)

Regarding In-Vehicle Signage (IVS), almost half of the participants (41,4%) were familiar with the service but have never used it before and 37,9% had zero knowledge about it. Very few participants stated that they have used IVS a few times (3,4%) or regularly (3,4%). Concerning the usefulness of IVS in daily driving, 34,5% of the participants considered the service as useful, 31% had a neutral opinion, and 29,3% rated the service as extremely useful. The number of participants that found the service usefulness was very low (5,1%). Almost half of the participants (43,1%) stated that they would absolutely use IVS regularly if the service was available to them and a high number (31%) agreed to that. Most of the participants (36,2%) had a neutral opinion on whether they would be willing to pay for IVS, 34,5% of them disagreed totally, while the rest either disagreed (12,1%) or strongly agreed (1,7%).

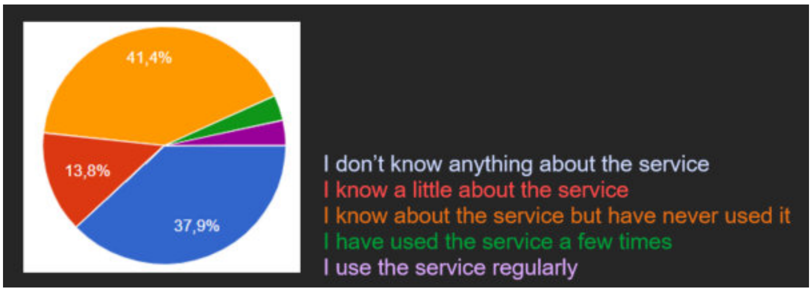


Figure 73 - Knowledge of IVS

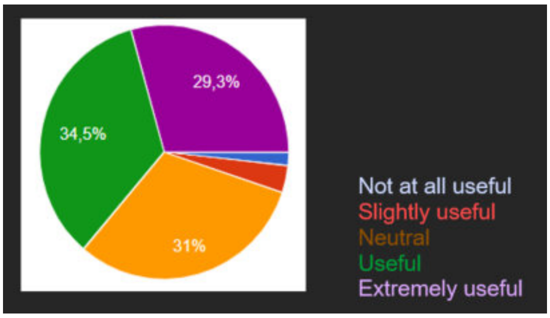


Figure 74 - Perception on the usefulness of IVS in daily driving

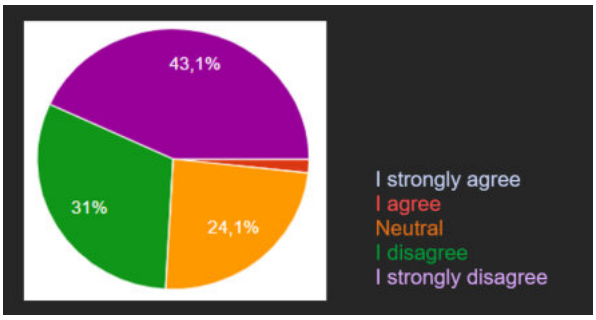


Figure 75 - Willingness to use IVS frequently

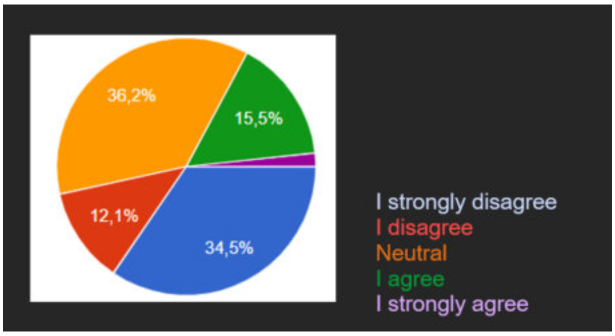


Figure 76 - Willingness to pay for IVS

6.4.7. 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 107shows 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 107 details the feedback obtained from the implementation in the Spanish pilot (Madrid and Andalusian sub-pilots).

Table 107 - 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.

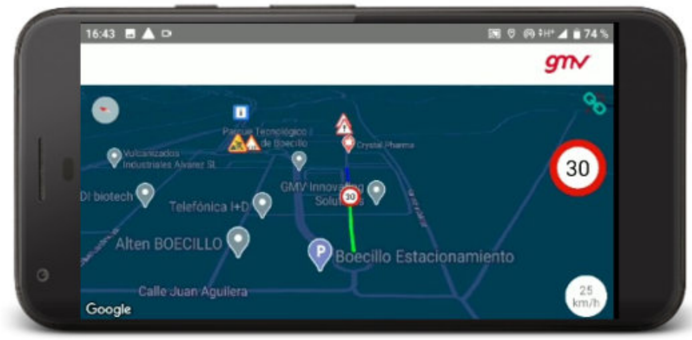
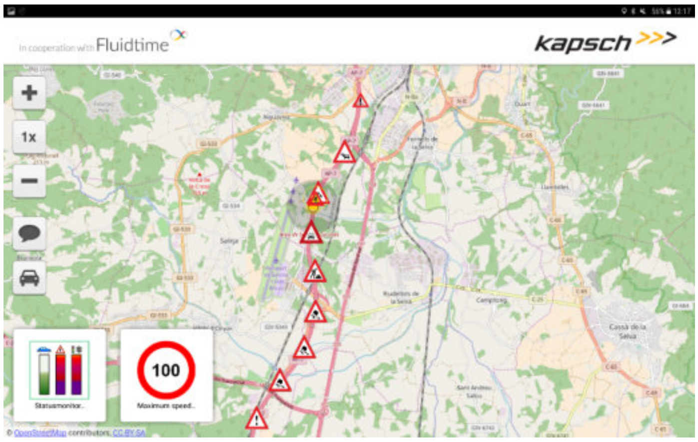
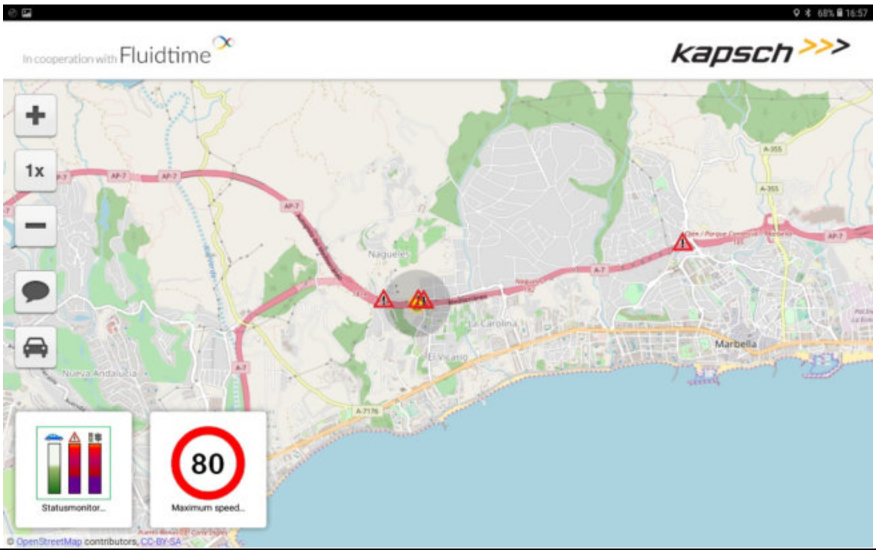
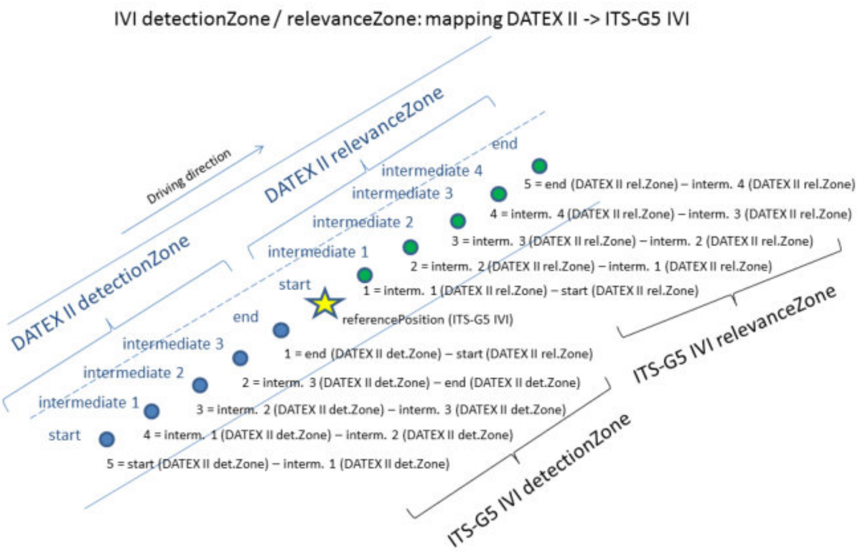
	 Kapsch deployed in all test vehicles included in this Pilot with an OBU and an HMI done with a tablet that is paired through a Bluetooth connection. All tablets had an app devoted to HMI purposes that provided all received info to the driver. For IVS-DSLI service, the next screenshot shows an example 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 108 - IVS-DSLI Functional evaluation. Spain. Andalusian sub-pilot

Service	IVS-DSLI
Lessons Learned	<u>Nature of the messages</u>: 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	<u>Trigger of IVI Based Events</u>  <u>Detection zone</u>: 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) <u>Relevance zone</u>: 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.

6.5.1. NordicWay 3

Traffic regulations are stored digitally using databases. Ensuring that these digital records are continuously up to date has been difficult and time-consuming. As a result, digital records of traffic regulations may be different to those indicated in the real world. With the increasing use of traffic regulation data, particularly speed limit data it is crucial to better understand the role of regulatory authorities as data producers/providers. A study was designed to reveal instances where the signs and regulations differ, potentially causing issues when both map data and sign information are used. (Thorn 2023)
For this study, data collection efforts were conducted in Gothenburg, specifically focusing on gathering an inventory of more than 12,000 speed signs and their positions. The study included comparing the themes and positions of road signs detected by the 3DAI City platform with the listed speed limits in NVDB (Swedish national road database) and, in the future, with the true digital representation of traffic regulations, known as TNE/HTR. The disparities between digitally stored data and the real-world features detected by 3DAI City were assessed dynamically. Any differences identified between the detected road signs and the obtained dataset were reported to Gothenburg and/or the Swedish Transport Administration. (Thorn 2023)
In Gothenburg, the results revealed that a 5.2% mismatch was found between the speed limits recorded in NVDB and the corresponding road signs on roads. The margin of error for this comparison was 100 meters. In Stockholm there was a 4.2% mismatch between speed limits in NVDB and road signs, with a margin of error of 200 meters. Helsingborg had a higher discrepancy rate of 10.9%, with a margin of error of 100 meters. (Thorn 2023)
Reasons for mismatches have been investigated in more detail, and some examples of the reasons for the mismatch have been that road works are present (if the road work is

shorter than 6 months it is not represented in NVDB), signs are positioned with additional signs downstream or that the database had not been updated for the sign in question. (Thorn 2023)

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 109. Further details are available in [RD.10].

Table 109 - 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 110 summarises the impacts on the KPI on mobility and their economic conversion.

Table 110 - 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	- +

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 (Safety – Spain).

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 111, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 111, 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 111 - 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%

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.

Co-funded by the European Union

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 77. We extrapolated that even while using the DARS Traffic Plus application, the drivers' focus was still mainly on the road ahead.

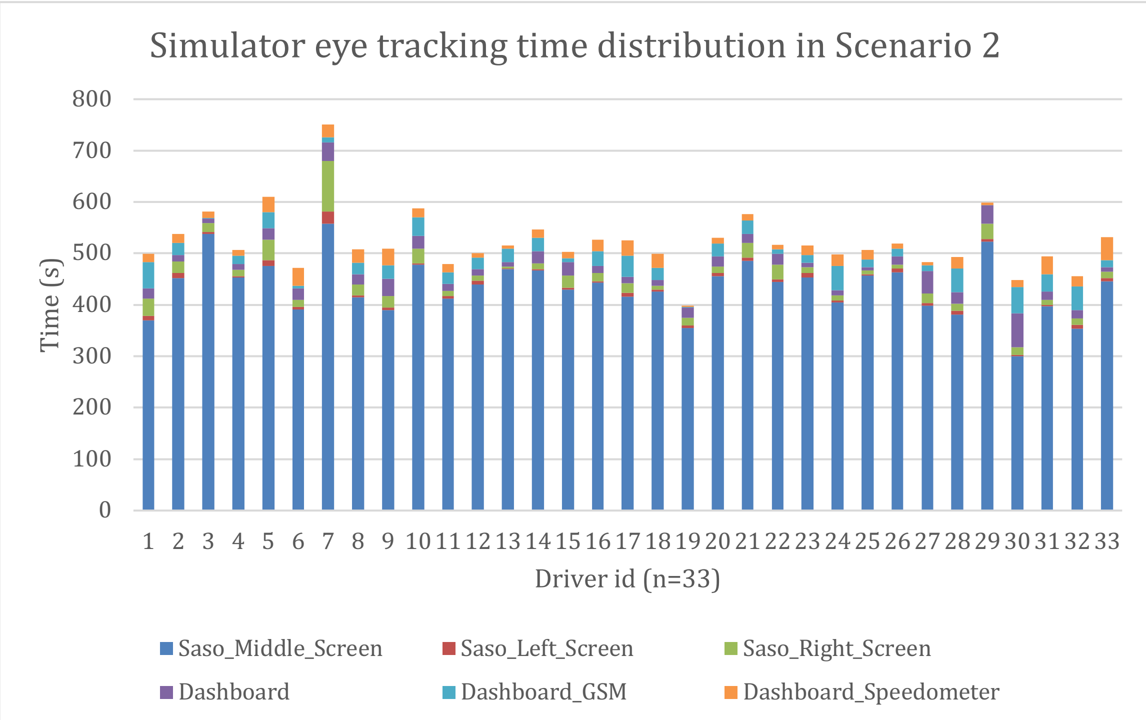


Figure 77 - Area of interest time distribution in Scenario 2

We performed statistical analysis for the frequency of simulator driving parameters and recorded the time distribution of views over the area of interest. Table 112 and Table 113 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 113) 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 112.

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 112 - 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 113 - 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 114 and Table 115.

Table 114 - 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 115 - 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 78 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.

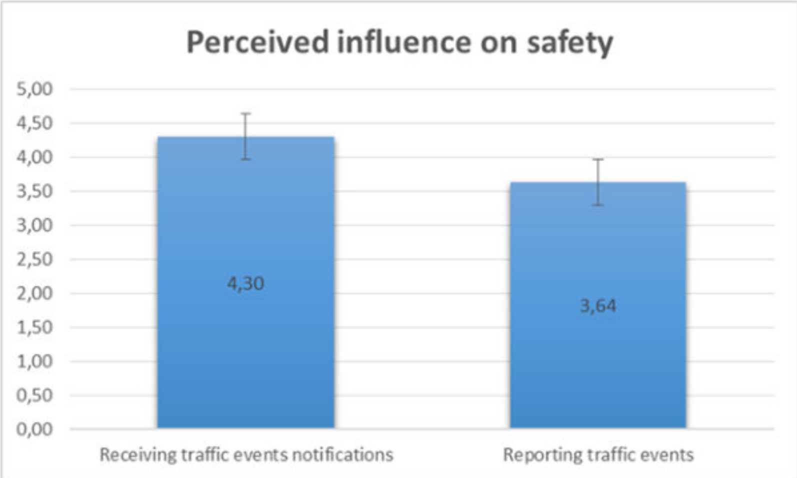


Figure 78 - Perceived influence of HLN notifications on safety

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 79 - Eye tracking results - Heatmap HLN AZ

Figure 80 - Eye tracking results -Scanpath HLN-AZ

Figure 79 and Figure 80 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 79) and the second representation is with so-called scanpath graphs (Figure 80). 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 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.

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

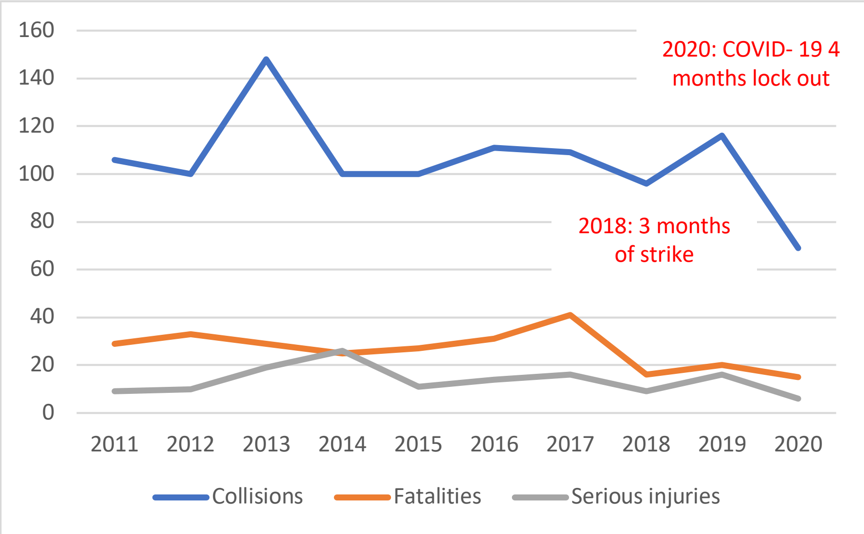


Figure 81 - Level crossing accidents

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.

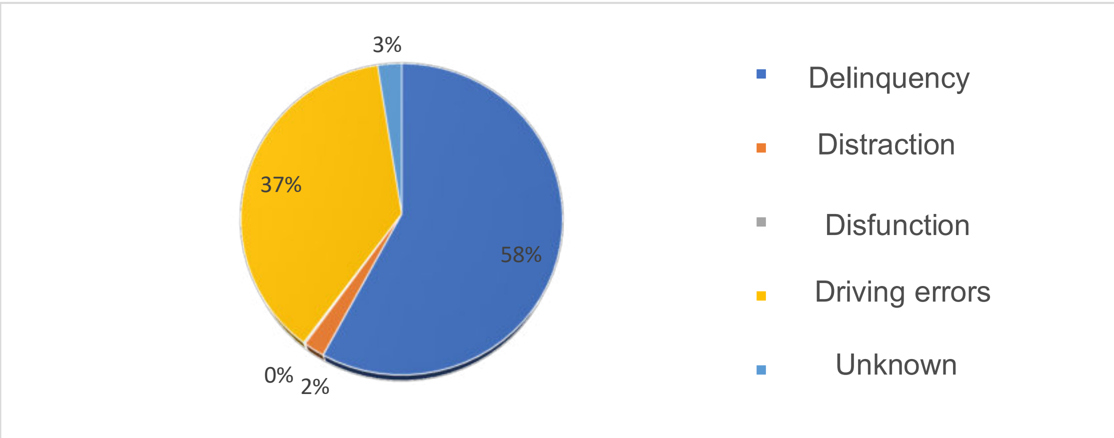


Figure 82 - Causes of accidents

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 83 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.

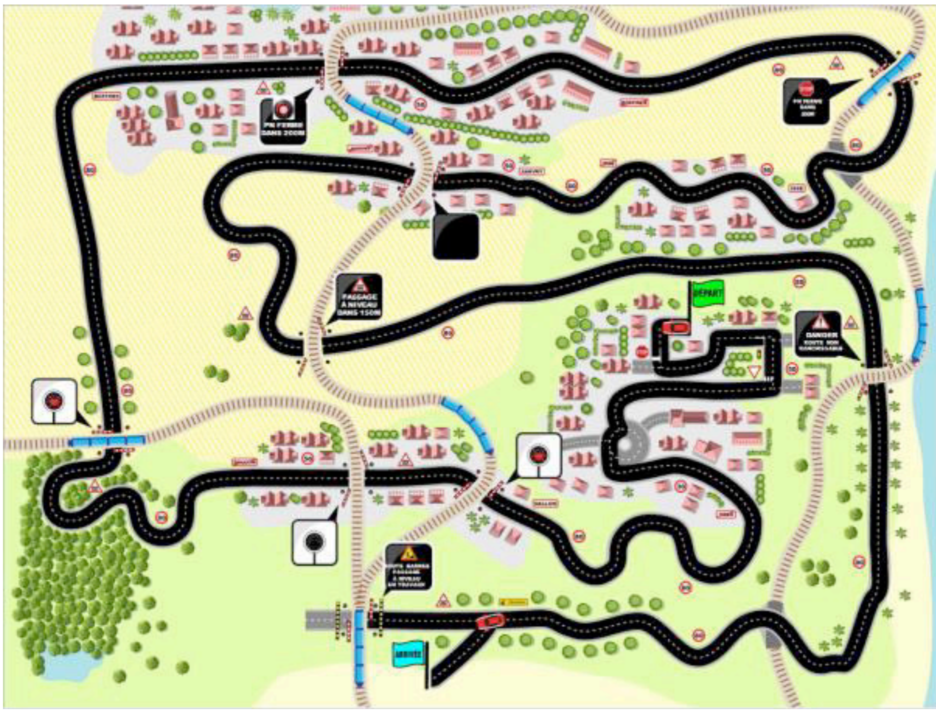


Figure 83 - Simulation course

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 84 and Figure 85. 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.

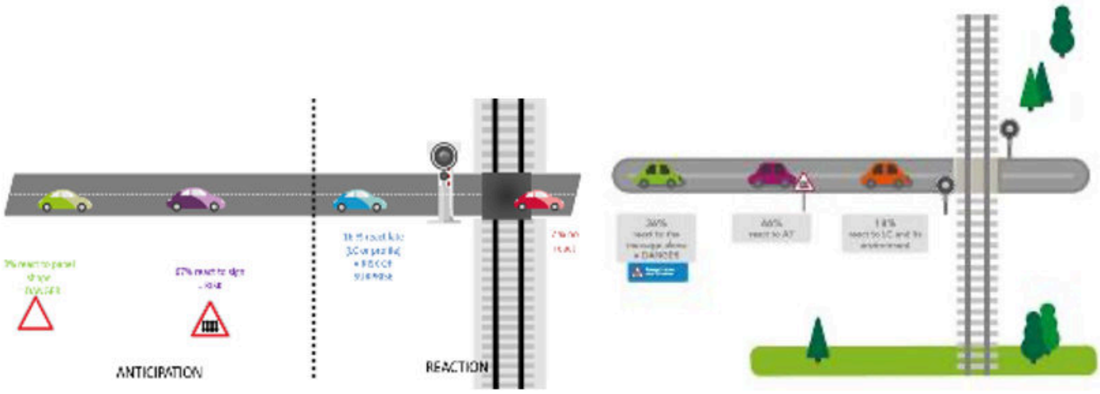


Figure 84 - Modeling of the behavior of subjects LC open without or with “LC at 200 meters” message

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.

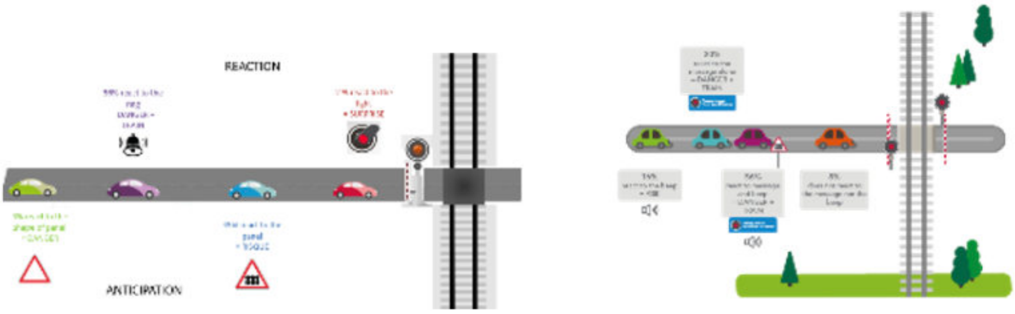


Figure 85 - Modeling of the behavior of subjects LC closed without message and with message

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
- HLN-EPVA: Emergency or Prioritised Vehicle Approaching

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.

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.

A further test session was organized as part of the C-Roads Italy 2 Project in December 2023 on the Autostrada Brescia – Padova, specifically between Verona Sud and Soave – San Bonifacio. In this second activity, a Maserati Ghibli with a gasoline engine, provided by Stellantis – CRF was used..

Virtual/simulated bad weather conditions (e.g., heavy rain) were created at specific road sections. The vehicle's C-ITS equipment was active to receive and display these messages, prompting a speed reduction from 130 km/h to 110 km/h, handled automatically but requiring driver authorization. In 8 out of 16 test runs, an additional Vehicle-to-Vehicle (V2V) alert message was generated by a preceding vehicle to confirm and reinforce the initial warning, leading to a downgrade in driving automation from level 2 (L2) to level 1 (L1).

The vehicle traveled at a speed close to 130 km/h. Upon receiving the WCW C-ITS messages, drivers were instructed to authorize the vehicle to slow down to 110 km/h. In scenarios involving V2V messages, the vehicle's automation level was downgraded from L2 to L1 upon message receipt. Detailed instructions for executing the test were provided to all involved personnel, including specific actions for on-board equipment and space for experimental notes.

HLN-EPVA

The aim was to evaluate the behavior of a driver when an Emergency or Prioritised Vehicle arrives from behind. A comparison between the case in which the C-ITS service is used (C-ITS ON) and the case of unavailability of the service (C-ITS OFF) is pursued.

With C-ITS ON, it is expected that road user can adapt the vehicle speed and the usage of the lane conforming to the information.

The test session was organized as part of the C-Roads Italy 2 Project along the Autostrada del Brennero (Highway A22), between Trento Nord and San Michele. The test involved two vehicles: a C-ITS equipped car and a simulated emergency vehicles equipped with a C-ITS station.

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 [$m/^s2$]
- 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.

For the tests part of the C-Roads Italy 2 Project the following data were collected during the test sessions:

- vehicular logs of all involved vehicles, containing instantaneous and continuous information on positioning and vehicle dynamics, enhanced with log data related to the receipt of C-ITS messages;
- switching status of the vehicular equipment for the reception and display of C-ITS in the different passages and time periods;
- exact positioning of the virtual bad weather condition events;
- any driver notes about, for example, anomalies in the display of C-ITS messages, conditions affecting driving behavior (e.g. inability to maintain a cruising speed close to the limit due to high levels of traffic), etc.

HLN-EPVA

The following data were collected during the test sessions:

- vehicular logs of all involved vehicles, containing instantaneous and continuous information on positioning and vehicle dynamics, enhanced with log data related to the C-ITS messages;
- specific data related to the C-ITS messages originated by the virtual emergency vehicle: reception flag of the V2V messages and distance between the vehicle and the virtual emergency vehicle.

Evaluation results – Field tests

HLN-SV

Heavy vehicles

Table 116 - 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	-

SV - Stationary Vehicles - Heavy Vehicles - Comparison C-ITS OFF vs C-ITS ON				
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/s²]	0,402	0,137	-0,265	-66%
Max instantaneous deceleration [m/s²]	1,32	0,65	-0,67	-51%
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 117 - 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/s²]	0,176	0,371	+0,194	+110%
Max instantaneous deceleration [m/s²]	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 118 - 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/s^2]	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 119 - 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/s^2]	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 120 - 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.

The test carried out as part of the C-Roads Italy 2 Project allowed further considerations on the features of the slowdowns maneuver with C-ITS, considering this time light vehicles.
The test showed that the presence of the C-ITS allowed the slowdown maneuver to be started on average 390 meters before the event starting point, at a better distance than a purely visual reaction to the event.
In the experiments where slowdown was necessary (the speed was above 110 km/h), the recommended speed was reached 109 meters from the start of the event.
Starting the slowdown in advance and reaching on time a suitable speed for the event in progress are behaviors in favor of safety; these aspects linked to the knowledge of a bad weather event allow a calmer and more controlled driving.

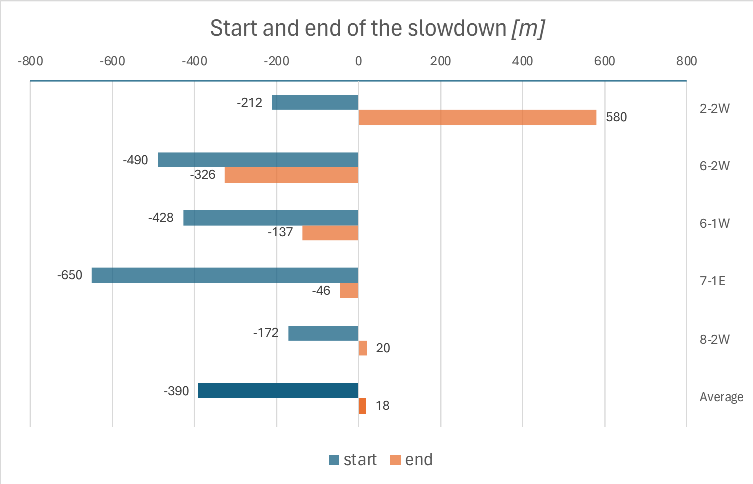


Figure 86 - HLN-WCW - Slowdown maneuver

HLN-EPVA

- Event detection: the C-ITS message allowed to increase the distance of the event detection by 73%, from an average of 370 m (C-ITS OFF) up to an average of 642 m (C-ITS ON)

- Lane change maneuver: the C-ITS message allowed to increase the time of activation of the lane change maneuver (from the fast lane to the slow lane) by 60%, from an average of 6,5 seconds (C-ITS OFF) to an average of 10,4 seconds (C-ITS ON) This increase witnesses a more careful choice of the timing of the maneuver and then a resulting safer attitude.
  The C-ITS message allowed to start the maneuver of lane change far in advance with respect to the C-ITS OFF configuration (785 m vs 360 m, on average, from the simulated emergency vehicle).
  This increase is even more meaningful considering the end of the maneuver. On average, in C-ITS ON configuration the maneuver end is recorded 743 m far from the simulated emergency vehicle, while in C-ITS OFF this distance is equal to 289 m.
  In C-ITS ON configuration the spatial extension recorded for the maneuver is on average lower (-28%) than in C-ITS OFF configuration (109 m vs 152 m). An analogous reduction is also featuring the temporal duration (-32%). Considering the parameter maximum steering angle, the highest values were recorded for the C-ITS ON configuration (+25%), considering the whole set of repetition.
  Since the driver was aware, far in advance, about the need to deploy the lane change maneuver (see previous "Event detection" section), he/she had the opportunity to choose the best moment to actually deploy it. Then the maneuver is performed more resolutely and quickly, suitably with the surrounding traffic conditions. These features were witnessed by all the three parameters considered.

- Emergency vehicle overtaking: the C-ITS message allowed to increase the temporal distance between the detection of the simulated emergency vehicle and its maneuver of overtaking by 142%, from an average value of 36 sec (C-ITS OFF) up to 87 sec (C-ITS ON). An analogous increase is recorded (+190%) for the temporal distance between the conclusion of the lane change maneuver and the overtaking (25 sec vs 73 sec)

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 121.

Table 121 - 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 122.

Table 122 - 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. Greece

Use Cases considered

- HLN-WCW: Hazardous Location Notification - Weather Condition Warning (Slippery Road)
- HLN-OR: Hazardous Location Notification - Obstacle on the Road (Slow/ Stationary Vehicle)

Figure 87 - Attica Tollway network in the SUMO environment

Evaluation method

Refer to Section 5.1.8 (Safety – Greece).

Data collected

Refer to Section 5.1.8 (Safety – Greece).

Evaluation results – Field tests

The number of vehicles (throughput) used in the simulation was around 4500 and is the maximum capacity in the Attica Tollway network based on actual traffic flows.

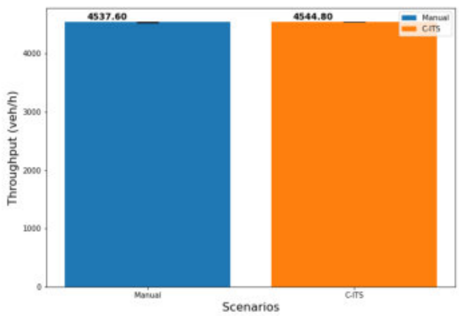


Figure 88 - HLN-WCW throughput for manual and C-ITS scenario

Regarding lane changes in the WCW use case, they are observed to decrease in the C-ITS scenario, which is an expected result as in this case vehicles are informed in advance about the slippery road; hence drivers tend to avoid lane changes as it is risky.

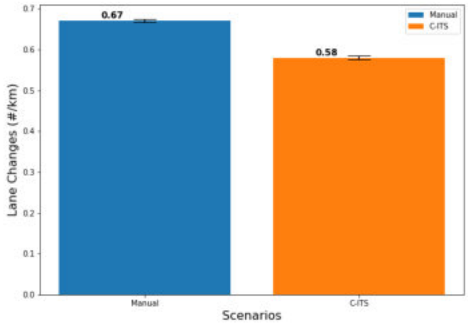


Figure 89 - HLN-WCW lane changes for manual and C-ITS scenario

The number of collisions shows a significant decrease in the C-ITS scenario. This is an anticipated result due to the timely provision of the C-ITS messages that make drivers aware of the slippery conditions on the road and they drive more carefully. HLN-WCW could be considered that contributes to road safety at an important level.

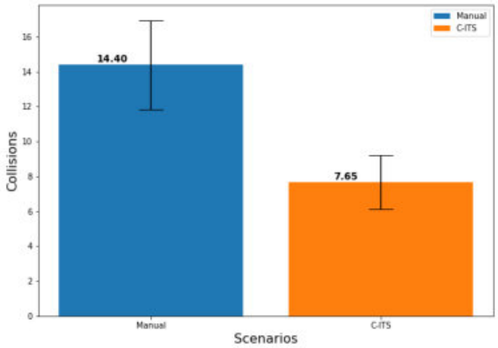


Figure 90 - HLN-WCW collisions for manual and C-ITS scenario

For the use case of Obstacle on the road in the Attica Tollways network, the indicator of lane changes doesn't show a significant difference in the C-ITS scenario as it has increased only slightly. This could be justified by the fact that since drivers are aware in advance about the existence of the obstacle on the road, they are able to perform lane changes timely and earlier than in the case of having no information in advance.

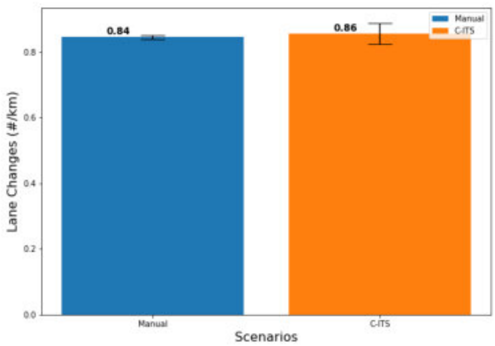


Figure 91 - HLN-OR lane changes for manual and C-ITS scenario

On the other hand, the number of collisions shows a very significant decrease in the case of the C-ITS scenario indicating that the service could have a high contribution to road safety since drivers would show more attentive driving reducing this way the possibility for a collision.

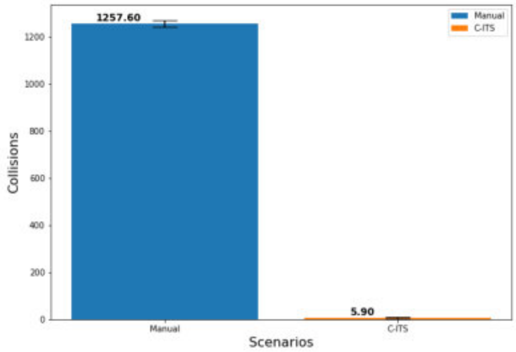


Figure 92 - HLN-OR collisions for manual and C-ITS scenario

The following figure presents the Egnatia Odos Tollways network in the SUMO environment.

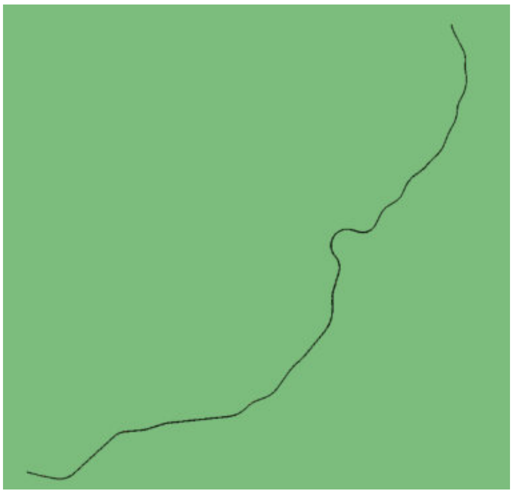


Figure 93 - Egnatia Tollways network in the SUMO environment

In the C-ITS Scenario the vehicles' speeds drop down to 0,8 500m upstream and to 0,6 when entering the edge where the event is located (speed decreases smoothly). In the manual scenario the vehicles' speeds drop down to 0,6 150m upstream. The number of vehicles used in the simulation is around 500 for the baseline scenario, both for C-ITS and manual scenario, and around 1200 for the high C-ITS penetration scenario respectively, both for C-ITS and manual scenario. The throughput is presented in the figure below.

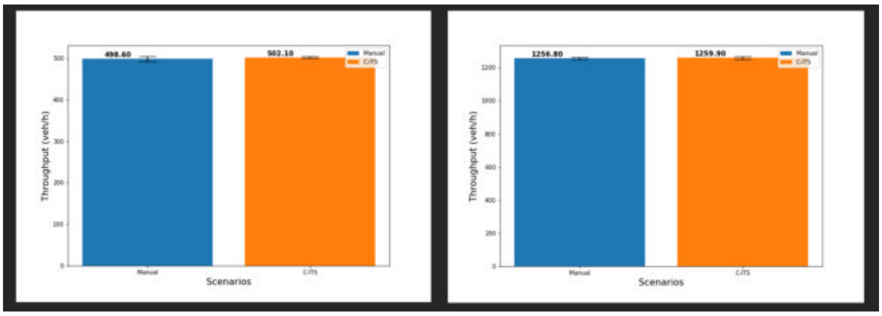


Figure 94 - HLN-WCW throughput for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

Concerning lane changes performed by the vehicles, a higher number of lane changes has occurred in the manual scenario for both baseline and high C-ITS penetration rate scenario, while the number of lane changes was observed to be lower in the C-ITS scenario. This could be explained because in the C-ITS scenario the vehicles are advised in the simulation to remain in the same lane and not to perform changes as all lanes are considered slippery, hence any change could be considered risky.

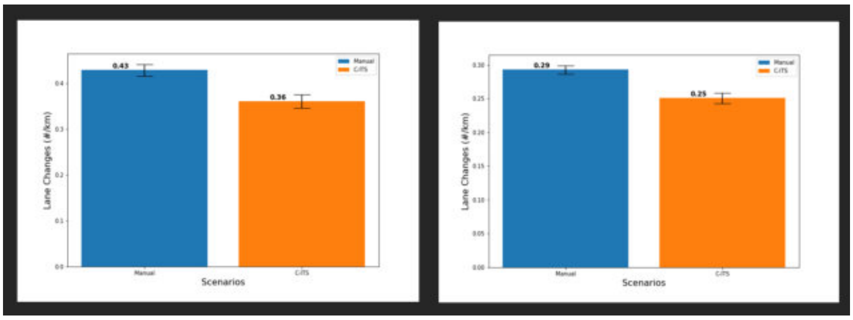


Figure 95 - HLN-WCW lane changes for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

For the use case of Obstacle on the road, the number of lane changes shows a significant increase in the C-ITS scenario for 500 vehicles, but the opposite happens in the same scenario for 1200 vehicles. Lane changes are expected to increase in the C-ITS scenario as drivers are aware in advance of the event through the provision of the C-ITS messages.

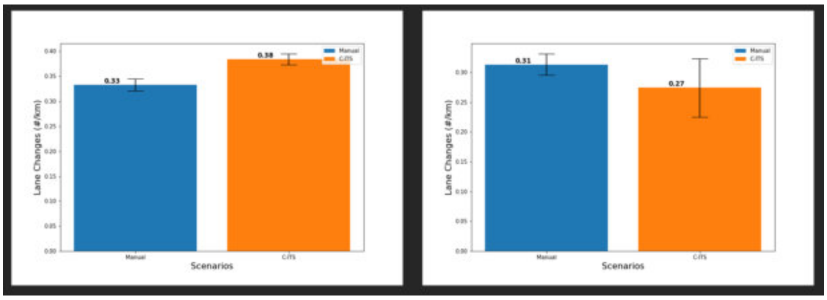


Figure 96 - HLN-OR lane changes for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

A very significant decrease is observed in the number of collisions in the C-ITS scenarios for both cases, 500 and 1200 vehicles, hence it could be considered that HLN-OR contributes at an important level to road safety.

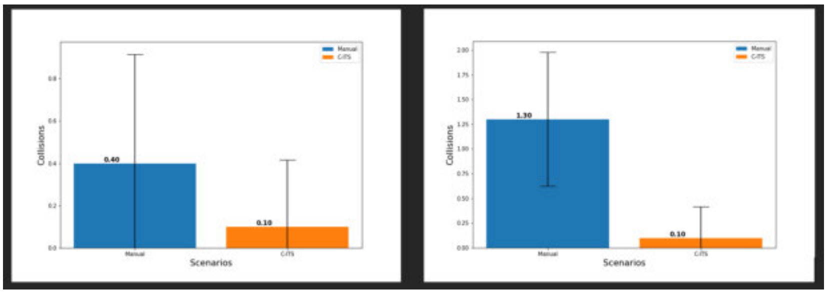


Figure 97 - HLN-OR collisions for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

7.1.7. Portugal

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-OR: Hazardous Location Notification - Obstacle on the road

Evaluation method

The evaluation method follows FESTA where the objective is to compare the behavior of the drivers receiving the in-vehicle information about the hazardous events and those not receiving and infer, in C-Roads PT supported in simulation tools how this change of behaviour can influence on safety, traffic efficiency and environment aspects.
For the stationary vehicle real life conditions have been implemented with a vehicle from IMT duly signalised to assure all safey conditions.

For the object on the road, message has been activated, though in reality there was no obstacle on the road. Nevertheless, given the distance to the object, drivers have reacted.

Main Research Questions for the HLN use cases are presented below.
Is traffic efficiency affected by changes in driver behavior due to HLN use cases? How does the HLN service affect to the journey time in the SV use case?
How does the HLN service affect to the traffic flow?
How does the HLN service affect the speed?

Is environment affected by changes in driver behavior due to HLN use cases? How does the HLN service affect the fuel consumption?
How does the HLN service affect the CO2 Emissions?
How does the HLN service affect the emissions of other pollutants (NOx, PM, CO, etc...)?

Given the small number of OBUs, the impact of the connected vehicles was low and therefore difficult to detect and evaluate. In order to estimate the potential impact of the connected vehicle for different degrees of penetration, a simulation / modeling environment with VISIM has been performed. Starting from the observed results as baseline, penetration rates of 10%, 25%, 50%, 80% and 100% have been modelled, upon which the main conclusions are taken. Traffic efficiency and environmental indicators were then obtained directly from Visim for the different penetration scenarios.
Socio economics is developed for the different services, extrapolating the results from tests/ modelling in CRIL to the C-Roads PT network considering a 100% penetration rate. In the absence of targeted data, impact ranges from C-ITS strategy (low /high ranges) have been adopted notably for safety related indicators.

Evaluation results – Field tests

This use case warns approaching drivers about stationary/broken down vehicles ahead, which may represent obstacles in the road with the objective of avoiding collisions (mostly rear-end) with stationary vehicles on the road and enhance road safety

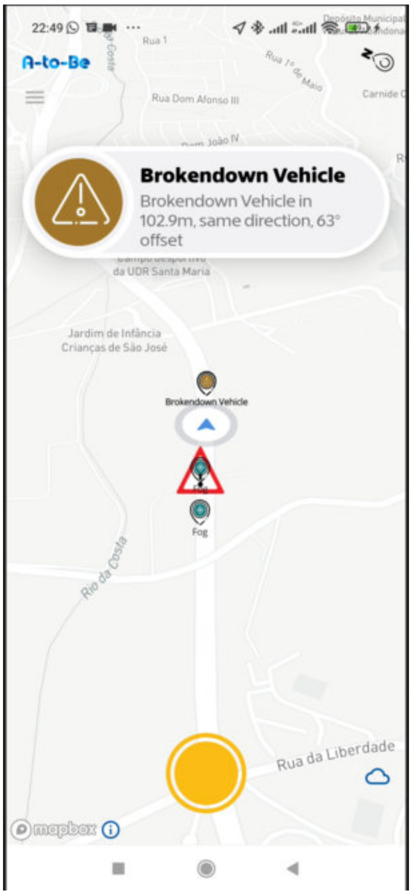


Figure 98 - HLN-SV message (A to Be)

In this use case driver is informed of one or several obstacles on one or several lanes (traffic can still pass not a blockage) of the road operator network who broadcasts the information to road users with the objective of alerting of a potential danger.

The analysis of data collected is sometimes inconclusive, the on/off difference do not change significantly, and it is difficult to understand if results are affected by other contextual factors. In general, for most of the drivers (particularly test group) there were cases where driver was already in deceleration before the HLN message but with the message increases its deceleration rates; other cases where the driver was accelerating and in face of the messages, decelerates.

As referred, results from tests have been used as input for modelling. Despite the variations in data collected, which up to a certain extent reflect the human behaviour when driving, the results obtained from the modelling exercise for the different penetration rates demonstrate that from 80% penetration rates the benefits occur.

7.1.8. 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.
Italy estimated an overall yearly impact on safety, considering a 100% C-ITS penetration rate as reported in Table 123.
Further results of C-Roads Italy 2 Project, considering light vehicles, highlighted a that the Use Case allowed to start the slowdown in advance, reaching on time a suitable speed.

Table 123 - 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%

Use Case HLN- EPVA - Emergency or Prioritised Vehicle Approaching
The C-ITS message allows to increase the distance of the event detection by 73%, from an average of 370 m (C-ITS OFF) up to an average of 642 m (C-ITS ON).
The lane change maneuver starts and ends far in advance with respect to the C-ITS OFF scenario, with reduced spatial and temporal durations (-28% and - 32% respectively). The maximum steering angle recorded is increased, highlighting a more resolute and quick maneuver, deployed suitably with the surrounding traffic conditions.
The temporal distance between the detection of the simulated emergency vehicle and its maneuver of overtaking by 142%, from an average value of 36 sec (C-ITS OFF) up to 87 sec (C-ITS ON)

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 (Safety – Spain).

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 124, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].

Note that in Table 124, 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).

Co-funded by the European Union

Table 124 - 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 125 and Table 126 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 126) 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 125.
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 125 - 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 126 - 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 127 and Table 128Table 115.

Table 127 - 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 128 - 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 129

Table 129 - 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 Table 130.

Table 130 - 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. Greece

Uses Cases considered

- HLN-OR: Hazardous Location Notification – Obstacle on the Road

Evaluation method

Refer to Section 5.1.8 (Safety – Greece).

Data collected

Refer to Section 5.1.8 (Safety – Greece).

Evaluation results – Field tests

In the Attica Tollways network the average vehicle speed shows a decrease in the C-ITS scenario. This is since drivers are informed timely about the event and they can adjust appropriately their driving behavior by reducing their speeds.

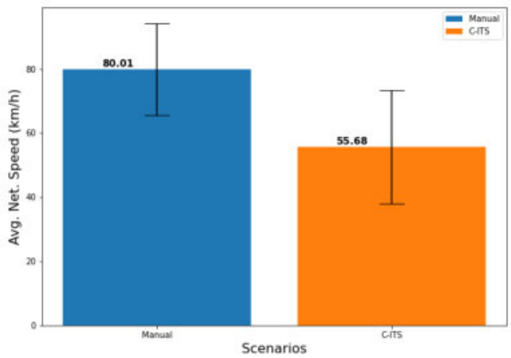


Figure 99 - HLN-OR average vehicle speed for manual and C-ITS scenario

The travel time is increased significantly in the C-ITS scenario. This is due to the vehicle speed increase which is observed as well in this case.

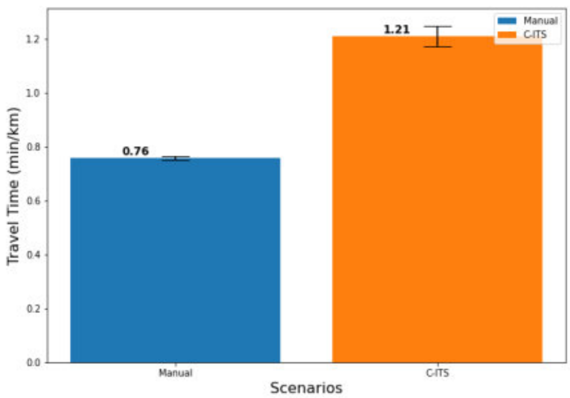


Figure 100 - HLN-OR travel time for manual and C-ITS scenario

Regarding the results from the Egnatia Odos Tollways network, the average vehicle speed shows a decrease in the C-ITS scenarios, and this could be explained by the fact that since drivers are informed timely of the existence of an obstacle on the road, they are able to start decreasing their speeds earlier and more smoothly.

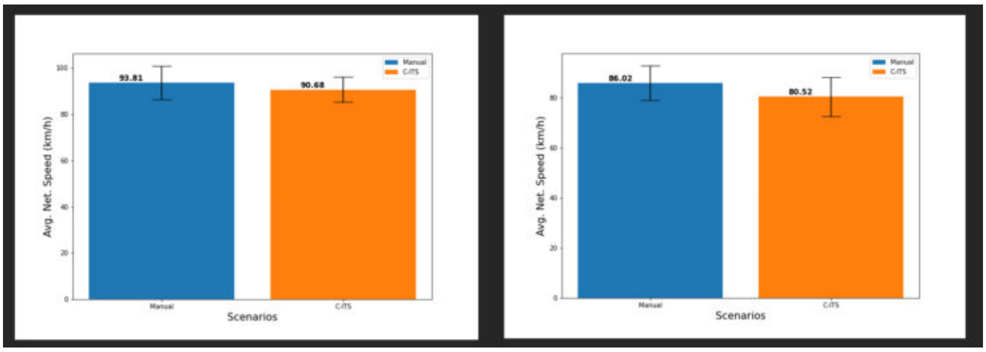


Figure 101 - HLN-OR average vehicle speed for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

Travel time is increased in the C-ITS scenarios which is anticipated as in the same scenarios vehicles speeds show a decrease.

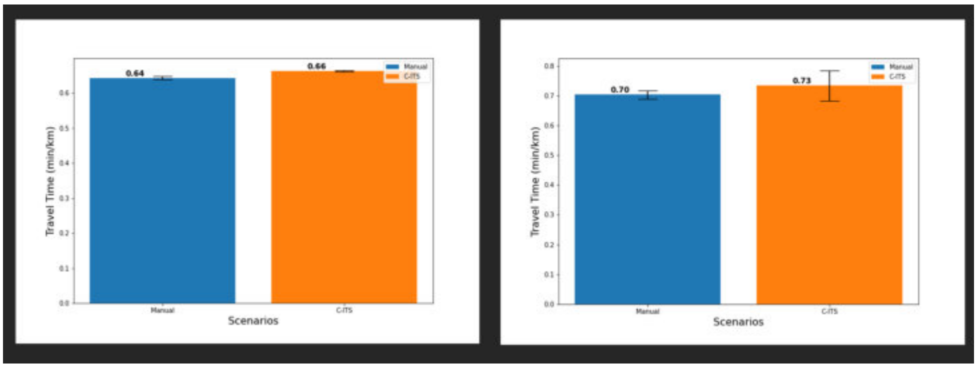


Figure 102 - HLN-OR travel time for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

7.2.5. Ireland

Use Cases considered

- HLN-SV: Hazardous location notification – Stationary vehicle

Evaluation method

Microsimulation traffic modelling was used to assess the following traffic efficiency related evaluation questions for the Hazardous location notification – stationary vehicle use case:

- How does this use case affect journey time at different levels of C-ITS vehicle penetration?
- How does this use case affect traffic flow at different levels of C-ITS vehicle penetration?
- How does this use case affect traffic speeds at different levels of C-ITS vehicle penetration?

The same approach to modelling this use was adopted to what is described for the Road works warning lane closure use case in Figure 29.

Table 131 shows the set of 11 scenarios that were run. A 'No Breakdown' scenario was run where no hazard was placed on the network. This provided a baseline against which all other scenarios were compared.

Two locations for the vehicle breakdown were tested in the model. Location 1 is a northbound two-lane section of motorway with a theoretical flow demand of 2100 vehicles / hour, and location 2 is a southbound three-lane section with a theoretical flow demand of 4600 / hour. The flow demand was set to represent scenarios where the traffic link would be approaching capacity.

Connected vehicle penetration was increased from 0% to 100% in 25% increments. Each scenario was run for 20 random seeds and all results are an average of these runs. It is common practice to run multiple random seeds to replicate day-to-day variations in arrival profiles.

Table 131 – HLN-SV modelling scenario summary

Use Case	Hazard Location	Connected Vehicle %	Number of Scenarios
None (No Breakdown)	n.a.	0%	1
HLN – Stationary Vehicle	Location 1	0%, 25%, 50%, 75%, 100%	5
HLN – Stationary Vehicle	Location 2	0%, 25%, 50%, 75%, 100%	5

Key performance indicators collected as part of the modelling assessment are:

- Journey times
- Traffic throughput

- Average speeds

Journey times were measured for each vehicle that passed the start and the end of the 5km long labelled journey time routes. The model outputs included the total number of vehicles that pass the start and end points and the average time taken per minute, aggregated by the time the vehicle completes the route.

Average speed data was collected for every 50m segments shown as a blue model link, aggregated into 5-minute periods. These were analysed from 2.4 kilometres prior to the incident to 400m downstream from the incident location.

The model has a 15-minute warm-up period which allows traffic to populate the model before results evaluation begins. A 'breakdown' vehicle was inserted at 28 minutes. It was routed through the model and stopped in Lane 1 at the predetermined breakdown location. It then remained stationary for 30 minutes before moving off.

Key model operation parameters are provided in Figure 103. Vehicle routes were rewritten to re-route all vehicles across the remaining available lane(s), reflecting the lane reduction.

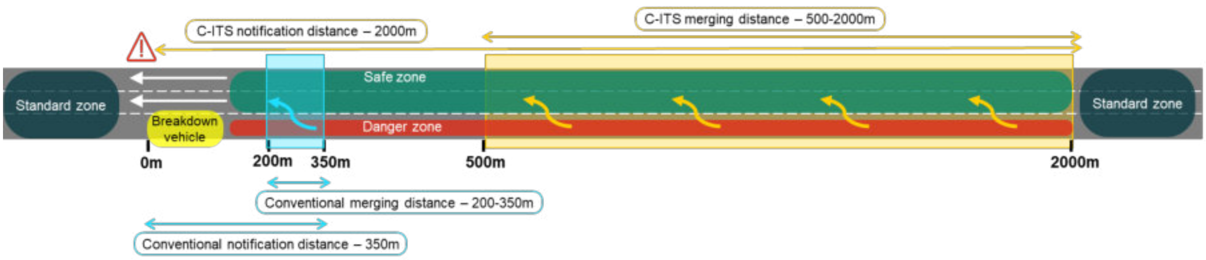


Figure 103 - HLN model operation schematic

It was assumed that connected vehicle drivers were notified of the stationary vehicle two kilometres in advance of the breakdown location (an upstream notification distance within acceptable C-Roads tolerances), meaning that each vehicle chooses to move out of the breakdown lane in advance of the breakdown at some distance within a given range. These vehicles were then assigned a desired lane change distribution range of 500m to 2000m upstream of the incident. This does not represent the range over which they are notified of the breakdown – as this is two kilometres for all connected vehicles – but rather the point at which they decide to act on the notification and change lane. The profile is such that only 10% of vehicles change lane between 500m and 1000m and the remaining 90% change lane between 1000m and 2000m upstream of the incident. Apart from this, the profile is linear.

Connected vehicles adjust their driving behaviour to 'cautious' in the notification zone with an increased propensity to merge.

The results evaluation continued for 15 minutes after the breakdown vehicle moved on to capture any effects after the incident.

Evaluation results

The microsimulation modelling results are shown in Figure 104 for each KPI (journey time, traffic flow and speed) for both locations 1 and 2 (representing 2 and 3 lane motorway sections.

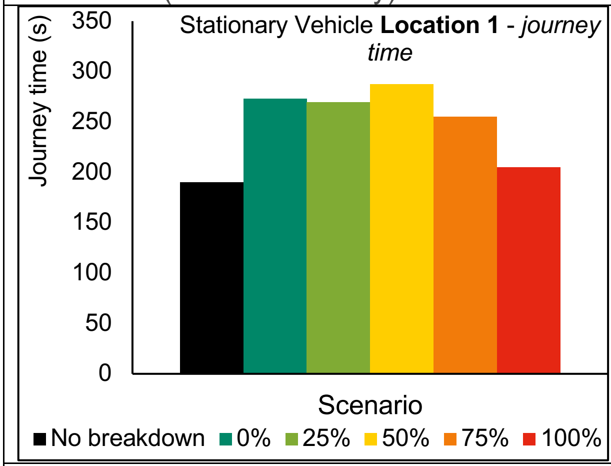
Co-funded by the European Union

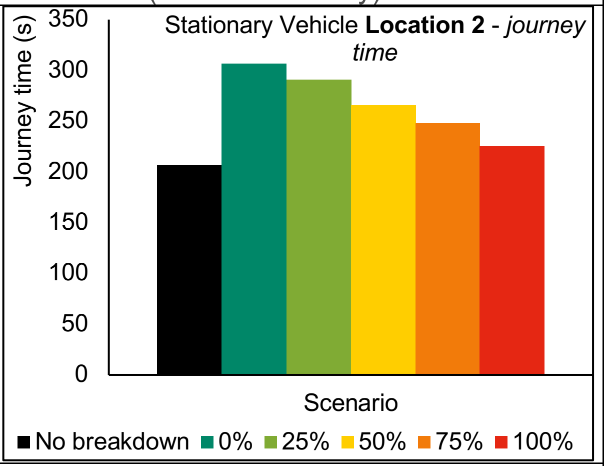
The microsimulation modelling assessment has suggested that the impact of the Hazardous Location Notification – Stationary Vehicle use case at different levels of C-ITS vehicle penetration is likely to vary depending on factors such as the incident location characteristics and volume of traffic flows. The results indicate that the flow breakdown patterns differ when there is a 2-to-1 lane merge compared with a 3-to-2 lane merge.
In both locations there is an overall traffic efficiency benefit with 100% penetration rate.
A comparison of the 100% penetration scenario versus the 0% penetration rate shows a 24% and 27% reduction in average journey times over a 5km section in Location 1 and 2 respectively.

Traffic flow patterns reflect those seen in the journey time analysis, with some deterioration in performance for lower penetration rates in Location 1, a two-lane section of motorway, whilst in Location 2 the traffic flow past the stopped vehicle during the breakdown period incrementally increase in line with the penetration rate increases.

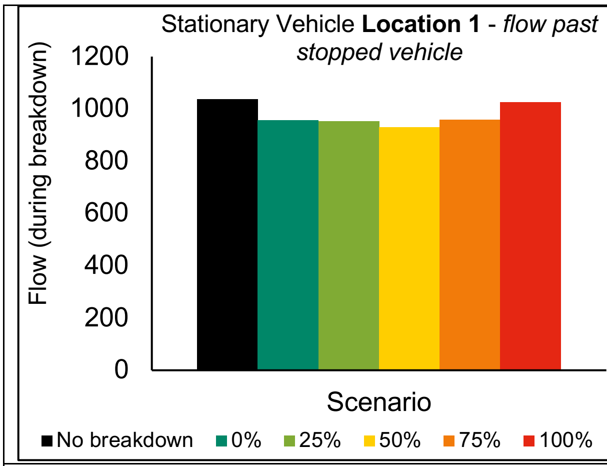
Traffic speed analysis shows that in Location 1 the breakdown in speed occurs closer to the incident but with increased severity with the lower penetration rates. This may suggest that for incidents of a greater duration the impacts of this are more severe, late flow breakdown could start to outweigh the benefits shown in this assessment of a later merge. In Location 2 the speed breakdown is seen to be worst in the 0% penetration scenario with incremental increases in average speed in the 800m prior to the breakdown location as the penetration rate increases.

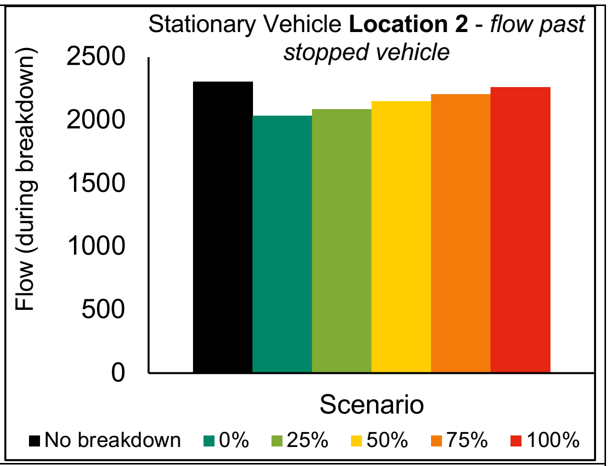
All model outputs are dependent upon the modelling assumptions made regarding the Hazardous Location Notification – Stationary Vehicle use case implementation and driver behavioural response. The variability of traffic efficiency impacts in different circumstances has been illustrated by the two scenarios selected for analysis. It is clear that a multitude of factors including, but not limited to, number of lanes; traffic flow demand; breakdown duration; notification distance; and the driver behaviour response to the notification; will all impact on if and when operational benefits of the use case will occur.

<table>
<tr><td>Journey time
Location 1 (2 lane motorway)</td><td>Journey time
Location 2 (3 lane motorway)</td></tr>
<tr><td>


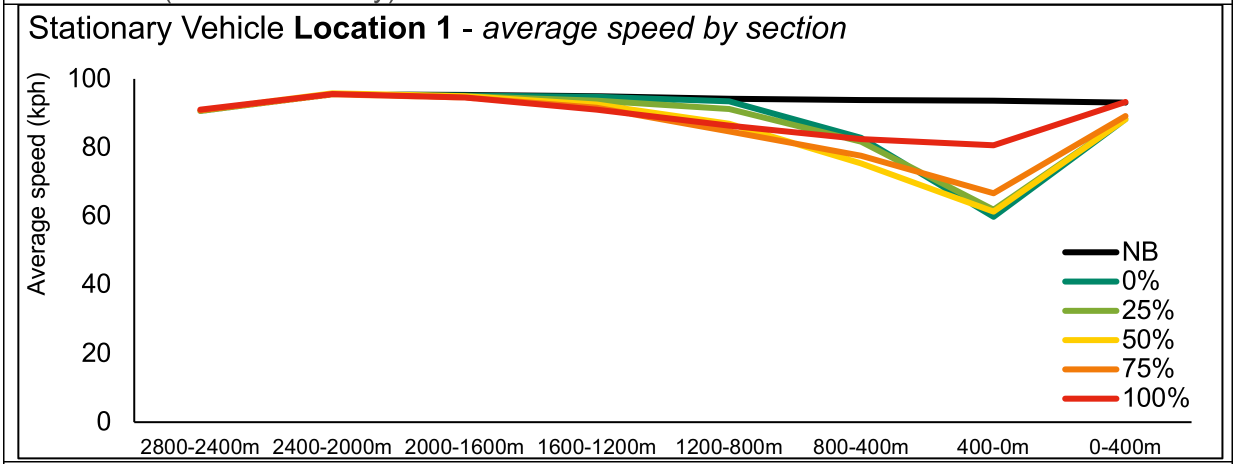
</td><td>


</td></tr>
<tr><td>Traffic flow
Location 1 (2 lane motorway)</td><td>Traffic flow
Location 2 (3 lane motorway)</td></tr>
</table>





Speed
Location 1 (2 lane motorway)



Speed
Location 2 (3 lane motorway)

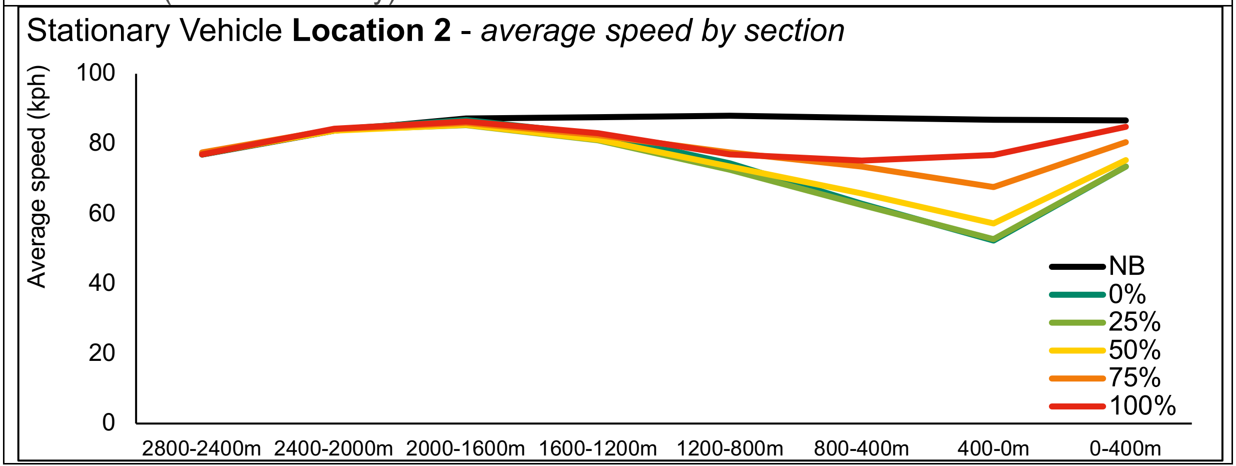


Figure 104 – HLN-SV modelling results

7.2.6. Portugal

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-OR: Hazardous Location Notification - Obstacle on the road

Evaluation method

Refer to Section 7.1.7 (Safety – Portugal).

Data collected

Refer to Section (Safety – Portugal).

Evaluation results – Field tests

Refer to Section (Safety – Portugal).

Evaluation results – KPIs on Mobility

Traffic efficiency is estimated for the different penetration rates, taking as reference the data collected during tests.

The presence of a stationary vehicle, could be at the origin of sudden breaks and ultimately originating accidents. Such events are supposed to be avoided by the deployment of the Use Cases.

The test for HLN-SV demonstrates that such event had no impact on travel speed, which remains constant against the differen penetration rates. This could be originated by the fact that vehicle was duly signalised with lights visible ahead, but also the quick addition of that stationary vehicle in Waze applications alerting users of that event.

The total travel time in the baseline (i.e. without C-ITS) is 6% higher than the one resulting for 100% penetration rates.

As stated the tests have occurred in the night period, when road works were planned. The modelling has been performed with the average daily traffic in the morning peak, it seems that the cooperative messages promote an earlier return to more efficient driving regimes.

While the results for the use case are somehow inconclusive, assuming that similar delays to the ones tested occur in the remaining C-Roads PT network, the hours saved for a 100% MP could reach 25.000 hours.

7.2.7. France

Use Cases considered

- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification - Slow (or Stationary) Vehicle
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Evaluation method

The C-ITS services under consideration (HLN-TJA / HLN-SV / HLN-OR) allow the end-users to detect the event and the associated recommendations in advance. Such anticipation is supposed to influence the safety performance of connected vehicles significantly. As such, specific surrogate safety metrics, like Time-to-Collision, were monitored and used as Key Performance Indicators. To feature the necessity to execute abrupt maneouvres, the acceleration and deceleration distribution were collected.

The key research questions identified for this set of use cases are the following:

- What is the impact on safety due to the C-ITS services under consideration?
- What is the impact of delayed responses to C-ITS services on safety indicators?
- Does the impact improve with an increasing market penetration of C-ITS services?
- What is the minimum required market penetration rate that improves traffic performance?

The deployed methodology relies on a traffic micro-simulation framework fed with real-world data featuring the response behaviour of drivers equipped with C-ITS services. Such a framework simulates a large set of configurations, called scenarios, and simultaneously collects a wide range of indicators about safety, traffic efficiency and pollutant emissions with the purpose of assessing the impact of the C-ITS services under consideration. The process lies in a 2-stage approach:

- Implementing a realistic simulation framework based on SUMO microscopic traffic simulator. It includes the following steps:
  - Featuring the behaviour of equipped drivers: it mainly consists of grouping data from the field, when available, and/or information from the scientific literature to produce indicators about the drivers' response to the stimuli (i.e. the C-ITS services). It enables incorporating latencies in the response to the received messages and
  - Mimicrying the process to automatically detect events and generate C-ITS messages.
- Implementing and testing a set of scenarios in the simulation framework with an exploration of the following factors:
  - Traffic demand, expressed by the volume-to-capacity ratio (v/c).
  - Market Penetration Rate (MPR), in percentage (%), matching with the rate of cars equipped and compliant with the C-ITS services.
  - Speed of the downstream obstacle, varying between 0 km/h (stationary obstacle) and 50 km/h (a dangerously slow vehicle).

Since the use cases under consideration are designed for a Motorway context, the traffic micro-simulation framework, based on SUMO, was calibrated by optimising a few driving behaviour parameters based on the loop detector data of a section of A63 highway near Bordeaux from the year 2017.

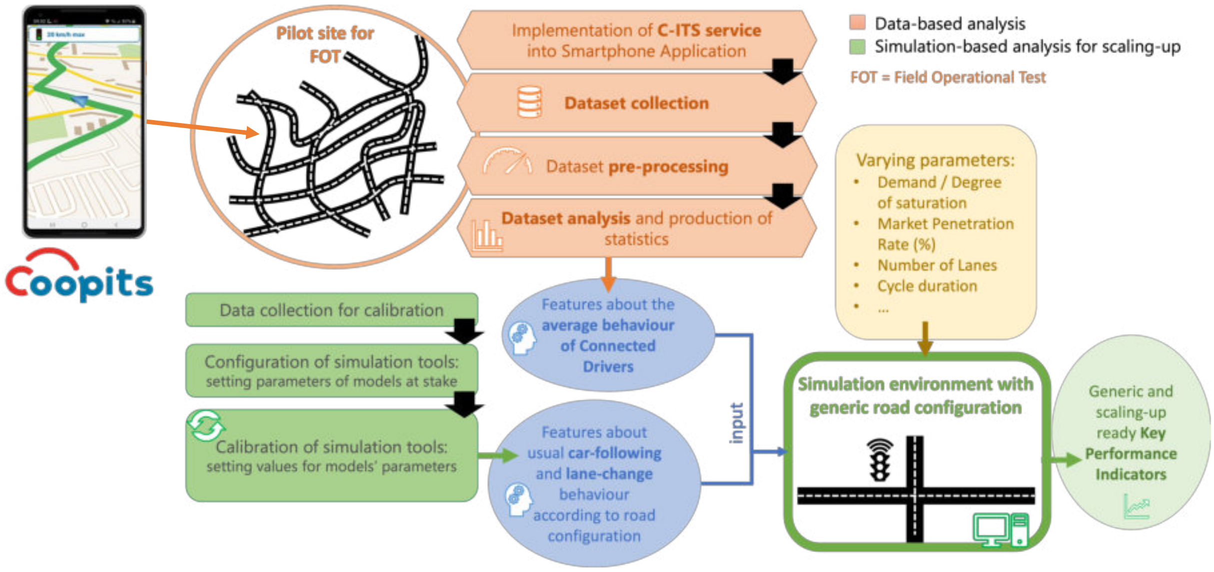


Figure 105 - Comprehensive methodology applied for C-ITS services impact assessment of safety, traffic efficiency or pollutant emissions in France.

Data collected

For the HLN-TJA / HLN-SV / HLN-OR use cases deployed on Motorways, the 2017 and 2018 loop detector data from a section of the A63 highway (Bordeaux, France) was used to extract speed and flow information for typical days with no adverse weather conditions, no traffic incidents and no irregular fluctuations in the traffic flow. This information was used to calibrate and validate the traffic simulator. No information related to applying the three use cases from FOTs could be collected and analysed due to a lack of recurrent and representative data within the INDID project for these use cases. For these specific use cases, the number of users for the smartphone app did not meet the requirements to achieve significant analysis.

Evaluation results – Field tests

Due to an insufficient amount of available data, field tests were not analysed for the C-ITS services under consideration (HLN-TJA / HLN-SV / HLN-OR). The evaluation was fed with findings resulting from the literature and/or field findings from European partners.

Due to the limited amount of available data resources, the design of the distribution will be supported by the works performed in Italy regarding roadworks warning and hazardous location notification. They include findings related to lane change maneuvers (e.g., maneuver start and end points, duration, steering angle) and slowdown behaviour (e.g., speed reduction, deceleration, duration of slowdown). The main finding highlights that Connected Vehicles anticipated the lane-change maneuver by starting it on average around 450m. In comparison, non-connected ones only performed lane-change 170m upstream of the stationary obstacle. Such findings were collected for a specific layout (i.e. fixed obstacle, maximal speed, number of lanes, visibility configuration, etc). Nevertheless, we will assume that they remain consistent in average for various layouts.
Figure 106 illustrates the connected drivers modelling process implemented into the microscopic simulation framework with respect to the non-connected drivers.
The modelling of connected drivers assumes that warning messages are received widely in advance by connected cars, then we further model the drivers' response when

approaching the estimated location of the "obstacle", i.e. the hazardous slow vehicle (HLN-SV), the stationary obstacle (HLN-OR), or the traffic jam (HLN-TJA). The connected drivers are assumed to react on average 450 meters upstream of the “obstacle” with a standard deviation set to 20% of the average distance. Furthermore, it is assumed that the connected driver will not react before reaching a distance of 1 km toward the “obstacle”, since such a distance is deemed too long for lane-change anticipation.

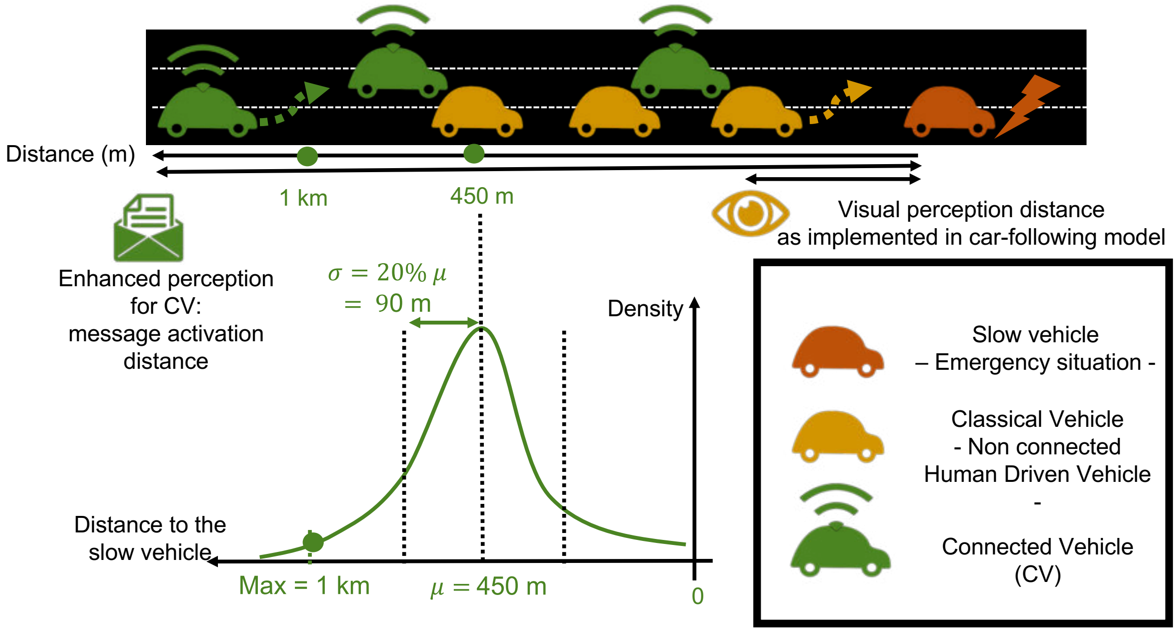


Figure 106 - Drivers Behaviours Modeling for Connected Vehicles when a warning message is broadcasted (with expectations about anticipated lane-change or slow down), in France.

Evaluation results – KPIs on Mobility

For most of the use case under consideration, the performance analysis was drawn according to three categories of modelling scenarios to point out the impact of delays and latencies on the comprehensive performance:

- Scenarios modelling latencies for the event detection and delays for the driver response.
- Scenarios modelling a perfect detection of the event, but delays for the driver response.
- Scenarios modelling a perfect detection of the event and a perfect anticipation of the driver, i.e. without latency.

Such a distinction by refinement of the modelling is adopted thereafter to describe the main findings with respect to the benefits in the average speed of Connected Vehicles, i.e. the ratio of speed growth.

Use Cases	KPI = Benefits in the Average Speed of Connected Vehicles only with respect to the baseline (MPR = 0%) and range according to MPR [between 10% and 50%]		
	With latencies on event detection and driver behaviour	**With driver latency**	**Without latency**

HLN-TJA	-	-	**With an anticipation distance < 1km: ~[0%; -7,5%]** **With an anticipation distance >1km : ~[-7,5%; -20%]**
HLN-SV	**Low Demand:** **-slow vehicle at 30 km/h ~ [+1% ; +2,5%]** **-slow vehicle at 50 km/h ~ [+1% ; +2%]** **High demand:** **-slow vehicle at 30 km/h ~ [+2,5% ; +3%]** **-slow vehicle at 50 km/h ~ +1,5%**	-	-
HLN-OR	**Low Demand:** **- stationary obstacle ~ [+2,5% ; +5,5%]** **High demand:** **-stationary obstacle ~ [+10,5% ; +12,5%]**	**Low Demand:** **-stationary obstacle ~ +5%** **High demand:** **-stationary obstacle ~ [-25%; +15%]**	**Low Demand:** **-stationary obstacle ~ +5%** **High demand:** **-stationary obstacle ~ [+20%; +50%]**

Mainly two findings are pointed out:

- For use case HLN-TJA, the warning about traffic jam downstream aims at urging anticipate a speed reduction when approaching the traffic jam. Consequently, it is expected to observe a reduction in speed performance among Connected Vehicles.
- For the HLN-SV or HLN-OR use cases, the speed performance of Connected Vehicles is marginally improved by 1 or 2%, but insensitive to variations in Market Penetration Rate. When the demand gets higher, the anticipated maneuvers of Connected Vehicles might affect the comprehensive traffic and generate congestion by preventing unequipped vehicles from doing a late lane change. Unequipped vehicles tend to remain stuck behind the obstacle, while the left lanes are saturated with Connected Vehicles anticipating the maneuver. Heterogeneity in information availability might lead to decrease in the average speed of the connected vehicles.

Notes:

- Please note that the scenario “with latency on event detection and driver delays” required a specific analysis framework. The period of analysis was split into three periods: T1 = [0s; 300s] depicting the elapsed time between the emergence of the event and its detection / T2 =]300s; 600s] delimiting the window with a reliable assessment of the event location and active C-ITS message dissemination processes / T3 =]600s; 900s] depicting long-term effects with potential estimation biases. The findings outlined in the table mainly results from analysis drawn on the second time period T2.
- Please note that the Key Performance Indicators are computed for the Connected Vehicles only. Side effects might affect unequipped vehicles.

7.2.8. 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

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 141, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 141, 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 132 - 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 133.

Table 133 - 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 134.Table 68

Table 134 - 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 135.

Table 135 - 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. Greece

Use Cases considered

- HLN – WCW: Hazardous Location Notification – Weather Condition Warning

Evaluation method

Refer to Section 5.1.8 (Safety – Greece).

Data collected

Refer to Section 5.1.8 (Safety – Greece).

Evaluation results – Field tests

In the Attica Tollways network and for the case of WCW, the CO_2 emissions are decreased also in the C-ITS scenario.

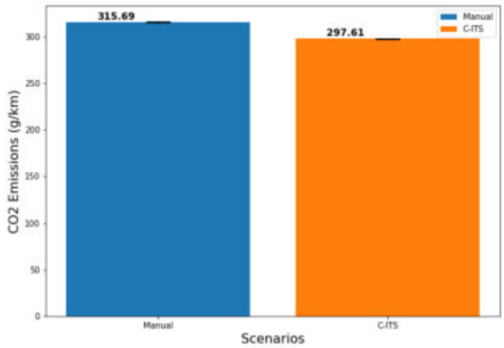


Figure 107 - HLN-WCW CO_2 emissions for manual and C-ITS

For the use case of Obstacle on the road, CO_2 emission are observed to have a slight increase in the C-ITS scenario compared to the manual one.

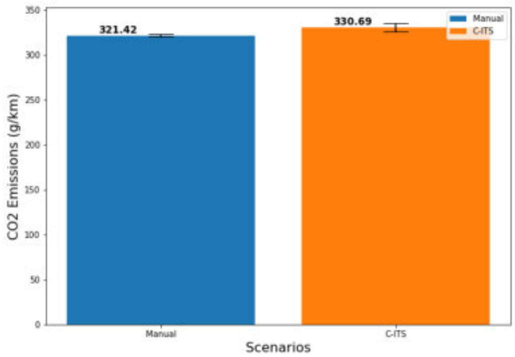


Figure 108 - HLN-OR CO2 emissions for manual and C-ITS scenario

In the Egnatia Odos Tollways network for WCW, concerning the indicator of CO_2 emissions, not such a significant difference has been observed in the two scenarios, but still there is a slight decrease in the C-ITS scenario for both penetration rates (500 and 1200 vehicles), leading to the conclusion that HLN - WCW does not contribute at an important level to CO_2 emissions reduction.

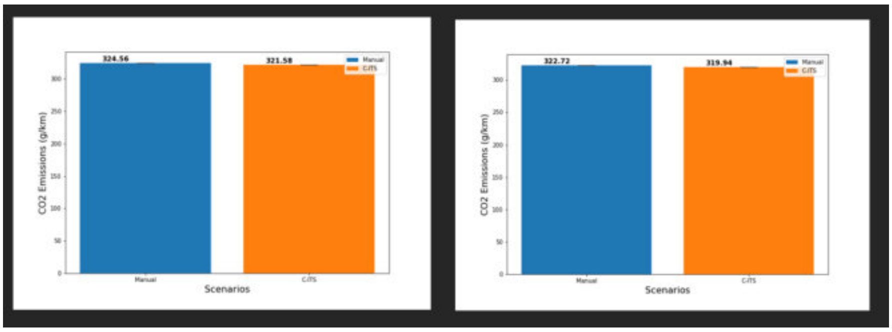


Figure 109 - HLN-WCW CO_2 emissions for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

With regards to the Obstacle on the road use case, a decrease is observed in the C-ITS scenario in both cases. It should be mentioned that CO_2 emissions decrease for HLN-OR is higher than for the abovementioned services.

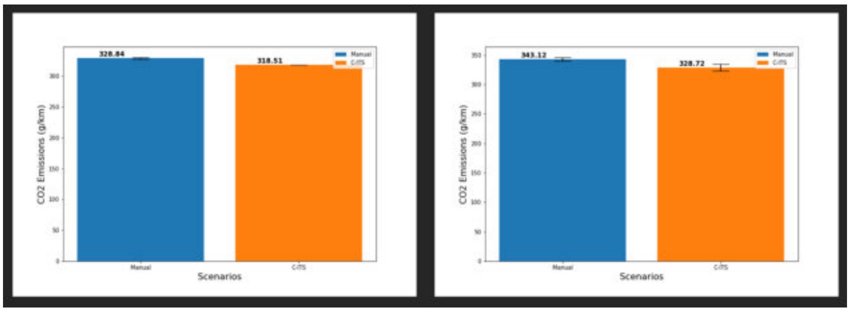


Figure 110 - HLN-OR CO_2 emissions for manual and C-ITS scenario in baseline (left) and high C-ITS penetration rate scenarios

7.3.4. Ireland

Use Cases considered

- HLN-SV: Hazardous Location Notification – Stationary Vehicle

Evaluation method

The Bosch instantaneous emissions modelling (IEM) Vissim add-on was used to assess emissions for the Hazardous location notification – stationary vehicle use case.

- How does this use-case affect emissions at different levels of C-ITS vehicle penetration?

The methodology described in section 7.2.5 is relevant to this section.

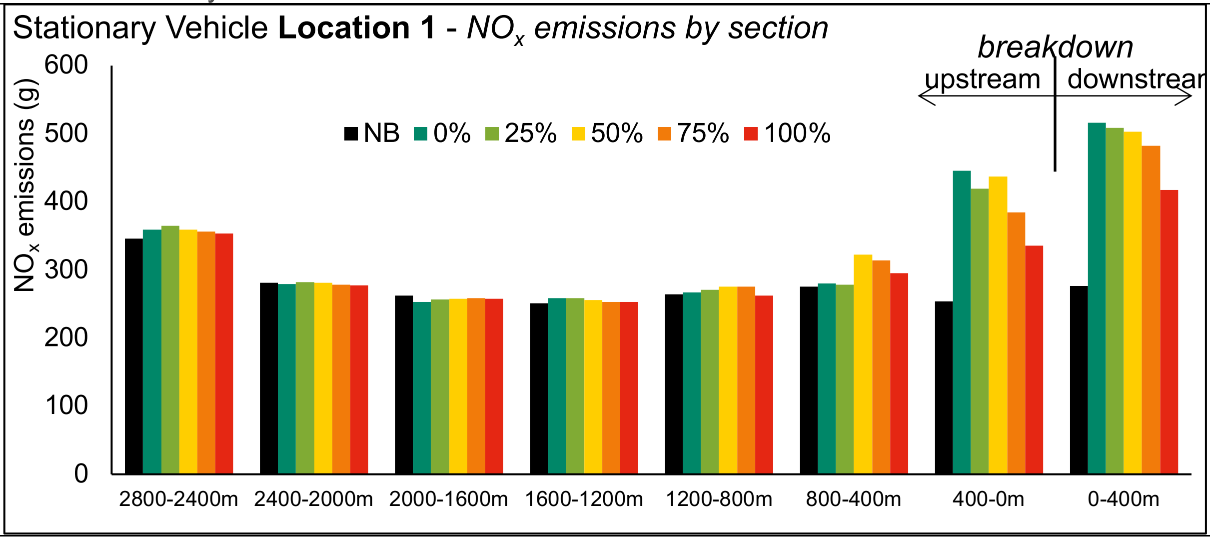
Evaluation results

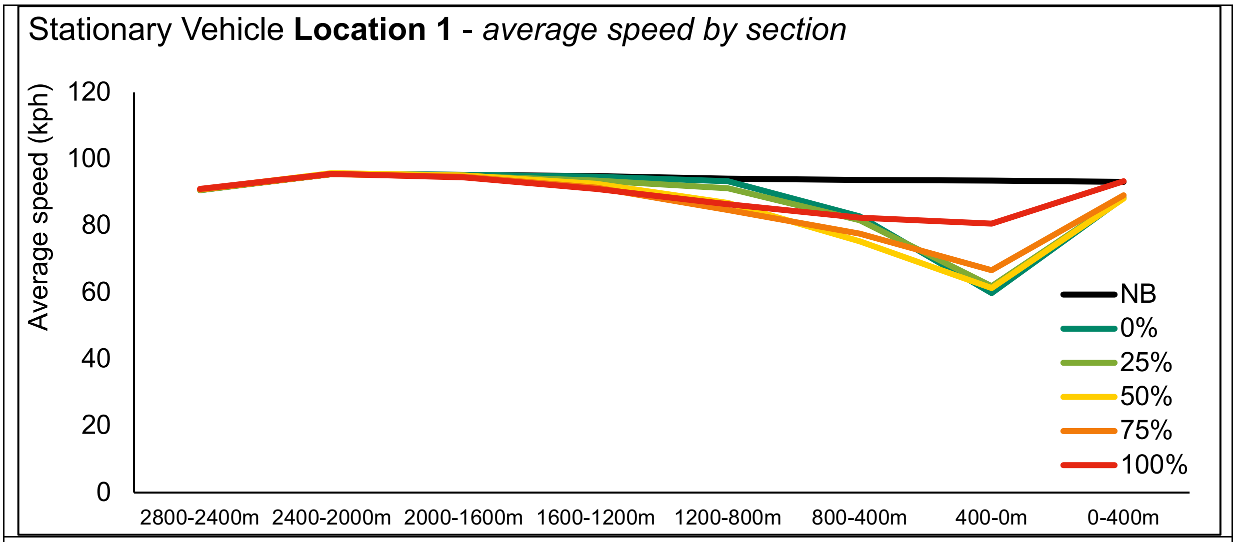
Results presented are NOx emissions (Nitrogen oxides). CO_2 emissions were also calculated but they show very similar trends to NOx emissions results, so have not been included to avoid repetition.

Results are aggregated across the same sections that were used for the average speed data and the average speed graphs presented in section 7.2.5 are provided alongside the emissions data for context and comparison.

Figure 111 shows total NOx emissions per section for Location 1 and 2.

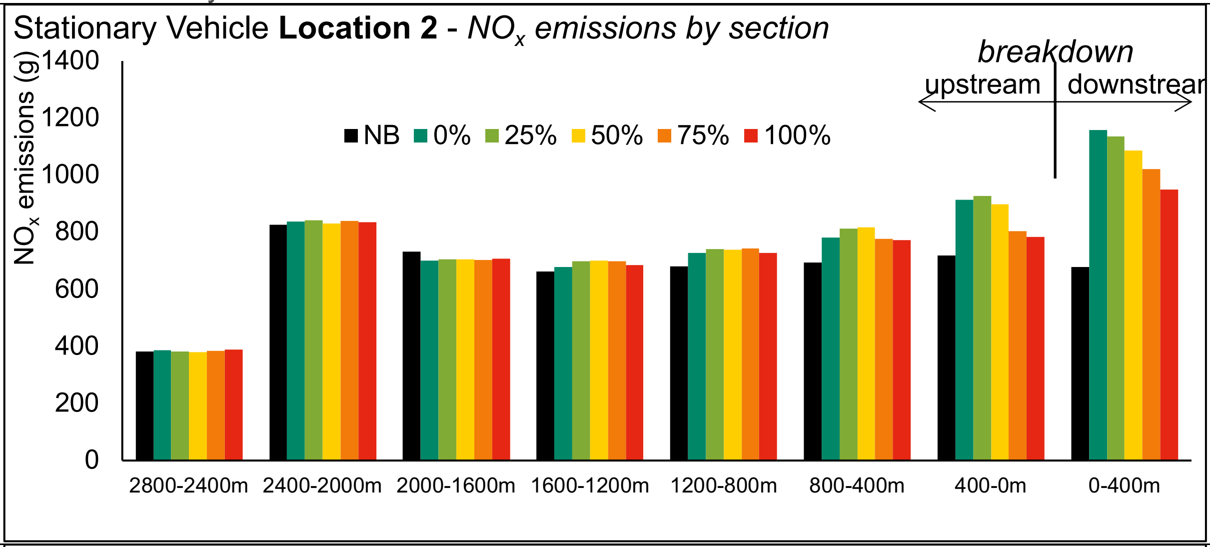
Location 1
2-lane motorway site





Location 2

3-lane motorway site



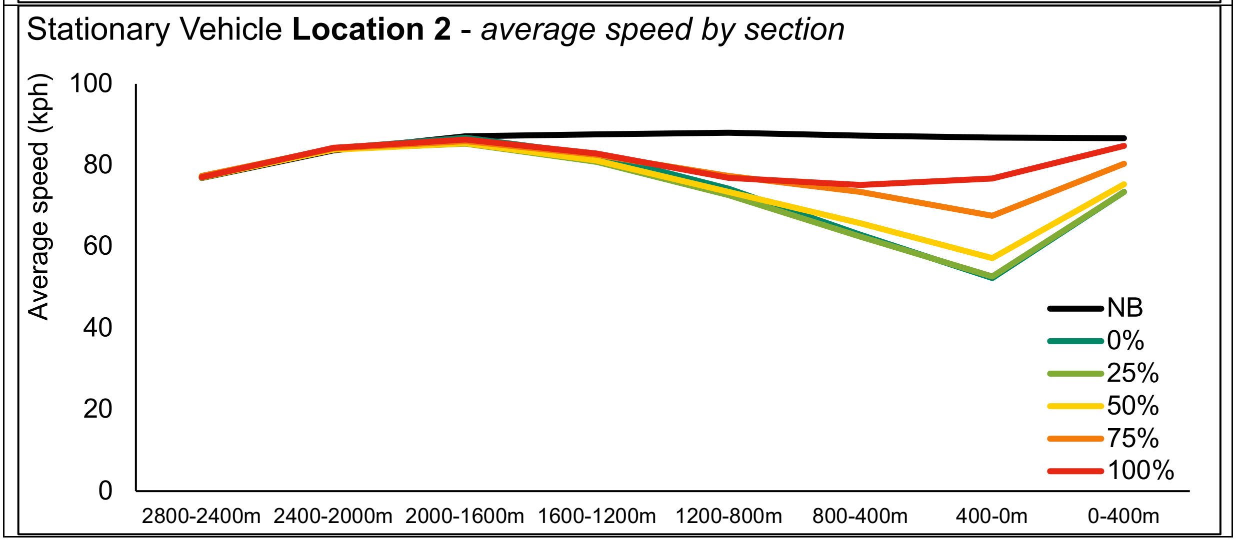


Figure 111 - NOx emissions/section (top) and average speed per section (bottom) for each scenario

At Location 1, the emission modelling suggests that as drivers approach the breakdown, vehicle emissions increase as queues are encountered and speeds drop. In the section immediately upstream of the breakdown, as drivers are able to accelerate back to higher speeds, emissions tend to decrease with increasing connected penetration. This may reflect the lower acceleration requirements of the scenarios where vehicles have higher average speeds passing the breakdown vehicle.

At Location 2, emissions are consistent across the scenarios where average speeds are similarly consistent. Approaching the breakdown, the trend becomes more obvious, but it is more similar to the trend seen in the traffic efficiency results for Location 1 than Location 2, whereby emissions rise before they fall . This is likely to be a balance between the two effects that contribute to tailpipe emissions: average speed and acceleration.

Figure 112 shows the total emissions aggregated across all sections for both locations.

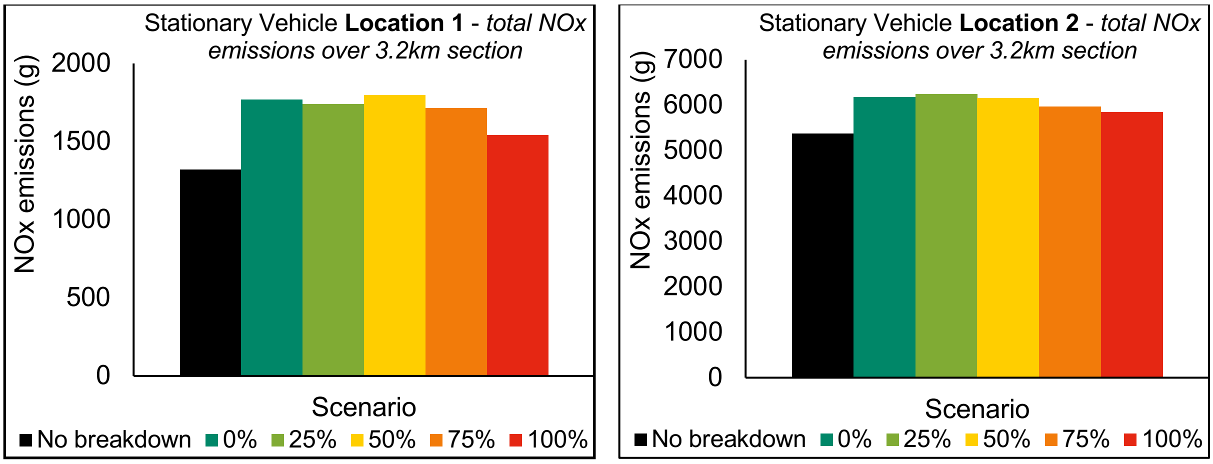


Figure 112 - Total emissions across all sections

Overall, emissions increase slightly with low connected penetration but decrease at higher penetrations in both locations. The additional NOx emissions created by introducing the breakdown are reduced by around half in the 100% penetration rate scenario compared to 0% connected.

In general, trends broadly follow those seen in the traffic efficiency analysis for the HLN use case. Total emissions – and emissions reductions for higher penetration rates – are greatest near the breakdown where congestion is worst and stop-start behaviour has the greatest effect on emissions.

Total emissions increase at low connected penetrations at both locations, reducing at higher penetrations.

7.3.5. Portugal

Use Cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-OR: Hazardous Location Notification - obstacle on the road

Evaluation method

Refer to Section 7.1.7 (Safety – Portugal).

Data collected

Refer to Section 7.1.7 (Safety – Portugal).

Evaluation results – Field tests

Refer to Section 7.1.7 (Safety – Portugal).

Evaluation results – KPIs on Mobility

The reduced congestion leads also to environmental benefits (i.e. reduced fuel consumptions and CO_2 and Nox emissions). Adopting consumptions and emissions factors, the estimation of environmental impacts can be provided.

The results from tests and simulation exercise shows that with the 100% MP rates, environmental benefit is high. With the HLN, the travel time results in more fuel consumption and higher emissions.

Overall the joint effect of fuel and emissions can go up to -39% when comparing the 100% MP with the baseline. Environmental impacts are assessed considering the avoided congestions and are thus a consequence of impacts on traffic efficiency, resulting directly from the Vissim modelling exercise. It is worth noting that this reflects still a predominance of fuel engine vehicles. With the expected change of fleets and entrance of newer cars in the market, environmental impact will be lower but not congestion.

7.3.6. France

Use Cases considered

- HLN-TJA: Hazardous Location Notification - Traffic Jam Ahead
- HLN-SV: Hazardous Location Notification – Slow (or Stationary) vehicle
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Evaluation method

The comprehensive methodology is similar as the one exposed in section 7.2.6 (Traffic Efficiency – France).
The only difference lies in the Key Performance Indicators (KPIs) under consideration and the targeted research questions.

The C-ITS services under consideration (HLN-TJA / HLN-SV / HLN-OR) allow the end-users to detect the event and the associated recommendations in advance. Such anticipation should improve the driving experience, but no benefits are specifically expected with respect to environmental dimensions. A wide range of pollutant emissions was computed thanks to PHEMLight and studied. It covers among others the following Key Performance Indicators:

- Fuel consumption.
- CO_2 emissions.
- NOx emissions.
- PMx emissions.

The key research questions identified for this set of use cases are the following:

- What is the environmental impact of the C-ITS services under consideration?
- What is the impact of delayed responses to C-ITS services on environmental indicators?
- Does the impact improve with an increasing market penetration of C-ITS services?
- What is the minimum required market penetration rate that improves environmental impact?

Data collected

Please refer to section 7.2.6 (Traffic Efficiency – France).

Evaluation results – Field tests

Please refer to section 7.2.6 (Traffic Efficiency – France).

Evaluation results – KPIs on Mobility

For most of the use case under consideration, the performance analysis was drawn according to three categories of modelling scenarios to point out the impact of delays and latencies on the comprehensive performance:

- Scenarios modelling latencies for the event detection and delays for the driver response.
- Scenarios modelling a perfect detection of the event, but delays for the driver response.
- Scenarios modelling a perfect detection of the event and a perfect anticipation of the driver, i.e. without latency.

Such a distinction by refinement of the modelling is adopted thereafter to describe the main findings with respect to the evolution of the following Key Performance Indicators:

- CO_2 emissions (same trends as Fuel consumption due to a linear correlation).
- NOx emissions.
- PMx emissions.

Use Cases	**KPI = Evolution of CO2 emissions <u>for Connected Vehicles only</u> with respect to the baseline (MPR = 0%) and range according to MPR [between 10% and 50%]**		
	With latencies on event detection and driver behaviour	**With driver latency**	**Without latency**
HLN-TJA	-	-	**<u>With an anticipation distance < 1km:</u> ~[0%; -50%]** **<u>With an anticipation distance >1km :</u> ~[-25%; -75%]**
HLN-SV	**<u>Low Demand:</u>** **-slow vehicle at 30 km/h ~ [0% ; -10%]** **-slow vehicle at 50 km/h ~ 0%** **<u>High demand:</u>** **-slow vehicle at 30 km/h ~ [0% ; -5%]** **-slow vehicle at 50 km/h ~ 0%**	-	-
HLN-OR	**<u>Low Demand:</u>** **-stationary obstacle ~ [-5% ; -15%]** **<u>High demand:</u>** **-stationary obstacle ~ [+5% ; +10%]**	**<u>Low Demand:</u>** **-stationary obstacle ~ [0% ; -15%]** **<u>High demand:</u>** **-stationary obstacle ~ [+20% ; 0%]**	**<u>Low Demand:</u>** **-stationary obstacle ~ [-10% ; -15%]** **<u>High demand:</u>** **-stationary obstacle ~ [-10% ; -20%]**

Use Cases	**KPI = Evolution of NOx emissions <u>for Connected Vehicles only</u> with respect to the baseline (MPR = 0%) and range according to MPR [between 10% and 50%]**		
	With latencies on event detection and driver behaviour	**With driver latency**	**Without latency**
HLN-TJA	-	-	**<u>With an anticipation distance < 1km:</u> ~[0%; -50%]** **<u>With an anticipation</u>**

			distance >1km : ~[-25%; -75%]
HLN-SV	Low Demand: -slow vehicle at 30 km/h ~ [0% ; -10%] -slow vehicle at 50 km/h ~ 0% High demand: -slow vehicle at 30 km/h ~ [0% ; -5%] -slow vehicle at 50 km/h ~ 0%	-	-
HLN-OR	Low Demand: -stationary obstacle ~ [-5% ; -15%] High demand: -stationary obstacle ~ [+0% ; +10%]	Low Demand: -stationary obstacle ~ [-10% ; -20%] High demand: -stationary obstacle ~ [+20% ; -10%]	Low Demand: -stationary obstacle ~ [-5% ; -20%] High demand: -stationary obstacle ~ [-10% ; -20%]

Use Cases	KPI = Evolution of PMx emissions for Connected Vehicles only with respect to the baseline (MPR = 0%) and range according to MPR [between 10% and 50%]		
	With latencies on event detection and driver behaviour	With driver latency	Without latency
HLN-TJA	-	-	With an anticipation distance < 1km: ~[0%; -50%] With an anticipation distance >1km : ~[-25%; -75%]
HLN-SV	Low Demand: -slow vehicle at 30 km/h ~ [0% ; -15%] -slow vehicle at 50 km/h ~ [0%; -5%] High demand: -slow vehicle at 30 km/h ~ [0% ; -10%] -slow vehicle at 50 km/h ~ [0%; 10%]	-	-
HLN-OR	Low Demand: stationary obstacle ~ [-5% ; -20%] High demand: stationary obstacle ~ [-10% ; +5%]	Low Demand: -stationary obstacle ~ [-5% ; -20%] High demand: -stationary obstacle ~ [+15% ; -15%]	Low Demand: -stationary obstacle ~ [-15% ; -20%] High demand: -stationary obstacle ~ [-5% ; -20%]

Mainly two findings are pointed out:

- For use case HLN-TJA, the warning about traffic jam downstream aims at urging connected drivers to anticipate a speed reduction when approaching the traffic jam. Consequently, it is expected to observe a reduction in speed, then in pollutant emissions.
- For the HLN-SV or HLN-OR use cases, the pollutant emissions of Connected Vehicles are mainly improved when the C-ITS service is applied in low traffic demand conditions. With high traffic demand, the benefits in terms of pollutant emissions are limited or event negative. When the demand gets higher, the anticipated manoeuvres of Connected Vehicles might affect the comprehensive traffic and generate congestion by preventing unequipped vehicles from doing a late lane change. Unequipped vehicles tend to remain stuck behind the obstacle, while the left lanes are saturated with Connected Vehicles anticipating the manoeuvre. Heterogeneity in information availability between vehicles might lead to further congestions.

Notes:

- Please note that the scenario “with latency on event detection and driver delays” required a specific analysis framework. The period of analysis was split into three periods: T1 = [0s; 300s] depicting the elapsed time between the emergence of the event and its detection / T2 =]300s; 600s] delimiting the window with a reliable assessment of the event location and active C-ITS message dissemination processes / T3 =]600s; 900s] depicting long-term effects with potential estimation biases. The findings outlined in the table mainly results from analysis drawn on the second time period T2.
- Please note that the Key Performance Indicators are computed for the Connected Vehicles only. Side effects might affect unequipped vehicles.

7.3.7. 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 136 - 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 137 - 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 138 - 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 139 - 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 140 - 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 141 - 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 142 - 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 143 - 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[12].

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.[13]

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 144 and Figure 113). 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 145 and Figure 114. 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

[12] https://www.ueq-online.org/
[13] http://mecue.de/english/background.html

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.

Table 144 - 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

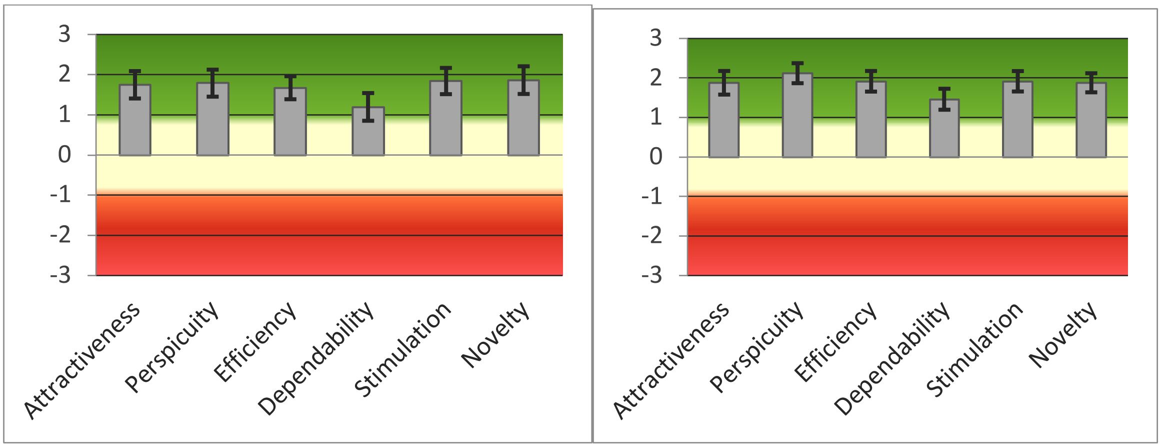


Figure 113 - UEQ questionnaire Scenario 1 and 2 results (left Scenario 1, right Scenario 2)

Table 145 - 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

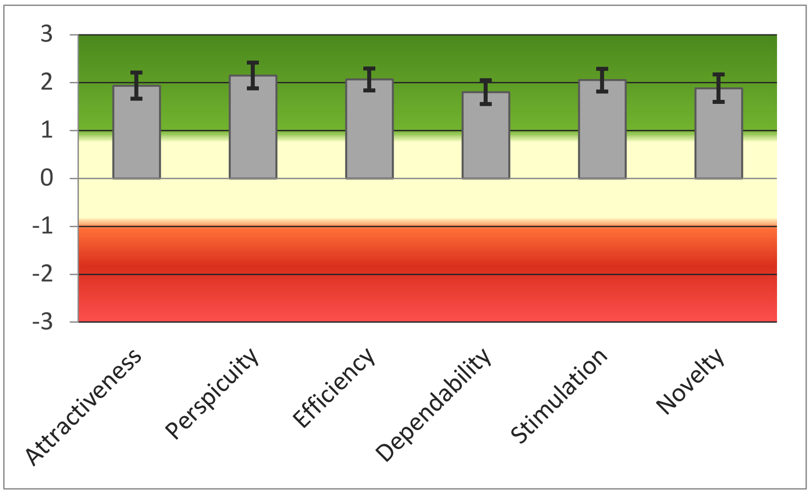


Figure 114 - UEQ questionnaire Scenario 3 results

In the meCUE questionnaire, we noticed measurable differences between the scales of Scenario 1 and Scenario 2 (see Table 146 and Figure 116). 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 146 - 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

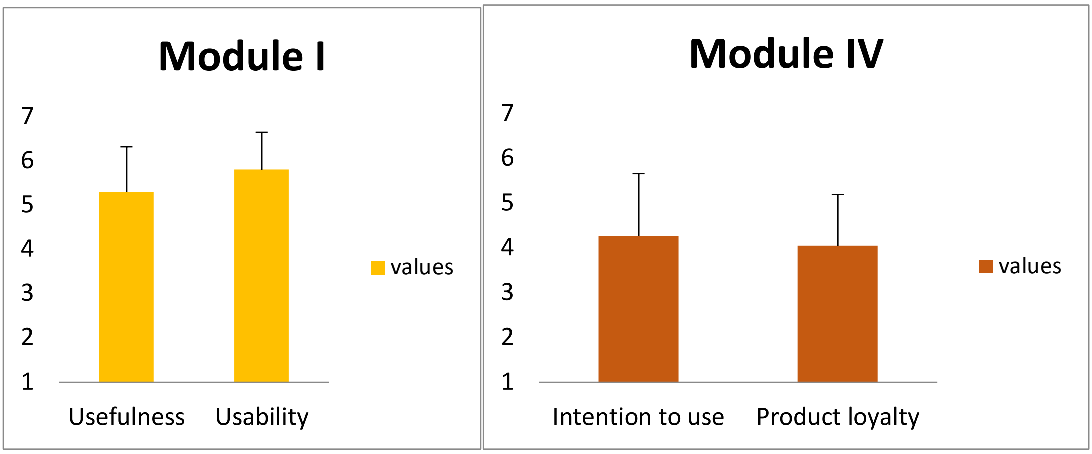


Figure 115 - meCUE questionnaire Scenario 1 results

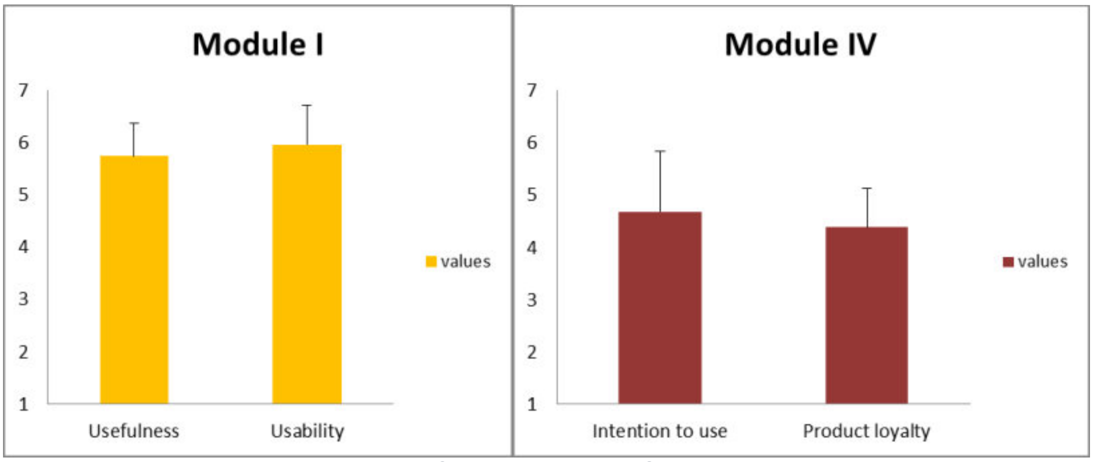


Figure 116 - meCUE questionnaire Scenario 2 results

We did not notice any significant improvement in scale scores for scenario 3 (see Table 147 and Figure 117). 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 147 - 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

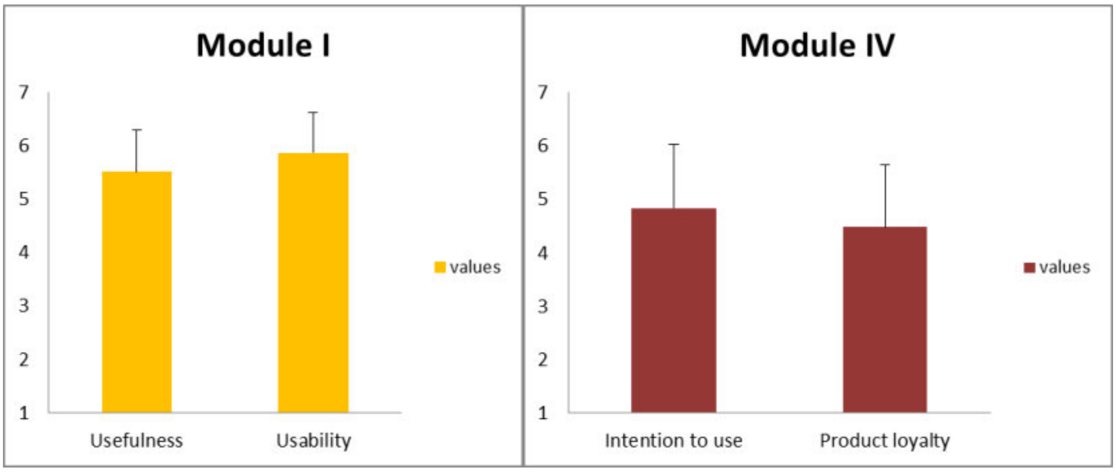


Figure 117 - meCUE questionnaire Scenario 2 results

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.

7.4.4. Greece

Uses cases considered

- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-WCW: Hazardous Location Notification - Weather Condition Warnings
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

Quantitative Test Results (Surveys)

Concerning the questions about Hazardous Location Notification (HLN), most of the participants (39,7%) had zero knowledge about the service and 31% of them knew about the service but had never used it in the past. Only a very low number of the participants mentioned that they had used the service a few times (5,2%) or used it regularly (1,7%). Most of the participants considered the service useful (32,8%) or extremely useful (31%) and the rest of them had a neutral opinion. A few participants (6,9%) rated the service as slightly useful. 41,4% of the participants stated that they agreed strongly to daily use of IVS if the service was available to them, and almost the rest half either agreed or had a neutral opinion. The highest number of the participants (32,8%) had a neutral opinion about willingness to pay for the service, while 29,3% disagreed strongly with that. Only a very low number (5,2%) showed a strong willingness to pay for HLN. The results are presented in the figures below.

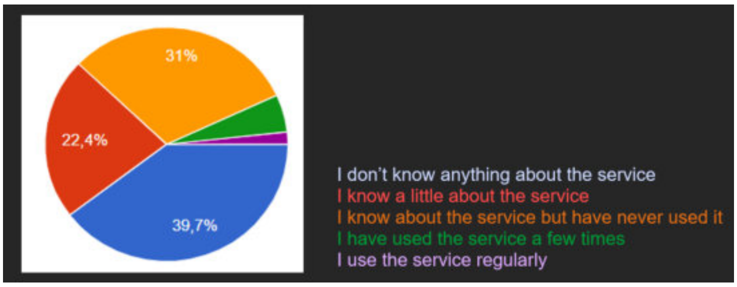


Figure 118 - Knowledge of HLN

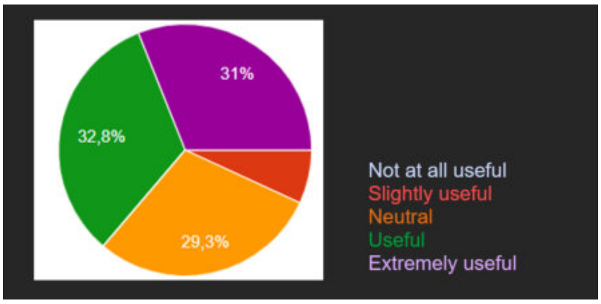


Figure 119 - Perception on the usefulness of HLN in daily driving

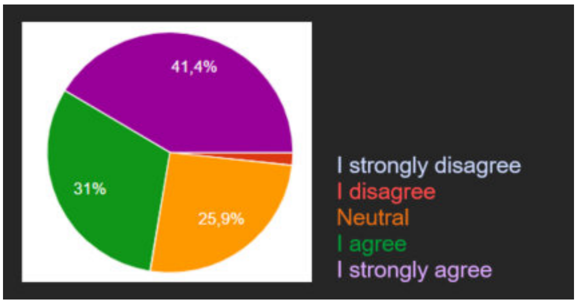


Figure 120 - Willingness to use HLN frequently

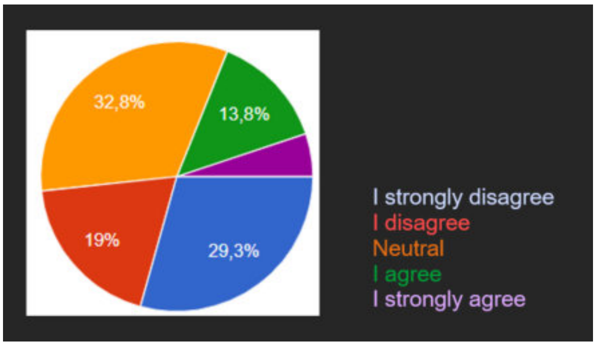


Figure 121 - Willingness to pay for HLN

7.4.5. Ireland

Preliminary findings across all service groups were grouped together and are provided in section 5.4.8.

7.4.6. Portugal

Use Cases considered

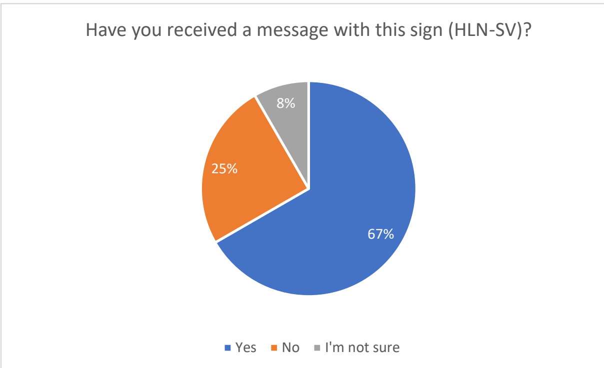
- HLN-SV: Hazardous Location Notification - Stationary Vehicle
- HLN-OR: Hazardous Location Notification - Obstacle on the Road

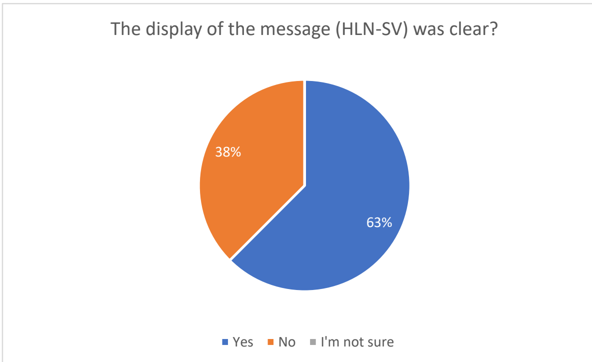
Test Results (Surveys)

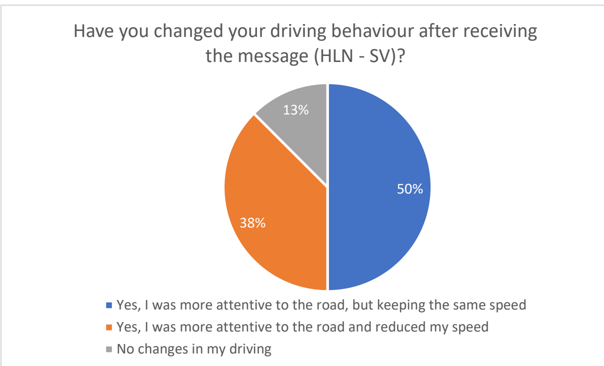
About 67% of the participants states that have received the message and that the display of the message clear.

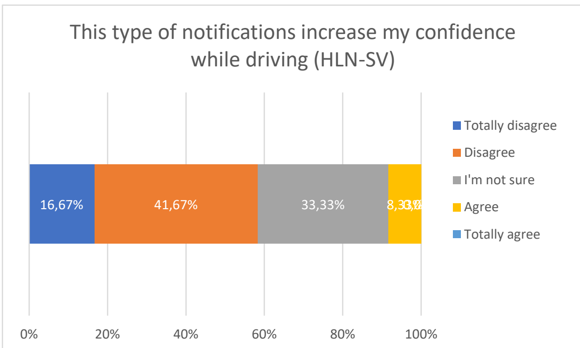
8 in 10 participants, acknowledge that receiving the HLN-SV message in advance enabled them to be more attentive to the road, with half reducing speed and 38% affirming that they were more carefull but didn't change the speed. 13% indicates no changes in the driving behaviour.

Asked on whether this type of advance notification increase the confidence while driving, more than half of the participants disagree or strongly disagrees with that statement and 13% is not sure. Only 8% of the participants states their agreement on an increased level of confidence.









7.4.7. 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."*

7.5. Functional Evaluation

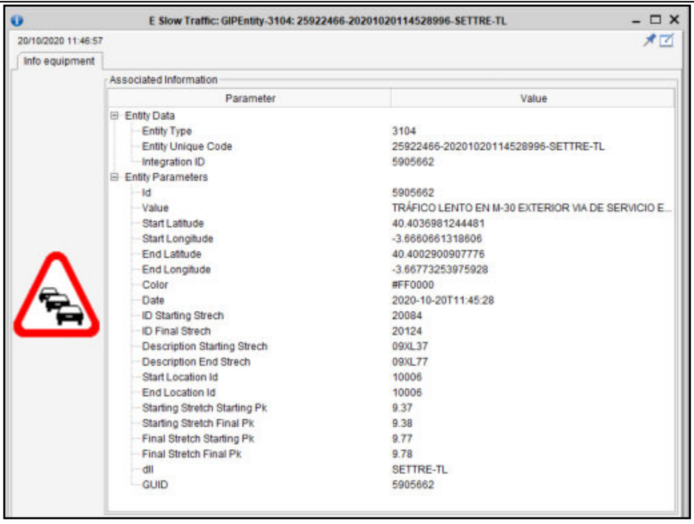
This section provides a list of the hazardous location notification use-cases evaluated from a functional evaluation perspective, a summary of the evaluation methodology, data collected and results from each of the following countries: Spain, NW2, Belgium-Flanders, Germany, Czech Republic

7.5.1. Spain

The Spanish pilot evaluated the functional evaluation on most of the services deployed. Table 148 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 148 details the feedback obtained from the implementation in the Spanish pilot (Madrid, Cantabrian and Andalusian sub-pilots).

Table 148 - 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.



E Slow Traffic: GIPEntity-3104: 25922466-20201020114528996-SETTRE-TL

20/10/2020 11:46:57

Info equipment

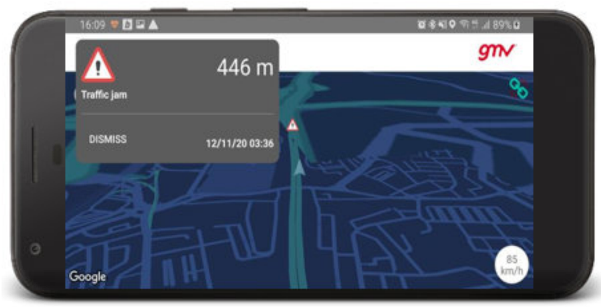
Associated Information

Parameter	Value
Entity Data	
Entity Type	3104
Entity Unique Code	25922466-20201020114528996-SETTRE-TL
Integration ID	5905662
Entity Parameters	
Id	5905662
Value	TRÁFICO LENTO EN M-30 EXTERIOR VIA DE SERVICIO E...
Start Latitude	40.4036981244481
Start Longitude	-3.6660661318606
End Latitude	40.4002900907776
End Longitude	-3.66773253975928
Color	#FF0000
Date	2020-10-20T11:45:28
ID Starting Strech	20084
ID Final Strech	20124
Description Starting Strech	09XL37
Description End Strech	09XL77
Start Location Id	10006
End Location Id	10006
Starting Stretch Starting Pk	9.37
Starting Stretch Final Pk	9.38
Final Stretch Starting Pk	9.77
Final Stretch Final Pk	9.78
dll	SETTRE-TL
GUID	5905662

[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.

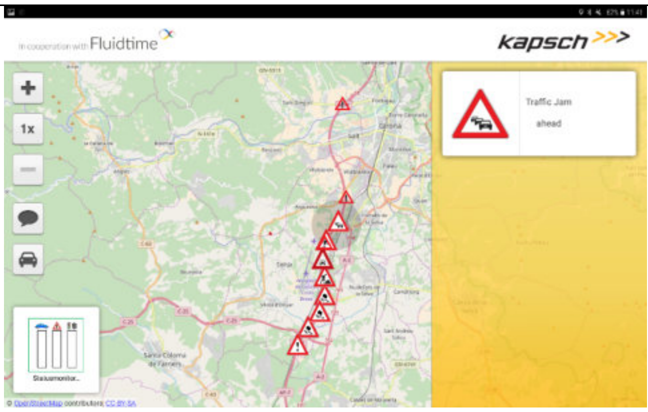
	
Quality of the Service	If the event had a trace/eventHistory, the event was shown to the user in the HMI when the vehicle entered the zone. If the event did not have trace/eventHistory, it was shown within the relevanceDistancevalue. The user had enough time to react. Some indications could confuse drivers in case of slow traffic transforms to a traffic Jam but generally the events were defined well and clearly 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.

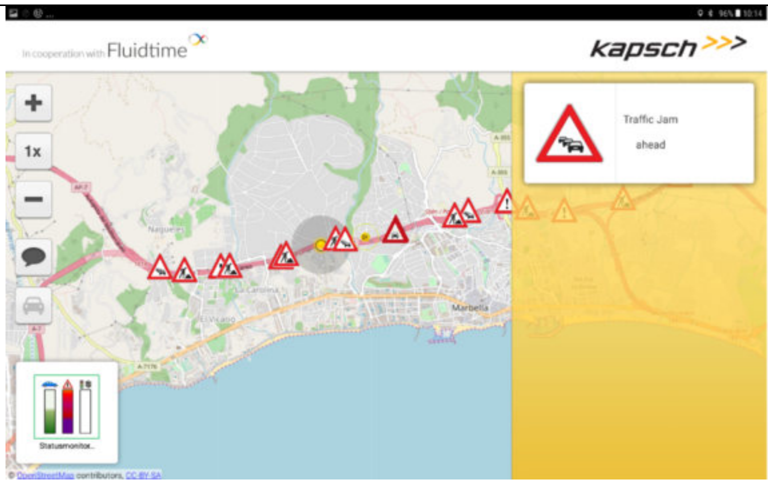
Table 149 - HLN-TJA Functional evaluation. Spain. Cantabrian sub-pilot

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 150 - 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: 
Quality of the Service	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. 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. Ireland

Interim functional evaluation analysis for the Hazardous location notification – traffic jam ahead use case is provided below. The project team will continue to capture feedback from pilot participants for the rest of 2024 and the analysis will be completed in the national evaluation and assessment report.

Table 151 - Function evaluation - Service implementation lessons learned: traffic jam ahead

Theme	What were the lessons learned during the implementation of the service in general?
Limitations of input data	The level of detailed Information needed for TJA messages was not readily available in NIMS, (e.g. information quality (level of certainty of congestion), location of start/end points of event, frequency of updates) even though C-ITS can integrate that level of details.
Configurable trace length data	Since it was difficult to determine the end of queue of a traffic jam, one fixed trace length does not work for all locations. There is a need for site and event specific trace configuration. The current C-Roads specification defines a minimum of 600m with no cap on the maximum distance
Sub cause code limitation	Since there are no provisions for detecting the end of queue in the traffic management system, the current C-ITS implementation does not include 'dangerous end of queue' sub cause code.
Mapping NIMS events to C-ITS use cases	In the current traffic management system, incidents are bespoke to TII's operational requirements and mapping them to C-ITS use cases was challenging e.g. in the TMS, congestion can be related to road works, weather and other incidents, whereas in C-ITS no cause of congestion is provided. Other use cases e.g. RWW notify potential causes (many to many mapping). The outcome of mapping exercise highlighted those benefits of C-ITS are constrained due to limited information available from the TMS. Following a common standard will avoid inefficient mapping.

Table 152 - Function evaluation - HMI implementation lessons learned: traffic jam ahead

Theme	What were the lessons learned specifically in relation to the implementation of the HMI?
Notification distance	Initial feedback highlighted that displaying notification for whole length of traffic jam was an unnecessary distraction as the participant already knows they are in a traffic jam. However, advanced notification of a traffic jam was seen to valuable and safety critical.

Table 153 - Function evaluation - technical performance of messages and warnings: traffic jam ahead

Theme	What observations were there in relation to the technical performance of how messages/warnings were displayed in the vehicle?
Results pending	[We have sought feedback from the participants on the reliability and timing of TJA notification. The results to be shared in the final report post survey]

Aural alerts	Feedback from participants highlighted that message notification sounds were distracting and is the same as what is shown on the screen. In-app option was provided to turn it off.
Length of message display	Some messages displayed for too long at the bottom of the HMI were seen as a distraction
Information overload	Too much information/notifications on the HMI caused some distraction/confusion to drivers

Table 154 - Functional evaluation – added value summary (general)

Theme	**What observations were there on the added value especially in relation to existing ITS road signage?**
Configurable up and downstream notification distances	C-ITS messages can be provided at configurable distances in advance and beyond physical message signs as long as they are relevant
C-ITS supplements physical signs	C-ITS messages can provide additional information to road users to what is displayed on physical message signs
Virtual VMS	C-ITS messages can be used in areas where there are no physical message signs to fill gaps in message coverage.
Improved situational awareness	Advance notifications and distances to events is seen as highly beneficial, improving situational awareness
Service potential	Feedback from the participants highlighted that there is more potential than just showing the information that was already shown on the motorway signs e.g., if a warning is no longer valid up ahead

7.5.4. 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.

7.5.5. Germany

Emergency Vehicle Approaching

In the Pilot Dresden the service EVA is evaluated on functional aspects (at time of writing still ongoing).

Lacking a sufficient penetration of C-ITS enabled vehicles, this evaluation could only be carried out as a show case, verifying the appropriate information is contained in the emergency vehicle's CAM and the other disseminated message, DENM.

So far, the correctness of all parameters has been successfully verified using a mirror setup implementation. Furthermore, the monitoring of the emergency vehicles in operation is ongoing and the respective fields in CAM and DENM were successfully observed on a random sampling basis. The data fields of interest are in the CAM `specialVehicleContainer -> emergencyContainer -> lightBarSirenInUse -> lightBarActivated`, and in the DENM `situation -> causeCode -> emergencyVehicleApproaching(95)`.

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 155. Further details are available in [RD.10].

Table 155 - 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 156 and 136 summarise the impacts on the KPI on mobility and their economic conversion for HLN-SV and HLN-WCW respectively.

Table 156 - 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 157 - 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**

For Portugal, considering the impacts for RWW and HLN, the economic benefit of C-ITS services in the C-Roads PT roads can be estimated at 18 M€.

	KPI	Economic Impact [M€ saved]
Safety Impact	-1 fatalities	1,35
	-4 serious injuries	1,5
	-55 injuries	4,6
Traffic Efficiency Impact	-1 104 048 hours	8,91
Environmental Impact	-2067 ton CO2	0,26
	-402 ton NoX	0,94
	Total	**17,56**

The roads included in this analysis cover to a large extent the infrastructure that has been prepared for connectivity with the installation of a large number of road side units. It proved to be effective in developing and deploying a significative ITS-G5 C-ITS interoperable and standardized capacity in the Portuguese network. Now the gap is on the vehicle side and not so much on the infrastructure.
Several hundreds of distinct ITS-G5 active vehicles are passing daily through the ITS stations of Pilot 2 partners and growing daily. Obviously, if more vehicle manufacturers don't join this trend, market penetration will never grow to a significative number. We're expecting that, when our networks join L2 security and start reaching the vehicles with real information, this may have already changed or is about to, with a quick adoption from automotive brands. Nevertheless, making this technology mandatory, like what was done with the eCall initiative, could help in getting a much deeper penetration in a shorter time, so that benefits could start occurring effectively in our roads.

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	+ +

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 (Safety – Spain).

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 175, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 175, 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 158 - 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%

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 159 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 122 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 159 - 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)

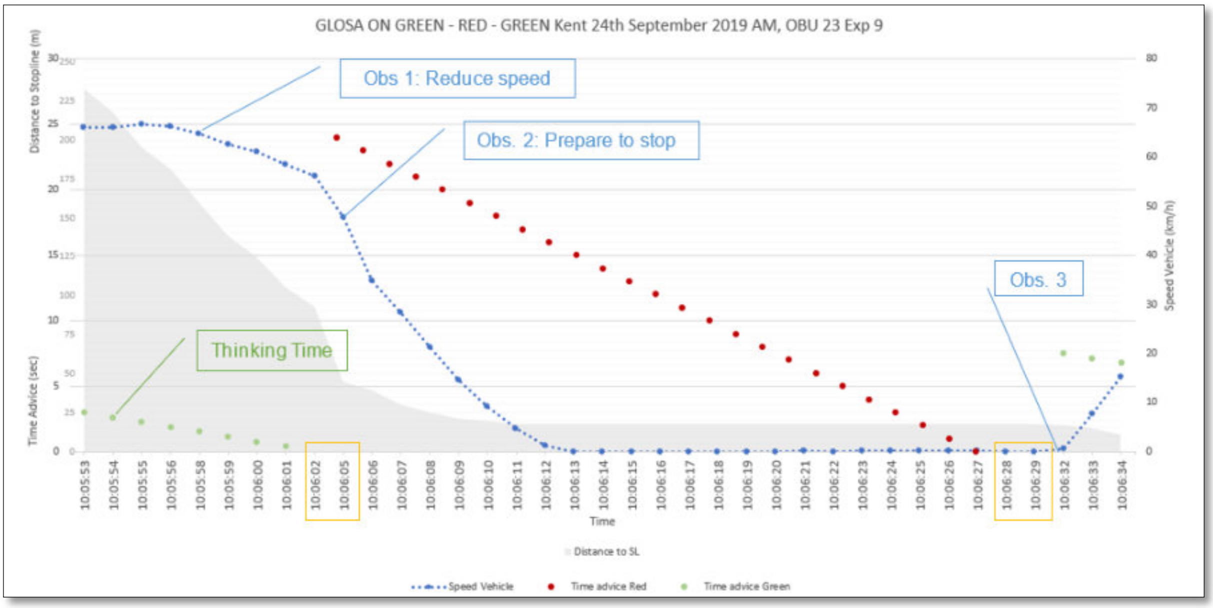


Figure 122 - Speed-time-distance profile of a driver (OBU23 Experiment 9) in the Kent (Rural) GLOSA section in FTE 4

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.

Co-funded by the European Union

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: Spain, UK, Hungary, Italy, France, NW3, Germany-

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 (Safety - Spain).

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 160.

Table 160 - 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 the 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 123 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.

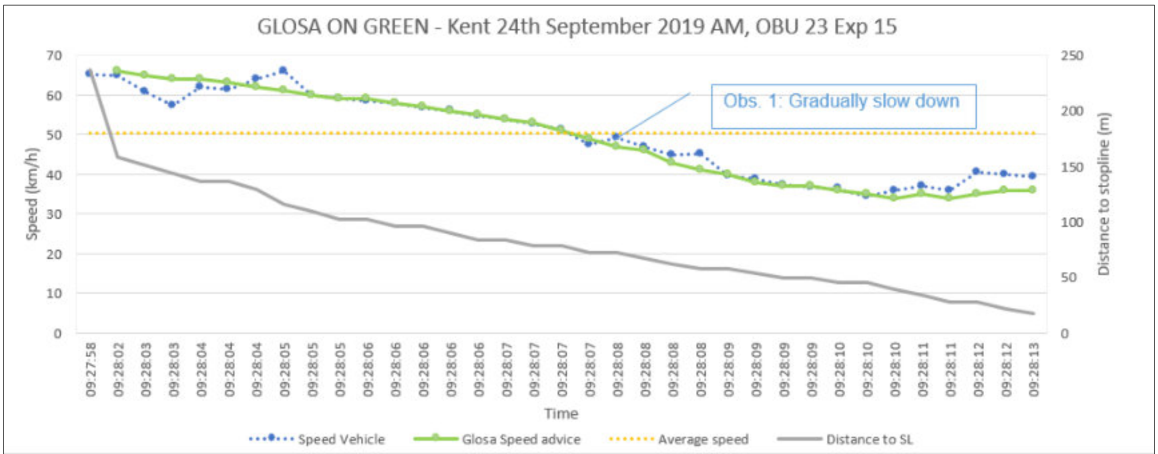


Figure 123 - Speed-time-distance profile of a participant (OBU23 Experiment 15) in the Kent (Rural) GLOSA section in FTE 4

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 124 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.

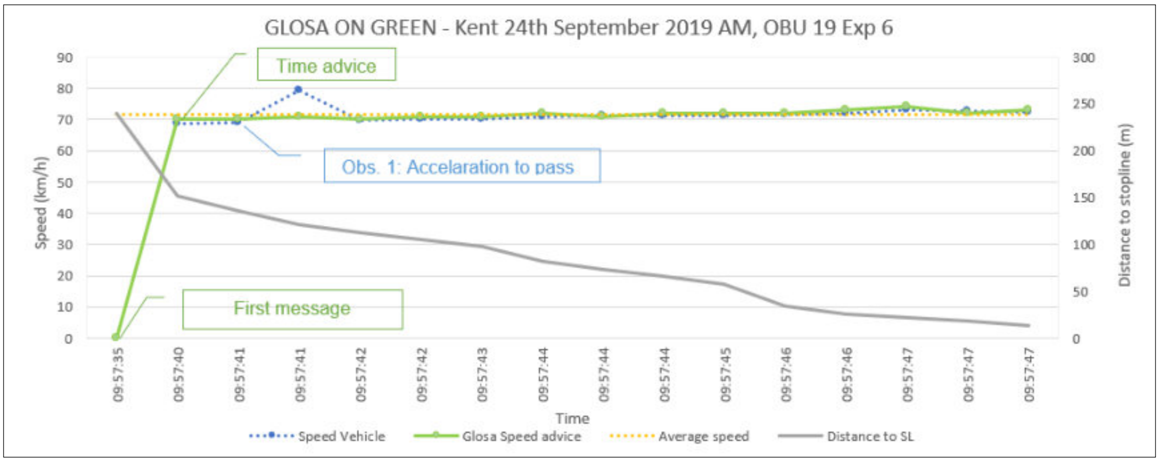


Figure 124 - Speed-time-distance profile of a driver (OBU19 Experiment 6) in the Kent (Rural) GLOSA section in FTE 4

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.

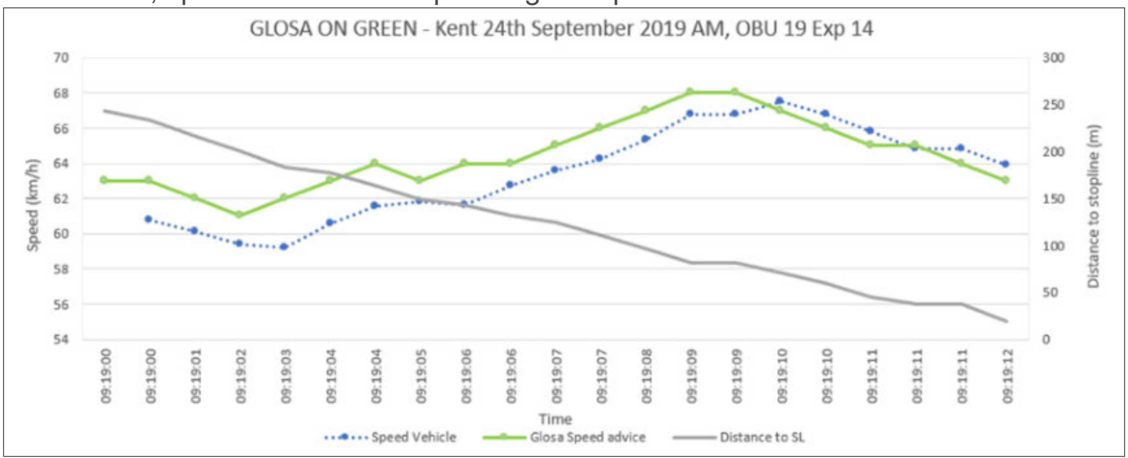


Figure 125 - Speed profiles from experiment 10 and 14 in FTE 4

This participant arrived at the intersection before the end of the green phase. In Figure 124, two other examples have been illustrated (Experiments 10 and 14) the same behavior (speeding up) was observed, Figure 125. 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 161. 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 161 - 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 126depicts 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.

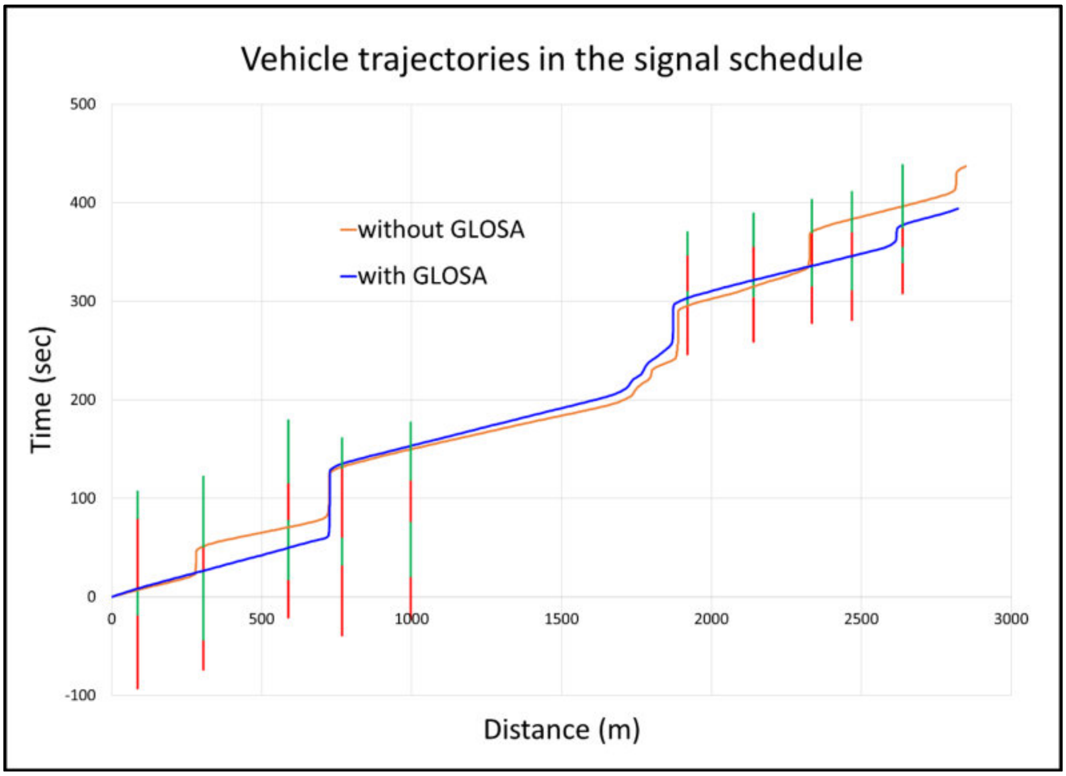


Figure 126 - Vehicle trajectories and signal schedule in a time-space diagram (GLOSA, Hungary)

8.2.4. Italy

C-Roads Italy 2 evaluated Use Case of Signalized Intersections both with modelling and relying on Field Tests. The two approaches are described separately.

Use Cases considered - Modelling

- 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 – Modelling

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 162 - 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 163 - 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
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 164 - 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.

Use Cases considered - Field Tests

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

Evaluation method – Field tests

Different field tests on GLOSA were carried out as part of C-Roads Italy 2.

Orbassano

The primary goal of the Orbassano test was to analyze how vehicles and their drivers behave when approaching a traffic light equipped with C-ITS technology. Conducted in a controlled environment, the test aimed to evaluate the effectiveness of GLOSA in influencing driver behavior and vehicle performance by providing speed advice through two specific algorithms: "Minimum Jerk" and "Smart e-Coasting." The controlled setting allowed for minimizing environmental variability and isolating the effects of GLOSA.
Tests were carried out at Stellantis Safety Center in Orbassano, Italy (2.5 km test track with two lanes, driven clockwise at a maximum speed of 70 km/h), using a Maserati Ghibli with a gasoline engine, equipped with the "Minimum Jerk" algorithm and a Jeep Compass (both provided by Stellantis – CRF) with hybrid propulsion, equipped with the "Smart e-Coasting" algorithm. Scenario were performed with GLOSA OFF and On, with different minimum recommended speed (20 and 30 km/h). Since tests were developed in a controlled environment, it was possible the consideration of multiple further variables: different road and traffic light conditions (traffic lighyt cycle and position) and different algorithm settings

Torino

The Turin test aimed to verify the functionality and benefits of GLOSA in a real-world urban environment. Unlike the controlled test in Orbassano, this test evaluated GLOSA's performance amidst typical urban conditions, such as varying traffic densities and public transport prioritization. The main goal was to see if the benefits observed in controlled settings would persist in more complex environments.
Tests were carried out involving the intersection of Corso Galileo Ferraris and Via Pastrengo. A Jeep Compass (both provided by Stellantis – CRF) with hybrid propulsion, equipped with the "Smart e-Coasting" algorithm was used. Scenario were performed with GLOSA OFF and On, with different minimum recommended speed (20 and 30 km/h).

Trento

Like the Turin test, the Trento test evaluated GLOSA in a real-world urban setting but with additional complexities such as pedestrian-activated traffic lights and dynamically implemented traffic light phases. The objective was to determine if GLOSA could still maintain efficiency and provide benefits under these challenging conditions.
Tests were carried out involving three consecutive pedestrian traffic lights along Via del Brennero in Trento, between the roundabouts at Via Franceschini/Via Zambra and Via Caduti di Nassirya. A Maserati Ghibli with a gasoline engine, equipped with the "Minimum Jerk" algorithm was used. Scenario were performed with GLOSA OFF and On, with different minimum recommended speed (20 and 30 km/h).

Data collected

The following data were collected for all the field tests:

- vehicular logs of the two involved vehicles, containing instantaneous and continuous information on positioning, vehicle dynamics and road information;

- additional vehicular logs including data specific to the SI - GLOSA service/use case: GLOSA information, MAP/SPAT information;
- sheets completed for each experiment, containing annotations for each single repetition regarding the macro-behavior of the vehicle at the traffic light, any technical anomalies experienced, etc.

Evaluation results – Field tests

Orbassano

Vehicles equipped with GLOSA ON stopped less frequently especially at red lights, showing a 39% improvement over GLOSA OFF in terms of reduced stops.
GLOSA ON consistently led to a lower standard deviation in speeds across all scenarios (with an observed reduction of 23%), indicating more uniform driving speeds and reduced need for speed adjustments.
Similar improvements were seen with acceleration, where GLOSA ON showed lower variability in vehicle acceleration (-23%), enhancing comfort and efficiency.
GLOSA ON reduced both maximum acceleration (-16%) and deceleration (-35%), particularly during the red phase (-18% for maximum acceleration and -41% for maximum deceleration), which translates to smoother driving experiences and enhanced comfort.
There were significantly less brake pedal pressures in GLOSA ON scenarios (-51%), particularly in the green/yellow light phase (-64%), reducing the frequency of abrupt slowdowns.
While GLOSA ON slightly increased travel times in green/yellow phases (+9,1%) due to adherence to recommended speeds, it reduced travel times in red phases (-1,5%) by enabling more efficient approaches to traffic lights.
During the red-light phase, the Smart e-Coasting (EC) algorithm tends to perform better than the Minimum Jerk algorithm (MJ): this emerges particularly when analyzing the effectiveness of the algorithms in reducing vehicle stops (62% reduction in stops compared to GLOSA OFF) and improving the regularity of speed (-33%) and accelerations (-42%).
GLOSA ON showed better outcomes at lower speed limit (50 km/h) across most indicators compared to higher speed limit (70 km/h), likely due to more effective speed management at lower speeds (more space is required to make effective corrections at higher travel speeds).
Extending the maximum activation distance of GLOSA enhances its effectiveness, reducing vehicle stops, and smoothing speeds and accelerations. The MJ algorithm particularly benefits from longer distances, suggesting its suitability for extended range implementations. These results advocate for configuring GLOSA systems with sufficient activation distances to optimize traffic management and improve driving conditions.
The EC algorithm performs better with shorter traffic light cycles, i.e., 30 seconds, while the MJ algorithm, in contrast, seems to perform better with longer traffic light cycles of 45 seconds.
When two vehicles travel close together, from the point of view of the need to brake and stop the vehicle, the greatest benefit is achieved with active GLOSA on the following vehicle: the brake is used only in 50% of repetitions, compared to 86% with GLOSA activated on the head vehicle and 71% with GLOSA OFF on both vehicles.
Conversely, indicators of smoothness and comfort are positive and better for the scenario with GLOSA activated on the head vehicle, as the following vehicle could benefit from a smoother driving behavior (thanks to GLOSA) of the leading vehicle.

Torino

In the GLOSA field test in Turin, all calculated indicators showed a positive impact of using GLOSA. Among the most significant improvements recorded, the GLOSA ON configuration achieved a 46% reduction in the need for vehicles to stop when approaching the traffic light and a 58% reduction in the brake usage (compared to the GLOSA OFF status).
For indicators related to the standard deviation of speeds and accelerations and to the maximum accelerations/decelerations, improvements ranging from 19% to 32% were recorded compared to the GLOSA OFF condition.
The average speed recorded along the approach paths to the traffic light (from - 125 meters to + 60 meters) is instead comparable between the GLOSA ON and GLOSA OFF configurations.
Comparing the results obtained with different settings of the Vmin of the GLOSA algorithm (20 km/h and 30 km/h), performances were generally better for the 30 km/h setting, although with some exceptions, such as the number of times the vehicle had to zero its speed.
These latter results, however, have limited statistical significance since the number of experiments with Vmin equal to 20 km/h for which a speed between 20 km/h and 30 km/h was actually recommended are very limited; therefore, it is not possible to attribute the better performances recorded to the setting of the Vmin itself with reasonable certainty.

Trento

In the GLOSA field test in Trento, almost all the indicators calculated on the basis of the nominal state of the GLOSA (GLOSA OFF and GLOSA ON) showed a slightly positive impact of using GLOSA (between 0% and 14% improvement of GLOSA ON compared to GLOSA OFF).
Only the indicators of the average speed and of the number of times the vehicle zeroes its speed show a slight worsening (between 7% and 14%) compared to the GLOSA OFF configuration.
Comparing the results obtained with different settings of the Vmin of the GLOSA algorithm (20 km/h and 30 km/h), performances are very similar, with very limited differences in the value of the indicators for the two scenarios.

A more in-depth analysis made it possible to evaluate performance differentially according to the current state of the traffic light (in the presence of an undefined green light or a pedestrian call in progress), as well as the actual state of GLOSA activation (provision of recommended speed or advice to stop). Although the outcome of this analysis is conditioned by the value attributed to specific thresholds, which were determined by means of expert judgement, it emerged that GLOSA does not appear to be able to provide any significant benefit to vehicles/drivers under the specific conditions of this field test, since most of the calculated performance indicators tend to show less favorable results precisely during the phases in which GLOSA is actually active.
This result, in countertendency with those obtained in the other GLOSA field tests (Orbassano and Turin), can be justified by some conditions that characterized the implementation of this field test, such as:

- the use during testing of traffic lights dedicated to pedestrian crossing, which limits the number of cases during which GLOSA can operate, as well as being subject to sudden changes in the expected phase when a pedestrian reservation is activated;

- the strong dynamic actuation of traffic lights as a function of traffic, which does not generate stable conditions for the calculation by the GLOSA algorithm;
- the non-negligible latency of communicating phase variations via C-ITS messages, which amplifies the criticalities highlighted above.

Overall results

Considering the results obtained in the three field tests carried out for the GLOSA Use Case (Orbassano, Turin, Trento) in a combined manner, the following observations can be made:

- The field test in Orbassano, thanks to the controlled environment and the absence of disturbances characteristic of real urban conditions, was able to confirm the basic and intrinsic goodness of the Service/Use Case and of the algorithms implemented by Stellantis – CRF. With the service active (GLOSA ON), a general improvement in most of the performance indicators used for evaluation was indeed noticed; in the same field test, conclusions could also be drawn regarding the configuration of some operating parameters of the service, albeit with more limited statistical reliability; in particular, it was deduced that:
    - greater activation distances of the GLOSA upstream of the traffic light bring greater benefit;
    - the system works better in the presence of lower speed limits (50 km/h compared to 70 km/h); the performance deficit at 70 km/h can probably be compensated by increasing the activation length/distance of the GLOSA;
    - in the case of two vehicles traveling at a reduced distance, the presence and use of the GLOSA on the lead vehicle can bring benefits in terms of regularity of travel and comfort to the following vehicle, even if it is not equipped with GLOSA;

- The field test in Turin confirmed the goodness of the service and the related use case, highlighting benefits for all calculated indicators, although slightly scaled down by the presence of possible vehicles between the test vehicle and the traffic light that are not contemplated by the current algorithms and by the traffic light actuation to give priority to public transport, which dynamically changes the remaining times of the ongoing traffic light phases;

- The field test in Trento, on the other hand, showed how some traffic light configurations are not fully compatible with the optimal functioning of the GLOSA, such as:
    - traffic lights dedicated to pedestrian crossings upon request, characterized by non-negligible intervals of time with green for vehicles without a change of phase prediction;
    - a highly dynamic implementation of traffic light phases, where the durations of the current traffic light phases are continuously updated and changed, challenging the GLOSA forecasting model.

It can therefore be concluded that GLOSA seems to obtain the greatest benefits in the presence of:

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- fixed traffic light cycles or in any case with not excessively dynamic traffic-dependent actuation levels (characterized by high update frequencies of residual phase times);
- traffic lights that are not exclusively for pedestrians; the latter may limit the effective operating time of the system, especially in the case of low pedestrian crossing flow and consequently a limited number of bookings.

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 127).

- 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.

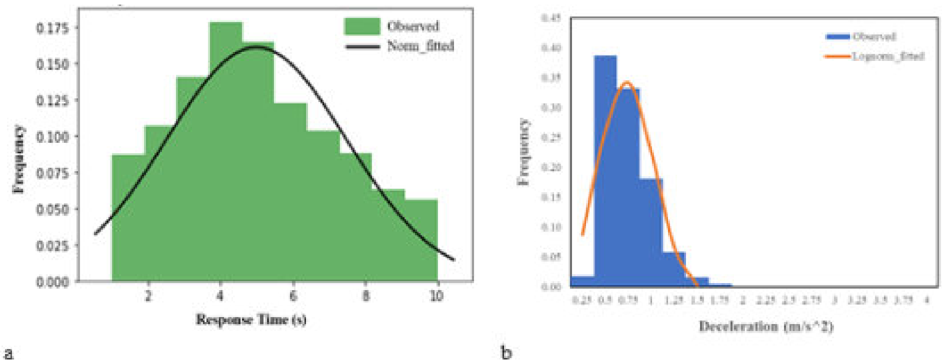

Figure 127 - (a) Response Time, and (b) Deceleration rate of the connected drivers

- 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 128):

- **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.

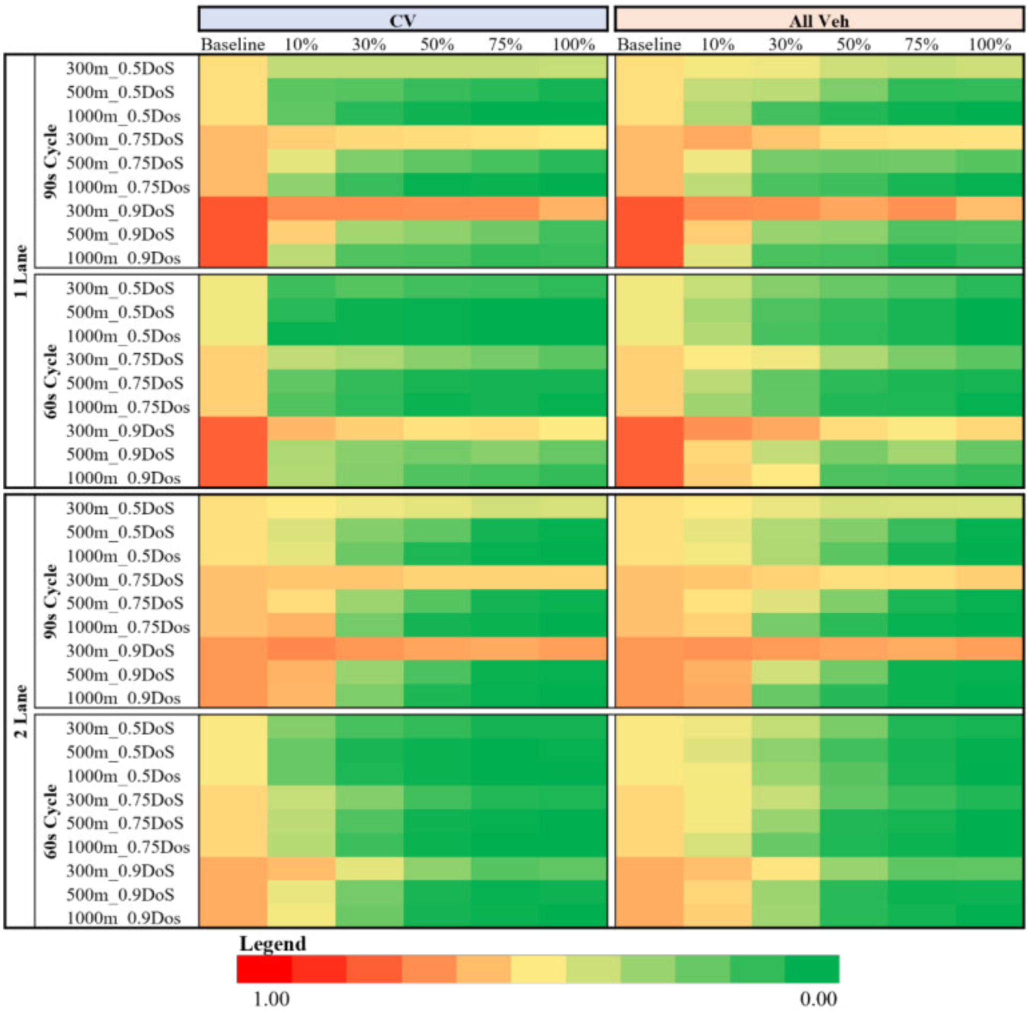

Figure 128 - Impact of SI-GLOSA on average number of Stops per vehicle

8.2.6. NordicWay 3

The societal impacts of GLOSA and TTG/TTR were investigated using the VISSIM micro simulation tool by Legêne et al. (2023). 16 simulations were made with selected combinations of traffic signalling type, penetration rate, traffic situation and different C-ITS service related parameters. These simulations resulted in a set of accessibility indicators (vehicle hours and stop delay, the number of stops). Regression analysis was used to investigate the relationship between variables and to explore their correlation to the outcomes of the application of these C-ITS services.

The results of the simulation study of Legêne et al (2023) showed for the use case of the solitary intersection that with low penetration (10-40%) of vehicles equipped with C-ITS the vehicle hours and stop delay were around 1% higher with GLOSA than with TTG/TTR regardless of traffic signalling, traffic situation or minimum speed in the advice. However, when the penetration rate increases, the effects of GLOSA are better than those of TTG/TTR. They assessed this to be caused by more homogenous traffic flow.

GLOSA had a positive impact on the number of stops. The effect is highly dependent of the penetration rate, with the largest impact when 70% of vehicles were equipped. The gains with GLOSA were more than 200% higher than for TTG/TTR. This shows the effectiveness in preventing cars from stopping. The results were positive in all conditions during “the rest of the day” scenario, but only for some in the morning and nighttime traffic scenarios. Vehicle actuated signalling improved the result. (Legêne et al 2023)

The second use case was a corridor with chained intersections. The results showed that the impact in terms of accessibility related to vehicle hours, stop delays and number of stops was not affected by the penetration rate of GLOSA when the traffic signalling was vehicle actuated. For the emissions, the impact improved with the increasing penetration rate. The reduction of the emissions was around 1.5-5.0%. When the C-ITS is deployed with fixed traffic signalling, the penetration rate has only little influence on the accessibility benefits. The impact was a 2% decrease in the number of stops and delay, without any increase with increasing penetration. The reduction in emissions was the same as for actuated traffic signalling. (Legêne et al 2023)

8.2.7. Germany

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisory

Evaluation method

In the pilot Hamburg, besides the classical GLOSA realisation (car speed adaption), test track users have also realised several other adaptations. For example, GLOSA has also been tested on pedelecs and eScooters. The MAPEM and SPATEM have also been used as a time to green service (TTG) to improve run-up performance for automated driving and control automatic start-stop systems. Various test track users have successfully developed and implemented a traffic light forecast service. Examples are Neusoft (TTG and GLOSA), Volkswagen AG (TTG) or NXP (TTG and GLOSA for cyclists). The test track user feedback indicates the importance of the possible time frame for any forecast to be communicated by all four parameters (likely, confidence, minimal and maximal switching time). Within the framework of the Hamburg pilot, no quality criteria for assessing the forecast have yet been defined, and thus, no final judgment has yet been made. Many traffic lights on the test track work with traffic-dependent control, which generally represents a high degree of uncertainty. The predicted times are within the expected range. The sooner the upcoming signal image change approaches, the more reliable the forecast becomes. The forecast data is calculated event-oriented. This means periodic recalculations occur, and the forecast can rapidly change several times until the signal change is reached. With fixed-time controls, the forecast data are much more reliable and usually show no jumps. It is planned to evaluate the quality of the various switching time forecasts in functional evaluation and to continue the process of a quality definition of the forecast.

The standardization and technical realization of the standard have a strong iterative component. This partially resulted in the sender and receiver sides implementing different versions or interpretations of the standard. Such discrepancies were uncovered by the test drives of the various users and could then be remedied.

In a master thesis, several test drives on a specific part of the test track have been made on an eScooter, and a before-and-after comparison has been made concerning the GLOSA service. Within this master thesis, a series of test drives and simulations were planned to investigate the effectiveness and benefits of the GLOSA service on the test track. The test drives aim to examine the changes in driving characteristics such as speed, travel time, number of stops, and idle time at the traffic lights that GLOSA causes in real traffic. The test drives have been carried out on an eScooter.

One hundred test drives were carried out on “Vorsetzen-Johannisbollwerk-Straße” between “Baumwall” and “Landungsbrücken”. Table 165 describes the test drives by number, quantity, use of GLOSA data and route.

Table 165 - Description of the GLOSA test drives

#	Quantity	Description	Test drive number
1	25	from Landungsbrücken (KN19) to Baumwall (KN228) without using the signal data from the GLOSA app (direction of travel Baumwall without GLOSA data)	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50
2	25	from Baumwall (KN228) to Landungsbrücken (KN19) without using the signal data from the GLOSA app (direction of travel Landungsbrücken without GLOSA data)	2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 31, 33, 35, 37, 39, 41, 43, 45, 47, 49
3	25	from Baumwall (KN228) to Landungsbrücken (KN19) using the signal data from the GLOSA app (direction of travel Landungsbrücken with GLOSA data)	51, 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, 75, 79, 81, 83, 85, 87, 89, 91, 93, 95, 97, 99
4	25	from Landungsbrücken (KN19) to Baumwall (KN228) using the signal data from the GLOSA app (direction of travel Baumwall with GLOSA data)	52, 54, 56, 58, 60, 62, 64, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100

Figure 129 - Test drive route from Baumwall to Landungsbrücken (illustration based on Google Maps)

The first test route starts in the west and passes along the black line to the east on several signalized intersections (labelled as “LSA”) LSA228 and continues via LSA2501, LSA2052, LSA2051, LSA2500 and LSA2053 to LSA19. Table 166 shows the distances of the traffic lights from the starting point (LSA228).

Table 166 - Distances of the traffic lights from the start of the route (direction of travel Landungsbrücken)

Traffic light	LSA228 K1	LSA228 K7	LSA2501 K1	LSA2052 K1	LSA2051 K1	LSA2500 K2	LSA2053 K1	LSA2053 K4	LSA19 K1
Distance (m)	0	50	150	250	400	500	600	650	900

Figure 130 - Test drive route from Landungsbrücken to Baumwall (illustration based on Google Maps)

The second route begins in the east at LSA19 and runs to the west via LSA2053, LSA2500, LSA2051, LSA2052 and LSA2051 to LSA228. Table 167 shows the distances of the LSAs from the starting point (LSA19).

Table 167 - Distances of the traffic lights from the start of the route (direction Baumwall)

Traffic light.	LSA19 K2	LSA2053 K3	LSA2053 K2	LSA2500 K2	LSA2051 K2	LSA2052 K2	LSA2501 K2	LSA228 K2
Distance (m)	0	250	300	450	550	650	800	900

Speed

The following figures show the recorded speeds and the resulting average speeds according to the route and use of the GLOSA data.

Direction of Baumwall without GLOSA data.

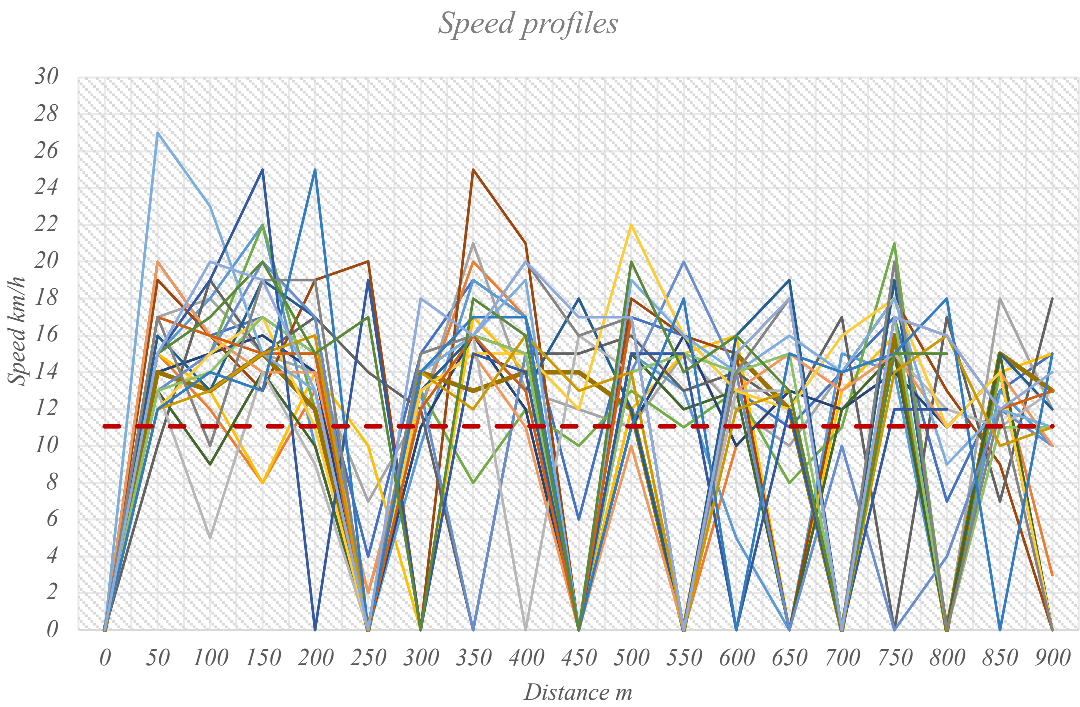

Figure 131 - Speed profiles from the test drives without GLOSA (direction Baumwall) (Source: LSBG)

Twenty-five test drives were carried out on Vorsetzen-Johannisbollwerk-Straße from Landungsbrücken (LSA19_K2) to Baumwall (LSA 228_K2). The route was travelled several times by eScooter without using the signal data from the GLOSA app. The data collected was recorded with a GPS device and visualized as speed profiles (Figure 131). The analysis of the speed profiles results in an average speed of 11 km/h, shown on the diagram with a red dashed line. Figure 131 shows many stops during the test drives along the road at various traffic lights, negatively affecting and reducing the average speed. Figure 131 shows that the drives without signal data led to stops at LSA2053, LSA2500, LSA2051, LSA2052, LSA2501 and LSA228, negatively impacting the total travel time and the average speed. The obstruction caused by other road users, such as parked vehicles in the right-hand lane (deliveries, cabs, buses) and slow-moving vehicles, contributed to gridlock in some places during the test drives.

Direction of Baumwall with GLOSA data

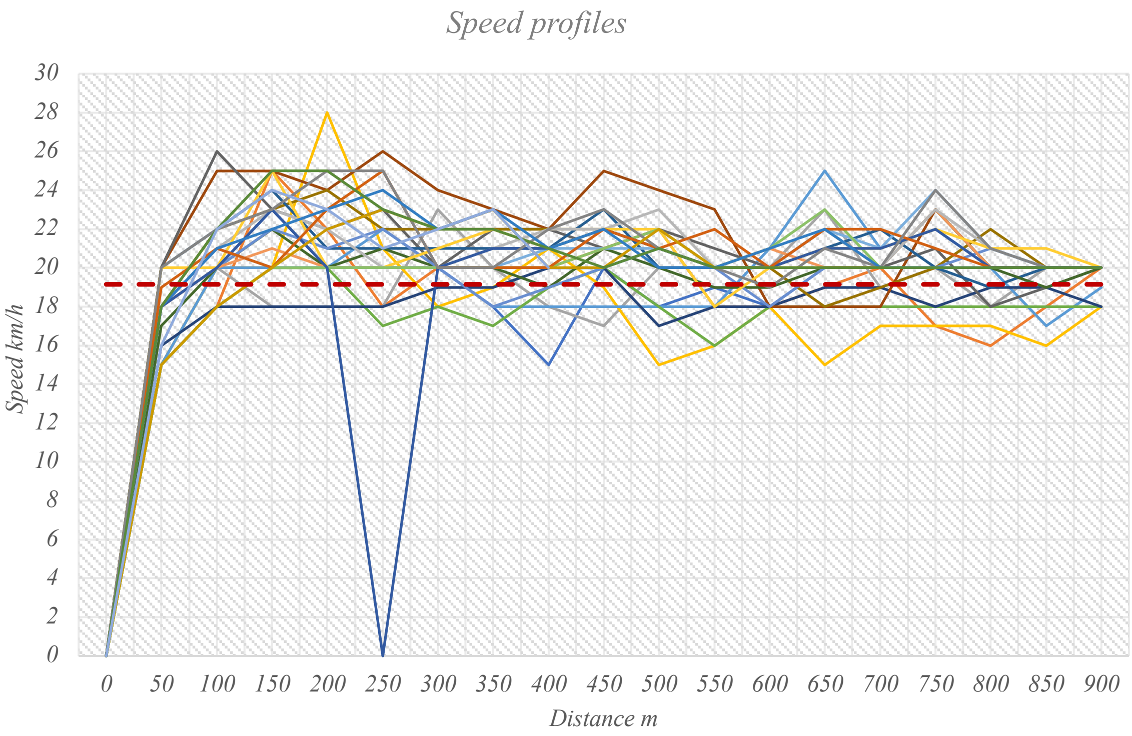

Figure 132 - Speed profiles from the test drives with GLOSA (direction Baumwall) (Source: LSBG)

The route from Landungsbrücken to Baumwall was covered twenty-five times on an eScooter. The signal data from the GLOSA app was used for the test drives. The speed profiles from the test drives are shown in the diagram above (Figure 132). The speed profiles show an average speed of 19 km/h and almost no stopping at traffic lights. During the test drives, the GLOSA app from T-Systems provides information on signal phases and times. This data enables the user to adapt their speed to the traffic light to reach the traffic light when it turns green. An anticipatory driving style ensures that traffic flows smoothly, resulting in stops being avoided or the number of stops at traffic lights being reduced. By preventing or reducing the number of stops and starts after traffic lights, the total travel time is shortened, and the average speed is increased.

Direction Landungsbrücken without GLOSA data

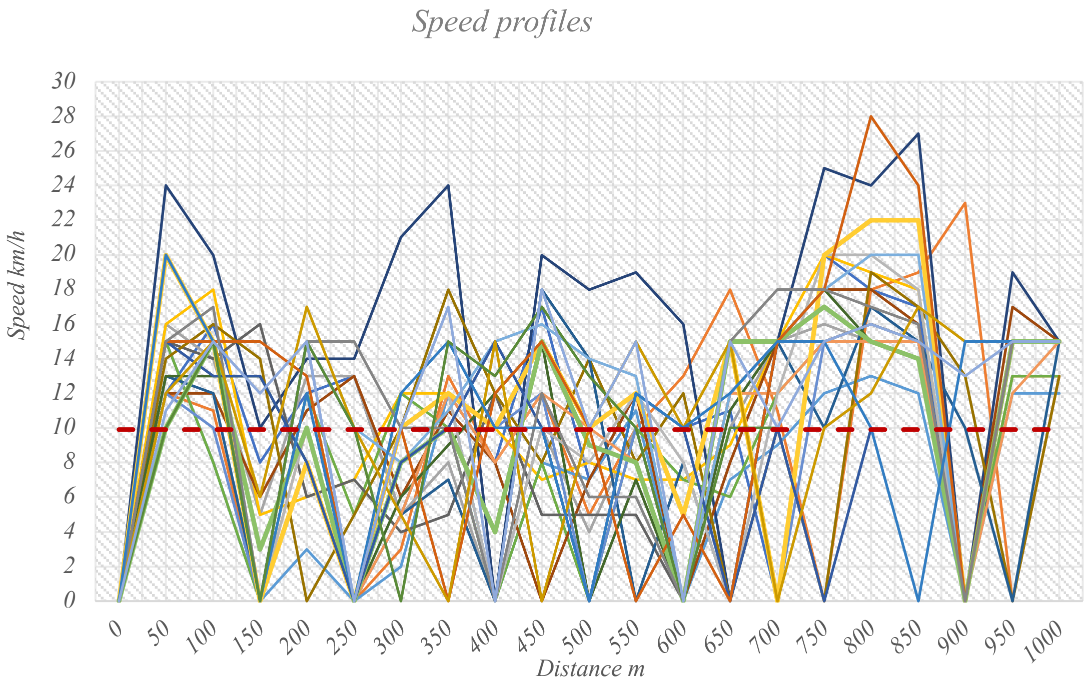

Figure 133 - Speed profiles from the test drives without GLOSA (from KN228 to KN19) (Source: LSBG)

Twenty-five drives without GLOSA were carried out on Vorsetzen-Johannisbollwerk-Straße from Baumwall to Landungsbrücken. No signal data from the GLOSA app was used for these test drives. Figure 133 shows frequent stops at LSA2501, LSA2052, LSA2051, LSA2500, LSA2053 and LSA19 between Baumwall and Landungsbrücken. In addition, the ride came to a standstill in some places due to obstruction by other road users. The speed profiles from the recorded GPS tracking coordinates are shown in the diagram above (Figure 133) and result in an average speed of 10km/h. The high number of stops behind traffic lights leads to a reduction in average speed and an increase in total travel time.

Direction Landungsbrücken with GLOSA data:

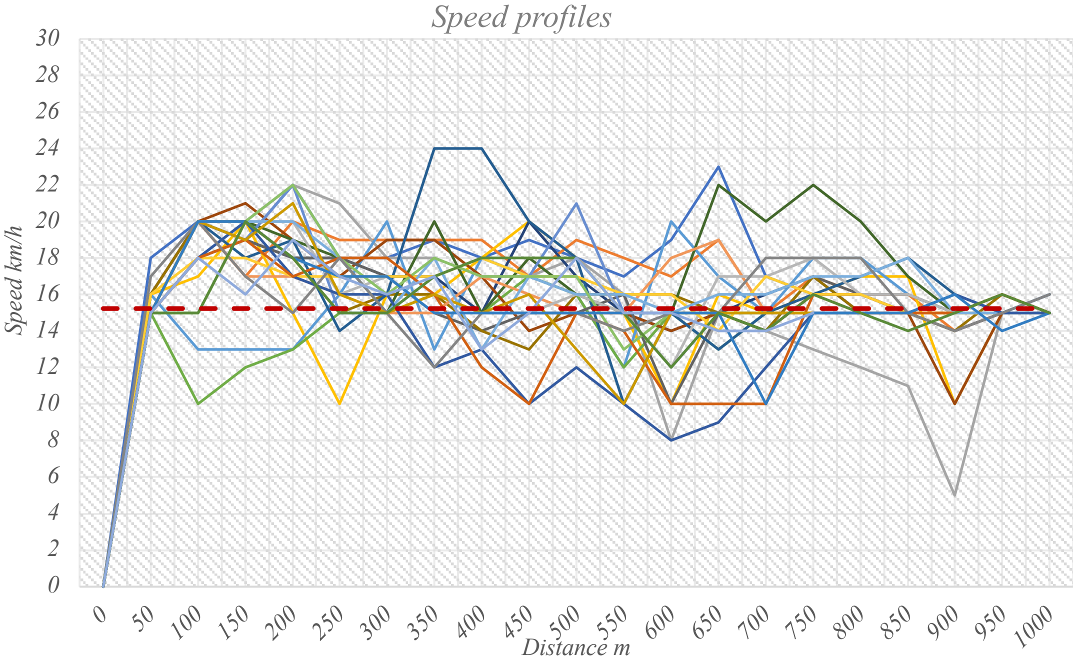

Figure 134 - Speed profiles from the test drives with GLOSA (from KN228 to KN19) (Source: LSBG)

Twenty-five test drives were carried out with the signal data from the GLOSA app on Vorsetzen-Johannisbollwerk-Straße from Baumwall to Landungsbrücken. The information on signal phases and timing from the GLOSA app from T-Systems was used for these test drives.

Using the GLOSA app's signal data, the route was travelled at a speed adapted to the traffic lights during the test drives. This made it possible to travel between Baumwall and Landungsbrücken without stopping at traffic lights. The speed profiles from the recorded GPS tracking coordinates are shown in the diagram above (Figure 134). The analysis of the speed profiles results in an average speed of 15 km/h, shown in the chart as a red dashed line.

Figure 134 shows there is no need to stop at traffic lights between Baumwall and Landungsbrücken, which shortens the total travel time and increases the average speed.

Conclusion:

One hundred test drives were carried out without and using signal data from the GLOSA app. The speed profiles recorded during the test drives were displayed in four different diagrams(Figure 131 - Figure 134) according to the direction and use of the GLOSA data. The following points emerged from the analysis of the speed profiles.

- On the test route in the direction of Baumwall, the average speed increased from 11 km/h to 19 km/h using the signal data from the GLOSA app.
- Using the GLOSA app's signal data, the average speed on the test route towards Landungsbrücken increased from 10 km/h to 15 km/h.
- The significant increase in average speed using signal data (signal phases and timing) is because stopping at the red phase along the road is avoided or minimized as much as possible by the signal data.

- Using signal-specific data on signal phases and times, stops at traffic lights can be avoided, or the number of stops at traffic lights can be reduced as much as possible.
- Minimizing the number of stops behind traffic lights reduces travel times with a higher average speed, which can contribute to a smoother flow of traffic in urban areas.

Travel time

Table 168 shows the number of stops, the stopping time and the total travel time for the test drives with and without GLOSA data. The values in the table are used to examine the extent to which the travel time, the number of stops and the standing time behind traffic lights can change due to the introduction of the GLOSA service in a real example.

Table 168 - Travel times of the test drives (without GLOSA data and with GLOSA data)

Test drives without GLOSA						Test drives with GLOSA					
test drive	from (traffic light)	to (traffic light)	Stop		Total travel time [min:sec]	test drive	from (traffic light)	to (traffic light)	Stop		Total travel time [min:sec]
			Quantity	stopping time					Quantity	stopping time	
1	KN19	KN228	1	00:15	04:01	**51**	KN228	KN19	0	0	03:15
2	KN228	KN19	2	00:20	05:24	**52**	KN19	KN228	0	0	03:20
3	KN19	KN228	5	01:45	05:52	**53**	KN228	KN19	0	0	03:35
4	KN228	KN19	5	01:25	05:20	**54**	KN19	KN228	0	0	04:06
5	KN19	KN228	1	00:30	04:22	**55**	KN228	KN19	0	0	03:53
6	KN228	KN19	3	00:50	05:44	**56**	KN19	KN228	0	0	03:07
7	KN19	KN228	5	01:30	05:40	**57**	KN228	KN19	0	0	03:35
8	KN228	KN19	1	00:20	04:32	**58**	KN19	KN228	0	0	03:16
9	KN19	KN228	4	01:48	06:00	**59**	KN228	KN19	0	0	03:13
10	KN228	KN19	4	01:19	06:30	**60**	KN19	KN228	0	0	03:04
11	KN19	KN228	3	01:00	05:09	**61**	KN228	KN19	0	0	03:06
12	KN228	KN19	3	01:00	06:10	**62**	KN19	KN228	0	0	02:36
13	KN19	KN228	3	01:10	05:20	**63**	KN228	KN19	0	0	03:31
14	KN228	KN19	3	00:58	05:10	**64**	KN19	KN228	0	0	03:31
15	KN19	KN228	4	01:00	05:07	**65**	KN228	KN19	0	0	03:50
16	KN228	KN19	4	01:03	06:11	**66**	KN19	KN228	0	0	03:17
17	KN19	KN228	4	01:07	06:13	**67**	KN228	KN19	0	0	03:31
18	KN228	KN19	2	00:35	05:40	**68**	KN19	KN228	0	0	02:55
19	KN19	KN228	5	02:43	06:55	**69**	KN228	KN19	0	0	03:29
20	KN228	KN19	3	01:33	05:41	**70**	KN19	KN228	0	0	02:54
21	KN19	KN228	5	02:35	06:50	**71**	KN228	KN19	0	0	03:25
22	KN228	KN19	6	02:05	07:26	**72**	KN19	KN228	0	0	02:40
23	KN19	KN228	5	02:36	06:50	**73**	KN228	KN19	0	0	03:29

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24	KN228	KN19	4	01:33	06:42	**74**	KN19	KN228	0	0	03:06
25	KN19	KN228	5	02:10	06:24	**75**	KN228	KN19	0	0	03:15
26	KN228	KN19	5	01:49	06:52	**76**	KN19	KN228	0	0	02:32
27	KN19	KN228	3	01:46	06:10	**77**	KN228	KN19	0	0	03:51
28	KN228	KN19	5	02:10	07:20	**78**	KN19	KN228	1	00:20	03:21
29	KN19	KN228	5	02:35	06:47	**79**	KN228	KN19	0	0	03:45
30	KN228	KN19	4	02:08	07:20	**80**	KN19	KN228	0	0	03:02
31	KN228	KN19	3	01:20	06:30	**81**	KN228	KN19	0	0	03:22
32	KN19	KN228	2	00:59	05:31	**82**	KN19	KN228	1	00:17	03:15
33	KN228	KN19	4	02:03	07:18	**83**	KN228	KN19	0	0	03:41
34	KN19	KN228	3	01:17	05:20	**84**	KN19	KN228	0	0	02:57
35	KN228	KN19	4	02:46	08:06	**85**	KN228	KN19	0	0	03:10
36	KN19	KN228	3	01:35	05:50	**86**	KN19	KN228	0	0	02:14
37	KN228	KN2053	4	02:15	06:20	**87**	KN228	KN19	0	0	03:45
38	KN2053	KN228	4	02:23	06:15	**88**	KN19	KN228	0	0	02:55
39	KN228	KN19	4	01:49	07:01	**89**	KN228	KN19	0	0	03:34
40	KN19	KN228	5	02:32	06:47	**90**	KN19	KN228	0	0	02:49
41	KN228	KN19	3	01:05	06:08	**91**	KN228	KN19	0	0	03:37
42	KN19	KN228	4	02:39	06:50	**92**	KN19	KN228	1	00:15	03:10
43	KN228	KN19	4	01:15	06:22	**93**	KN228	KN2053	0	0	02:51
44	KN19	KN228	3	01:30	05:38	**94**	KN2053	KN228	0	0	02:11
45	KN228	KN19	5	02:14	07:24	**95**	KN228	KN19	0	0	03:31
46	KN19	KN228	5	02:41	06:50	**96**	KN19	KN228	0	0	03:34
47	KN228	KN2053	3	01:30	05:04	**97**	KN228	KN19	0	0	03:35
48	KN2053	KN228	3	01:41	05:56	**98**	KN19	KN228	0	0	02:47
49	KN228	KN19	1	00:19	05:23	**99**	KN228	KN2053	0	0	02:50
50	KN19	KN228	3	01:06	05:17	**100**	KN2053	KN228	0	0	01:22
Average travel time					**06:06**	**Average travel time**					**3:21**

The left part of Table 168 refers to the test drives 1 to 50, which were carried out on Vorsetzen-Johannisbollwerk-Straße between Baumwall (KN228) and Landungsbrücken (KN19) in both directions without using the signal data (signal phases and timing). After analysing the data collected during the test drives, the average travel time was 6 minutes

and 6 seconds, with an average of 4 stops at traffic lights and 1 minute and 35 seconds stopping time at the traffic lights along the road.
The right part of Table 168 contains the data of test drives 51 to 100, carried out on the same road section using the signal data from the GLOSA app. The recorded data gives an average travel time of 3 minutes and 21 seconds and hardly any stopping time at the traffic lights between Baumwall and Landungsbrücken.

Use Cases considered

- SI-TLP: Signalized Intersection – Traffic Light Prioritization

In the Pilot Hamburg, the TLP service was evaluated by DLR (German Aerospace Center) in the framework of the BiDiMoVe project.

Demand-oriented prioritisation

With the introduction of the BiDiMoVe system, conventional bus prioritisation via analog radio using R09 telegrams was replaced by a C-ITS-based prioritisation on parts of the Metrobus line M26. For buses equipped with onboard units (OBUs), the following figures show whether they have caused a high, normal or no influence on the traffic light control. Figure 135 shows the distribution of the priority level of the equipped BiDiMoVe buses since the system was introduced. No prioritization (with a priority number less than 64) has occurred 41 times during the recording period. Due to the small number of buses that were not prioritized, these are not visible in the graph below. Normal prioritization (with a priority number greater than 64 and less than 115) was performed for 19,090 requests from BiDiMoVe buses. Strong prioritization (priority number greater than 114) was applied to 13,899 bus requests.

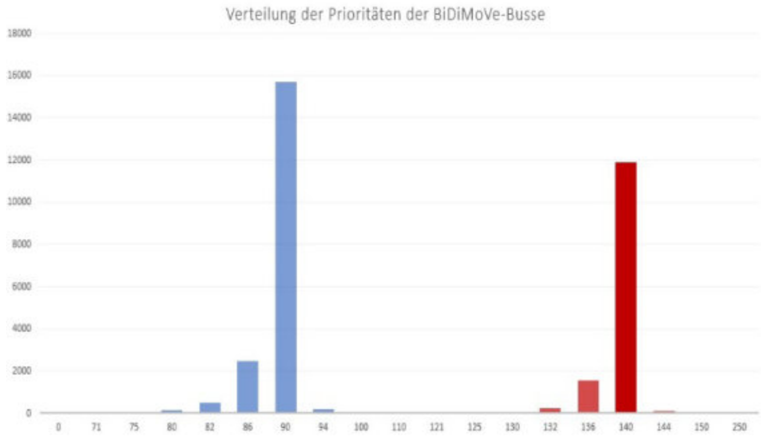

Figure 135 - Calculated priorities of the BiDiMoVe buses.

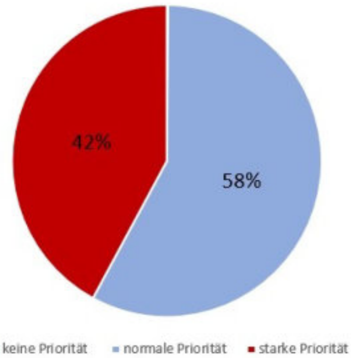

Figure 136 - Distribution of the calculated priorities of the BiDiMoVe buses in the public transport strategy calculator.

Figure 136 shows the relationship between “no priority”, “normal priority”, and “high priority” of the buses. The “no priority” range is so small that it is not shown. More than half of the bus requests result in a “normal priority” number. However, a high prioritisation is also triggered for 42% of the bus requests. This indicates that these buses were initially registered at the intersection with a delay in their schedule. The high prioritisation is an attempt to reduce this delay. Compared to the R09 buses, the BiDiMoVe buses are on average less delayed and therefore have a higher punctuality.

Timetable position

The average delays (median) of BiDiMoVe and R09 buses are evaluated for their timetable position. The data is recorded on the days the BiDiMoVe system was in operation and the priority was not disrupted by maintenance work or system failures. Therefore, the diagrams contain the adjusted average delays for both bus directions. The dashed lines show the monthly average for BiDiMoVe and R09 buses. The points connected by solid lines represent individual data sets (centre of the recorded periods).
Figure 137 and Figure 138 show that the BiDiMoVe buses are on average less delayed than the R09 buses. On average, the BiDiMoVe buses in October had a delay of 0.4 minutes in direction one (direction Rahlstedt, Amtstraße) - this corresponds to approximately 24 seconds - and a delay of 0.7 minutes in direction two (direction Kellinghusenstraße) - this corresponds to approximately 42 seconds.

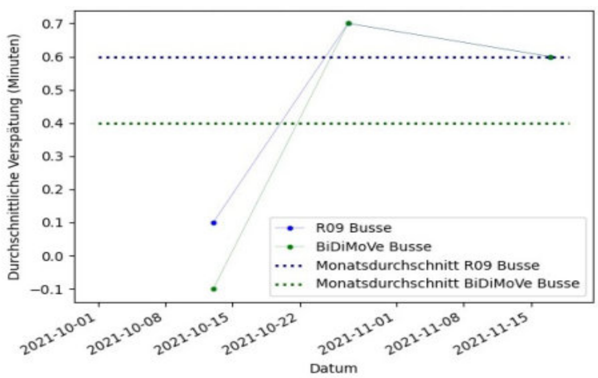

Figure 137 - Change in the average delay of BiDiMoVe and R09 buses in direction 1.

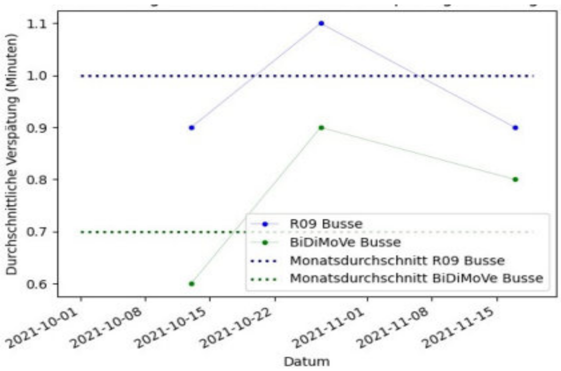

Figure 138 - Change in the average delay of BiDiMoVe and R09 buses in direction 2.

In addition to the general timetable, the delay around 2 pm is considered separately, as the buses regularly arrive very late at this time.
The average delay around 2 pm is higher than the daily average. Usually, the BiDiMoVe buses are significantly less late than the R09 buses, even at 2 pm in October. The BiDiMoVe buses are, on average, 1.5 minutes late at 2 pm in direction one (direction Rahlstedt, Amtstraße) - this corresponds to approximately 90 seconds - and 1.1 min late in direction two (direction Kellinghusenstraße) - this corresponds to approximately 66 seconds.

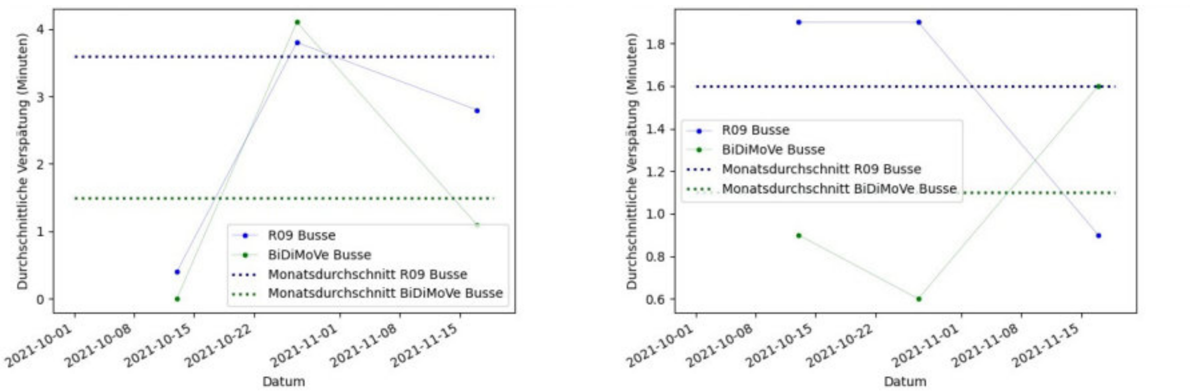

Figure 139 - a. Change in average delay at 2 pm (direction 1), b. Change in average delay at 2 pm (direction 2)

The following overview shows the delay of the buses in the entire evaluation period (1st October 2021 – 19th November 2021) depending on the time of day. It can also be seen here that the BiDiMoVe buses have a better timetable position on average than the R09 buses. Due to the high prioritisation that can be applied to delayed BiDiMoVe buses, the most extended average delay for BiDiMoVe buses (direction one at 1 pm) is significantly lower than the most extended delay for R09 buses (direction one at 2 pm).

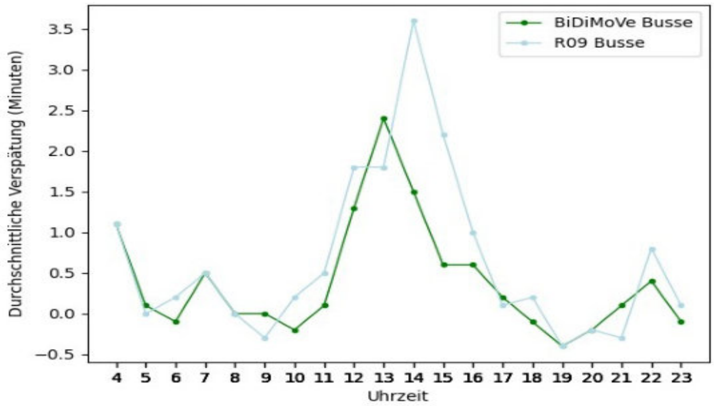

Figure 140 - Representation of the average delay depending on the time (direction 1).

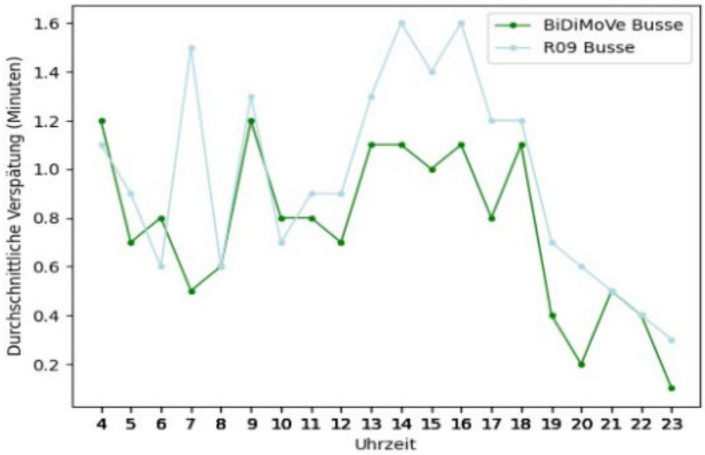

Figure 141 - Representation of the average delay as a function of the time (direction 2).

Stops outside the bus stop and bus travel time

HOCHBAHN's Intermodal Transport Control System (ITCS) collects data on stops due to traffic situations and travel times between bus stops. A vehicle stops if it falls below a certain speed (currently 2 km/h) for at least 3 seconds. The average number of stops between bus stops, shown in the following figures, also includes rides free of unplanned stops.

The figures for the number of stops between the bus stops show that the BiDiMoVe buses in the direction one (direction Rahlstedt, Amtstraße) have to stop more frequently on average than the R09 buses. Still, this behaviour is reversed in the opposite direction. Possible reasons for the comparatively poor performance of the BiDiMoVe buses in direction one are explained at this section's end.

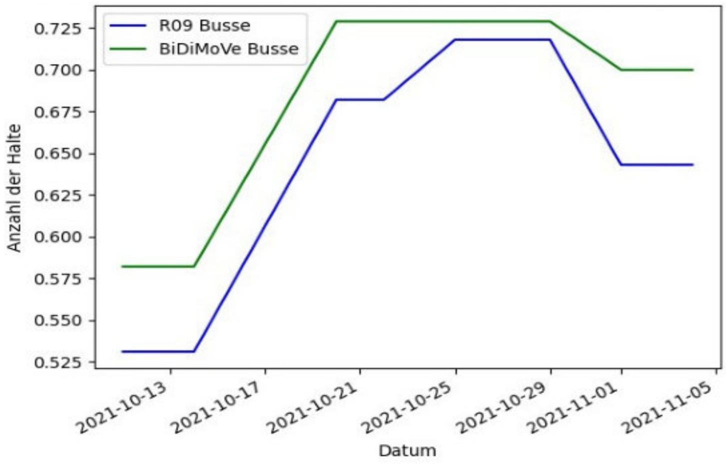

Figure 142 - Average number of stops between bus stops (direction 1).

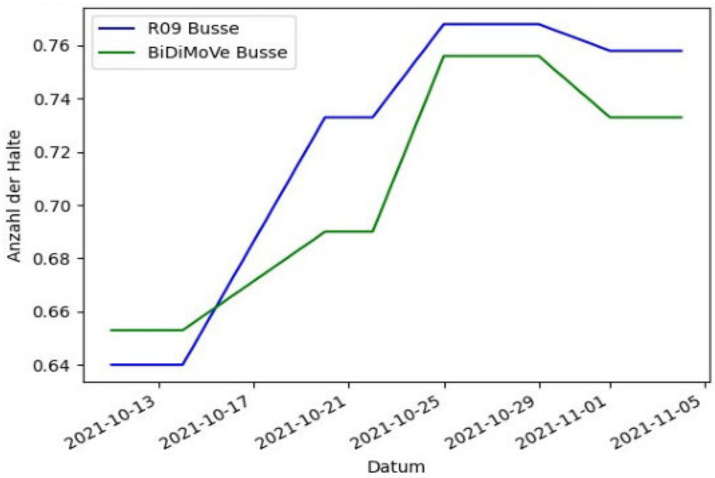

Figure 143 - Average number of stops between bus stops (direction 2).

The following two figures show the percentage of rides without a stop between the bus stops. The figure correlates strongly with the previously visualised number of stops between two bus stops. In direction one, the percentage of trips without a stop for BiDiMoVe buses is, on average, approx. 3 % lower than for R09 buses, while in direction two, the percentage is, on average, 1 % higher.

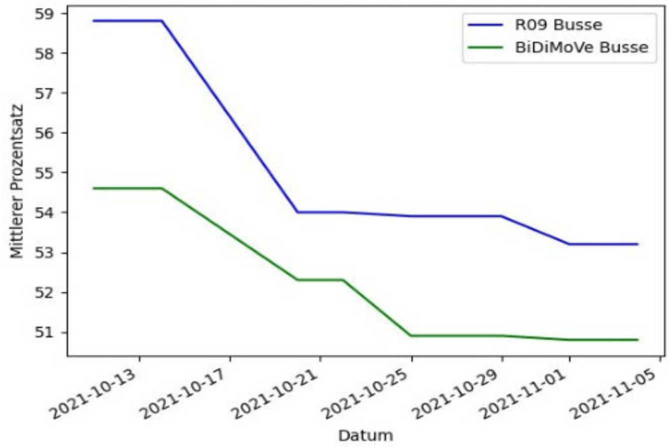

Figure 144 - Number of rides without a stop between bus stops (direction 1).

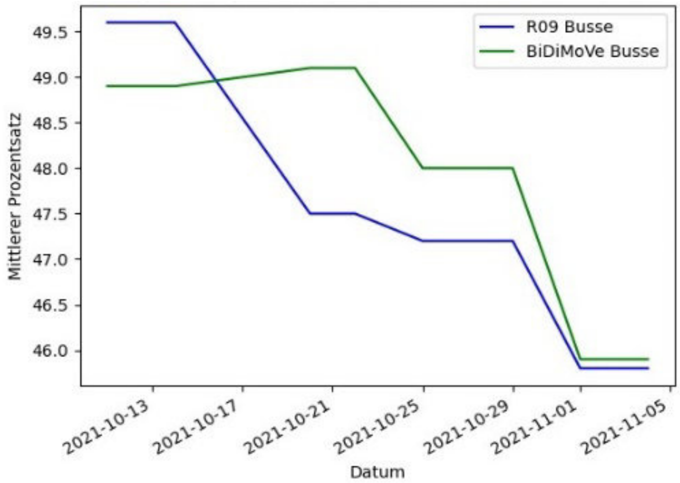

Figure 145 - Number of rides without a stop between bus stops (direction 2).

The next aspect evaluated is the average duration of stops between bus stops. The following figures show that the duration of stops varied considerably during the observation period. In direction one, the stopping time of the BiDiMoVe buses and the R09 buses is almost the same, while in direction two, the BiDiMoVe buses have to stop for longer on average.

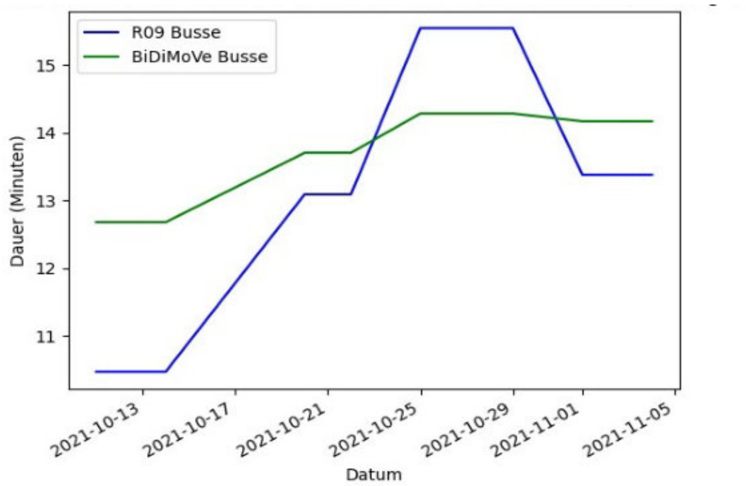

Figure 146 - Average duration of unplanned stops (direction 1).

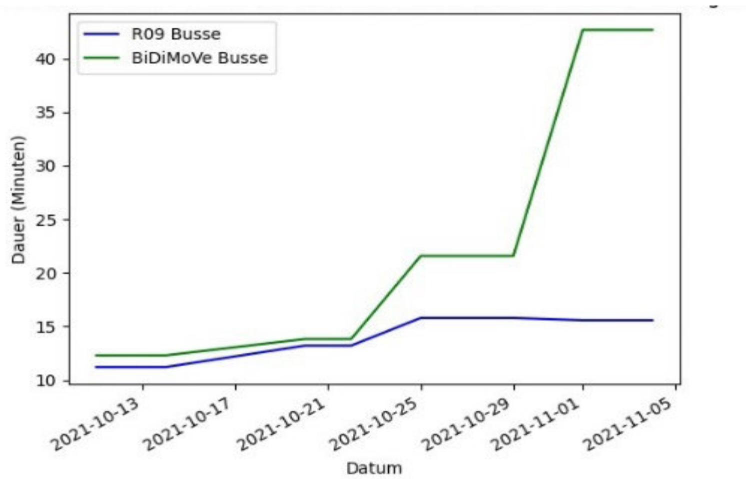

Figure 147 - Average duration of unplanned (direction 2).

The following diagrams show the net travel times (without the stopping time at the bus stop) and the total travel times for both directions. The BiDiMoVe buses and the R09 buses are also compared here. The BiDiMoVe buses take longer to cover the route than the R09 buses on almost every measurement day.

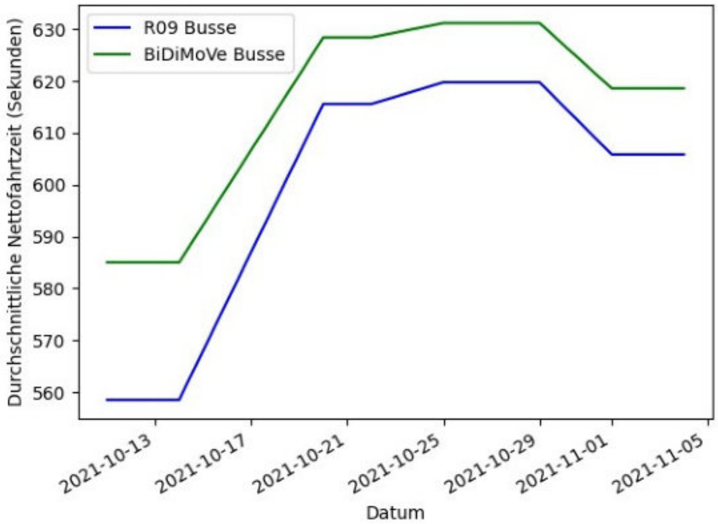

Figure 148 - Average net travel times (direction 1).

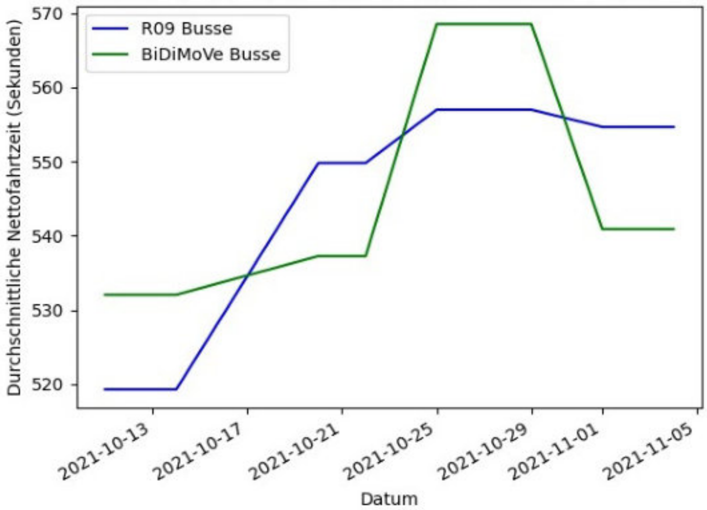

Figure 149 - Average net travel times (direction 2).

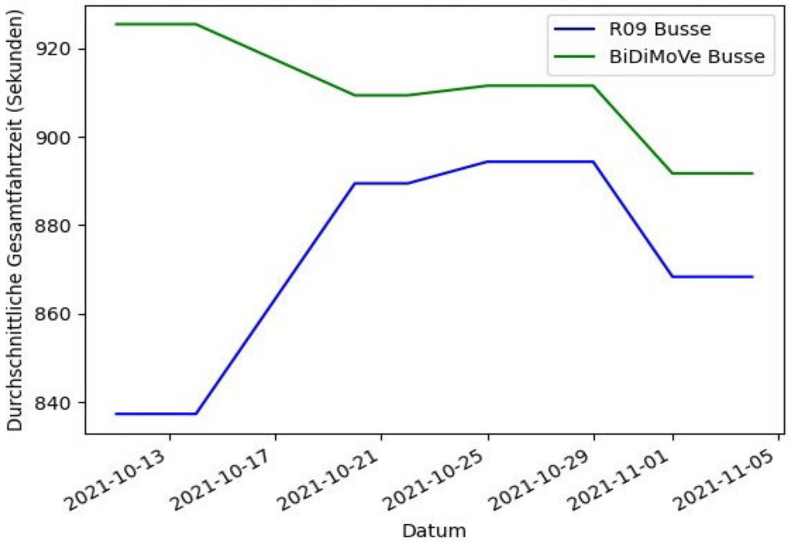

Figure 150 - Average total travel time of the BiDiMoVe and R09 buses (direction 1).

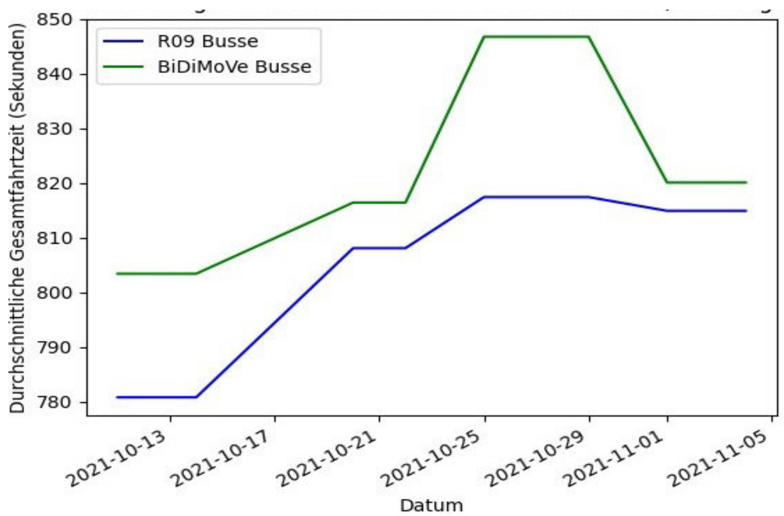

Figure 151 - Average total travel time of the BiDiMoVe and R09 buses (direction 2).

Possible reasons for the increased number of stops, the longer duration of the stops and the longer travel times of the BiDiMoVe buses:

- Overall, only a tiny proportion of buses are equipped with BiDiMoVe technology. While outliers are not significant for the R09 buses, individual traffic events or driving styles could have strongly influenced the average number and duration of stops of the BiDiMoVe buses.
- BiDiMoVe buses are not given priority at traffic lights in the test area if they run too early. This allows them to slow down at the traffic lights, bringing them closer to the timetable.
- BiDiMoVe buses are not prioritised over R09 buses if they do not have a high degree of delay. Therefore, BiDiMoVe buses may not receive a higher priority if they are on time.

Failures in the RSU or OBUs that were not detected and therefore included in the evaluation may have led to the BiDiMoVe buses not being prioritised at intersections in some cases and, therefore, being included negatively in the evaluations.

8.2.8. 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.

Field tests in Italy (C-Roads Italy 2) confirmed the positive impacts of the GLOSA: a general improvement in most of the performance indicators used for evaluation was indeed noticed. Observation on the effectiveness of the Use Case under different conditions were allowed: greater activation distances of the GLOSA upstream of the traffic light bring greater benefit; the system works better in the presence of lower speed limits (50 km/h compared to 70 km/h. GLOSA seems to obtain the greatest benefits in the presence of fixed traffic light cycles or in any case with not excessively dynamic traffic-dependent actuation levels

In Germany, in the Pilot Hamburg, GLOSA has also been tested on pedelecs and eScooters, using a series of test drives and simulations. The following conclusions emerged from the analysis of the speed profiles:

- On the test route in the direction of Baumwall, the average speed increased from 11 km/h to 19 km/h using the signal data from the GLOSA app.

- Using the GLOSA app's signal data, the average speed on the test route towards Landungsbrücken increased from 10 km/h to 15 km/h.
- The significant increase in average speed using signal data (signal phases and timing) is because stopping at the red phase along the road is avoided or minimized as much as possible by the signal data.
- Using signal-specific data on signal phases and times, stops at traffic lights can be avoided, or the number of stops at traffic lights can be reduced as much as possible.
- Minimizing the number of stops behind traffic lights reduces travel times with a higher average speed, which can contribute to a smoother flow of traffic in urban areas.

The Traffic Light Prioritization use case was also tested in Germany, with the introduction of the BiDiMoVe system in Hamburg. In this project, conventional bus prioritisation via R09 telegrams was replaced by a C-ITS-based prioritisation on parts of the Metrobus line M26. Buses equipped with onboard units (OBUs) received strong prioritization in ~42% and normal prioritization in ~58% of bus priority requests. BiDiMoVe buses were on average less delayed than the R09 buses: On average, the BiDiMoVe buses in October had a delay of 24 seconds in direction one (direction Rahlstedt, Amtstraße) and a delay of 42 seconds in direction two (direction Kellinghusenstraße), compared to 36 and 60 seconds respectively of the R09 buses. Considering the delay around 2 pm separately, the BiDiMoVe buses were, on average 90 seconds late at 2 pm in direction one (direction Rahlstedt, Amtstraße) and 66 seconds late in direction two (direction Kellinghusenstraße), compared to 220 seconds and 96 seconds respectively for the R09 buses. Finally, it was observed that the BiDiMoVe buses had a better timetable position on average than the R09 buses. Due to the high prioritisation that could be applied to delayed BiDiMoVe buses, the most extended average delay for BiDiMoVe buses was significantly lower than the most extended delay for R09 buses.

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 189, taking into account the definitions presented in Annexes 2, 3 and 4 in the final report of Spain [RD.3].
Note that in Table 189, 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 169 - 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 8.1.2 and 8.2.2 that describe the approach taken for evaluating GLOSA.

Data collected

This is fully detailed in the RWW UK Section 5.1.2 as the 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 adopted 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 170 - 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 171 - 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 172 - 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 (Traffic Efficiency – France).

Data collected

Please refer to Section 8.2.5 (Traffic Efficiency – France)..

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 152):

- 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.

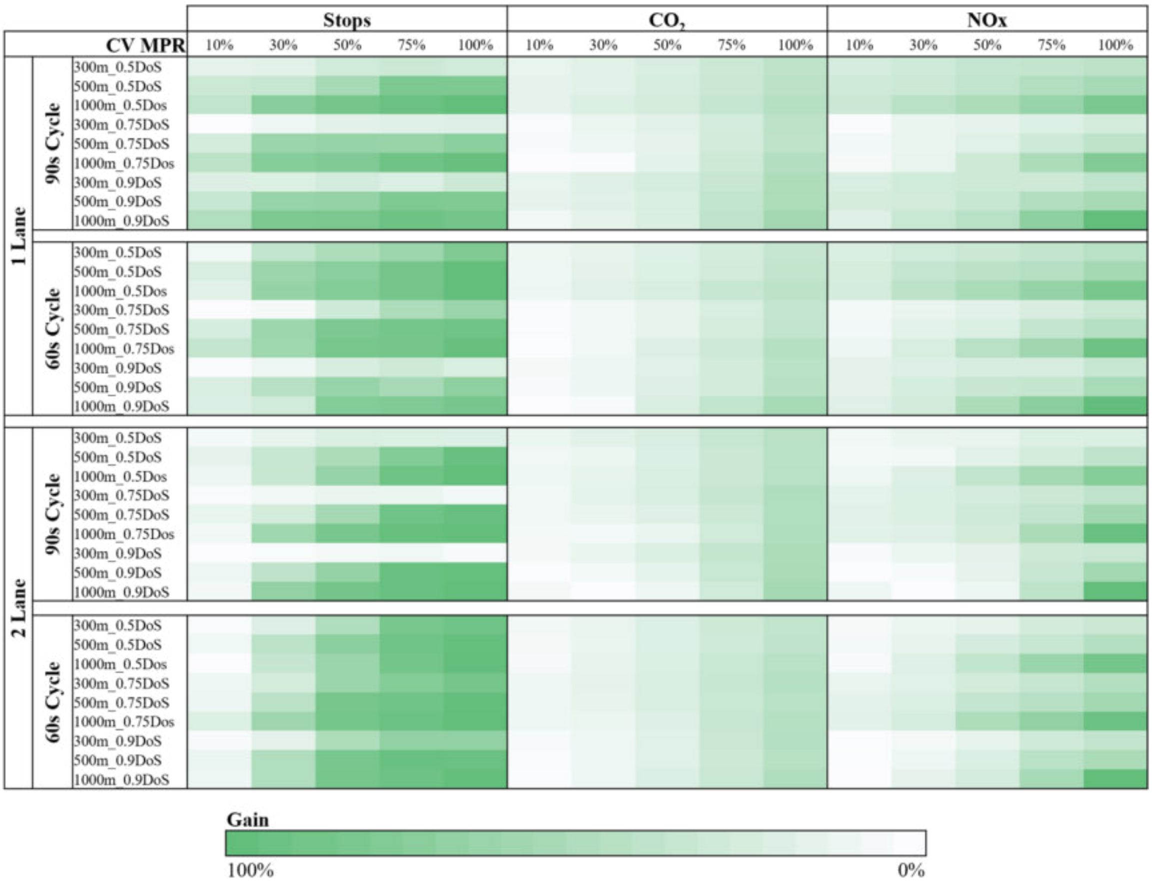

Figure 152 - Summary of Impact of SI-GLOSA use-case on traffic and environment performance

8.3.5. NordicWay 3

The societal impacts of GLOSA and TTG/TTR were investigated using the VISSIM micro simulation tool by Legêne et al. (2023). 16 simulations were made with selected combinations of traffic signalling type, penetration rate, traffic situation and different C-ITS service related parameters. These simulations resulted in a set of environmental (CO_2, NOx) indicators. Regression analysis was used to investigate the relationship between variables and to explore their correlation to the outcomes of the application of these C-ITS services.

Overall, the study showed environmental gains under different circumstances for both GLOSA and TTG/TTR. Yet, the traffic signalling and traffic situation played important roles. GLOSA was found to reduce NOx and CO_2 emissions by 0.7% on system level and by 0.3% per vehicle. During the morning peak hour no impact was found for emissions on neither level. Thus, the benefits can be gained only in rather low traffic volumes. GLOSA requires fixed traffic signalling to provide reliable information. Although it can improve traffic flow, it cannot overcome the benefits of vehicle actuated traffic signals. (Legêne et al 2023)

Result comparison showed that the vehicle actuated traffic signalling led to higher environmental gains (3% less CO_2 emissions, 5% less NOx) than fixed signalling. Fixed traffic signalling reduces stops and delay by 5% while vehicle actuated signalling reduces them by 14%. However, the study cannot confirm that C-ITS performs better with vehicle actuated signalling than with a fixed one. (Legêne et al 2023)

8.3.6. 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 173 - 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 174).

Table 174 - 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. France

Quantitative Test Results (Surveys)

Procedure. After entering their e-mail address in the application, a questionnaire was distributed to Coopits users around three weeks after they had downloaded it. Participants were rewarded with 15-euro vouchers.

Population. 101 participants had used Coopits at least once, and 60 had not yet used it. 19 of the 101 participants who used Coopits had some connection with C-ITS projects.

Material. The questionnaire, comprising 84 questions, was designed to assess the use of Coopits, its acceptability, and to understand its added value compared with other applications. This data collection was reviewed by the ethics committee of Rennes 2 University (Ref 2023-015).

Qualitative Test Results (Interviews)

Procedure. In addition to the questionnaire, one-hour interviews were conducted. Participants were compensated with 30-euro gift vouchers.

Population. 7 users, road management professionals, participated in the interviews.

Material. The interviews were organized around a 34-question guide. The aim was to understand initial interest in the application, describe usage and gather user opinions.

Conclusions

The low intention to continue using the application was strongly linked to users' attitudes, influenced by confirmation of expectations, confidence in Coopits and subjective norms. A perceptible gap between users' initial expectations and the reality of the application led to disappointment, impacting their judgments.

Both experimented users and novice reported difficulties in understanding how Coopits works. These findings suggest we need to provide more assistance to users to clarify its use as much as possible. These findings suggest the need to check that the application is working properly technically, and to provide more assistance to users to clarify its use as much as possible.

The three most anticipated features are: a large number of alerts, the possibility of event reporting (little used but considered very useful), and the "overlay" function. Coopits was evaluated as being rather compatible with the driving environment. The “overlay” function and the reliability of the information transmitted were considered to be major advantages. Confidence in this new technology is therefore good.

The study identified certain areas for improvement to develop Coopits: better ergonomics, a greater number of messages and integration with Android Auto. The evaluation highlighted Coopits' strengths: qualified information, real-time and predictive information on interventions on the tracks (e.g., construction sites), traffic restrictions, diversion routes adapted to the volumes of traffic to be diverted or services related to the infrastructure such as information on the state of traffic lights

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8.4.6. Germany

Use Cases considered

- SI-TLP: Signalized Intersection - Traffic Light Prioritization

In the pilot site Hamburg and in the framework of the BiDiMoVe project, a user acceptance study of the TLP service took place. Feedback from bus drivers on Metrobus line M26 was collected online and offline using questionnaires that bus drivers could complete after their shifts.

The TLP service was displayed to the bus drivers using a specifically developed HMI. The HMI features were directly integrated into the onboard system of the bus and presented on the dashboard of the vehicles. The three different features are presented in Figure 153.

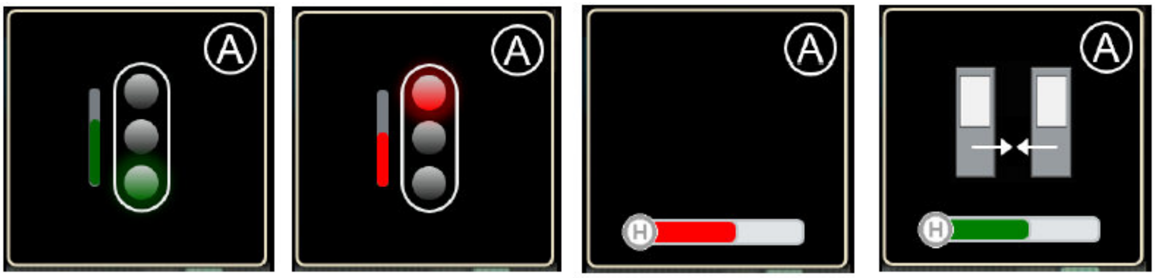


Figure 153 - HMI features for BiDiMoVe buses

It included a green or red horizontal bar next to a traffic light icon indicating the remaining green or red time. An “A” signal provided a feedback from the infrastructure to the bus driver if their priority request was detected and processed at the upcoming intersection. And another feature using the icon of bus doors to assist the on- and offboarding process of passengers at a stop to proceed at the right time for a signal switch.

The following evaluations refer to 28 anonymously submitted questionnaires between 25th October 2021 and 11th November 2021.
Before the evaluations, the feedback from bus drivers was divided into negative, neutral, no function, positive with comments and positive. The comments are listed after the graphics.

<u>What is your impression of the remaining Red/Green time display? Was the display helpful?</u>

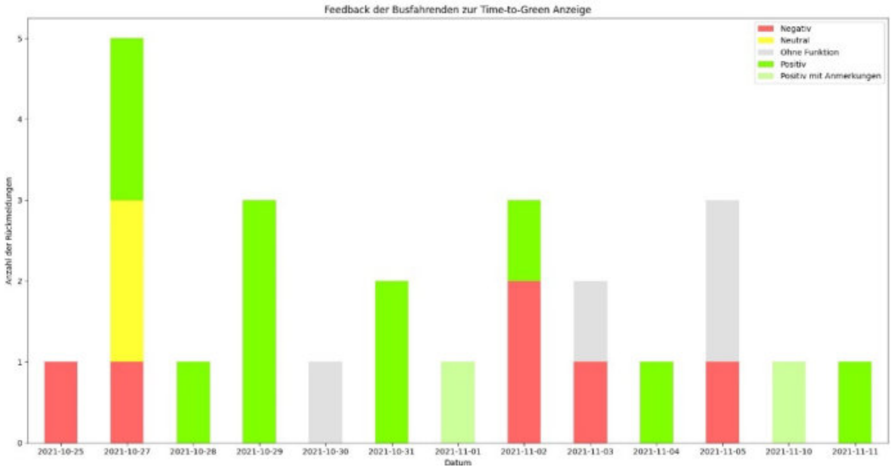


Figure 154 - Feedback on the Time-To-Green display broken down by day; selected comments from bus drivers.

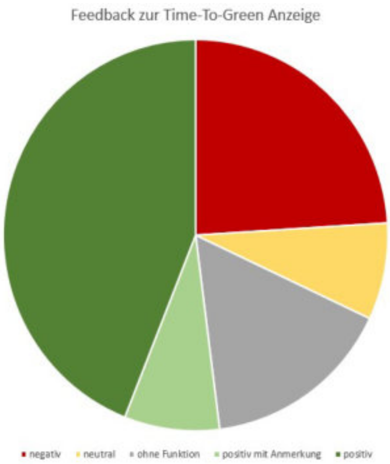


Figure 155 - Cumulative feedback from bus drivers on the Time-To-Green display.

- *"Partly still faulty, as the display sometimes fills up again, and you get a bit confused."*
- *„The bar continued to go down, but the display jumped up a little and down again faster than before."*
- *“Rest red is less interesting, rather rest green.“*
- *„Very useful if it were more accurate", "The running counter could be displayed in seconds", and "[useful if] the traffic light phases [were] displayed in seconds."*
- *„Helpful at traffic lights on blind bends" or "Very helpful in flowing traffic."*
- *"No [not helpful]. I see the traffic lights myself.“*
- *"[I couldn't] see any added value, as I could already see many of the traffic lights the system showed me from a distance."*

<u>What is your impression of the door closing/departure recommendation? Was the display helpful and could you use the information when changing passengers?</u>

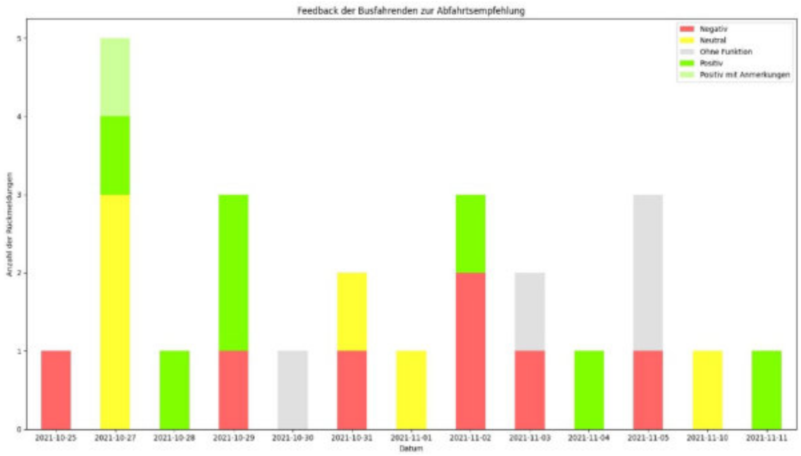


Figure 156 - Feedback from bus drivers on the departure recommendation, broken down by day.

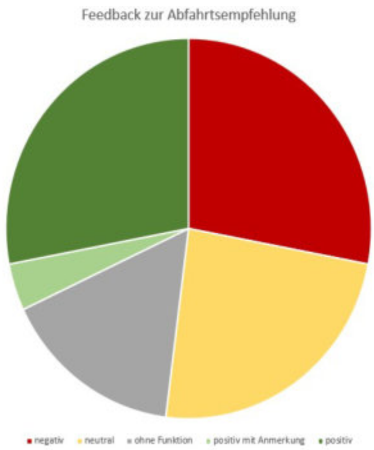


Figure 157 - Cumulative feedback from bus drivers on the departure recommendation.

Selected comments from bus drivers:

- *"Still very unfamiliar."*
- *" Distracts a lot from what is happening to the passenger."*
- *"Once you have opened all the doors via the stadium circuit, you can't get the doors closed at all in the very short 'time slot.'*
- *"The passenger change is too individual."*
- *"Especially if you're running late because I close the doors again as soon as the passenger change is complete and drive off."*
- *"More out of the corner of my eye. So far, I am just observing via mirrors and the surroundings."*
- *"Exterior mirror + interior mirror [are used]"*
- *"An additional timer as a digit would be even better."*
- *"This display [tempts] you to possibly not open the doors again for someone still approaching."*

<u>What is your impression of the A signal on the display? Could the A signal at the traffic light be dispensed with if it is shown on the display?</u>

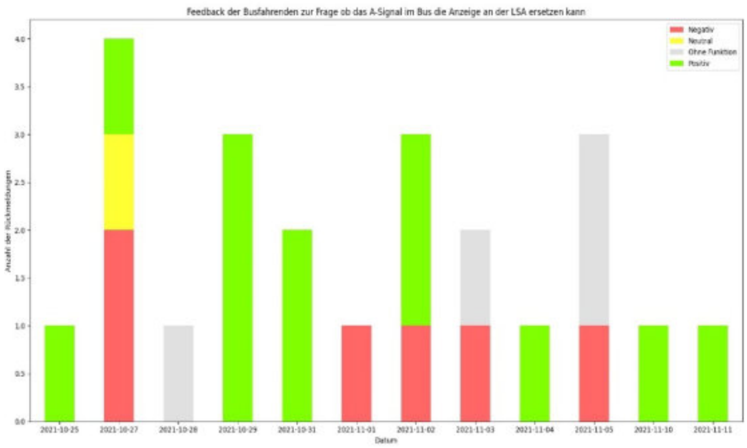


Figure 158 - Feedback from bus drivers on the display of the A signal on the bus, broken down by day.

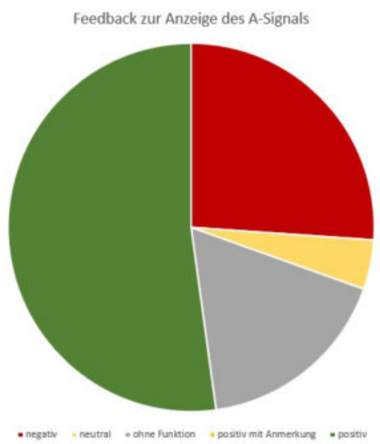


Figure 159 - Cumulative feedback from bus drivers on the display of the A signal on the bus.

Selected comments from bus drivers:

- *"I would still prefer the A signal at traffic lights, at least while driving, as you can concentrate better on the traffic and surroundings in front of you."*
- *"Better at the traffic lights than on display. Every additional glance at the display only distracts from the traffic situation."*
- *"For safety reasons, the visible "A" at the traffic lights [should] remain as a backup."*
- *"The signal [at the traffic light] could be dispensed with."*

Overall score for BiDiMoVe system: rating from 0 (bad) to 5 (very good)

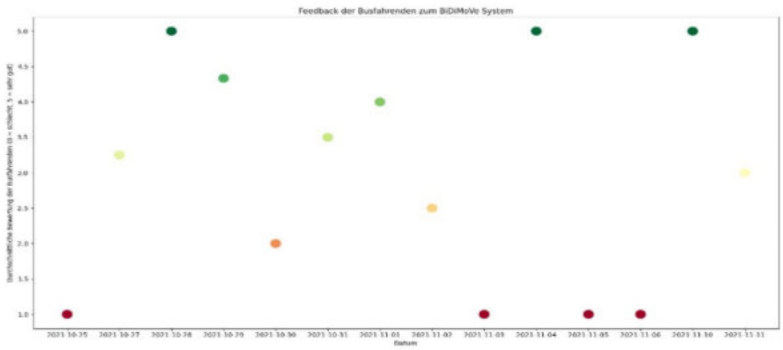


Figure 160 - Overall assessment of the BiDiMoVe system by bus drivers, broken down by day.

The average rating of the BiDiMoVe system is 3.1 points.

Selected comments from bus drivers:

- *"Training in anticipatory driving probably helps more. Too many displays only distract."*
- *"Distraction from traffic due to unnecessary glances at the display"*
- *"[You] look at the display more often and for longer because of the displays."*
- *"An interesting but still very unfamiliar system"*
- *"An additional display or a head-up display would be much more pleasant."*
- *"Generally, I prefer a monitor with this display. More at eye level."*
- *"Prefer an external monitor [...] above the dashboard."*
- *"Unfavourable placement [of the button to hide the BiDiMoVe displays]."*
- *"At Rahlstedt and Alsterdorf, the video overlay appears without content."*
- *"The display is much too bright in the evening/night hours."*

Linking feedback from bus drivers with failures or errors in the BiDiMoVe system

In the graphs shown, there are some days on which there is only "no function" or negative feedback across all functions. On the following days, the negative feedback, or the feedback that the display is "without function", is due to a temporary failure of the BiDiMoVe system:

- *05.11.: The non-functioning display in the HMI for bus drivers is due to missing PKI certificates in OBUs 1 to 9. The error was rectified on 10.11.*
- *06.11.: The non-functioning display in the HMI for bus drivers is due to missing PKI certificates in OBUs 1 to 9. The error was rectified on 10.11.*
- *10.11.: The non-functioning display in the HMI for bus drivers is due to missing PKI certificates in OBUs 1 to 9. The error was rectified on 10.11. As the ride time is not included in the questionnaire, the positive feedback is likely due to rides made after correcting the error.*

8.4.7. 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 175 - 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.

8.5.3. 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.

8.5.4. NordicWay 3

The quality of the TTR/TTG prediction solution developed by Swarco for Trondheim City was tested with a traffic simulation (Vissim) in a real environment in one intersection in Trondheim. The quality was measured as an acceptable level of difference to actual signal change at different intervals be-fore the change (less than 1.0s difference for the last 10s, less than 2.0s difference in the 11-20s period, less than 3.0s difference in the 21-30s period before the signal change) and an average difference from the actual signal change for the last 30s change in the best proposed scenario/control mode. Testing covered both peak hour and off-peak hour time. The test intersection had a rather low traffic volume compared to the intersection capacity. (Swarco 2021)

According to the results, all tested Fixed Time Adaptive variants of traffic signal control improved the TTG/TTR prediction quality significantly compared to the original Vehicle Actuated control which showed better traffic control performance in terms of delays to traffic. This Fixed Time Adaptive control mode fixes the green timings and estimated optimum green timing for the next (fixed time) cycle based on traffic characteristics. The prediction differed from the actual signal change time for only less than 0.5 s for the last 30 s of the TTG prediction period. The prediction quality was found acceptable and fulfilling the set criteria with results such as for afternoon peak period with the differences max 0.6s in the last 10s, max 1.3s in the 11-20s and max 2.1s in the 21-30s period. (Swarco 2021)

8.5.5. Germany

Use Cases considered

- SI-GLOSA: Signalized Intersection - Green Light Optimal Speed Advisor

In Germany, the functional evaluation of the GLOSA service took place in all three pilot sites Dresden, Hamburg and Hessen/Kassel.

Pilot Dresden

In Dresden, the GLOSA service is evaluated mainly for functional aspects, considering accuracy and usefulness of the generated advice. Towards this goal, Fraunhofer IVI developed the so-called Testing App, which visualizes V2X information and test driving directions. So far, the ongoing functional evaluation has been successful. Although the tests are still in progress, the preliminary results indicate that the parameters meet the required standards. The successful outcomes obtained in the ongoing functional evaluation suggest that the GLOSA service is functioning properly.

Figure 161 is a screenshot of Fraunhofer IVI's V2X Testing App, showing the GLOSA service in action at the V2X corridor Airport in Dresden. Visible is the planned route of the vehicle (necessary to determine which signal has to be used for velocity recommendation), remaining time for the next signal along the route as well as a speed recommendation, considering the maximum speed allowed (received from MAPEM).

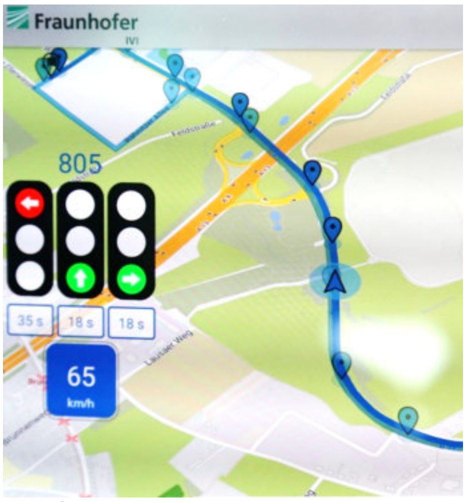


Figure 161 - Screen shot of Fraunhofer IVI's V2X Testing App, showing the GLOSA service in action at the V2X corridor Airport in Dresden.

Pilot Hamburg

The pilot Hamburg has successfully implemented the GLOSA Service at the test track for automated and connected driving and it is operational since the end of June 2021.
To ensure the functionality of the installed roadside units (RSU) and the correctness of the MAP and SPAT messages, Schlothauer & Wauer carried out RSU measurement runs in 2022. Seven intersections on the test track were visited, and an onboard unit recorded the MAP and SPaT messages sent on these routes. At one intersection, no MAP or SPaT messages have been received. It was assumed that all roadside units send standard-

compliant (SAE/ETSI) messages on the junction geometry (MAP) and on the current and, if applicable, future signalization status (SPaT - Signal Phase and Timing).

Range measurement

The transmission range of the SPaT and MAP message was determined for each system. In the north-facing graphs (Figure 162 to Figure 164) of the range measurements, the intersection is shown with different coloured concentric circles, each 250 m wide, illustrating the distance. The red markings represent a reception point, and the black lines show the distance travelled. The 7-digit station ID is in the centre. The distances vary per intersection arm, as bends, bridges, and other local conditions influence the transmitter range. The aim is to achieve a range of 250 m to 300 m, which generally corresponds to the length of the lanes in the MAP. This goal was generally achieved for all the displayed intersections.

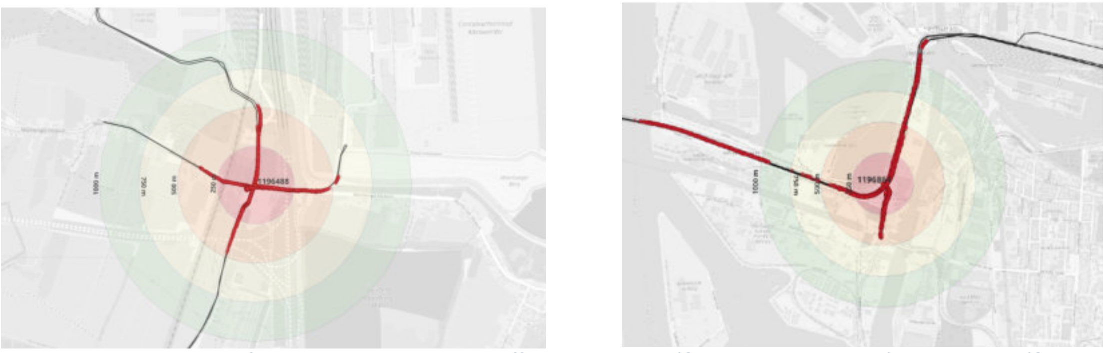


Figure 162 - Examples of range measurement traffic light 17070 (Station ID 1196488) and 17106 (Station ID 1196864)

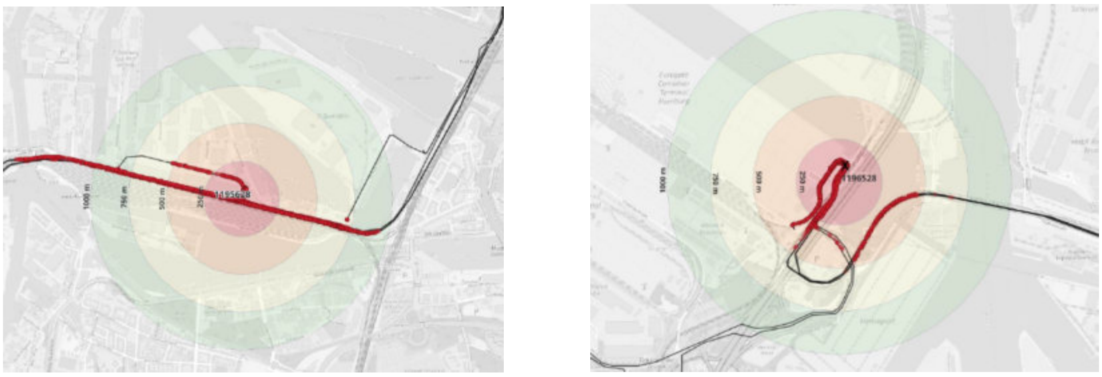


Figure 163 - Examples of range measurement traffic light 17173 (Station ID 1196528) and 17204 (Station ID 1195628).

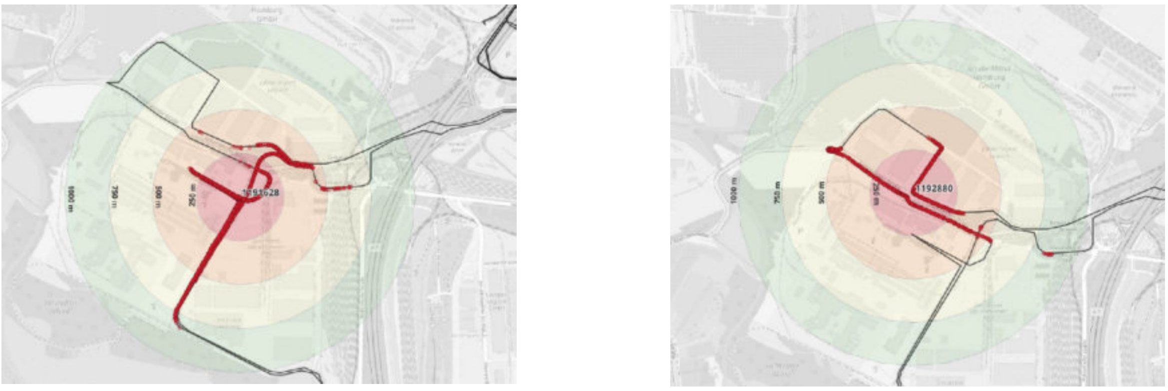


Figure 164 - Examples of range measurement traffic light 17213 (Station ID 1191628) and 17231 (Station ID 1192880).

Position check

To identify inaccuracies in the geometric positions, all lanes were checked regarding their geometric position and the ID numbers stored were compared with the ID numbers in the underlying LISA planning tool. The following causes can lead to inaccuracies or errors in the geometry of a MAP message:

- Conversion of coordinates during export/import or supply (ETRS89 vs. WGS84-based site plans)
- Inaccurate coordinates for the georeferenced point in the site plan
- Inaccurate placement of reference points or drawings in the planning tool
- Site plans not aligned to the north or rotation angle not considered
- Missing objects (lanes, connections, etc.)

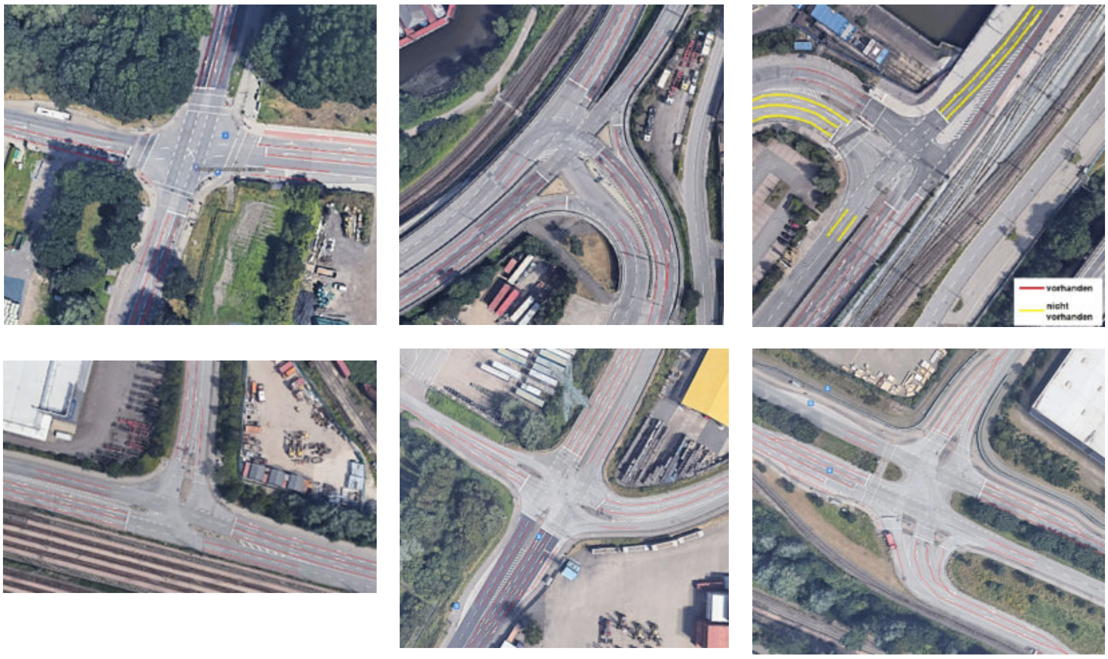


Figure 165 - Display of the received MAPs on an aerial image – traffic light 17070, 17106, 17173, 17204, 17213 and 17231.

The site inspection showed that some lanes deviate from the centre of the lane by up to approximately one meter.

Attribution

The MAPs were checked for mandatory attributes following ISO /TS 19091:2019 and are presented for information purposes in the evaluations. It was assumed there would be no deviations from ISO, as the messages would be incorrect from a technical point of view and could not be validated and sent. In addition, the MAPs are checked for other attributes whose supply is recommended by C-Roads and C2C-CC. These essentially correspond to the recommendations from DiMAP. A qualitative check of the attributes and values was carried out randomly. The tables are broken down by sub-attributes, which are used in the MAPs in the following scheme:

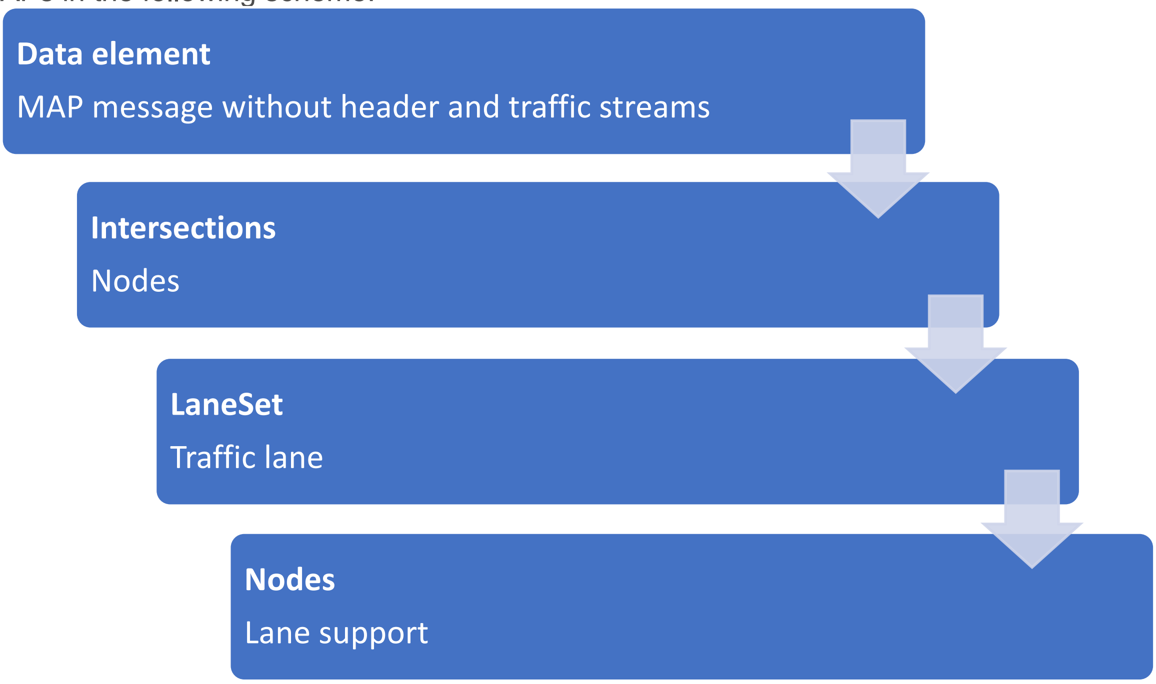


Figure 166 - Structure of the MAP attribute tables.

The following indicators are used to classify the attributes and the scores:

- ✓ Supplied
- ✗ Mandatory, but not supplied (according to ISO obligation)
- ! Recommended, but not supplied (according to C-Roads recommendations)
- / Not required/ not relevant

According to the respective guideline, an attribute marked with an "x" is mandatory or recommended. An attribute marked as "(x)" is mandatory or recommended according to the respective guideline if the use case applies.

Data elements
Applicable for all traffic lights:

Ebene 1	Ebene 2	Ebene 3	ISO	C-Roads	Versorgt
msgIssueRevision			X		✓
intersections			X		✓

Sub-attributes “Intersections”
Applicable for all traffic lights except 17213, was not provided with a region ID:

Ebene 1	Ebene 2	Ebene 3	ISO	C-Roads	Versorgt
id					✓
	region			X	✓
	id		X		✓
revision			X		✓
refPoint			X		✓
	lat		X		✓
	long		X		✓
laneWidth				X	✓
laneSet			X		✓

Sub-attributes ”LaneSet”
Applicable for the following traffic lights 17070, 17173, 17204, 17213, and 17231:

Ebene 1	Ebene 2	Ebene 3	ISO	C-Roads	Versorgt
laneID			X		✓
in-/egress Approach				X	✓
laneAttributes			X		✓
	directionalUse		X		✓
	sharedWith		X		✓
	laneType		X		✓
		vehicle			✓
		crosswalk			✓
		bikeLane			/
		trackedVehicle			/
nodeList			X		✓
	nodes		X		✓
connectsTo				(X)	✓
	connectingLane		X		✓
		lane	X		✓
		maneuver		X	✓
	signalGroup			X	✓

Applicable for traffic light 17106:

Ebene 1	Ebene 2	Ebene 3	ISO	C-Roads	Versorgt
laneID			x		✓
in-/egress Approach				x	✓
laneAttributes			x		✓
	directionalUse		x		✓
	sharedWith		x		✓
	laneType		x		✓
		vehicle			✓
		crosswalk			/
		bikeLane			/
		trackedVehicle			/
nodeList			x		✓
	nodes		x		✓
connectsTo				(x)	✓
	connectingLane		x		✓
		lane	x		✓
		maneuver		x	✓
	signalGroup			x	✓

Sub-attributes "Nodes"
Applicable for all traffic lights

Ebene 1	Ebene 2	Ebene 3	ISO	C-Roads	Versorgt
delta			X		✓
	nodeXY1-6				✓
		x	X		✓
		y	X		✓
	node-LatLon				/
		lon	X		/
		lat	X		/
attributes					✓
	localNode				✓
		stopLine		(X)	/
		merge/diverge point		(X)	✓
	dis-/ enabled				/
		doNotBlock		(X)	/
		taperToLeft		(X)	!
		taperToRight		(X)	!
	dWidth			(X)	✓

The "taperToLeft" and "taperToRight" attributes are marked as recommended (!), which show the end or the beginning or the start of a warping direction of lanes of a point, but those are not supplied. The "node" attribute "divergePoint" is provided in the lane widening area. This concerns "mergePoints" and applies to all access roads.

Signal group assignment and SPaT plausibility

A comparison of the MAP signal groups with the traffic engineering (VT) signal groups was carried out to check the plausibility of the signal states transmitted in the SPaT messages as well as for the commissioned provision of the VT signal group data for later comparison with the traffic computer process data.

The MAP and SPaT messages contain virtual signal groups. The signal groups supplied in the traffic streams are only used within the RSU. The background to the traffic stream is that there is only one signal group per lane relationship (connection) in the MAP, but two actual signal groups can signal a turning flow. Vehicles receive the signalling status of the virtual signal group in the SPaT message. The signalling status of the virtual signal group is derived from the colour images of the actual signal groups (up to two).

The signal groups of the SPaT are assigned to the signal groups of the traffic streams provided or to those of the LISA data, and the SPaT messages are checked for plausibility regarding the transmitted signalling states and their sequence. (e.g. red - red-yellow - green - yellow - red for vehicle signals). The signal timetables or forecasts were not checked.

All transmitted signalling states of the motorised traffic and their sequence were assessed as plausible. There were discrepancies in the signal group assignment of the pedestrian signal groups, which may be attributable to the cases mentioned in the situation check. A more detailed analysis of the traffic streams revealed an incorrect configuration of the pedestrian signal groups:

Empfangen (MAP)			LISA Daten (Soll)		Traffic Streams (Ist)	
Quellstreifen	Zielstreifen	SGR-ID	SGR-Name	SGR-ID	SGR-Name	SGR-ID
16	17	7	F10/ AV10	14/ 20	H8b	11
17	16	8	F10/ AV10	14/ 20	AV7	17
14	15	13	F9/AV9	12/ 19	H9	13
15	14	14	F9/AV9	12/ 19	AV8	18
20	21	17	F8/AV8	9/ 18	F7	7
21	20	18	F8/AV8	9/ 18	H10a	15
18	19	19	F7/AV7	7/ 17	F8	9
19	18	20	F7/AV7	7/ 17	H10b	16

Figure 167 - Signal group comparison at the traffic light.

In addition, the virtual signal groups ("Receive/SGR-ID" column, blue marking) 8, 14, 18 and 20 were permanently sent the "Enable" status. At one traffic light, no forecast data was received. All transmitted signalling states of the IV and their sequence were assessed as plausible. The signal group assignment was incomplete due to the missing lanes (see position check). The virtual signal groups 10 to 13 show "Dark". These are presumably the signal groups of the missing lanes.

Pilot Hessen/Kassel

The service GLOSA was functionally evaluated by receiving the MAPEM and SPATEM via V-ITS-S and by using the app trafficpilot. Regarding the quality of the service, the technical performance (e.g. timing, their accuracy of forecast) has been evaluated.

Figure 168 shows the implemented system architecture for the GLOSA service in the city of Kassel with the sub-systems involved. While using the harmonized interoperability specifications from C-Roads, the detailed specifications of the system integration is described in the pilot Hessen/Kassel M43 specification (CRG-UN M43, 2020).

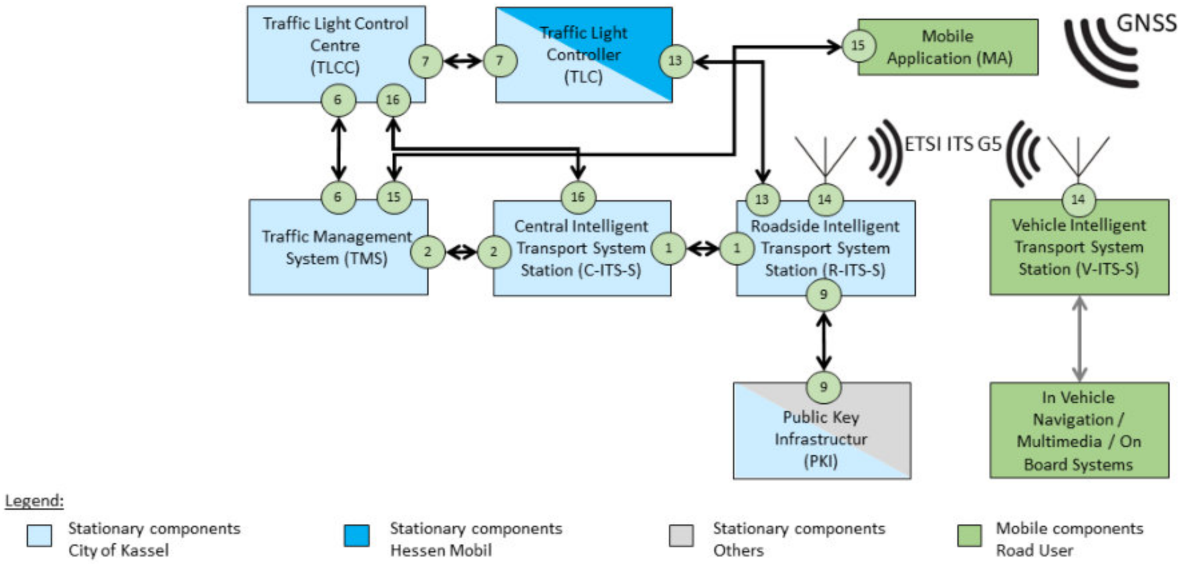


Figure 168 - System architecture of the GLOSA service in the city of Kassel

Evaluation of ETSI ITS G5 communication:

The functionalities of the GLOSA service were implemented at 15 C-ITS equipped traffic lights. The GLOSA service has been deployed in the digital test field for connected driving Kassel on the routes ‘Holländische Straße’ to ‘Ständeplatz’ and ‘Grüner Weg’. The map of the city of Kassel illustrates these C-ITS equipped traffic lights (see Figure 169) (within the CRG-UN project, the GLOSA service is rolled out in the test field at 75 traffic lights along the main routes of the city of Kassel).

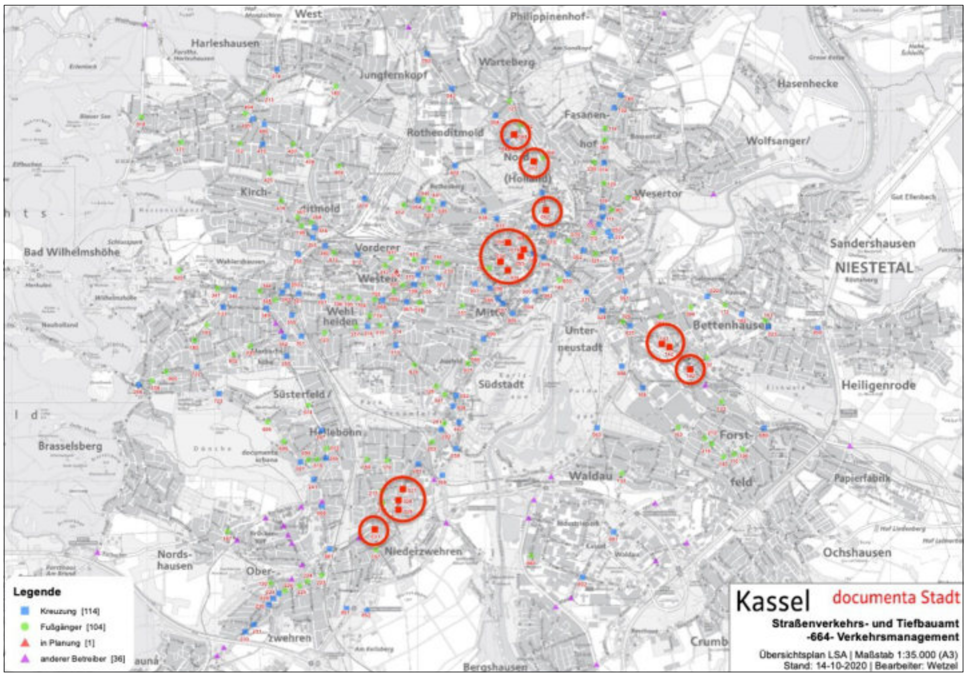


Figure 169 - GLOSA deployment in the city of Kassel – overview of the C-ITS equipped traffic lights including R-ITS-S

The functional evaluation of the GLOSA service via the R-ITS-S was done by receiving of SPATEM with a special service V-ITS-S (see Figure 170).

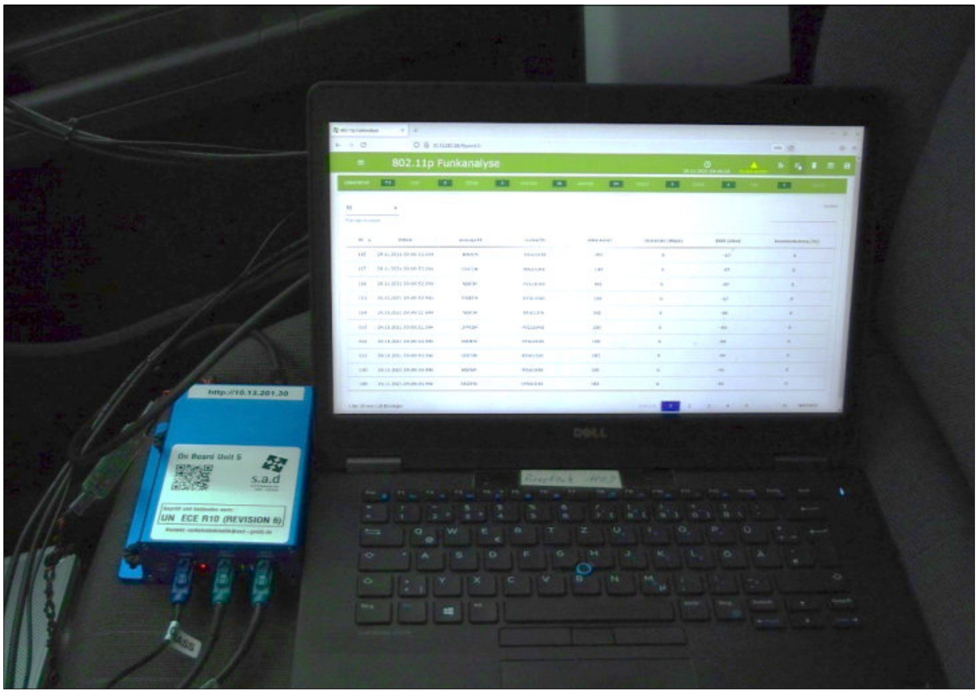


Figure 170 - GLOSA with ETSI ITS G5 communication test system – V-ITS-S equipment for the receiving of MAPEM and SPATEM

Evaluation using trafficpilot app:

The GLOSA service was also evaluated by functional and quality tests in the frame of the acceptance test of the smartphone app "trafficpilot" in the city of Kassel in 2021. The trafficpilot app uses current position data to display the next traffic lights with both the green-light-optimal-speed-advisory while driving/riding and the time-to-green while standing at red light in the queue in front of the stop line. Different shades of colour indicate the certainty of the forecast for red or green in the GLOSA mode in order to support the end user with information of quality of the forecast. The main focus was the accuracy of the prediction quality (see Figure 171 and Table 176).

At the time of the tests, the GLOSA related prediction using the trafficpilot app, was available for a total of 163 traffic signals.

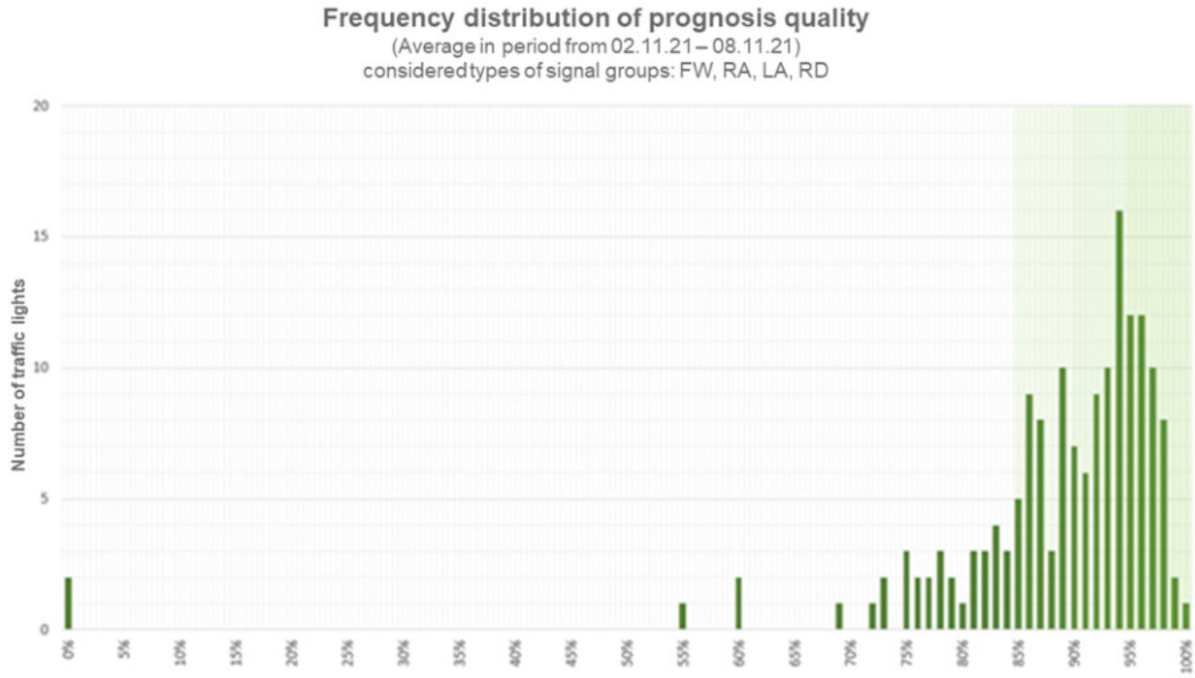


Figure 171 - Distribution scale of the prediction quality

Table 176 - Analysis of the prediction quality

prediction quality class	quantity of traffic signals/class	percentage of traffic signals/class
0%	2	1%
>0% to 80%	20	12%
>80% to 85%	18	11%
>85% to 90%	37	23%
>90% to 95%	53	33%
>95% to 100%	33	20%
total	**163**	**100%**

A further detailed analysis was carried out for the 15 C-ITS equipped traffic lights, which were designated to the GLOSA service as part of the CRG-UN project. The analysis took place in the time from 01.-07.11.2021. The location of the traffic lights extends from "Rathaus" via "Scheidemannplatz" and "Lutherplatz" northwards to "Holländische Straße". A section at the "Leipziger Straße" was also part of the analysis. The selected traffic lights and their location are illustrated at the map in Figure 172 - Overview map of routes for GLOSA service.

From the selected 15 traffic lights:

- the forecast is currently blocked at one traffic light (016: Lutherplatz) and
- two traffic lights have not yet been classified as prediction- traffic light:
    - 142: Leipziger Straße / Agathofstraße and
    - 143: Bettenhausen Mitte (the signaling only runs on demand).

The selected traffic lights were assigned to four routes (see Table 177).

Table 177 - Route description

Route	Description	TL number
1	Rathaus – Fünffensterstr.	7, 56, 8, 931, 372, 373
2	Ständeplatz – Lutherplatz	35, 55, 16, 168, 15
3	Holländische Str.	62, 13, 12, 44, 58, 42
4	Leipziger Str.	26, 25, 143, 142, 182, 122

034 (Hauptbahnhof) and 036 (Erzberger Str./Grüner Weg) are reviewed individually.

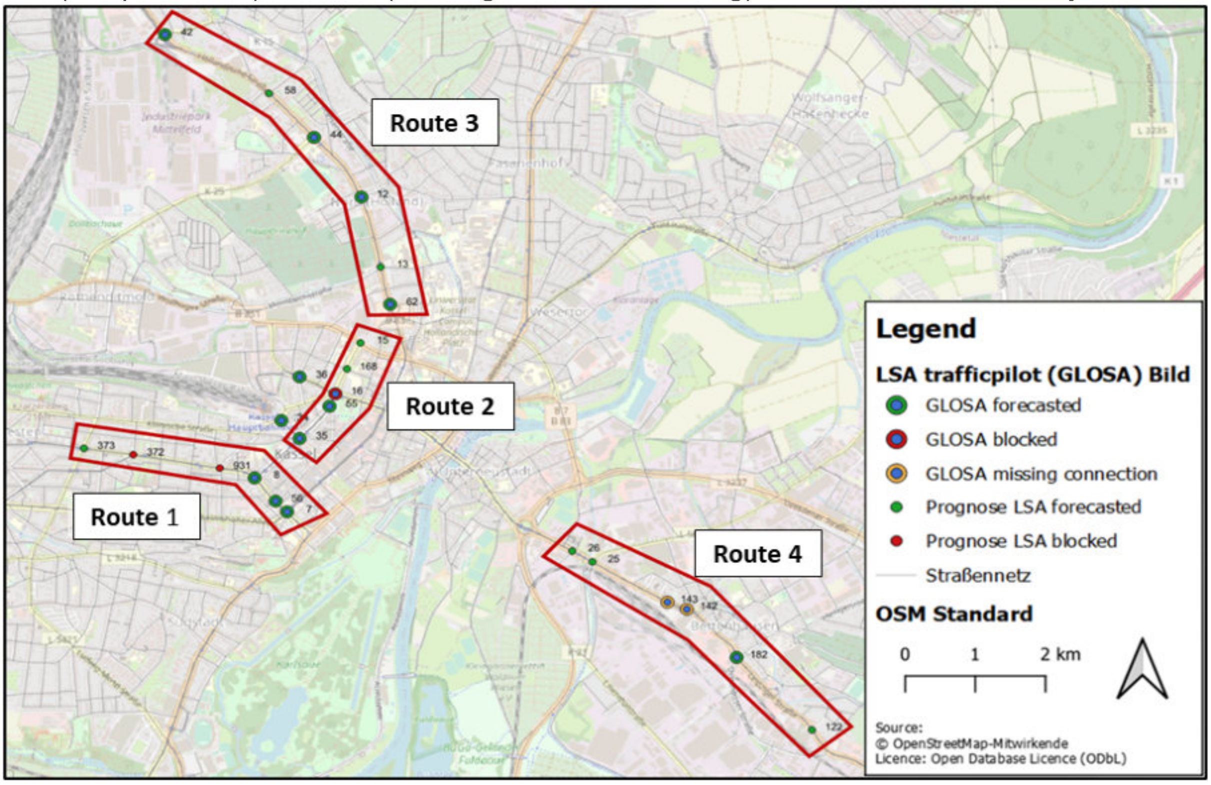


Figure 172 - Overview map of routes for GLOSA service

Route 1: Rathaus – Friedrich-Ebert-Straße

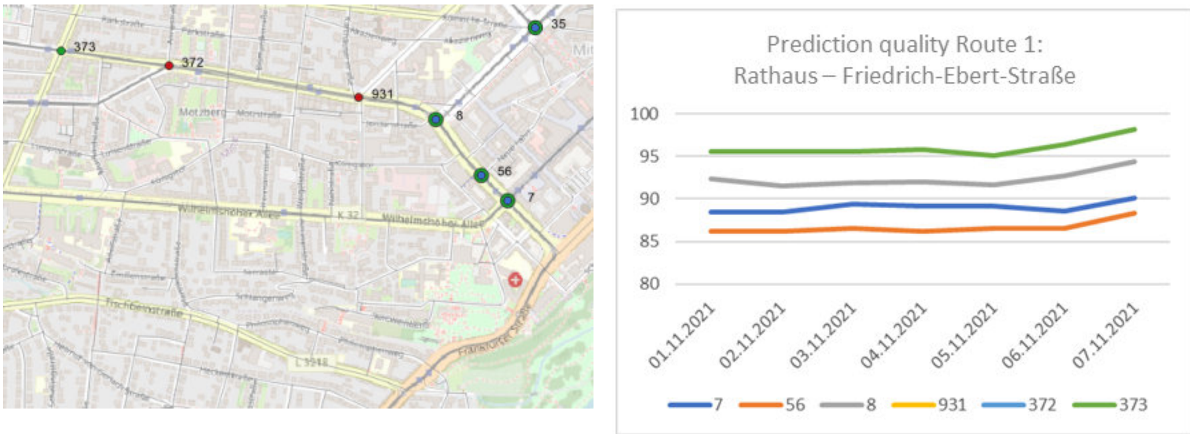


Figure 173 - Route 1: overview of the prediction quality

Table 178 - Route 1: detailed values of the prediction quality

TL	Description	01.11.2021	02.11.2021	03.11.2021	04.11.2021	05.11.2021	06.11.2021	07.11.2021	Mean value
7	Rathaus	88,4	88,5	89,4	89,2	89,2	88,6	90,1	**89,1**
56	Fünffensterstraße / Neue Fahrt	86,2	86,2	86,5	86,2	86,6	86,5	88,3	**86,6**
8	Ständeplatz	92,4	91,5	91,9	92	91,6	92,7	94,4	**92,4**
931	Friedrich-Ebert-Straße / Bürgermeister-Brunner-Str	No data							
372	Friedrich-Ebert-Straße / Annastraße								
373	Friedrich-Ebert-Straße / Querallee	95,5	95,5	95,5	95,8	95,1	96,4	98,2	**96,0**

The prediction quality of the considered traffic lights of route 1 is consistently above 85% and thus at least in the medium quality range. Three of the traffic lights considered in the GLOSA service are released in the trafficpilot app. Therefore, the predictions can be used by the traffic participants in Kassel.

Route 2: Ständeplatz to Feuerwache (via Lutherplatz)

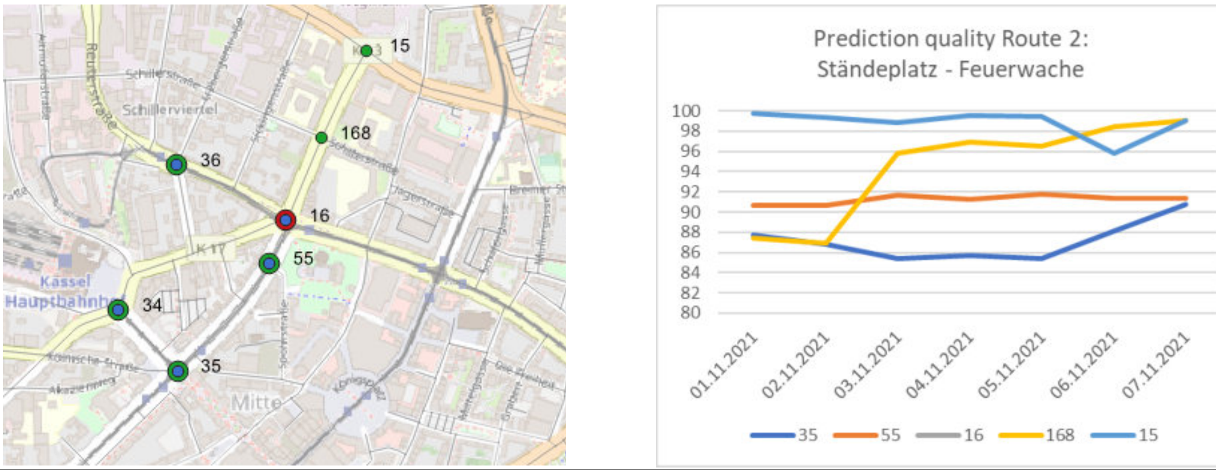


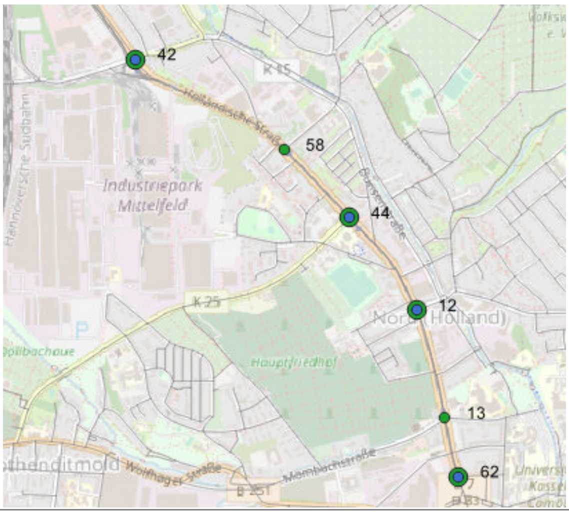
Figure 174 - Route 2: overview of the prediction quality

Table 179 - Route 2 detailed values of the prediction quality

TL	Description	01.11.2021	02.11.2021	03.11.2021	04.11.2021	05.11.2021	06.11.2021	07.11.2021	Mean value
35	Scheidemannplatz	87,7	86,8	85,4	85,7	85,4	88,1	90,8	**87,1**
55	Rudolf-Schwander-Str./ Spohrstraße	90,7	90,7	91,7	91,3	91,8	91,4	91,4	**91,3**
16	Lutherplatz	No data							
168	Hoffmann-von-Fallersleben-Straße / Schillerstraße	87,4	86,9	95,8	96,9	96,5	98,4	99	**94,4**
15	Wolfhager Str. / Hoffmann-von-Fallersleben-Str.	99,7	99,3	98,8	99,5	99,4	95,8	99	**98,8**

The prediction quality of all the traffic lights considered on route 2 is over 85% and therefore in the medium quality range. During the test period traffic light 016 (Lutherplatz) did not provide any data, so any prediction or evaluation of the prediction quality is not possible here. Basically, the three traffic lights considered in GLOSA are suitable for trafficpilot. The traffic lights 035 and 055 have already been released at the traffic pilot app.

Route 3: Holländische Straße



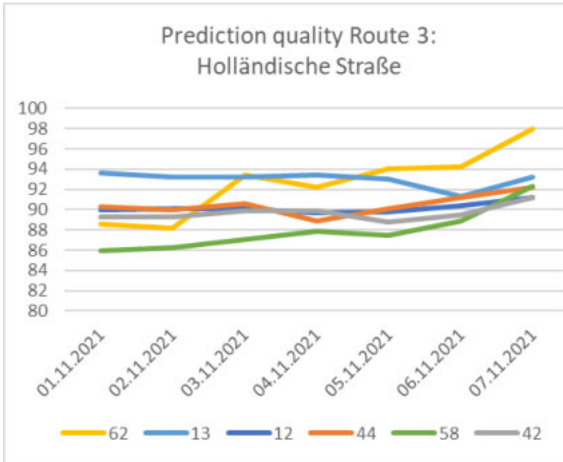


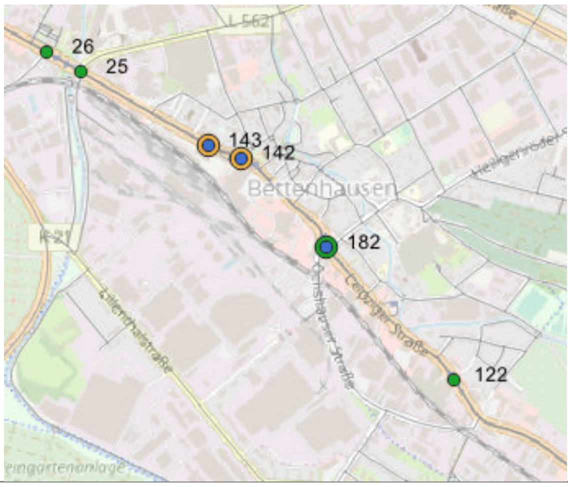
Figure 175 - Route 3 overview of the prediction quality

Table 180 - Route 3 detailed values of the prediction quality

TL	Description	01.11.2021	02.11.2021	03.11.2021	04.11.2021	05.11.2021	06.11.2021	07.11.2021	Mean value
62	Holländische Straße/ Ludwigstraße	88,6	88,2	93,4	92,2	94	94,2	98	92,7
13	Holländische Straße / Mombachstraße	93,6	93,2	93,2	93,4	93	91,3	93,2	93,0
12	Holländische Straße/ Eisenschmiede	90,0	90,1	90,1	89,7	89,8	90,4	91,2	90,2
44	Holländische Straße / Wiener Straße	90,3	90,0	90,6	88,9	90,1	91,2	92,2	90,5
58	Holländische Straße / Hegelsbergstraße	85,9	86,3	87,1	87,9	87,5	88,9	92,3	88,0
42	Holländische Str. / Bunsenstr.	89,3	89,3	89,9	89,9	88,8	89,5	91,2	89,7

The prediction quality of all traffic lights considered in GLOSA on Route 3 is consistently above 85% and in the medium quality range. Hence, they are released at the trafficpilot app.

Route 4: Leipziger Straße



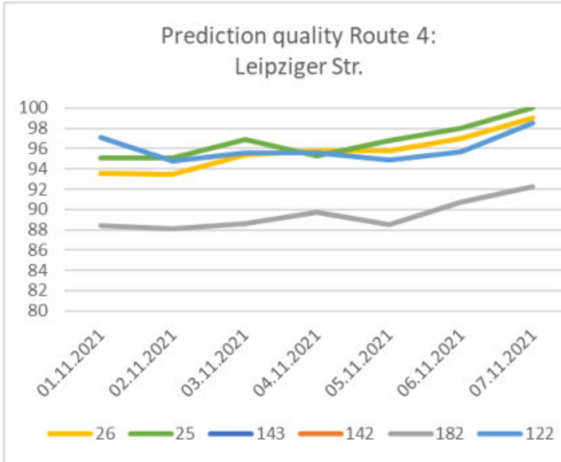


Figure 176 - Route 4 overview of the prediction quality

Table 181 - Route 4 detailed values of the prediction quality

TL	Description	01.11.2021	02.11.2021	03.11.2021	04.11.2021	05.11.2021	06.11.2021	07.11.2021	Mean value
26	Leipziger Straße/ Yorckstraße	93,6	93,5	95,4	95,8	95,8	97	99	**95,7**
25	Leipziger Straße / Sandershäuser Straße (Hallenbad	95,1	95,1	96,9	95,3	96,8	98	100	**96,7**
143	Bettenhausen Mitte (Abfangsignalisierung)	No data							
142	Leipziger Straße / Agathofstraße								
182	Leipziger Platz	88,4	88,1	88,6	89,7	88,5	90,7	92,2	**89,5**
122	Leipziger Straße/ Drahtmühlenweg	97,1	94,8	95,6	95,6	94,9	95,7	98,5	**96,0**

The prediction quality of the traffic lights considered on route 4 is over 85% and thus at least in the medium quality range. It should be noted that traffic light 143 (Bettenhausen Mitte) and traffic light 142 (Leipziger Straße / Agathofstraße) currently are not sending any data; as a result prediction or evaluation is not possible for these two traffic lights. The three traffic lights considered in GLOSA are suitable to show at the trafficpilot.

Further traffic lights (traffic light 34 & 36)

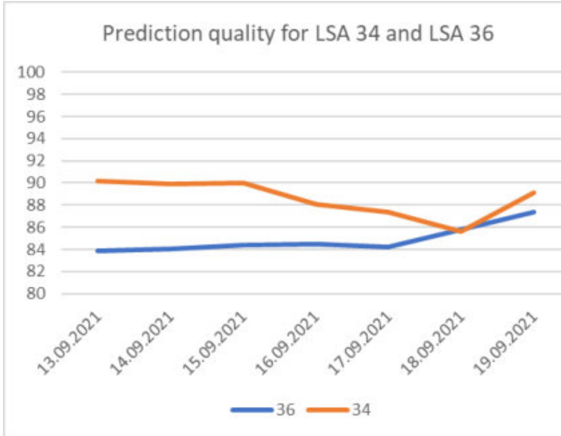


Figure 177 - Traffic light 34 & 36 overview of the prediction quality

Table 182 - Traffic lights 34 & 36 detailed values of the prediction quality

TL	Description	01.11.2021	02.11.2021	03.11.2021	04.11.2021	05.11.2021	06.11.2021	07.11.2021	Mean Value
36	Erzberger Str. /Grüner Weg	83,9	84	84,4	84,5	84,2	85,8	87,4	**84,9**

TL	Description	13.09.2021	14.09.2021	15.09.2021	16.09.2021	17.09.2021	18.09.2021	19.09.2021	Mean Value
34	Hauptbahnhof	90,2	89,9	90	88,1	87,4	85,6	89,1	**88,6**

Note: traffic light 34 (Hauptbahnhof) did not provide any data in the period from 01.11.2021 to 07.11.2021. Therefore, a different time period was considered here.

Traffic light 36 (Erzberger Str. /Grüner Weg) and 34 ("Hauptbahnhof") have not been assigned to any route. Traffic light 36 shows a prediction quality of over 84 % on average. No data was recorded in November 2021 for traffic light 34, so for comparison a time period from September has been selected. The prediction quality here was also consistently over 85%. These two traffic lights are therefore suitable for the trafficpilot app.

Use Cases considered

- SI-TLP: Signalized Intersection – Traffic Light Prioritization

In Germany, the functional evaluation of the TLP service took place in all three pilot sites: Dresden, Hamburg and Hessen/Kassel.

Pilot Dresden

In the pilot Dresden TLP is evaluated only for functionality. In this regard, first tests have already been carried out. These tests consisted of sending registration/deregistration messages at the appropriate locations and verifying the correct handling of these messages within the traffic light controller. An example result is shown in Figure 178, where the TLP activation at intersection Fritz-Foerster-Platz is displayed in 3 phases: Before activation (1), in activated state (2) and (3) and after clearing the intersection (4). Activation was realized using the R09 container within the CAM, as SSEM/SREM is currently not supported by the traffic light controller.

Figure 178 - TLP activation at intersection Fritz-Foerster-Platz.

Further tests have been carried out with regards to maximum range of communication. This is especially relevant, as the first iteration of the implemented service relies on the R09 data field in the CAM, i.e., a message which is not forwarded. As a visualization, a heat map of distance measurements for an intersection in the city of Dresden is exemplified in Figure 179. A comparison against a TLP service based on SSEM/SREM has not yet been conducted.

Figure 179 - Distance measurements at an intersection for non-hopping ITS-G5 messages from roadside stations.

<u>Pilot Hamburg</u>

In the pilot Hamburg a functional evaluation of the TLP service within the framework of the BiDiMoVe project took place:

The public transport strategy computer uses the provided traffic light data to forecast signalling states and switching times. The public transport strategy computer learns about the switching times as the BiDiMoVe system runs longer.

The following graphic shows the average evaluation of the switching time forecast for all signal groups in the BiDiMoVe area. The evaluation is carried out using the DevSecV evaluation method, in which the deviations between the actual and predicted signal pattern are compared second by second and weighted according to the significance of the respective (possible) error. The figures are given as a percentage.

Figure 180 - Average forecast quality of all signal groups in the BiDiMoVe area.

The forecast of the switching time becomes increasingly accurate over time. In the first half of September, an average of approximately 92.06% of the forecasts are correct. The forecast for the first half of November is, on average, approximately 93.19% accurate. Data disruptions and work on the system can explain the failure on 2nd September and the downward outliers.

The following figure shows the underlying analyses for the intersection Scharbeutzer Straße / Rahlstedter Bahnhofstraße for the signal groups K2 and K3. The lower part of the program window shows the switching time forecast, the actual signal pattern (designated K2 and K3) and the resulting forecast errors. The accuracy of the forecast is evaluated based on the error frequency or severity. In the daily overview (here, 18th October 2021), the accuracy of the forecast can be recognized for each signal group for the day.

Figure 181 - Forecast accuracy of signal group K2 at junction 1989 on 28.11.2021.

Figure 182 - Forecast accuracy of signal group K3 at junction 1989 on 28.11.2021.

In the case that the system detects that the forecast accuracy at a signal group is below a defined value for a more extended period, it can automatically stop sending the switching time forecast so that bus drivers are not shown incorrect forecasts.

<u>Pilot Hessen/Kassel</u>

The service TLP was evaluated by its functional aspects. Figure 183 shows the implemented system architecture for the TLP service in the city of Kassel with the sub-systems involved. The detailed specification of the interfaces is described in the pilot Hessen/Kassel M43 specification (M43 2020).

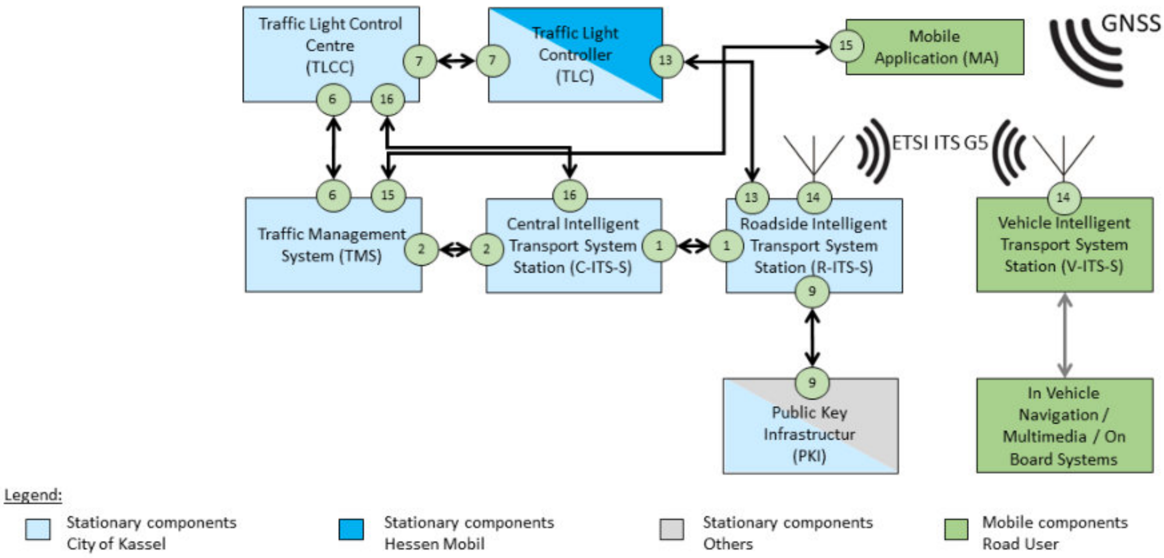


Figure 183 - System architecture of the TLP service in the city of Kassel

The functionalities of the TLP service for public transport vehicles are implemented at 15 C-ITS equipped traffic lights. In the interurban area of Kassel additional six traffic lights are equipped with R-ITS-S, where the TLP service is available for emergency vehicles. The map of the city of Kassel illustrates these C-ITS equipped traffic lights (see Figure 184).

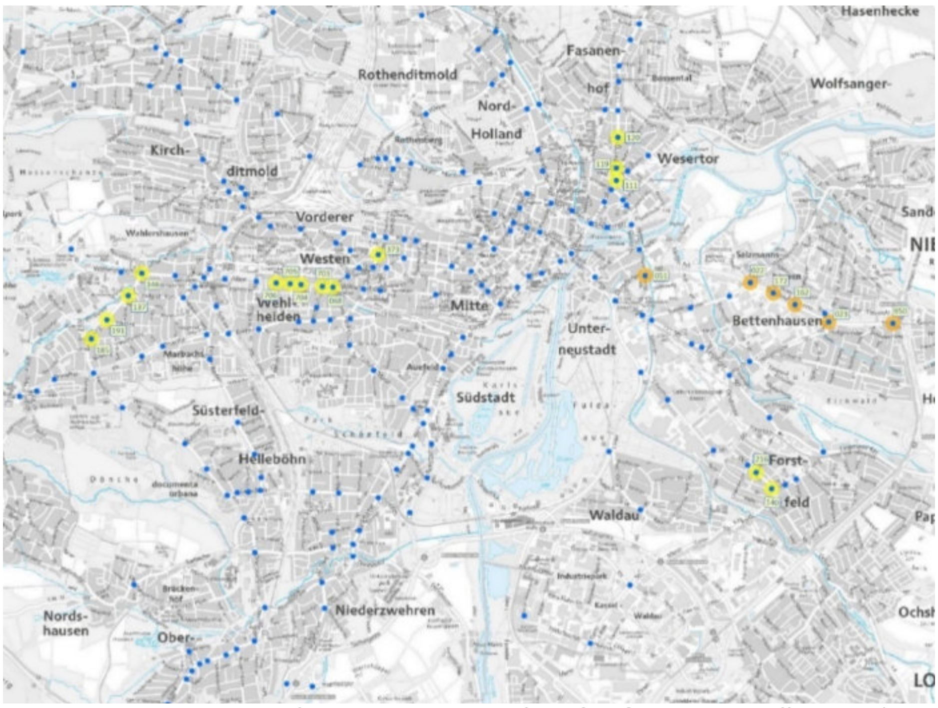


Figure 184 - TLP service in the city of Kassel – overview of the C-ITS equipped traffic lights (yellow) / traffic lights in in the interurban area of Kassel (orange) including R-ITS-S

TLP for public transport vehicles

The service TLP for public transport vehicles was functionally evaluated in a series of long-term tests. The following test scenarios have been considered so far:

- approach at a traffic light on open road
- bus/tram stop directly in front of a traffic light
- bus/tram stop at some distance to the traffic light
- registration at several following traffic lights
- deregistration at the traffic lights

The tests were performed at the intersection „Erzberger Straße/Grüner Weg“ (bus-line 37/38), at the street „Frankfurter Straße“ (bus-line 500) and at the streets „Leuschnerstraße/Heinrich-Schütz Allee“ (bus-line 11).

The following information were analysed by its content and transmission frequency:

- SREMs send by V-ITS-S of public transport vehicles
- CAMs of the public transport vehicles for localisation
- data logging of the V-ITS-S
- parallel send R09/16 messages of the public transport vehicles using analog radio
- process data of the traffic light controller

The SREMs and the CAMs were recorded at the Central ITS Station (C-ITS-S). The R09/16 messages and the process data were recorded by the traffic light control centre (TLCC).
As part of the tests, the predicted arrival time transmitted in the SREM was compared with the real arrival time and with the travel time from the R09/16 telegrams.
Table 183 illustrates the evaluation of the estimated travel time, predicted by the public transport V-ITS-S, in comparison to the real travel time. Each row belongs to a “Signal Request Message” (SREM), sent by the V-ITS-S.

Table 183 - By V-ITS-S estimated travel time and real travel time at the traffic light 610 „Leuschner Straße/Meißner Straße“ in Kassel

timestamp	stationID	Role	requestType	inBoundLane	outBoundLane	requestDate	estimated traveltime [sec]
2024-05-06 07:47:09	113	PUBLIC_TRANSPORT	priorityRequestUpdate	4	2	2024-05-06 07:47:19	**10**
2024-05-06 07:47:10	113	PUBLIC_TRANSPORT	priorityRequestUpdate	4	2	2024-05-06 07:47:23	**13**
2024-05-06 07:47:12	113	PUBLIC_TRANSPORT	priorityRequestUpdate	4	2	2024-05-06 07:47:22	**10**
2024-05-06 07:47:22	113	PUBLIC_TRANSPORT	priorityRequestUpdate	4	2	2024-05-06 07:47:25	**3**
2024-05-06 07:47:26	113	PUBLIC_TRANSPORT	priorityCancellation	4	2	2024-05-06 07:47:26	**0**

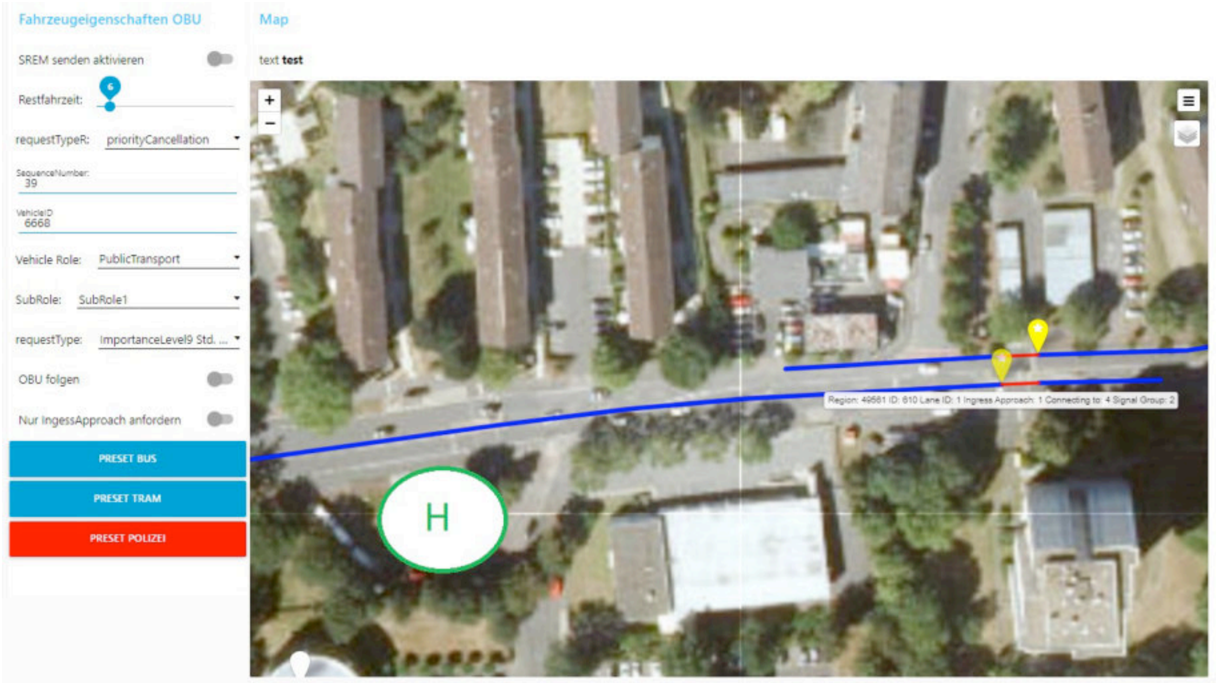


Figure 185 - MAP data and deposited aerial view of traffic light "Leuschner Straße/Meißner Straße“

Additionally, the reaction of the traffic light controller, initiated by the SREM, has been proven. The following figures illustrate this reaction. The signal plan contains in the first lines the signal status of the different signal groups, followed by the submitted travel time of the public transport vehicles (the following blue lines).

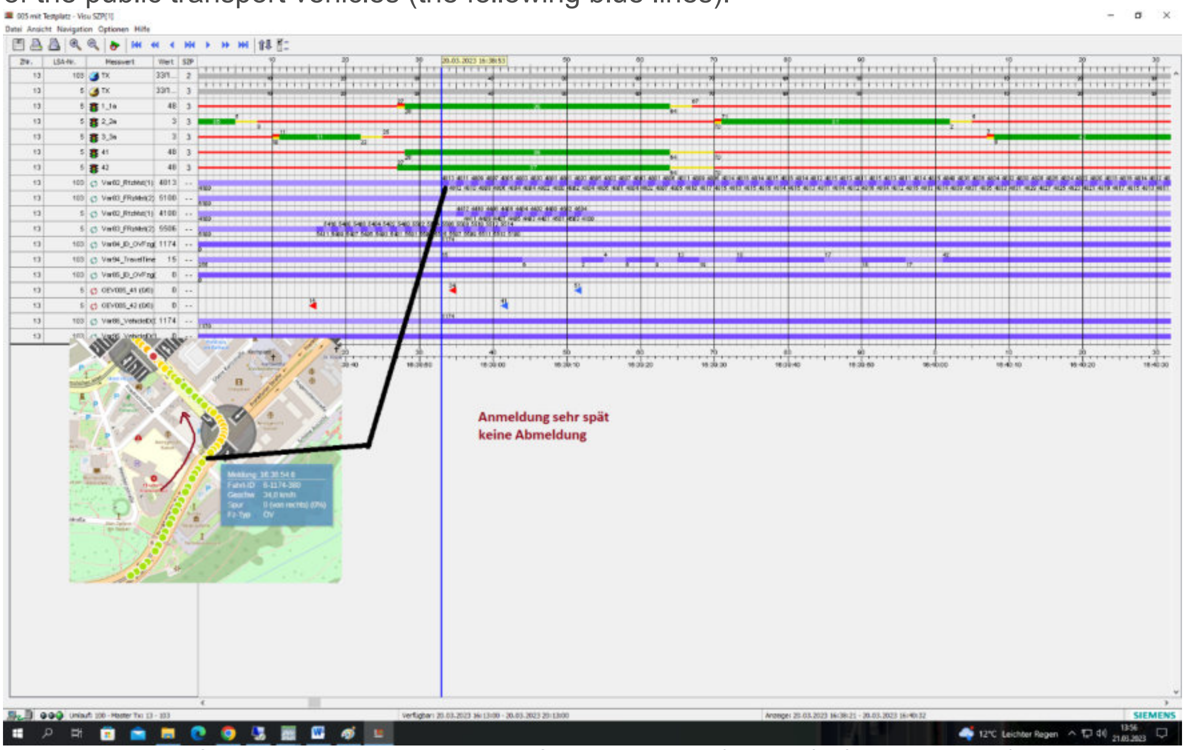


Figure 186 - TLP for public transport evaluation of online protocol (date 20/03/2023, 16:38pm) showing late registration and no cancellation

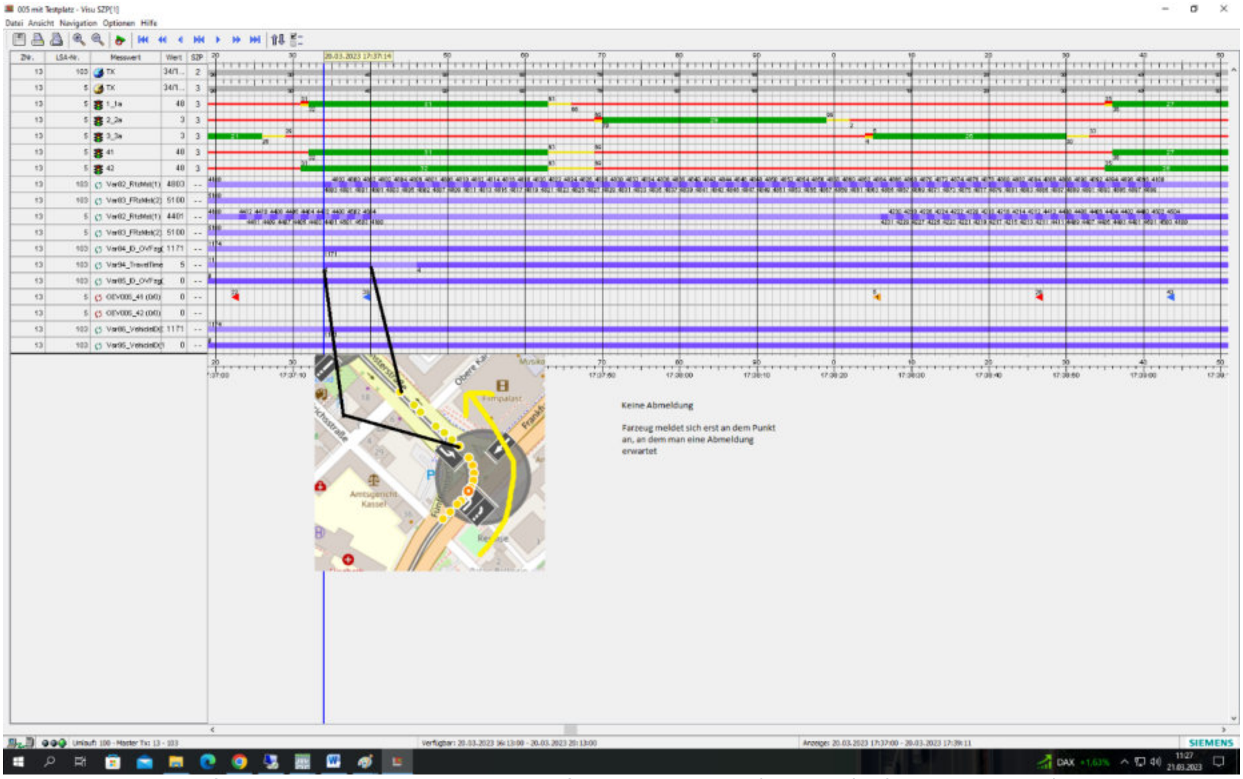


Figure 187 - TLP for public transport evaluation of online protocol (date 20/03/2023, 17:37pm) showing registration at the time of cancellation requirement

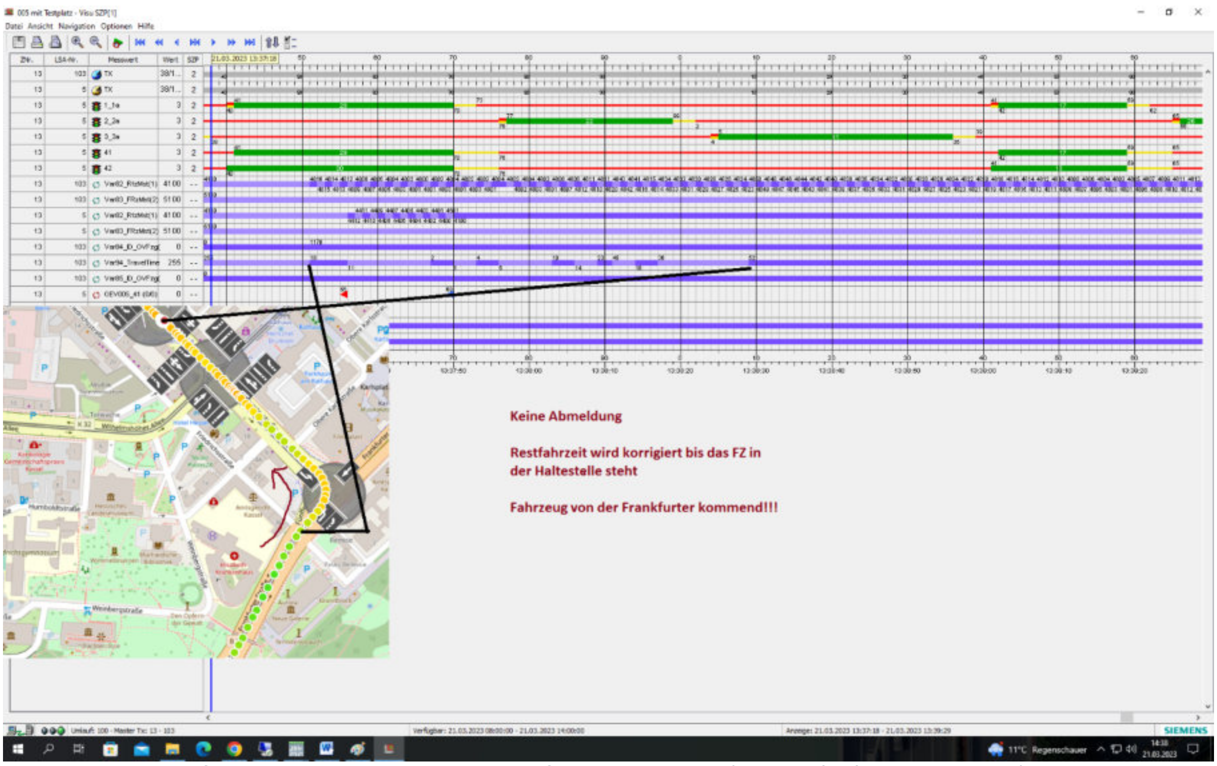


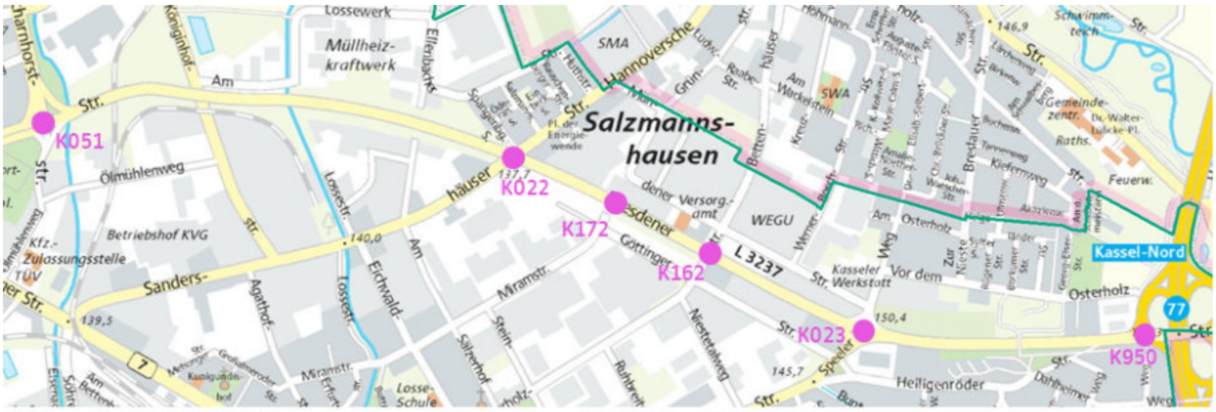
Figure 188 - TLP for public transport evaluation of online protocol (date 21/03/2023, 13:37pm) showing no registration but the correction of travel time

The following findings were made:

- Because the positioning of the public transport vehicle is inaccurate, the deregistration of the vehicle should take part at least ten metres after the stop line. Otherwise, there is the risk of a deregistration before the vehicle has passed the stop line.
- The waiting time of the public transport vehicle at the bus stop has a wide variation. This results from varying time for the boarding and alighting of the passengers. Also, the bus was often waiting at the bus stop, if the arrival time was earlier than contained in the timetable. So, the prediction is sensitive to errors.
- The driving dynamics was considered in a simplified linear acceleration. Until now, this modelling seems to be accurate for the prediction of the arrival time.
- Some V-ITS-S show insufficient positioning accuracy via GPS. This was caused by an inadequate installation position of the radio antenna of the V-ITS-S devices. In this case, an inaccurate request time was calculated and sent via the SREM.
- The evaluation of the request via SREM showed that this function works very well in many cases. This could be determined for the R-ITS-S, the V-ITS-S as well as for the processing in the traffic light controller.
- The prediction for the estimated time of arrival in the V-ITS-S was a challenge. The correct parameterization of the V-ITS-S and of the route of the public transport vehicle requires a lot of working time.

TLP for emergency vehicles

The service TLP for emergency vehicles was functionally evaluated at the six C-ITS equipped traffic lights in the interurban area of Kassel in the Dresdener Straße. The test was carried out on the 17/10/2023. Two equipped police vehicles (model: Volkswagen Passat) passed the test route using a V-ITS-S equipped light-bar system to send SREM. The V-ITS-S started transmitting SREM by approaching the signalised intersections. The lightbars were covered during the test drives, The sirens weren´t active at this time. No special rights were exercised by the police vehicles in traffic.



LSA Hessen Mobil / AVT STOYE:

- K022 – Dresdener Straße / Sanderhäuser Straße PTC9000
- K023 - Dresdener Straße / Speeler Weg PTC9000
- K950 – BAB 7 Anschlussstelle Kassel-Nord PTC9000

LSA Stadt Kassel / Yunex (Siemens):

- K051 – Dresdener Straße / Scharnhorststraße C920ES
- K172 - Dresdener Straße / SMA (Fußgängerüberweg) C940ES
- K162 - Dresdener Straße / Osterholzstraße C940ES

Figure 189 - C-ITS equipped traffic lights along the test route

The following test cases were performed:

- 2 vehicles approaching in a row

- 2 vehicles approaching from different directions
- Cancellation of the emergency signal prioritisation

The following data were collected:

- Record of broadcasted SREM and SSEM messages
- Record of the process data of the traffic light controller, including state of traffic lights
- Photos of the executed test were taken

Figure 190 - Test case emergency vehicle approaching (from different directions)

The test drives showed that the basic function of the TLP-EV service works. Requests were sent out by the vehicles and received, analysed, processed and answered at the traffic lights. Figure 191 shows the registration of a test vehicle at traffic light 51, signal group 2, taken from the traffic light control centre on the test day.

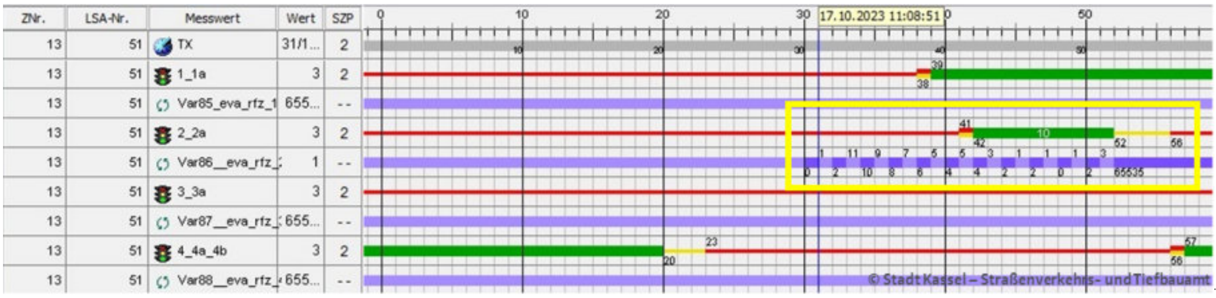


Figure 191 - Emergency vehicle registration at traffic light 51, illustrated in the traffic light control center

The tests revealed weaknesses in the implementation at 2 traffic lights. At traffic light 51, there was an incorrect link between a requested signal group and the related signal phase. At traffic light 162, there was a lack of extra signal phases planned for the service. Instead the standard signal phases for the requested directions were requested.

Technically, the service and the interfaces worked reliably.

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. Navigation Information

9.1. Traffic Efficiency

This section provides a list of the navigation information use-cases evaluated from the perspective of traffic efficiency, a summary of the evaluation methodology, data collected and results from Italy

9.1.1. Italy

Use Cases considered

- Navigation Information: Parking Information
- Navigation Information: Smart Routing

Evaluation method

Two test sessions were conducted in Verona to test both the Use Cases. The first session on April 2023, served as a warm-up to assess the technical functionality. An intermediate off-ground test was performed to solve technical issues. The second session, two days on November 2023, aimed to evaluate potential time savings for drivers using the system.

Parking Information

The test was designed identifying two locations close to some off-road parking.
The six drivers involved in the test were divided into two groups, only one of which was equipped with the C-ITS parking information app.
All the drivers started the test from the same place and they received instructions to find parking nearby by providing them with a sheet showing the map of available parking facilities, with no indication of the level of occupancy of parking structures. Drivers with the app could search for information using also the app itself to check the availability of free parking spaces.
For the purposes of the test, some parking facilities were reported as full by the traffic control center (and consequently by the app), although in reality they were not.
The aim was to assess how providing real-time off-street parking information provided via C-ITS through a smartphone app could reduce the time drivers spend searching for free parking spaces, thus decreasing overall travel times.

Smart Routing

The traffic info and smart routing with minimal congestion/travel time is provided to end user by a Mobile App (developed by Almaviva). The same App integrates the parking information services described in paragraph 4.4.
A service provider collects the official information published by the Traffic Control Centre of the city of Verona (in particular the presence of roadworks, lane and carriageway closures and/or the presence of queues / traffic jams) in TMC DATEX II format and exposes them on a C-ITS server.
Based on the current position and travel destination inserted in the App's interface, the information published on the C-ITS server are used to calculate and obtain the optimal route, taking into account the anomalies present on the network.
The test was designed identifying two itineraries that can be characterized by high traffic flows during rush hour, due to the presence of a road construction site that requires the closure of several important road segments within the city.

In fact, the first itinerary involved the above-mentioned construction site area. The second tested itinerary represents the access route to the city of Verona for those arriving from the A4 motorway, exit Verona South, and is also affected by the consequences generated by the road construction site.
The routes were covered by two groups of vehicles. The first group traveled the itineraries only with a navigator without access to smart routing information, the second instead equipped with the smart routing App.
Each test session involved the timed departure of the vehicles in order to have the same traffic conditions but to limit any mutual interference (departure of a vehicle about two minutes after the previous one).The objective was to evaluate how access to smart routing information, enhanced by real-time data on road network conditions provided via C-ITS, could reduce travel times for drivers. The focus was on determining the potential time savings and efficiency improvements under conditions of heavy congestion.

Data collected

Parking Information

The following data were collected during the test sessions:

- information on positioning of all involved vehicles;
- starting time and ending time of the itinerary;
- logs related to the route and parking suggested for the vehicles equipped with the smart parking app;
- any driver notes about, for example, traffic congestion, problems to follow the suggested route, etc.

Smart Routing

The following data were collected during the test sessions:

- information on positioning of all vehicles involved;
- starting time and ending time of the itinerary;
- logs related to the route suggested for the vehicles equipped with the smart routing app;
- log of the published events on C-ITS server;
- any driver notes about, for example, traffic congestion, problems to follow the suggested route, etc.

Evaluation results – Field tests

Parking Information

Each individual vehicle session was analyzed in detail, extracting the following "field test indicator KPIs":

- pre-departure time (time taken between the handing over of the information sheet to the driver and the actual departure of the vehicle in direction of the car park);
- actual travel time (spent driving);
- total travel time.

The average value of the indicators was then calculated for all the test sessions and for the two groups of vehicles/drivers (with and without App). This way, it was possible to evaluate the average benefit of the use of the Smart Parking App.

Table 184 - Navigation Information: Parking Information - Field tests KPIs

	C-ITS status	Total travel time (min)	% time saved with C-ITS ON
Test Session - Park 1	C-ITS ON	8,7	35%
	C-ITS OFF	13,3	
Test Session - Park 2	C-ITS ON	6,7	53%
	C-ITS OFF	14,3	

The presence of the C-ITS which provides information on the occupancy rate of car parks and at the same time guides the driver to the closest available parking space has allowed a significant saving of time. In fact, the first test saved 35% of time and the second 53% of time compared to those who did not have the smart parking app available (C-ITS OFF). The tests were conducted in medium traffic conditions, not during rush hour. The tested C-ITS can therefore lead to even more significant results in terms of time savings in congested traffic conditions.

Smart Routing

Each individual itinerary for all vehicles involved was analyzed in detail, extracting the following "field test indicator KPIs":

- pre-departure time (time taken between the handing over of the information sheet to the driver and the actual departure of the vehicle in direction of the car park);
- actual travel time (spent driving);
- total travel time;
- free flow travel time.

The average value of the indicators described above was then calculated for all the test sessions and for the two groups of vehicles/drivers (with and without App). In this way, it was possible to evaluate the average benefit of the presence of the Smart Routing App compared to the sessions without it.
Two itineraries were under test; both were covered over the two test days.
On the first day the tests were carried out in the late afternoon approximately during the evening rush hour; on the second day in the morning during the rush hour (
A total of 12 routes with C-ITS ON and 10 with C-ITS OFF were therefore collected.

The results of the test sessions are presented inTable 185; the total travel time is the result of the sum of the pre-departure time and of the actual travel time.

Table 185 - Navigation Information: Smart Routing - Field tests KPIs

Test session – Route 1 - 29th November – Evening time				
C-ITS status	**Vehicle ID**	**Pre-departure time (min)**	**Actual travel time (min)**	**Total travel time (min)**
C-ITS ON	A1	2	17	19
	A2	1	22	23
	A3	1	21	22
Average		**1,3**	**20,0**	**21,3**
C-ITS OFF	P1	2	29	31
	P2	1	31	32
Average		**1,5**	**30,0**	**31,5**

Test session – Route 1 - 30th November – Morning time				
C-ITS status	**Vehicle ID**	**Pre-departure time (min)**	**Actual travel time (min)**	**Total travel time (min)**
C-ITS ON	A1	2	19	21
	A2	2	20	22
	A3	2	24	26
Average		**2,0**	**21,0**	**23,0**
C-ITS OFF	P1	2	27	29
	P2	2	28	30
	P3	1	31	32
Average		**1,7**	**28,7**	**30,3**

Test session – Route 2 - 29th November – Evening time				
C-ITS status	**Vehicle ID**	**Pre-departure time (min)**	**Actual travel time (min)**	**Total travel time (min)**
C-ITS ON	A1	2	17	19
	A2	1	14	15
	A3	1	15	16
Average		**1,3**	**15,3**	**16,7**
C-ITS OFF	P1	2	33	35
	P2	2	27	29
Average		**2,0**	**30,0**	**32,0**

Test session – Route 2 - 30th November – Morning time				
C-ITS status	**Vehicle ID**	**Pre-departure time (min)**	**Actual travel time (min)**	**Total travel time (min)**
C-ITS ON	A1	1	11	12
	A2	1	12	13
	A3	1	13	14
Average		**1,0**	**12,0**	**13,0**
C-ITS OFF	P1	1	12	13
	P2	1	13	14
	P3	1	15	16
Average		**1,0**	**13,3**	**14,3**

Route 1 highlighted an average total travel time saving of 10,2 minutes (32,4% less than with C-ITS OFF) for vehicles equipped with C-ITS ON in the evening time session and a time saving of 7,3 minutes (24,1% less than with C-ITS OFF) in early morning session. In this case, the large time saving also did not result in a noticeable increase in the distance travelled: in fact, the route followed by vehicles without C-ITS is 5,55 km long, while the route followed by vehicles with C-ITS ON is 5,75 km long (only 200 meters more).
Route 2 registered in average a total travel time savings of 15,3 minutes (47,8% less than with C-ITS OFF) in the evening session of the 29th of November and 1,3 minutes (9,1% less than with C-ITS OFF) in the morning session. Also in this case, the large time saving also did not result in a noticeable increase in the distance travelled: in fact, the route followed by vehicles without C-ITS is 4,61 km long, while the route followed by vehicles with C-ITS ON is 4,79 km long (only 0,18 kilometers more).
Morning sessions resulted in less time savings than evening sessions, as the level of traffic recorded on the main route was considerably reduced compared to what was recorded in the other test sessions.

A further analysis conducted allowed to compare the average travel times recorded in the tests against the free flow travel time (that can be obtained in the total absence of traffic).
Route 1 has a free flow travel time of 11 minutes; the comparison with the tests results highlighted an increase of average travel time of 9 minutes in the evening session and 10 minutes in the morning for vehicles with C-ITS ON, instead the C-ITS OFF vehicles registered 19 minutes more in the evening test and 18 minutes more in the morning session, see Figure 192
Route 2 has a free flow travel time of 7 minutes; the comparison with the tests carried out highlighted an increase of average travel time of 8 minutes in the evening session and 5 minutes in the morning for vehicles with C-ITS, instead the C-ITS OFF vehicles registered 23 minutes more in the evening test and 6 minutes more in the morning session, see Figure 193.

Figure 192 - Navigation Information: Smart Routing – Route 1. Comparison between the free flow travel time and the average travel time recored

Figure 193 - Navigation Information: Smart Routing – Route 2 in Verona. Comparison between the free flow travel time and the average travel time recored

10. C-ITS services as a bundle

10.1. Safety

10.1.1. 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

Safety impacts were calculated for all networks studied for 2030 for the low and high effectiveness scenarios (see Table 186) 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 187. 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 186 - 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 187 - 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).

10.2. Traffic Efficiency

10.2.1. 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 188 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 189 shows the same benefits in terms of vehicle hours driven and vehicles hours spent in congestion.

Table 188 - 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 189 - 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).

10.2.2. 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[14], or sometimes a transportation projects evaluation national framework (France for us[15]).
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.

[14] https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1
[15] https://www.ecologie.gouv.fr/evaluation-des-projets-transport

Co-funded by the European Union

	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.

Use Cases considered (Lane Merging)

Lane merging situations consisting in an insertion from a secondary road onto a main road, are particularly complex to manage by an AV because they require 1) to detect other road users, 2) to predict and detect their intentions, 3) to take and realize adapted decisions in order to avoid any conflict that could lead to an accident.

These situations are specified through two use cases that consider the deployment of an assistance service providing alerts on insertion zones on main roads via an infrastructure-to-vehicle (I2V) communication:

- Use Case A (UC-A) considers the transmission of information by the connected infrastructure to vehicles driving on the insertion lane (Figure 194)
- Use Case B (UC-B) considers the transmission of information from the connected infrastructure to vehicles on the main road (Figure 195)

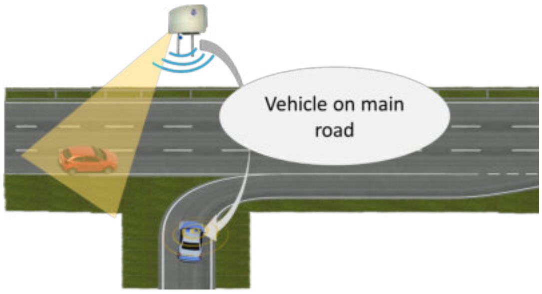


Figure 194 - Illustration of use case UC-A

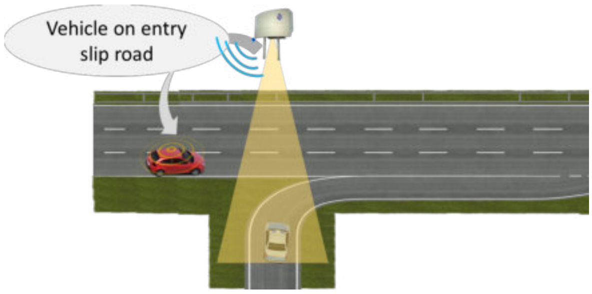


Figure 195 - Illustration of use UC-B

Evaluation method (Brief)

In "lane merging" situations, the perception functions may be limited, for example due to short sensor range or the presence of masking areas, or imprecise due to the complexity of the environment. In these conditions, an AV has partial information, which can limit its decision making. Thus, different risks can be identified for the crossing of areas in which the AV may come into conflict with other users:

- The inability of an AV driving on the secondary road to initiate a maneuver in order to insert itself into the existing traffic on the main road
- The potentially dangerous braking or lane change of a vehicle on the main road due to the lack of anticipation of the arrival of a vehicle from the secondary road.

Through vehicle-to-vehicle (V2X) communication and, in particular, infrastructure-to-vehicle (I2V) communication, extended information can be provided to a connected and automated vehicles (CAV) and have the effect of reducing the risks identified above. Thus, the study set up aims to evaluate the following research question:

What is the contribution of entry slip road insertion warning services (UC-A and UC-B defined above)) when at least one interacting vehicle is automated?

The experiment focused mainly on UC-B, due to the availability of the test site and the automated vehicle for these tests. This use case involves warning a vehicle on a main road of a risk of collision with a vehicle on a non-priority lane, i.e. an insertion lane. In the InDiD project, the use case is based on I2V communication, where a roadside infrastructure is responsible for detecting vehicles in the non-priority lane. Using a roadside unit (RSU), the roadside infrastructure sends a warning message to vehicles approaching the danger zone and located on the main road. Two types of messages have been specified and can be used depending on the detection and transmission capabilities of the RSU:

- 1 DENM (Decentralized Event Notification Message) warning of a hazard on the merging lane between the main road and the non-priority lane;
- 1 CPM (Collective Perception Message) indicating the position and speed of vehicles detected on the non-priority lane.

As set out in the initial methodology, the aim of the test scenarios was to assess the benefits of implementing this service, compared with a reference situation in which an AV can only rely on its on-board sensors. With the UC-B service, a vehicle on the main section can anticipate the insertion of another vehicle coming from the on-ramp road. This translates into speed regulation that minimizes heavy deceleration and conflict situations.

Two scenarios were defined for the tests:
1) A reference scenario in which an automated vehicle (AV) drives on the main section and sees a manual vehicle (MV) insert itself in front of it.
2) A target scenario in which a connected and automated vehicle (CAV) drives on the main section and sees a manual vehicle (MV) insert in ahead of it.
Figure 196 illustrates the area in which the experimental scenarios take place.

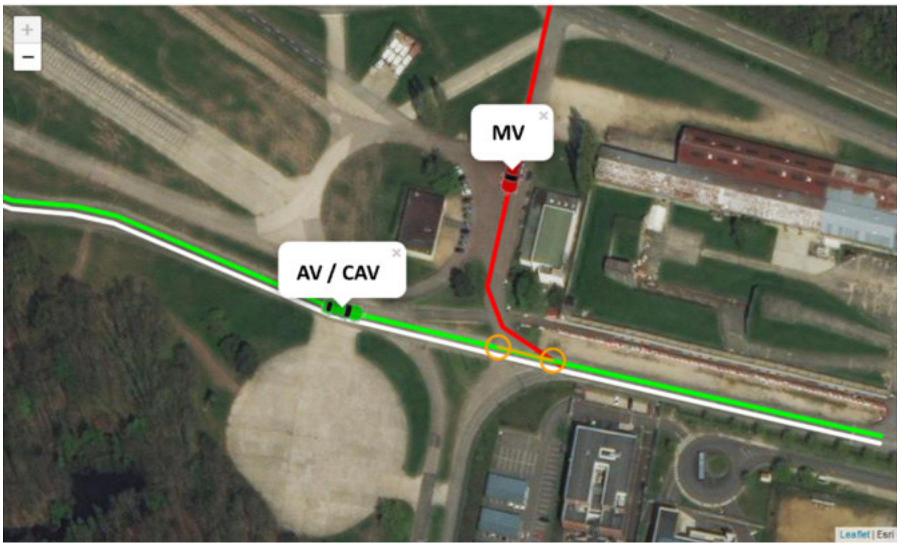


Figure 196 - Satory Test track used for the evaluation

The service deployed to carry out the tests for this study relies on the emission of DENMs based on the detection of the presence of a vehicle on an insertion lane. At the test site, the manual vehicle was equipped with a station to send CAM (Cooperative Awareness Message) messages, which the infrastructure uses to analyze the situation on the insertion lane. When a conflict situation arises, the RSU triggers a DENM to alert the connected automated vehicle. This enables the vehicle to take evasive action. In this experiment, the manoeuvre chosen was that of a lane change, justified by the absence of knowledge of the precise location of the approaching vehicle on the insertion lane (MV).
The CAV priority is to avoid the conflict zone. This experiment therefore assumes that the vehicle has the ability to change lanes (no other vehicle in the adjacent lane), which may not always be possible in open road situations.

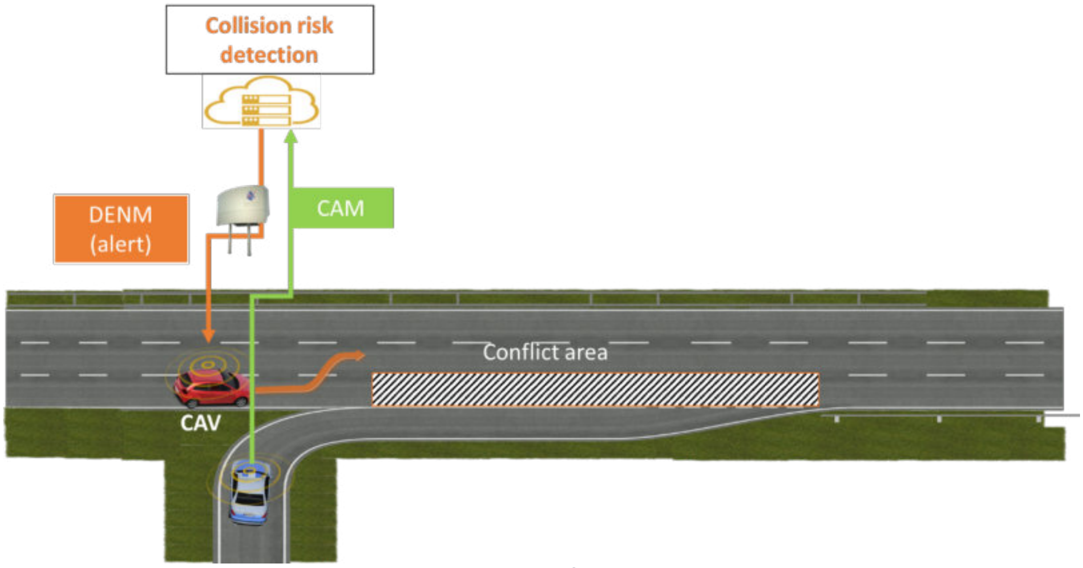


Figure 197 - Alert on conflict at merging zone

Data collected

In this work, the main key performance indicators (KPI) to be measured are illustrated in Table 1 where four indicators reflecting the road safety conditions in which the vehicles are located (AV / CAV) were selected. In addition, since vehicles have to react to the conflict situation, we also propose to evaluate indicators related to the reaction of vehicles (AV/CAV) such as reaction time or full response time of the maneuver.

Evaluation results – Field tests (Extended)

The equipment used are defined as follows:

- CAV is a robotized vehicle providing automated lateral and longitudinal control. A planning and supervision system has been developed to control the vehicle based on information gathered by proprioceptive and exteroceptive sensors. During tests, the automated driving mode is activated by a trained operator who remains behind the wheel to regain control of the vehicle if necessary. A vehicle on-board unit (OBU) has been installed to enable communication with the infrastructure, in particular, the reception of DENMs for the use case.
- MV is a conventional vehicle driven by personnel trained in track testing. Awas installed in this vehicle to generate CAMs enabling the infrastructure to detect this vehicle. An identical driver took part in the various tests.
- A roadside unit developed is deployed close to the lane merging zone to detect the vehicle in the insertion lane and trigger the warning message.
- In addition, monitoring cameras are installed around the circuit, enabling a remote operator to coordinate the various tests.

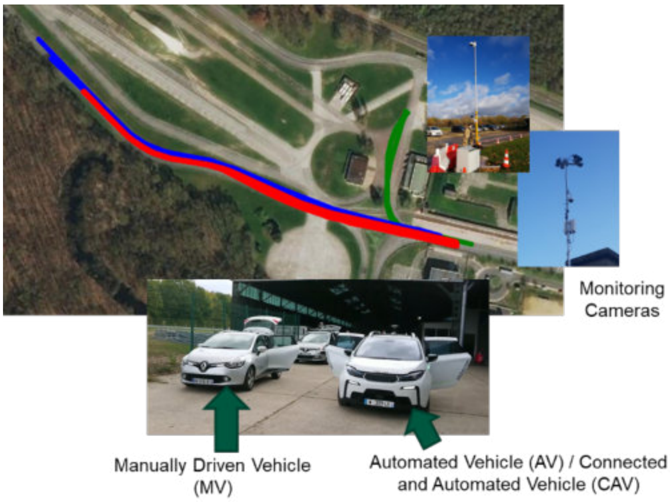


Figure 198 - Illustration of experimentation platforms

Figure 199 illustrates the approach of the lane merge section by the vehicles where location of the vehicles is shown in the map and video feeds from on-site cameras. Different statistics are collected from the vehicles. Then, Figure 200 highlights the lane change done by the CAV upon the reception of alert message.

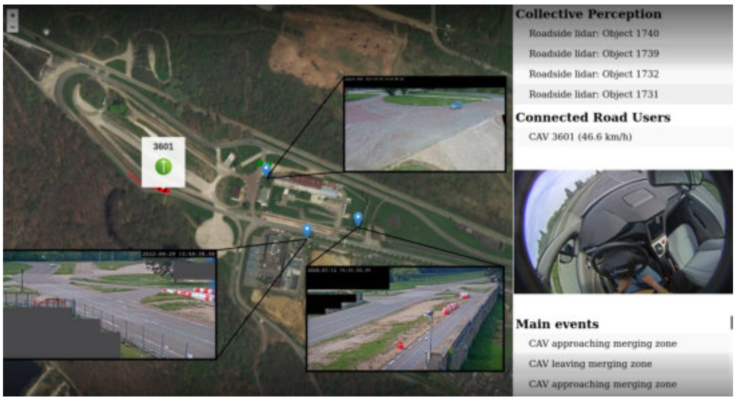


Figure 199 - CAV approaching the lane merging and detection from roadside infrastructure

Figure 200 - Alert received by CAV and triggering lane change

Evaluation results – KPIs on Mobility

Use Cases	**KPI 1**	**KPI 2**	**KPI 3 …**
RWW - WM	Time to collision	Inter-vehicle time gap	Maximum deceleration
DAY 1.5 SERVICES - Smart Slip Ramp	Vehicle time to react	Response time	

In a first step, we were able to carry out a few tests with the automated vehicle without the contribution of the connected infrastructure to manage the use case. Under these conditions, we noted the vehicles' inability to manage this situation, as the driver in the manually driven vehicle was obliged to stop his manoeuvre due to his difficulty in interpreting the automated vehicle's behaviour.

This observation is confirmed by Figure 201, in which we observe the speed profiles of the two vehicles as they approach the merging zone. We can see that both vehicles tend to decelerate, and even stop for the manually driven vehicle. This figure illustrates the difficulty for the automated vehicle to cope with this dangerous situation, leading it to slow down sharply to reduce the risks it observes.

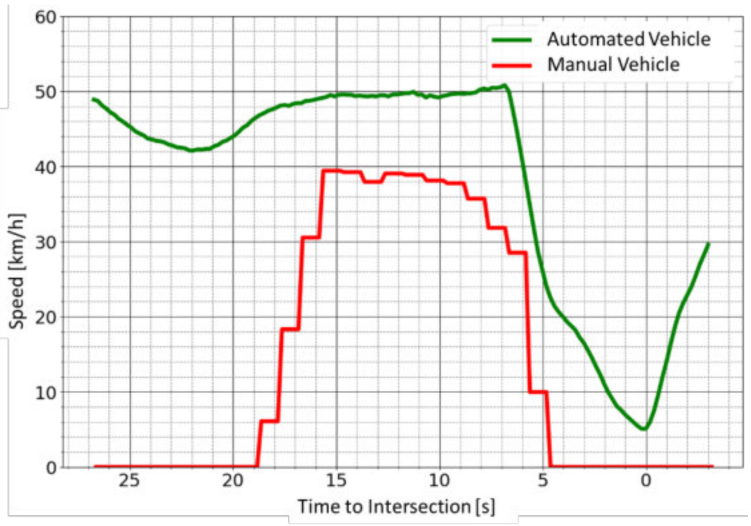


Figure 201 - Speed profile of an AV when conflicting with a manual vehicle

With the service provided by the infrastructure, the automated and connected vehicle changes lanes when danger and a possible collision with another vehicle are detected. Figure 202 shows the statistical distribution of these two indicators, time at intersection and time after encroachment, at the end of the tests. First of all, we can see that the time after encroachment is mostly less than 2 seconds, which characterizes dangerous situations. We also note that the avoidance maneuver can be triggered in an average of 12 seconds with the contribution of the connected infrastructure. This provides the CAV with a substantial time interval in which to carry out the maneuver.

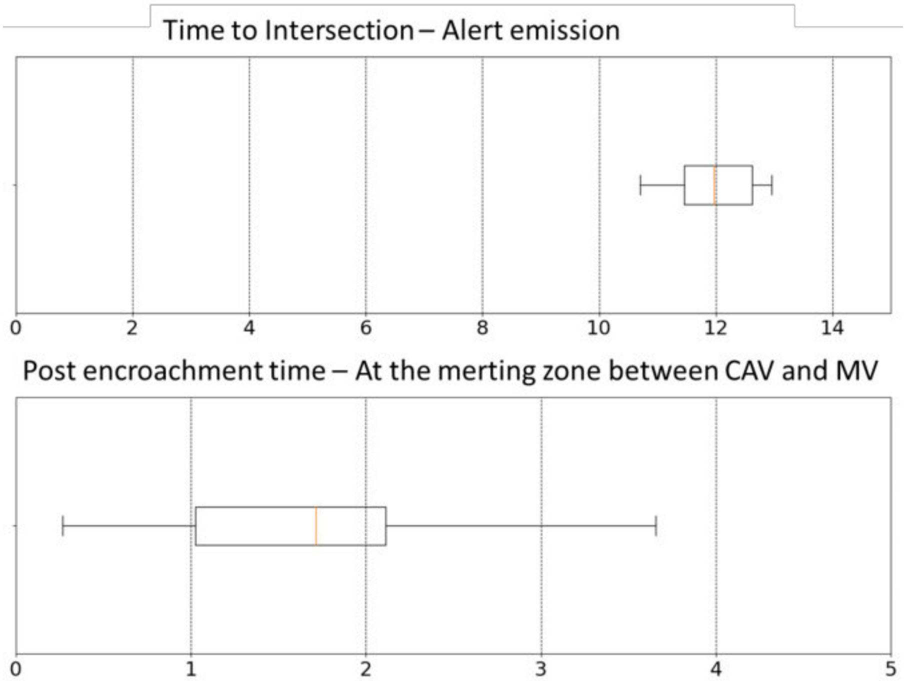


Figure 202 - Statistical distribution of time to intersection and post encroachment time

Finally, Figure 203 illustrates the speed profile of the automated and connected vehicle during these different test scenarios. We can see that the vehicle manages to maintain its cruising speed of 50 km/h during these tests. On this figure, we note that the speed is reduced between 25 and 15 seconds before the intersection, due to a curve on the test track and not to the handling of the danger situation. The same characteristic can be observed during the tests for the reference scenario.

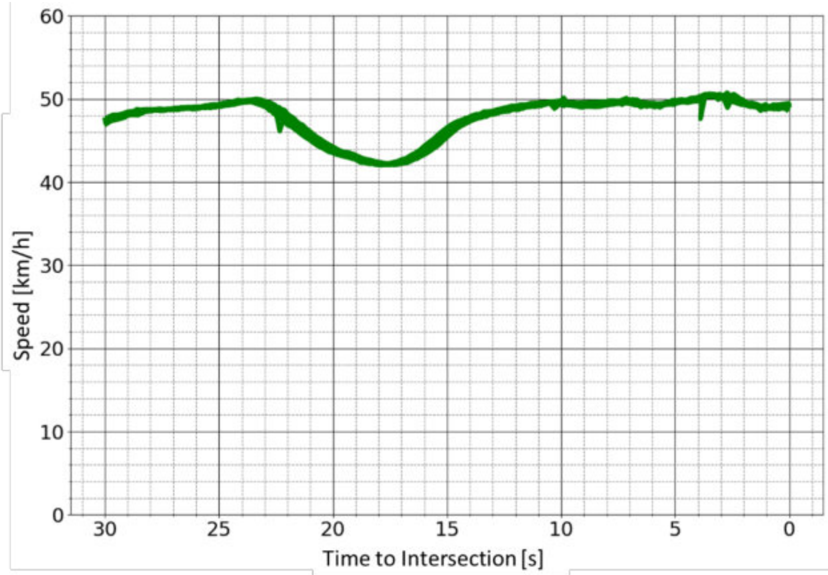


Figure 203 - Speed profile of CAV during test scenarios

Despite a limited number of trial runs recorded, the iterations carried out confirmed certain initial hypotheses about the two scenarios. In particular, we were able to observe:

- The inability of the automated vehicle to handle these situations when it has to interact with a manually driven vehicle. Indeed, during these tests, an emergency braking situation was recorded, and the automated vehicle operator was obliged to take over control of the vehicle when no information was received from the connected infrastructure. We also noted that the driver of the manually driven vehicle had difficulty understanding the behavior of the automated vehicle, which led him to stop his vehicle on the insertion lane in cases where the connected infrastructure was absent. These situations generate considerable uncertainty, which can lead to potentially dangerous situations.
- The benefit of a connected infrastructure to enable an automated, connected vehicle to deploy certain strategies to avoid and adapt to these conflict zones. For example, we have been able to demonstrate that an automated vehicle can initiate a lane change to avoid a possible collision while maintaining its cruising speed when it receives an alert between 11 and 13 seconds before the danger zone.

10.3. Environment

10.3.1. NordicWay 2

Use Cases considered

All C-ITS services and use cases.

Evaluation

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

Environmental impact assessment was based on national statistics, findings from literature and expertise of the evaluation partners.

Evaluation results – KPIs on Mobility

Table 190 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 190 - 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 191 - 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).

10.4. User Acceptance

10.4.1. 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.

10.4.2. NordicWay 3

Use Cases considered

All C-ITS services and use cases.

Evaluation method

In NordicWay 3 a study was carried out to clarify the views of the transport industry on real-time traffic information services like C-ITS. The study included an online survey for freight drivers, as well as interviews with representatives of transport companies working on driving arrangement and transportation planning, as well as representatives of companies providing transport information services. In total, 79 drivers from different performance sectors responded to the survey. Eight representatives of the transport companies, as well as three representatives from service provider companies, were interviewed. (Lauhkonen & Lehtonen 2021)

Results (Surveys and interviews)

According to the results of the survey, drivers had some real-time information services at their disposal. The most common information types that drivers received through these services were

- speed limit information
- service station information
- data on roadworks
- maximum road weights and widths permitted on the road, and
- estimated time of arrival.

In the services currently in use, users of the information were rarely the producers of the information. Some services took advantage of crowdsourced data collection, but the information was rarely automatically transmitted by vehicles. So far, the co-operative dimension of the information services in use was limited. Attitudes towards the introduction of services and the sharing of traffic information were mainly positive. Services were considered useful, and the drivers were prepared to use them. The interviewees from the transport companies did not experience problems with paying for the services, provided that the benefits the services bring to the company are verifiable. (Lauhkonen & Lehtonen 2021)

Both the interviewed transport company representatives and surveyed freight drivers had a fairly congruous positive general view of the importance of information related to hazardous situations, road weather and the situation on the route. The importance of different information types for the freight transportation was rated separately for summer and winter time with information being statistically significantly more important in winter conditions than during summer. The positive impacts of real-time information services were clearly identified, improvement in safety being the most-agreed upon one. (Lauhkonen & Lehtonen 2021)

Conclusions

In conclusion, the views of interviewed service providers supported the perceived need for real-time warnings and weather and driving data in the sector, especially for road weather information and for incident and hazard warnings. Better pre-information on challenges on the route or on importance of route change was highlighted. In addition, there was a high demand for width, height, and mass restriction data on roads, but problems have been identified in the timeliness of the information available publicly. (Lauhkonen & Lehtonen 2021)

10.4.3. 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 204 depicts the proportions of respondents concerning their willingness to share travel data.

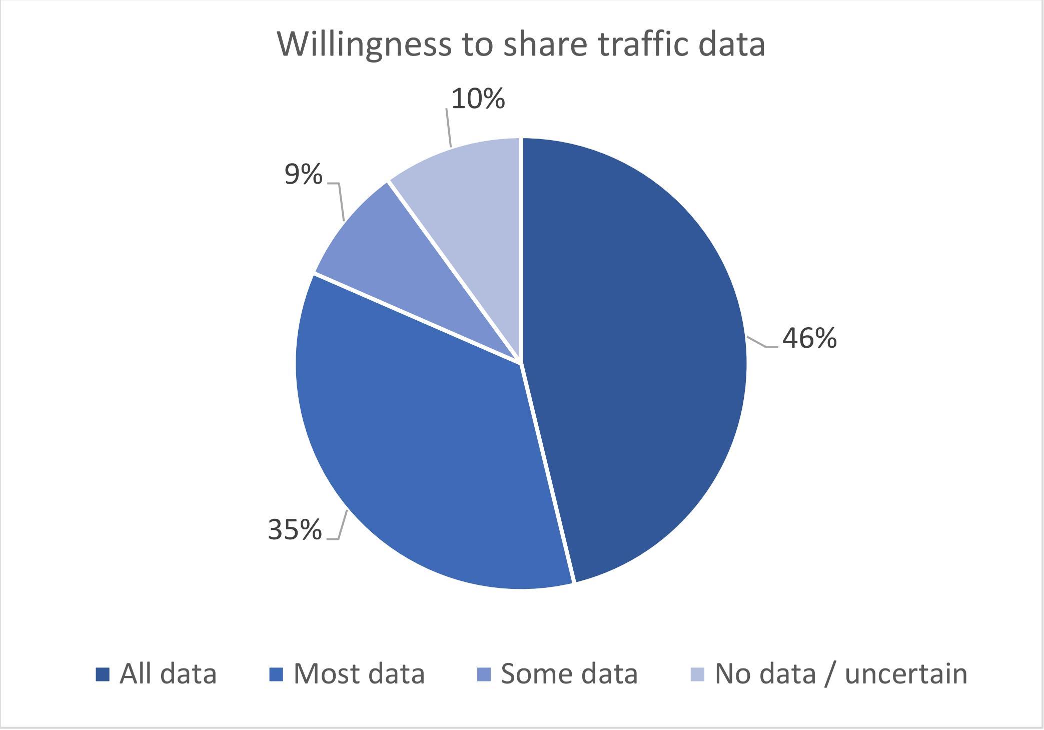


Figure 204 - Willingness to share traffic data (Hungary)

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.

10.4.4. 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 integration of the C-ITS in 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 hybrid application 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 hybrid application 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 hybrid application.

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 hybrid application.

Main results

Use of the C-ITS

First, the interviews showed that most professionals used the C-ITS 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 hybrid 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 hybrid 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 C-ITS 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.

Conclusion

In conclusion, the C-ITS and their merge with 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.

<u>Population</u>. 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.

<u>Material</u>. 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

<u>Population Description</u>. 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.

<u>Download and use the SP APP.</u>

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 91.1% of people said they like the interface, 92.4% didn't encountered tehcnical 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).
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, only 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, 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".
<u>Evaluation of the SP APP and Lee's determinants (2010).</u>
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 192 - 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)

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.

10.4.5. Summary

Nordic Way 2 & 3

C-ITS services were considered relevant by the Nordic drivers, 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.

Interviewed transport service providers supported the perceived need for real-time warnings and weather and driving data in the sector, especially for road weather information and for incident and hazard warnings. Better pre-information on challenges on the route or on importance of route change was highlighted. In addition, there was a high demand for width, height, and mass restriction data on roads, but problems have been identified in the timeliness of the information available publicly.

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, we have to improve the training in reporting the events as many users 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.

10.5. Functional Evaluation

10.5.1. 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).

10.6. 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 193 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 193 - 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.

Figure 205 - Body worn P2V device (antenna integration scenario)

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.
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.

Illustration: Epictura, Uni. Eiffel

Figure 206 - 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 207.

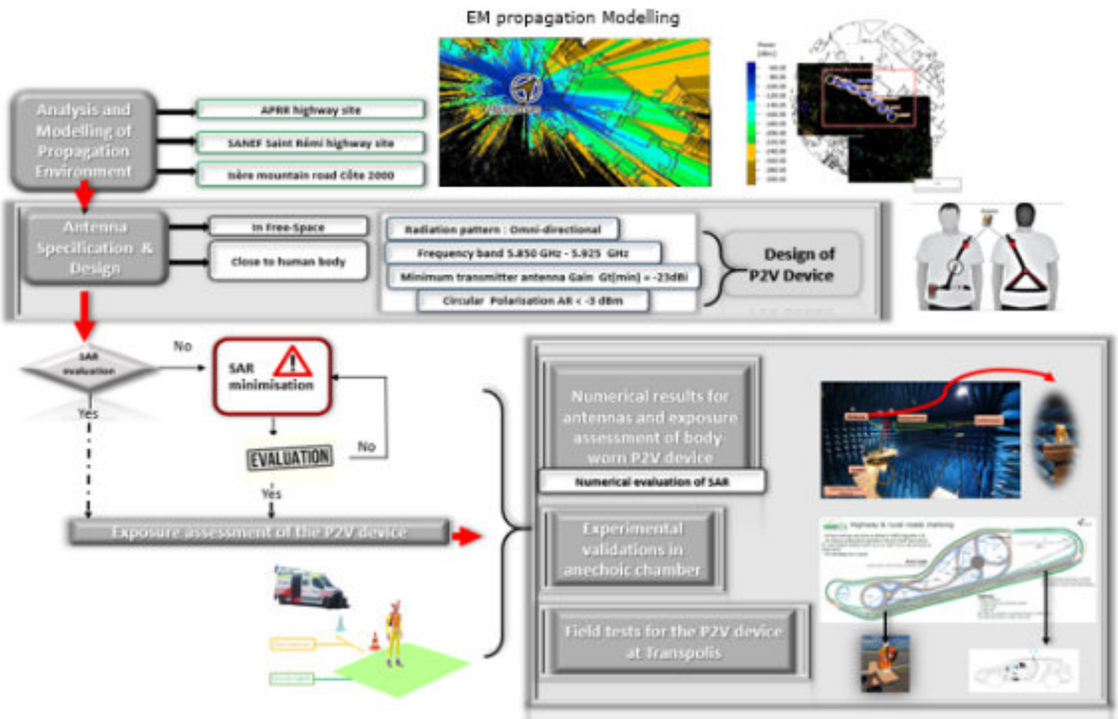


Figure 207 - Overview of the methodology for management of RF electromagnetic exposure "by design" of P2V device prototype (at a proof-of-concept stage)

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 208. 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 211.

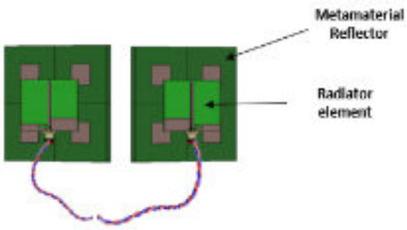


Figure 208 - Antenna system structure

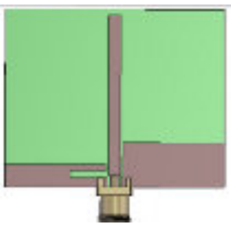


Figure 209 - Antenna design.

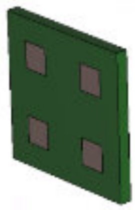


Figure 210 - Metasurfa reflector.

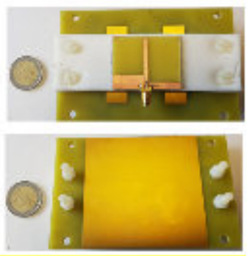


Figure 211 - Fabricated antenna system (Front and Top View)

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 194, 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 194 - 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 212 and Figure 213. 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

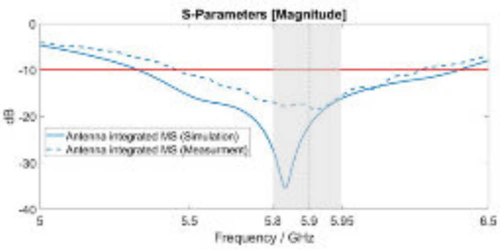


Figure 212 - Simulated Return Loss, validated by experimental.

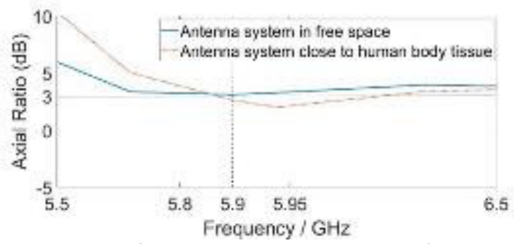


Figure 213 - Simulated Axial Ratio with/without body tissue effect.

The 3D radiation patterns in φ plane of the antenna system back-to-back, at 5.9 GHz, is shows in Figure 214 -. 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.

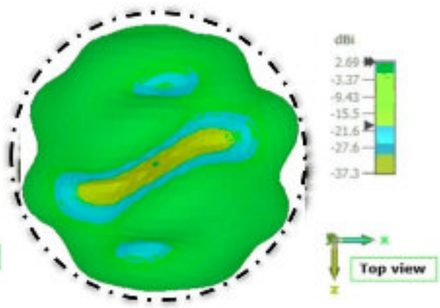


Figure 214 - 3D simulated radiation pattern, for the monopole antenna system - P1 version

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 215. Generally, the measured results match the simulations well in both the E- and H-planes.

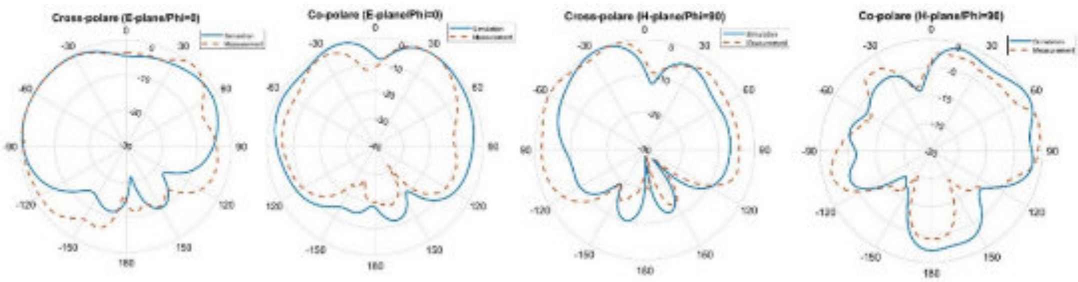


Figure 215 - Simulation validates with experimental measurements in E-plane and H-plane Cross polarization and Co polarization at 5.9 GHz.

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 216, when the antenna was put on the body tissue.

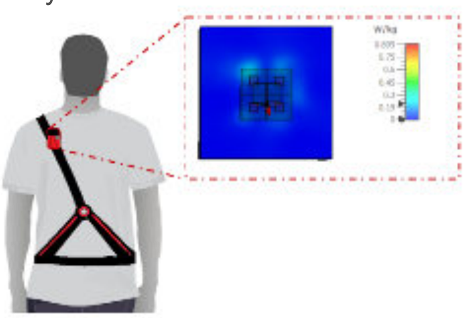


Figure 216 - Distribution of SAR values when the antenna with metasurface was placed on the body tissue at 5.9 GHz.

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.

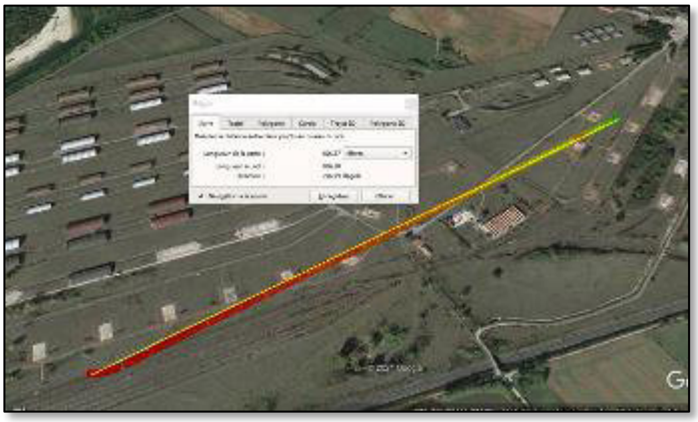


Figure 217 - Received Power Vs. Distance (dBV/Km) test on Transpolis highway road

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.

Additional Use Case: Approaching a Toll Station

The Figure 218 introduces the use case scenario, automated vehicle approaching a toll station.

When an automated vehicle (AV) is approaching a toll station, a specific message is sent by the traffic manager (TCC or the Toll Management Center (TMC)) to help it to orient itself to the electronic toll collection lane. The tolling zone can be approximated by a 10m long box measured from the DSRC Antenna position opposite the driving direction and a width that includes all lanes of one direction.

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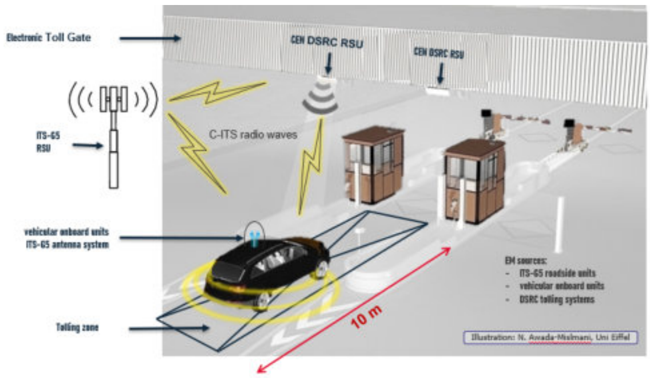

Figure 218 - Automated vehicle approaching a toll station (at the entrance).

Constraints:

- Risk of radio disturbance for electronic toll equipment that operates in a frequency range close to the G5 when approaching toll booths. This risk is addressed by installing RSUs well upstream of toll stations. Mitigation strategies have been described in standards.
- The incident C-ITS wave originating from RSU installed upstream of toll stations would not easily reaches the vehicles in the given target zone, due to the presence of metallic obstructions.
- The technological choices to address the above challenges should consider the electromagnetic exposure issues.

Evaluation method

The methodology proposed for connectivity solution at toll gates for deployment of IEEE 802.11p Road Side Unit, consists in the different steps depicted in Figure 219.

The different steps are as follows:

- formulating the mathematical models of the object and of the hologram;
- the numerical calculation of the generalized law of reflection and 2D Bessel Beams, resulting in a matrix that represent final phases distribution of the surface for generating 3D curved beam;
- encoding the phase information on the physical recording medium (metasurface)
- fabricating the metasurfaces,
- Measuring and testing;

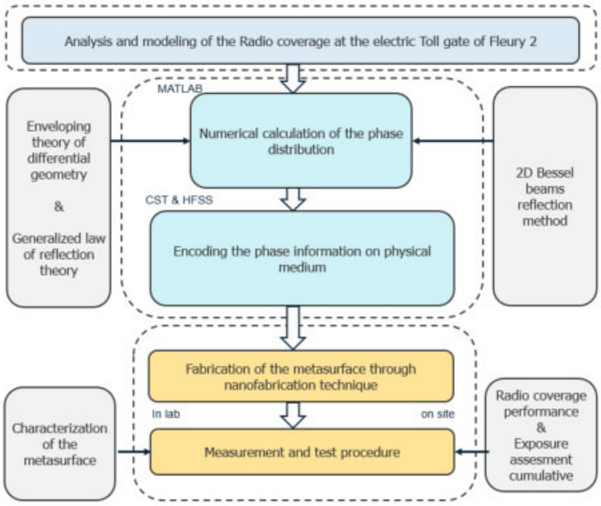

Figure 219 - Overview of the methodology for connectivity solution.

Proposed solution

Figure 5 shows the integration scenario at a toll roof for deployment of IEEE 802.11p Road Side Unit at a frequency of 5.9 GHz.

An incident wave originating from a Roof top RSU (6m height) would not easily reaches the vehicles in the given target zone, due to the presence of metallic obstructions.

In this case, we propose to introduce a metasurface at the roof in order to reflect the incoming RSU waves as a curved beam under the roof. It is based on an anomalous reflection of waves into a three-dimensional curved beam by relying on holographic techniques and the design of unconventional two-dimensional planar and passive metasurfaces.

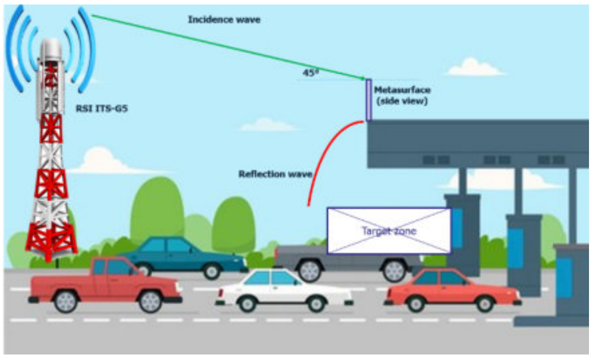

Figure 220 - Integration scenario at toll roof.

Concept description

In this section, we introduce a novel approach for anomalous reflection of waves into a three-dimensional curved beam. The surface phase distribution can be obtained by combining generalized law of reflection with the method for generating Bessel beams in 2D space in order to establish the input admittance of metasurface. Figure 221 shows the schematic of the

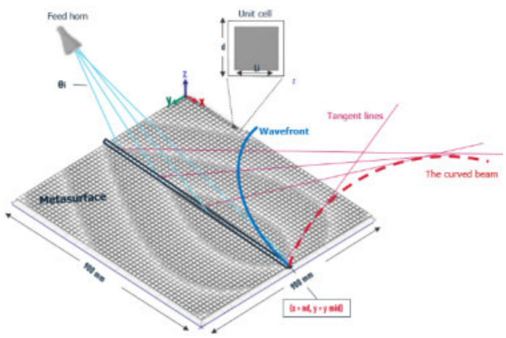

Figure 221 - The schematic of the curved beam generated from the holographic metasurface in xoz plane.

trajectory of the three-dimensional curved beam in xoz plane, generated by the metasurface.

The red bold dashed line is the self-bending beam we desire, defined as c(z). This envelope caustic is formed by a family of tangential geometrical rays. The blue line is the wave front of the beam, and the red lines are tangents to the curve.

Evaluation results

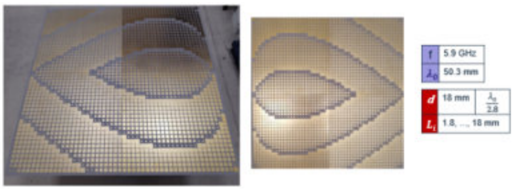

Figure 222 - Realized metasurface of dimensions 900 cm x 900 cm

In Figure 222, a realized prototype of the 2D passive metasurface of dimensions 900 cm x 900 cm is given. Figure 6 displays the scanning results of the electric fields distributions in the in x0z plane, representing the curved beam. The position of the brightest points of the simulated and measured curved beams in the z0x plane are extracted in Figure 6(right), comparing with the theoretical trajectory. It is obtained that the measured results coincide with the theorical and simulated results

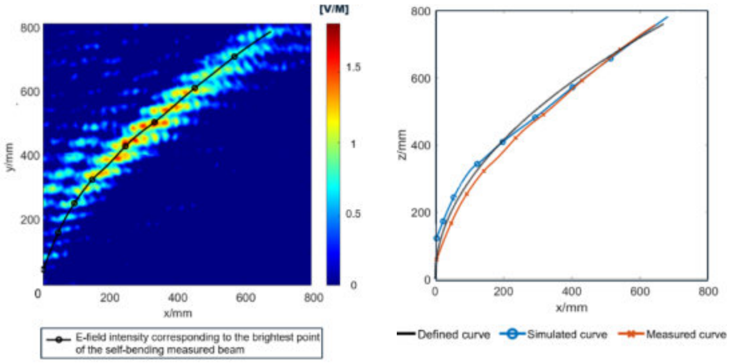

Figure 223 - (left) The experimental measurement of the curved beam. (right) E field intensity corresponding to the brightest point of the self-bending simulated and measured beam, with the defined curve.

Numerical evaluation of exposure: comparisons

We propose to evaluate the difference between the exposure levels for two scenarios, namely the case when the metasurface solution is deployed and the case when a simple deployment solution such that the one described inFigure 224. An antenna is installed under the toll gate to represent a RSU that could be deployed to solve the connectivity issue in the target zone.

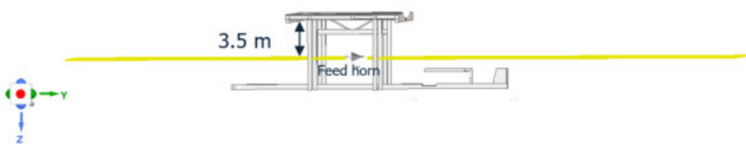

Figure 224 - Modeling approach depicts the feed horn antenna and the visualization plane positioned under the toll station.

The power levels are evaluated in the target area for identical input power levels. The difference in the power levels obtained is then calculated and shown in figure 8. The difference of electric field levels is directly proportional to the difference in EM exposure. From figure 8, one can observe that a difference of up to 50 dB in certain areas. This means that the exposure level would be around 300 times higher.

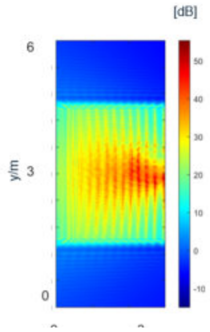

Figure 225 - Difference in the electric-field distribution (in dB) levels at z=3500 mm in x0y plane, under the toll gate at 5.9 GHz.

This clearly depicts that the connectivity solution based on the metasurface is highly beneficial to minimise the exposure level while ensuring good performances of the ITS-G5 system. Furthermore, it gives an additional degree of freedom for the deployment of RSUs in highly-metallic environments where EM waves propagation is difficult to tailor.

10.7. 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 195 - 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 196 - 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 197 - 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.

Co-funded by the European Union

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]	Innamaa, S. NordicWay 3 Evaluation Report. 25 April 2024. 46 p.
[RD.6]	Blomkvist A, Pedersli P, Andersson T, Andersson S, Oremus S, Almgren I (2024). Final report Activity 5: Road works warning. NordicWay 3.
[RD.7]	Swarco (2021). TLA Trondheim project report, rev. 3.0. SWARCO ITC controller SI_TLA Fixed Adaptive mode Intersection 016001227. 186 p.
[RD.8]	Thorn (2023). Email from Johanna Thorn, Univrses, to Satu Innamaa, VTT, on May 25, 2023.
[RD.9]	Legêne M, Montes Rojas A, Suijs L (2023). Draft of simulation results Uppsala. 9 p.
[RD.10]	C-Roads Italy - Evaluation and Assessment Report. Version 1.0. March 2022. C-Roads Italy 2 - Ex-post Evaluation Report. Version 1.0. December 2023. C-Roads Italy 3 - Evaluation and Assessment Final Report. Version 1.0. December 2023.

A. Appendix - Associate Member Queensland Pilot

The safety evaluation only focused on participants' response to the first five use cases listed in Table 47. IVS (Speed) was not evaluated due to the already large body of existing evidence which has already demonstrated its safety benefit.
For the five use cases being evaluated in the ICVP, there were nine warning messages available for the participants when the driving situation met the safety criteria. The number of safety warnings that were conveyed to the Treatment participants is listed in Table 198.

Table 198 - Number of warnings displayed by use case

Use case	Approach warning	Event warning
Road Work Warning	5,820	13,924
Back-of-Queue	4,981	Not applicable
Road Hazard Warning	504	Not applicable
Turning Warning for Vulnerable Road Users	6,063	6,821
Advanced Red-Light Warning	51,818 (Medium) 4,819 (High)	631

Out of the five use cases, the ARLW issued the highest number of warnings as the 29 intersections were permanently activated throughout the FOT, unlike the cellular use cases where the events were only temporary, such as the road works traffic congestions on motorways. The 57,000 ARLW warnings displayed equated to an average of one ARLW warning per participant per day.

A.1 Safety Evaluation

It was hypothesised that receiving a C-ITS warning on the HMI retrofitted in their car would lead to: Lower average speed, Lower celeration and Fewer near crashes. Five C-ITS use cases were analysed, these warnings were conveyed when drivers were approaching these compromised traffic conditions at an unsafe speed ("scenarios").
Drivers in the treatment group (90%) experienced the safety warnings for six months and no warnings for three months as baseline condition. The remaining 10% of drivers (the control group) did not experience any safety warnings. The analysis focused on comparing the driving profiles with and without warnings during the scenarios.

A.1.1 Safety results from the Pilot

The driving data from the pilot, showed positive safety results, overall, demonstrating improved driver behaviour. The analysis focused on testing if the display of safety warnings via the HMI had a significant safety impact on driving behaviour. Overall, most use cases indicated an improved safety outcome as speed and celeration reductions were reported, meaning the drivers might have more control of their vehicle to avoid any potential road hazards.

RWW was highly effective within the roadwork zone, potentially due to the HMI providing both the current roadworks speed limits and an alert when this was exceeded. In the approach to roadworks, the early warning resulted in a lower speed and also significantly greater deceleration (resulting in a higher celeration value) in the treatment group than the control group; the control group tended to not react prior to the roadworks.
ARLW and TWVR improved participants' driving behaviour by alerting participants as they approached traffic signals. A 22% reduction was found in red-light running when participants with and without the ARLW warnings were compared.
The dynamic spatial and temporal nature of BoQ created challenges in providing accurate warnings and in repeatability for the safety analysis. While there was no identified speed difference between the groups, the warnings encouraged smoother travel through the events indicating participants' greater awareness of the risk.
Analysis regarding RHW was limited with so few participants encountering the warning, as a result, the statistical modelling did not yield any conclusive findings on driving behaviour.

A.1.1.1 South East Queensland (SEQ) crash reduction estimates

The speed results were scaled from the pilot level to the SEQ 100% market penetration level. The principle of Nilsson's power model was used to estimate crash reduction factors for fatal and serious injury types. The crash reduction rates for the individual use cases ranged from 3-11% of the relevant crash types and additionally 22% reduction was determined from the ARLW red-light running analysis. By considering all the use cases which indicated a significant reduction in speed, the overall crash reduction rate with reference to all crashes in the SEQ road network is estimated to be 2-7%.
To provide an overall crash reduction factor for future foundational C-ITS deployment, the estimation of crash reduction factors was extended to include two other use cases unable to be tested on-road and so were tested in a driving simulator instead. These vehicle-to-vehicle use cases were: Slow-Stopped Vehicle (SSV) and Electronic Emergency Brake Light (EEBL). The cumulative reduction was estimated at 5-12%. When including the In-Vehicle Speed (IVS) as a likely early use case which has been assessed in another Australian study (Doecke & Woolley, 2010), the overall crash reduction rate for the fatal and serious injury types is estimated to be 13-20%.

A.1.2 Study Methodology

The primary research question for the safety evaluation was:

Does the system improve road safety?

It was expected the C-ITS warnings produced by the system would result in a positive impact on driving behaviour and consequently, a reduction in the number and severity of crashes. The expected effects on the three surrogate safety measures employed in the evaluation were:
Lower average speed – the average speed on approach to and/or within use case events would be lower when the HMI was enabled (i.e., when the HMI was on).
Lower celeration – the value of the celeration on approach to and/or within use case events would be lower when the HMI was enabled. Celeration is defined as the average of absolute acceleration and deceleration values, as an indicator of the smoothness of the drive. The concept is illustrated in Figure 226. A lower value of celeration indicates a smoother driving profile, most likely with less abrupt braking and accelerating over the course of a drive.

Reduced near-crashes – the likelihood of near-crashes on approach to and/or within use case events would be reduced when the HMI was enabled (i.e., when the HMI was on).

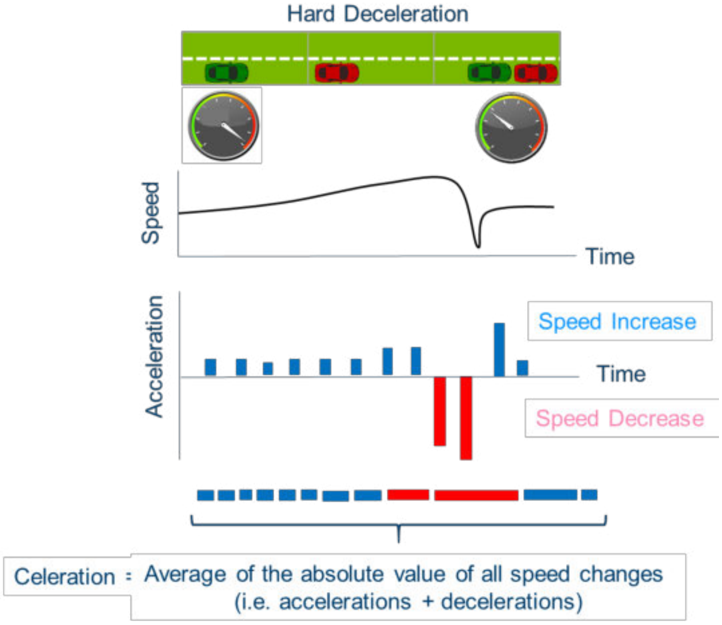

Figure 226 - Derivation of the measure of celeration from the driving response

A.1.2.1 Experimental Design

The pilot successfully recruited 355 drivers to participate in the ICVP for a nine-month period. The participants were randomly assigned to different experimental conditions for statistical rigour and comparative purposes. One group of participants drove their own vehicle for six months with the retrofitted C-ITS system to experience the safety warnings (treatment condition) and for three months without the warnings displayed on HMI (baseline condition). Another group of participants was assigned to a control condition whereby no warnings were shown, to account for seasonal effects and balance the driving observations in the baseline condition.
Of the 355 recruited participants, only 349 participants were found to produce sufficient valid objective data for analysis. The number of participants (n) assigned to each cohort and the duration of each condition is shown in Figure 227.

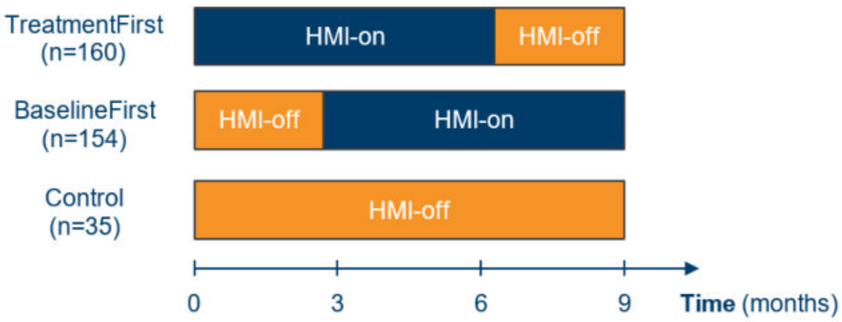

Figure 227 - Sample size and duration of experimental conditions

To ensure sufficient driving data were collected, participants were required to drive a minimum of three hours per week within the pilot area. The driving data showed that most participants consistently met this requirement during their nine-months of participation.

A.1.2.2 Scenario-based assessment

The safety evaluation focused on participants' driving behaviour only within windows where participants encountered a use case event (referred to as a "scenario"). The scenarios generally covered 30 seconds before the warnings were warranted and 30 seconds after the driver had passed by the safety hazards. A single journey could consist of multiple scenarios when driving within the pilot area as illustrated in Figure 228.
For comparative purposes and to increase statistical rigour of the findings, scenarios with (treatment) or without (control/baseline) HMI warnings were included in the safety analyses. The different levels of HMI warning are shown in **Errore. L'origine riferimento non è stata trovata.**.

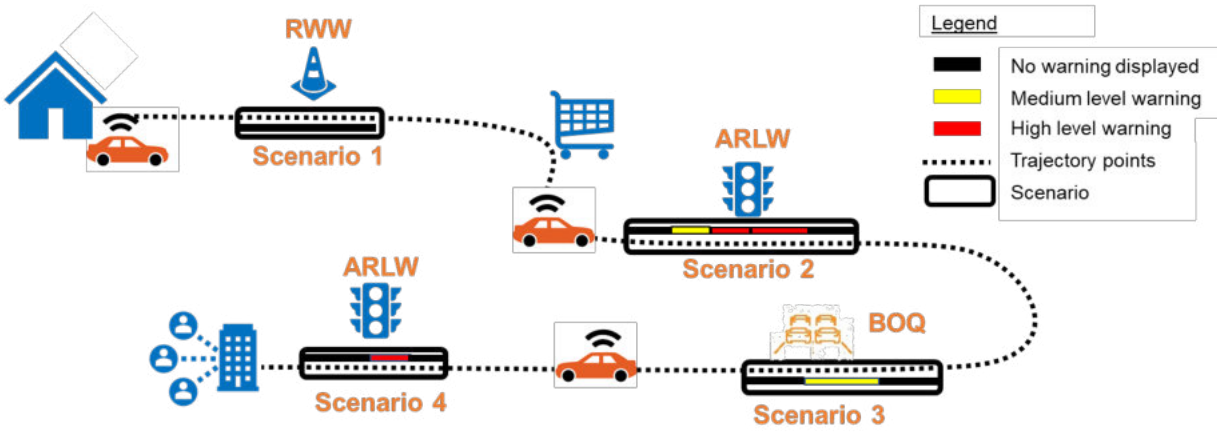

Figure 228 - Example of a Treatment participant encountering multiple scenarios in a single journey

A.1.3 Safety Findings

After the driving data were processed into over 100,000 valid scenarios, the three safety surrogate measures were analysed for the five use cases. Statistical modelling was employed to determine if the individual use cases had a significant impact on the driving speed, celeration and near-crashes. Other environmental factors, such as the prevailing road conditions and participants' demographic characteristics, were also considered in the models.

A.1.3.1 Average Normalised Speed

The speed measurements for each scenario were divided by the displayed speed limit to obtain a normalised speed ratio which allows analysis with a combination of different road types. A normalised speed value above 1 means the observed speed exceeded the displayed speed limit.
RWW, TWVR and ARLW showed a beneficial impact on the average normalised speed, with a statistically significant reduction of 1-2% in driving speeds as participants approached the safety event as is shown in Table 199. Although 1-2% change might not be considered "significant" in magnitude, the statistical testing indicated that the reduction was consistently observed across the participants who had the HMI enabled. Road safety research indicates that for every kilometre reduction in impact speed, the risk of serious injury in vehicle crashes reduces, especially in high-speed environments.
The RWW warning within the road work zone was found to reduce speeds by 3.1% reduction for those participants who had the HMI enabled. RWW event warnings could be

issued multiple times within the road work zone, serving as continuous reminders when the Treatment participants exceeded the road work speed limit.

BoQ and RHW did not show any significant difference between the participants with or without the HMI enabled. The study was thus unable to draw any conclusive findings due to the variability in conditions found in triggering these two use cases. For BoQ, the dynamic nature of congestion on the motorway context was difficult to capture in the analysis model. For RHW, the low number of scenarios meant that no conclusive findings could be determined.

Table 199 - Speed comparison between HMI-on and HMI-off conditions

Use case	Impact of C-ITS warnings on average speed	
	Approach zone	Event zone
RWW	**1.1% reduction**	**3.1% reduction**
BoQ	Nonsignificant change	Not applicable
RHW	Nonsignificant change	Not applicable
TWVR	**1.2% reduction**	Not applicable
ARLW	**1.9% reduction**	Not applicable

What does this mean?

The participants in Treatment group were consistently driving **2.1km/h slower** than those without the warning available.

The speed analysis was generally undertaken in the approach zone because the purpose of the use cases was to increase awareness of drivers through the warning of a changing condition in advance of the event. The increased awareness served as a preventative measure; by contrast, analysing speed in the event zone does not give an indication of the warning effectiveness on safety, given a driver would have already encountered the event. Except for RWW, some road work sites spanned over a few hundred metres (e.g., the Centenary Highway Sumners Road Interchange Upgrade, as shown in Figure 229), so the continual Event warnings were found to be effective in terms of Treatment participants driving below the road work speed limit throughout the site.

Figure 229 - RWW displayed on Centenary Highway at Sumners Road Interchange

A.1.3.2 Average Celeration

The average deceleration/ acceleration upon receiving a warning can be an indicator of participants' preparedness for the safety event. If the Treatment group (HMI-On) showed reductions in celeration, these reductions would suggest the warnings had provided them more time to gradually adjust their speed, rather than braking or accelerating abruptly closer to the hazards.

All use cases, except for RHW, showed a statistically significant change in celeration after the Treatment participants received a warning. As shown in Table 200, RWW (in Event zone), BoQ, TWVR and ARLW reported a 0.9-7.9% reduction for the participants with the HMI enabled, suggesting the warnings were effective in minimising aggressive manoeuvres. In contrast, RWW in the Approach zone reported an increase of 4.7%. Investigation of the RWW Approach driving profile revealed that the Treatment participants reacted to the advanced warning by braking prior to the roadworks (compared to the control group who tended to not react in this approach analysis window). This finding was considered a positive safety outcome in that participants were braking prior to the roadworks despite the higher variance in celeration that was recorded in their driving behaviour.

The evidence of a large percentage reduction in celeration, combined with a reduction in average speed, indicated that TWVR could improve driver's awareness of pedestrians' presence as the drivers approached an intersection. Consequently, the drivers could adjust their speed appropriately.

Table 200 - Celeration comparison between HMI-on and HMI-off conditions

Use case	Impact of C-ITS warnings on average celeration	
	Approach zone	Event zone
RWW	4.7% increase	3.7% reduction
BoQ	2.8% reduction	Not applicable
RHW	Nonsignificant change	Not applicable
TWVR	7.9% reduction	Not applicable
ARLW	0.9% reduction	Not applicable

Is an increase necessarily a bad safety outcome?

An increase could be caused by participants correcting their driving in response to the warnings. It might not be a bad safety outcome as they would have reached the event at a safer speed.

A.1.3.3 Near Crashes

As there were no crashes reported in the proximity of the safety events during the pilot, near-crashes were proposed as a surrogate measure to infer the likelihood of being involved in a crash. A near-crash are generally defined as any circumstance that requires a rapid, evasive manoeuvre by a participant's vehicle to avoid a crash. A rapid, evasive manoeuvre is defined as excessive steering, braking, or accelerating that can cause discomfort to the passengers.

As near-crashes have not previously been used to evaluate any C-ITS applications, three near-crash analysis methodologies which had been applied in other naturalistic driving studies were tested in parallel in the ICVP. The three methodologies employed were kinematic performance thresholds, machine learning models and driving volatility measures. All these methodologies focused on the longitudinal acceleration and deceleration, lateral acceleration and yaw rate logged by the vehicle station.

From these three methods, only BoQ suggested a potential reduction in near-crashes of 30-50% as a result of the HMI being enabled. All other use cases were unable to detect any near-crashes or significant impacts, based on kinematic performance and machine learning methods. There are two main reasons for the lack of near-crashes findings: (1) near-crashes are rare and potentially severe events and by only focusing on small time windows around the warnings, the chance of observing a near-crash is even narrower, and (2) the absence of video footage data to support calibration of the models to local driving conditions.

A.1.3.4 Additional ARLW Observations

Apart from the three key safety measures being tested, the ARLW offered opportunity to investigate other safety outcomes including:

Fewer red-light running instances

As red-light violation is a serious traffic offence and could result in a serious safety outcome, the occurrences of red-light running were compared between the Treatment and Control conditions as an extension analysis. The analysis suggested a positive outcome, with 22% reduction found in red-light running between the two conditions.

Less chance of receiving high-level warning after receiving medium-level warning

Warning escalation is defined as a driver receiving a subsequent high-level "take action" warning after receiving a medium-level "heads up" warning. This could be seen as driver's compliance with the initial warning, as they would slow down attentively to avoid the next level of warning. The analysis revealed a positive outcome, as the participants with HMI enabled were 27% less likely to receive a high-level warning than those without the HMI enabled after they received the medium-level warning.

A.1.4 Potential Crash Reductions

Converting the safety impact estimates into crash reduction factors assists with community communication regarding the effects of C-ITS. The crash reduction factors were scaled up to reflect the future scenario of when C-ITS being used by all vehicles, therefore assuming a 100% market penetration in Southeast Queensland (SEQ). To this end, the safety evaluation estimated the crash reduction rate for each use case.

A.1.4.1 Crash reduction by FOT use cases

To estimate a crash reduction rate for each use case, a widely accepted speed scaling model, known as the Nilsson Power Model was adopted. The main tenet of Nilsson's Power Model is "the safety of the transport system is strongly related to the speed levels in the system". The premise of the model is that a small reduction in speed adopted by the driving population leads to large and measurable reduction in risk.

As only RWW, ARLW and TWVR demonstrated a significant speed impact in the FOT, only these three use cases were scaled for crash reduction estimation. As shown in Table 201, the reduction rates ranged from 3-11%, with the fatal crash type being higher than the serious injuries type, due to the "power" for fatalities being higher. As expected from the speed analysis, RWW in the event zone showed the highest reduction rate for those crashes resulting in fatality or serious injury.

Based on the driving data from the participants, the ARLW warnings could reduce the likelihood of running red traffic signals and thus reduce a potential intersection crash by 22%.

Table 201 - Crash reduction rate of FOT use cases

Use case	Estimation method	Crash reductor factor	
		Fatalities	Serious Injuries
RWW (Approach)	Speed scaling model	5.3%	3.0%
RWW (Event)	Speed scaling model	11.4%	6.8%
TWVR	Speed scaling model	6.1%	4.3%
ARLW (Approach)	Speed scaling model	9.7%	5.9%
ARLW (Event)	Red-light running likelihood	22.0%	22.0%

A.1.4.2 Overall crash reduction for all ICVP use cases

It should be noted that the crash reduction factors reported in Table 201 are only relevant to the crash types which are targeted by the individual use cases. For example, RWWs are expected to be effective in reducing crashes in the proximity or within road work zones, while TWVRs are expected to reduce crashes involving pedestrians at signalised intersections.

This assessment also considered the crash reduction rate of other ICVP use cases that were not evaluated as part of FOT as they were considered likely to be incorporated in future C-ITS implementations. In the simulator study, the Slow-Stopped Vehicle (SSV) and Electronic Emergency Braking Light (EEBL) warnings both reported significant reductions in average speed, ranging from 2.4 km/h to 5.0km/h. The speed reductions were then converted to the crash reduction rates using the Nilsson's power model, resulting in 4.5% to 25.3% crash reductions as shown in the shaded columns in Table 202.

In the Intelligent Speed Assist review undertaken for most states in Australia[16], IVS was reported to reduce the crash rate by 7.7%. As IVS is planned to be available for the entire whole road network, it can be assumed that the reduction rate would be applied to all types of crashes.

In order to determine the overall safety benefits for SEQ, the use case crash reduction factors were applied to the relevant fatal and serious injury crashes within a five-year period (from 1 July 2016 to 30 June 2021). The network-wide crash reductions were provided in ranges. The lower bound values were estimated based on a conservative approach, whereby only the crash types that were specifically targeted by the individual C-ITS use cases were considered. The upper bound values took a broader approach by considering the environment that the C-ITS use case could impose a positive safety impact. For example, the lower bound value for ARLW (Event) was exclusively applied to the crashes with "disobey red traffic light" as a crash contributing factor, while the upper bound value was derived by considering any crashes occurred in the proximity of signalised intersections in the urban area. Table 202 summarises the crash reduction rates for the SEQ road network (refer to the columns with lime green heading in Table 6).

Table 202 - Crash reduction rates for the SEQ road network

Use case	Information source	Crash reduction (relevant crash types)		Crash reduction (SEQ network)	
		Fatalities	Serious Injuries	Fatalities	Serious Injuries
RWW (Approach)	ICVP FOT	5.3%	3.0%	0.0%	0.0% - 0.2%
RWW (Event)	ICVP FOT	11.4%	6.8%	0.0% - 0.6%	0.0% - 0.2%
TWVR	ICVP FOT	6.1%	4.3%	0.2%	0.1%
ARLW (Approach)	ICVP FOT	9.7%	5.9%	0.2% - 0.4%	0.4% - 1.0%
ARLW (Event)	ICVP FOT	22.0%	22.0%	1.0% - 5.6%	1.2% - 5.1%
SSV	ICVP Simulator	7.5%	4.5%	0.6% - 1.2%	0.9% - 1.4%
EEBL	ICVP Simulator	25.3%	15.1%	1.4% - 3.6%	2.6% - 4.4%
IVS	Literature	7.7%	7.7%	7.7%	7.7%
			Cumulative total	**11.1% - 19.3%**	**12.9% - 20.1%**

Table 202 shows that three ICVP FOT use cases could cumulatively reduce up to 6.8% of fatal crashes and 6.6% of crashes involving serious injuries. When the vehicle-to-vehicle use cases (SSV and EEBL) are included, the cumulative reduction rates are 11.6% and

[16] Doecke, S. & Woolley, J.E. (2010) *Cost Benefit Analysis of Intelligent Speed Assist.* Centre for Automotive Safety Research, The University of Adelaide.

12.4% for fatalities and serious injuries, respectively. By including IVS, the overall reduction rates are estimated as 19.3% and 20.1% for fatalities and serious injuries, respectively. It should be noted that including IVS in the assessment does introduce some potential duplication of warning impacts.
In a broader context, with a total of 526 fatalities and 20,826 serious injuries being reported from crashes on the SEQ road network over the five-year period of 1 July 2016 and 30 June 2021, the eight C-ITS use cases implemented in the ICVP could have prevented up to 101 fatalities and 4,198 serious injuries from crashes. This equates to an average of 20 fatalities and 840 serious injuries prevented each year in SEQ.

A.2 User Acceptance

A.2.1 ICVP Subjective Evaluation Study: Study Methods and Design

As a longitudinal study extending over nine months (of driving) and featuring various data collection points and methods, sample sizes did vary as a function of these aspects. As Figure 230 shows, the subjective evaluation comprised self-report data collection throughout the Field Operational Test (FOT) of the ICVP in the form of four questionnaires as well as individual interviews. At the conclusion of the FOT, once the C-ITS equipment had been removed from all participants' vehicles, focus groups were conducted.

Although the questionnaires were a study requirement and completed by most ICVP participants at each time (refer to Figure 230), the interviews and focus groups were optional and based on a subsample of the total sample. As Figure 230 shows, N = 53 and N = 47 participants completed the interviews and focus groups, respectively.

Figure 230 also highlights participants were randomly assigned into either of two groups; Treatment, that had an active HMI (received warnings), and Control, that had an inactive HMI. As Figure 230 shows, ICVP Treatment participants were counterbalanced into baseline- or intervention- first conditions. The numbers of participants cited in these conditions (as denoted by the numbers within the red dotted circle shown in Figure 230) reflect those who participated for the duration of the FOT (i.e., nine months). Driving (objective) and self-reported (subjective) data were collected over nine months regardless of experimental group. A counterbalanced between-groups methodological design with random allocation, such as that employed in the ICVP ensures that robust statistics can be calculated, and analyses performed. This gives greater confidence that findings are less likely to be a result of random chance and are therefore generalisable to the larger driving population.

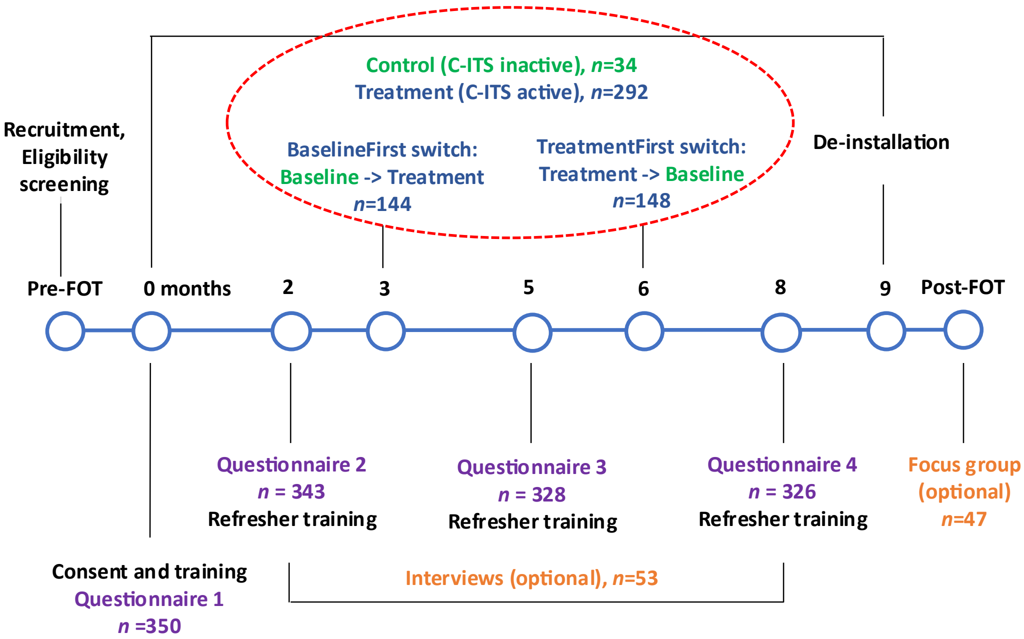

Figure 230 - The design of and methods used within the Ipswich Connected Vehicle Pilot (ICVP).

A.2.2 Participant sample representativeness

The ICVP participant sample was considered relative to TMR licensing statistics[17]. Although the ICVP sample was slightly younger with a mean age of 46.61 years (SD = 13.76 years) (see Figure 231), any potential impacts of self-selection bias were considered minimised to the extent that the sample was considered representative of the licensed driver population in Queensland.

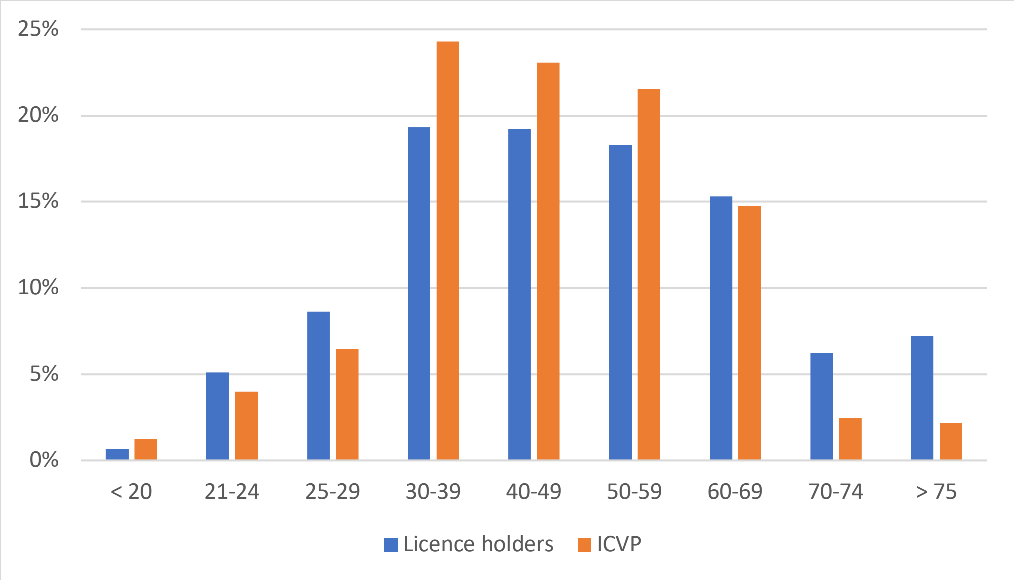

Figure 231 - ICVP sample and QLD licence holders age distribution comparison.

The final sample of participants in the ICVP were equally divided between those identifying as male and female and had a diverse range of education, with the majority reporting having completed either university or TAFE (see Figure 232).

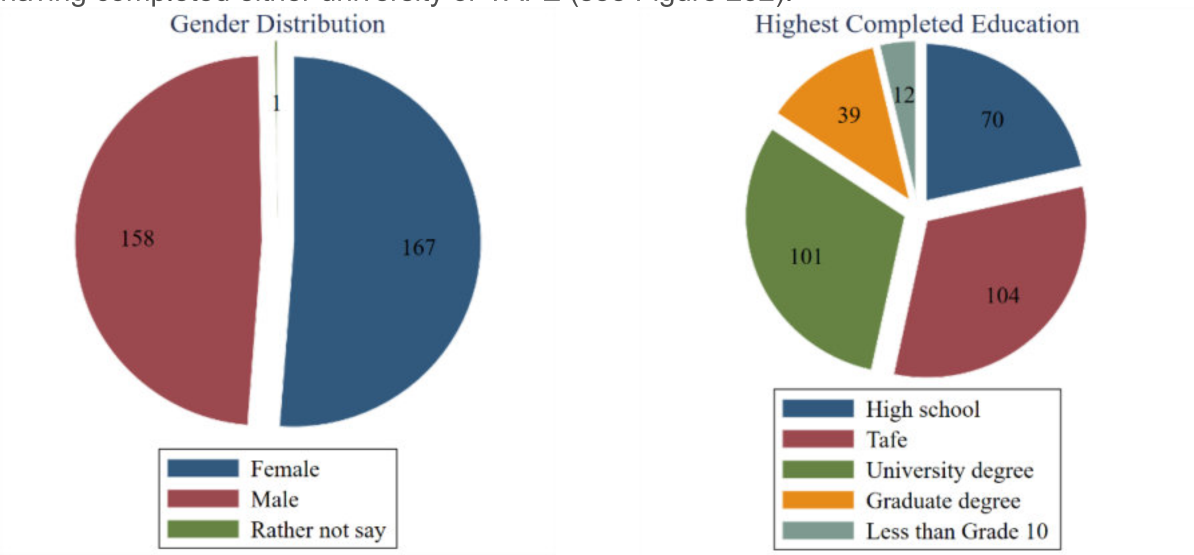

Figure 232 - Snapshot of the demographics of the final sample of ICVP participants

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17 https://www.tmr.qld.gov.au/safety/transport-and-road-statistics/licensing-statistics.aspx

A.2.3 Self-report Method 1: Questionnaires

The questionnaires (four in total, comprising Questionnaire 1 [Q1], Questionnaire 2 [Q2], Questionnaire 3 [Q3], and Questionnaire 4 [Q4]; see Figure 230 for timing of administration and sample details) investigated participants' acceptability before in-vehicle equipment installation (Q1) and acceptance following experience with the C-ITS equipment (Q2-Q4 inclusive). Also assessed were participants' perceptions of safety, experiences relative to warnings, and the overall design of the system. Most items used Likert-type response scales ranging from 0 to 100 with higher scores indicating greater agreement. Linear mixed effects regressions were conducted to analyse the questionnaire data.

Key findings related to six overarching aspects, including:

- **Positive expectations of C-ITS.** Participants had positive expectations regarding the C-ITS prior to the equipment being installed in their vehicle and, overall, their expectations remained positive throughout their time in the FOT. Such findings suggest that C-ITS is likely to be well-received by Queenslanders more broadly when commercially deployed.
- **C-ITS perceived as beneficial to safety.** Overall, participants reported that the C-ITS had safety benefits for them and that the HMI had the ability to capture awareness without being distracting.
- **System design generally approved.** Participants generally approved of the ICVP's system design (e.g., HMI display, warning content, and timing) acknowledging it was a pilot of the technology. However, findings also suggested that it would be beneficial for warning timings to align more with drivers' expectations of when they should occur. Improvements to the timing of warnings may encourage more effective interactions with the system and support drivers' decision-making and safer driving behaviour.
- **Experiencing HMI warnings not directly associated with lower acceptance but a deterrent for continued use of the system.** There did not appear to be a direct relationship between participants' acceptance ratings and the actual number of warnings (simple count) they experienced (as obtained from data collected from vehicles). However, participants who experienced warnings more often were less likely to opt-in for continued use of the C-ITS.
- **Decreased attitudes toward C-ITS from expectations after experiencing active HMI.** The results suggested that experiencing the active HMI warnings slightly reduced participants' acceptance towards the C-ITS technology compared to their expectations reported in the previous questionnaire when the C-ITS was inactive. This finding was detected via small decreases in ratings over the four questionnaires in acceptance, intent-to-use, intent-to-buy, and usefulness of the use cases. The ratings remained positive with the average rating sitting above 60%; however, as shown in Figure 233 after a group changed to an active HMI condition there was an approximately 3.5-4% drop from their original expectation. These data suggest that the implementation of the C-ITS deployed in the ICVP did not meet participants' expectations; however, their overall attitudes toward C-ITS were still positive. Assessing Figure 234, between Questionnaire 1 and Questionnaire 4 the Treatment groups reported lower predicted usefulness of the collective use cases although responses are still weighted towards the 'useful' end of the scale suggesting that participants' expectations remained positive overall.

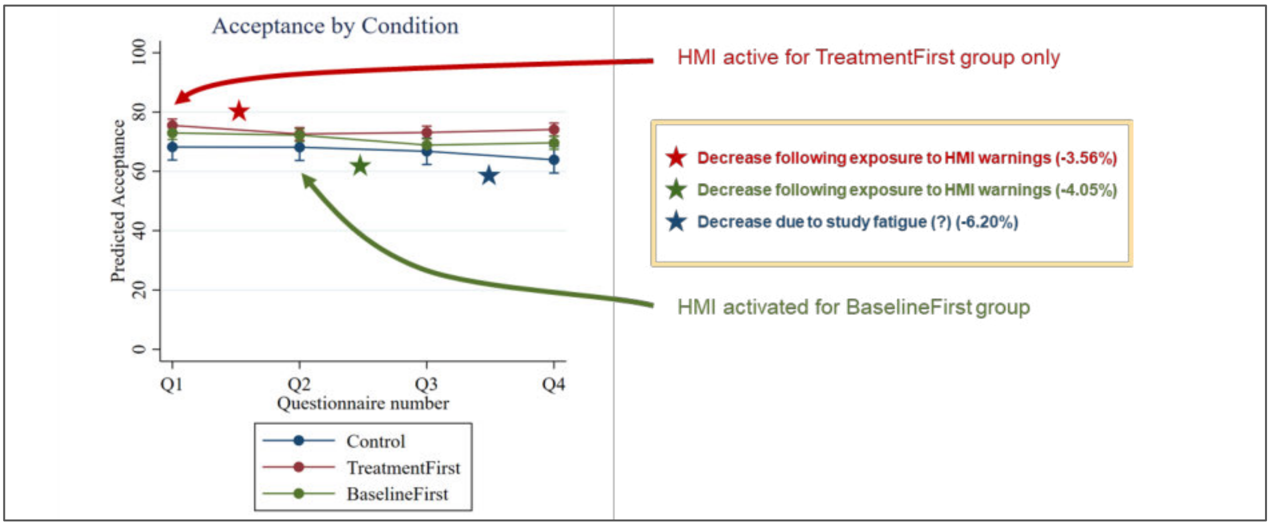

Figure 233 - View of the Acceptance data which measured participants' expectations and attitudes towards C-ITS. The generally positive (high) ratings and slight negative trends following exposure to the HMI were detected for many measures.

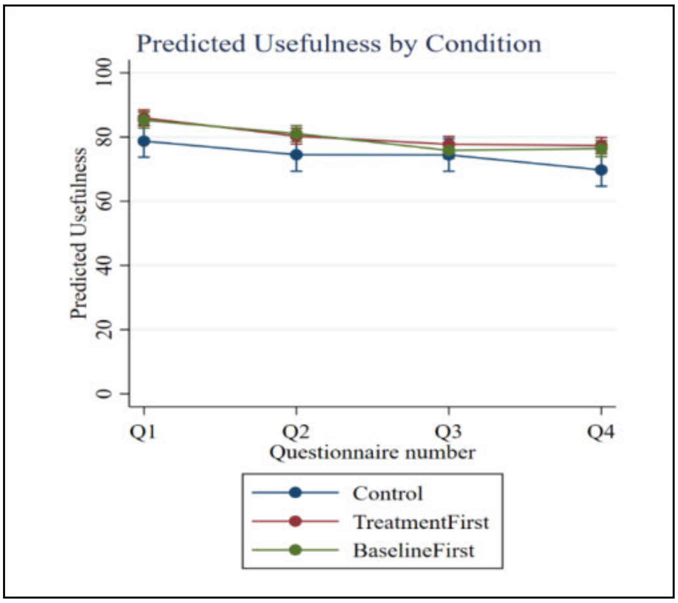

Figure 234 - Marginal effects of the usefulness of each use case based on condition and questionnaire number.

- **Use cases perceived as useful.** Participants' ratings of the usefulness of each independent use case remained high throughout the FOT. Figure 234 and Table 203 depict the usefulness findings overall as well as for each individual use case, respectively. Uniformly, over the four questionnaires, treatment participants rated in-vehicle speed (IVS) as the most useful (Table 203, rightmost column, rows labelled "IVS") while advanced red-light warning (ARLW) and turning warning for vulnerable road-user (TWVR) tended to be the two use cases rated the lowest. Other than IVS, the use cases tended to have lower usefulness rating and greater variability in latter questionnaires, compared to earlier questionnaires (see Table

203 , “Q Grand mean” rows, columns Questionnaire 1, Questionnaire 2, or Questionnaire 3 versus column Questionnaire 4). As shown in Figure 235, most (>65%) participants reported that none of the individual use cases should be removed, suggesting they could see benefit in all of them. In Figure 235, there is clear indication across experimental conditions and consistently throughout the four questionnaires that participants indicated no use cases should be removed.

Table 203 - Mean usefulness ratings (Standard Deviation) of use cases across the 4 questionnaires and study group and overall.

Group		Questionnaire 1	Questionnaire 2	Questionnaire 3	Questionnaire 4	Use case Grand mean (SD)
	Use case	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Control	ARLW	75 (21)	67 (26)	74 (20)	67 (21)	71 (22)
	BOQ	82 (15)	76 (20)	78 (20)	71 (24)	77 (20)
	TWVR	74 (19)	70 (26)	68 (23)	65 (23)	69 (23)
	RHW	83 (14)	78 (19)	77 (19)	72 (22)	78 (18)
	RWW	77 (19)	75 (22)	74 (23)	67 (25)	73 (22)
	RWW-Speed	79 (20)	73 (23)	75 (19)	70 (23)	74 (21)
	IVS	85 (13)	87 (15)	82 (20)	82 (18)	84 (16)
	Q Grand mean (SD)	79 (17)	75 (22)	75 (20)	71 (22)	
TreatmentFirst						
	ARLW	83 (17)	75 (24)	73 (25)	72 (24)	76 (23)
	BOQ	88 (14)	81 (19)	78 (23)	77 (21)	81 (19)
	TWVR	81 (20)	73 (25)	68 (27)	68 (26)	73 (25)
	RHW	88 (13)	82 (17)	81 (20)	77 (19)	82 (17)
	RWW	85 (17)	79 (20)	76 (25)	77 (19)	79 (20)
	RWW-Speed	87 (15)	83 (19)	81 (20)	80 (20)	83 (19)
	IVS	90 (14)	91 (14)	90 (17)	90 (18)	90 (16)
	Q Grand mean (SD)	86 (16)	80 (20)	78 (22)	77 (21)	
BaselineFirst	ARLW	83 (17)	79 (18)	68 (27)	72 (26)	75 (22)
	BOQ	89 (13)	82 (19)	75 (25)	75 (26)	80 (21)
	TWVR	78 (18)	77 (20)	67 (27)	67 (28)	72 (23)
	RHW	86 (14)	81 (17)	75 (26)	76 (23)	80 (20)
	RWW	85 (15)	79 (18)	75 (25)	77 (23)	79 (20)
	RWW-Speed	86 (14)	81 (20)	78 (22)	78 (21)	81 (19)
	IVS	88 (17)	88 (18)	90 (15)	88 (18)	89 (17)
	Q Grand mean (SD)	85 (16)	81 (19)	76 (24)	76 (24)	

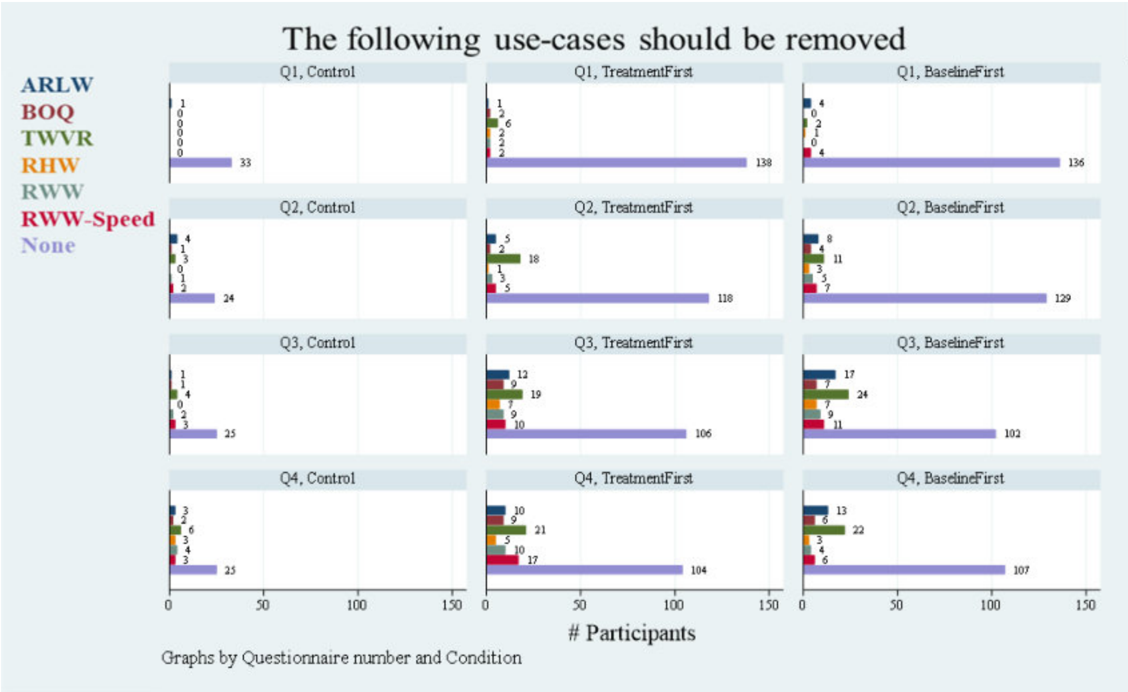

Figure 235 - Use cases that participants perceived should be removed.

Note: The labels on the Y-axis are the same for each graph, but only displayed once, enlarged in the top left corner. The bottom bar for each graph (i.e., purple bar labelled as “none”) indicates that most participants reported that all the use cases should remain as part of the system.

A.2.4 Self-report Method 2: Interviews

The aim of the interviews was to gather qualitative data about participants’ views of the ICVP C-ITS technology. Specifically, their experience of the technology, willingness to use it, perceptions of the technology’s impact on their behaviour, and ultimately its impact on safe driving. The telephone interviews were of about 10 minutes’ duration and were conducted in three phases (refer to Figure 230 for timing and sample details) throughout the FOT. They were guided by a semi-structured interview schedule and were audio recorded. Owing to data saturation (i.e., no new or novel information emerging), and in line with qualitative methods, the schedule was modified for each phase to ensure thorough exploration of participants’ experiences with the technology. Question-by-question deductive conceptual content analysis was conducted, whereby the analysis of data sought to capture in-depth insight relevant to each of the questions explored. Data analysis was based on notes documented by the research team. The findings of the interviews were generally consistent across all three phases of data collection, despite interview schedules being amended to explore new issues over time.

Overall, findings were generally positive and related to six main concepts, including:

- **In-vehicle Speed (IVS) was perceived most positively.** IVS was the most discussed and most well-liked use case across all three phases of interviews. Nearly all participants reported that IVS was a helpful addition to their driving with it representing a trusted information source to confirm the speed limit in unfamiliar or inadequately signed areas.
- **Advanced Red-Light Warning (ARLW) and Turning Warning Vulnerable Road-User (TWVR) warnings were not that useful because they came too**

early, too late, or when not needed. ARLW and TWVR were discussed less often than IV**S**. Nevertheless, many participants mentioned experiencing them. When discussed, these use cases were typically associated with neutral or negative comments regarding their accuracy, timing, and participants' general experience when presented with them. Many participants suggested that timing needed to be adjusted for these use cases to be helpful, but also that the warnings were triggered inappropriately resulting in false or nuisance alarms.

- **Reactions to other warnings were mixed but the amount of experience with these warnings was lower.** In Phases 1 and 2, Road-Works Warnings (RWW) were deemed by many participants to be conceptually helpful, but the implementation was perceived to lack accuracy. Back of Queue (BoQ) and Road Hazard Warnings (RHWs) were not experienced often and therefore, discussions were limited. Some participants described BoQ warnings as relevant, mostly those interviewed in Phase 3, however, there were locations that individuals thought they should occur but did not. Discussions related to traffic congestion often included suggestions to incorporate navigation and route planning as a potential improvement to the C-ITS. Few, if any, participants recalled experiencing a RHW but many participants reported wanting that type of information (e.g., general roadway obstructions) on the HMI.
- **ARLW alert tone was shocking or annoying.** Many participants commented that they found the alert tone accompanying the ARLW as 'shocking' because it occurred when they perceived it was not needed. However, improvements to ARLW timing and accuracy may negate these perceptions.
- **Integration, such as in-dash display, with the vehicle was desirable, and more control of volume and screen brightness is needed**. Most participants generally wanted the system to be more integrated into their vehicles thus removing the need for an external antenna or an extra screen. Many participants reported wanting increased control of the HMI volume, mostly in relation to turning the device volume down (which was often connected with discussion about the ARLW alert tone). Several participants reported wanting to control screen brightness which was often perceived as being too bright at night.
- **C-ITS is a beneficial idea but further development and increased accuracy is needed to improve road safety.** Many participants reported that the C-ITS was a beneficial addition to their vehicle and nearly all participants expressed positive expectations that future, improved systems could provide significant safety benefits. This aligned with criticisms across each phase of interviews about the accuracy and timing of warnings being current pain points but are expected to improve in future systems.

A.2.5 Self-report method 3: Focus groups

The focus groups sought to explore findings more deeply from the previous subjective studies and the preliminary analyses of the objective driving data. They also sought to explore participant perceptions about broader, future-oriented issues related to C-ITS but not necessarily specific to the ICVP.

The focus groups were conducted post-FOT, approximately one month after removal of the C-ITS equipment from all participants' vehicles (see Figure 230 for timeline and sample details). The discussions were conducted virtually via Zoom and were guided by a semi-structured interview schedule. The discussions were audio recorded and professionally transcribed. A thematic analysis was conducted on the transcriptions.

Seven overarching themes were identified, including:

- **Increased awareness and safer driving behaviours**. Several participants with active HMI warnings reported feeling both more aware and safer on the road. Conversely, several others indicated that although they were more aware, they did not feel safer. When the HMI was inactive, many participants said that they were also more aware of their own driving behaviours because of the mere presence of the C-ITS equipment or via the need to log-in to the system. These participants reported driving more safely and conservatively as they were aware or reminded of being monitored. Several participants said that they returned to their old driving style when the C-ITS was removed.

“Oh yeah, definitely, you know you're being monitored, so yeah. Just making sure that you're doing the right thing there.” – Female, Group Seven, Discussing C-ITS messages disabled (i.e., a blank HMI)

- **The use of C-ITS as a support mechanism to complement and improve situation awareness**. Several strengths and limitations of the technology were discussed. IVS was almost universally reported as being the most helpful use case. Many participants criticised ARLW as being inaccurately timed, which resulted in an unnecessary alert tone sounding in their vehicle. Many participants described this alert tone as shocking or distracting, and some said it had changed the way they drove to avoid triggering the unpleasant alert tone. However, it is noted that comments about the unpleasantness of the alert tone may not have been made had it arrived, as intended, in driving situations where it was likely that the participant would perform a risky or dangerous behaviour.

“No, I just, it was, just aware that it was there… but still was aware of what was happening on the outside.” – Female, Group Twelve, Discussing the use of C-ITS as a support mechanism to complement and improve situation awareness

“But when it turned off, towards the middle, the end of the trial, and I no longer got any warnings, it was like losing a friend.” – Male, Group Nine, Discussing the use of C-ITS as a support mechanism to complement and improve situation awareness

- **More C-ITS information and involvement**. Most participants did not seek out additional information about C-ITS other than the information provided to them as an ICVP participant. However, most participants in the focus groups (60%) suggested they would be interested in participating in future C-ITS projects.
- **Some participants wanted to receive personalised feedback about their driving.** Participants expressed interest in a future system that would provide them with personalised feedback about their driving. Generally, while most participants identified themselves as safe drivers, they liked the prospect that feedback provided by the system could confirm this self-perception. Alternatively, the

feedback could help to reveal potentially bad driving habits that participants could improve.

"Because you might be doing something absent-mindedly. So yeah, I think that feedback, I agree, would've been great to receive during that. To also know that you're just doing the right thing." – Female, Group Seven, Discussing Receiving personal driving statistics and feedback

"It's potentially a good thing for changing habits that develop over many years." – Male, Group Eight, Discussing Receiving personal driving statistics and feedback

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- **Data privacy**. Most participants were open to having their data collected and shared. There was some discussion about the need for legislation to regulate its use and that collection should be for road safety or insurance purposes, and not for sales and marketing. Some participants expressed concerns about the potential for hacking and data misuse that could accompany widespread deployment of C-ITS.

"…It's all well explained. So, once it started, you know, once you knew that they weren't tracking your speed and going to send you out speeding tickets or something as a result, you felt a lot more comfortable." – Male, Group Three, Discussing Data collected in the ICVP

"I think governments are going to have to watch it, control these companies, but for the most part I'm willing to take a swing." – Male, Group Eleven, Discussing Confidentiality: ensuring anonymity and data aggregation

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- **Customisation.** Key improvements that were suggested related to system customisation, such as, to control the volume and the brightness levels of the HMI.
- **Broadening types of road hazards or events presented.** Possibly due to the low incidence of Road Hazard Warning (RHW) use case during the ICVP, several suggestions were made to include types of information or warnings (e.g., road obstructions, stopped vehicles) that would already be captured in the RHW use case. Additional suggestions were made about other types of information that could be included in RHW such as information about approaching emergency vehicles.

A.2.6 Overall Findings from the subjective evaluation Study

Overall, some of the key findings emerging across the three self-report studies suggested that participants were generally positive towards the system, could see the potential for

safety benefits afforded by C-ITS technology, and had interest in future use of the technology (presuming maturation of the technology).
Broadly, the findings across the three studies could be conceptualised in terms of two overarching categories: (i) the use cases (i.e., warnings); and (ii) future implementation of C-ITS (see Figure 236).

Figure 236 - Overarching categories and findings emerging from the three self-report studies.

Use cases

- Overall, participants perceived the use cases positively.
- Participants perceived the technology as benefical to safety and reported interest in adopting it in the future when it is more mature.
- Participants rated the In-vehicle Speed (IVS) use case most positively.
- Participants could see, conceptually, the value of the various types of the warning-based use cases.
- Participants reported the need to improve the timing and accuracy of the warnings, including potential personalisation to individual's driving style.
- Participants' direct experience of some of the use cases was relatively infrequent (e.g., RHW). The amount of experience with a use case should be considered when assessing perceptions regarding its effectiveness, value, or usefulness.
- Participants had increased awareness of their surroundings but did not always perceive the system contributed to behaviour change or increased safety.

Future implementatior

- The ICVP, as a pilot, required standardisation of system features. Thus, the aspects noted below are those features for consideration in future implementation of C-ITS.
- Most participants wanted greater control of the system's features such as selection of its volume and the HMI-screen brightness.
- Participants generally wanted the system to be more integrated into their vehicles such as the removal of the external antenna or extra screen for the HMI.
- Some participants wanted to receive personalised feedback about their driving.
- Participants reported improvements in timing and accuracy would be important for future implementations.
- Participants were accepting of their driving data being shared in the context of system improvements, road safety and insurance purposes but not for sales and marketing purposes.