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Technical evaluation of C-ITS services in Flanders

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Abstract The InterCor project is an international partnership between Flanders (Belgium), the Netherlands, France, and the United Kingdom. It has the aim of forming a corridor with different use cases that are interoperable across national borders. This paper focuses on the technical evaluation of the C-ITS service. The C-ITS service was made available in Flanders during one year and included technical and user tests. The ITS-G5 services with security and the IF2 service through cellular communication were piloted. The C-ITS services successfully provided variable message sign information and road works warnings to drivers.

Keywords: C-ITS, technical evaluation, ITS-G5, cross border interoperability

1. Introduction

Cooperative intelligent transport systems(C-ITS) are systems where information is exchanged between the roadside (or traffic centre) on the one hand and vehicles on the other hand (or among each other), called vehicle-to-infrastructure (V2I), infrastructure-to-vehicle (I2V), vehicle-to-vehicle (V2V), or more generally vehicle-to-anything (V2X) communication. All this communication can be done with different technologies. Typical examples are:

- Wi-Fi-p or ITS-G5: this is a variant of the Wi-Fi protocol. Here, sender-receiver systems are installed along the road and in vehicles. Along the road these are called road-side units(RSU), whereas in vehicles they are referred to as on-board units (OBU).

- Cellular communication (4G/5G): here no infrastructure is built on the roadside, but the existing cellular networkis used.

The InterCor project is an international partnership between Flanders (Belgium), the Netherlands, France, and the United Kingdom. It has the aim of forming a corridor with different use cases that are interoperable across national borders. Examples of so-called Day 1 use cases that are deployed and tested in InterCor are in-vehicle signage (IVS), road-works warning (RWW), probe vehicle data (PVD), green light optimised speed advice (GLOSA), … In the Flemish pilot, all of these are implemented using dedicated ITS-G5 road-side infrastructure, as well as the available 4G cellular network.

In order to test the impact of these new C-ITS services, we performed different evaluations, i.e. a technical evaluation, an impact evaluation, and an assessment of user acceptance. In this paper we focus on the technical evaluation of IVS and RWW services in Flanders of ITS-G5 and 4G, whereby the information currently is provided by the traffic centre on variable message signs and road-works is offered directly to the road user in the vehicle. For the impact and user acceptance evaluation we refer the reader to the relevant deliverable [1].

2. Test setup

The following day 1 C-ITS services are evaluated on the E313 – E34 motorway: IVS, RWW and PVD. Both, ITS-G5 and 4G cellular communication are used on different HMI (or apps) separately and tested. The services were provided through ITS-G5 RSUs and the IF2 IP-based channel.

The ITS-G5 road side units (RSUs) were broadcasting at the following locations:

- E313 between Antwerp and Ranst: 10 km of continuous coverage. Motorway equipped with dynamic lane signalling, peak lane and bus lane.
- E34 between Vorselaar and Ranst: 13 km of intermittent coverage.
- GLOSA Test site: 2 intersections on the N12 in Schilde (only operational during cross-border interoperability TESTFEST in March 2019).

The Flanders' IF2 IP-based channel covered the whole motorway network in Flanders.

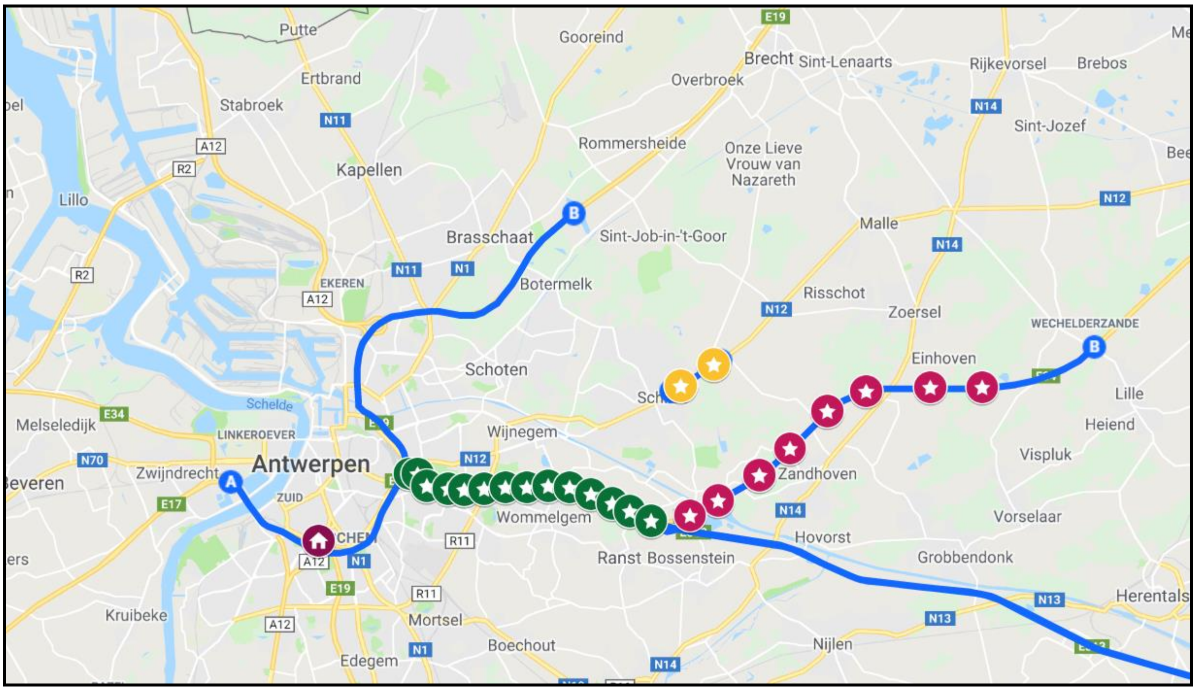

Figure 1: Pilot and test sites in Flanders.

In total 26 ITS-G5 RSUs were installed, attached to gantries, poles or traffic lights.
5 vehicles were equipped with an OBU and had an exterior roof-mounted antenna. The information was provided on the smartphone by using an app.
The 4G cellular C-ITS service was made available for all motorways in Flanders by an application.
In the table 1 a description is made of the environmental characteristics where the RSUs were placed.

Table 1: Environmental characteristics of the RSU.

RSU		**RSU**	
Site 1	In curve	Site 11	Bridge in direct neighbourhood
Site 2	In curve, noise barrier, trees	Site 12	Slightly curved
Site 3	In curve, noise barrier, trees	Site 13	Bridge nearby
Site 4	Curved road, noise barriers, trees	Site 14	Bridge nearby
Site 5	Noise barrier, trees	Site 15	Bridge nearby
Site 6	Noise barrier, trees	Site 15b	
Site 8	Rather open	Site 16	Bridge in direct neighbourhood
Site 9	Open	Site 28	Bridge nearby, more open
Site 10	Bridge in direct neighbourhood	Site 30	
Site 11	Bridge in direct neighbourhood		

3. Research methodology

3.1 Data-provision

The data was provided by the service providers for the ITS-G5 service and the 4G communication service. The data from the ITS-G5 service provider was mad available in partly InterCor, partly JSON format and needed to be converted in human readable files. The 4G data was provide in different CSV files and needed to be merged to conduct further research.

3.2 Tool – development

For data handling a tool was developed to convert the JSON format logs into CSV files that could be used for further analysis. For technical analysis an Excel-based tool was developed. This tool was very rudimentary and was not always able to do more complex analysis. However, almost all the technical questions could be answered.
Analysis for the backend delay, HMI activation ratio for 4G IVS had to be made manually by using QGIS. Some analysis could not be made due to the limitations of the tool or due to the data that was offered, e.g., revocation and last message received before leaving RZ based on 4G data. This figure was based on the measurement of only two points within the RZ neighbourhood. We did not take the speed of the vehicle into account which was not able to do within the program. The tool was mainly built for analysis of the OBU data where the logged data also differed with the 4G data.

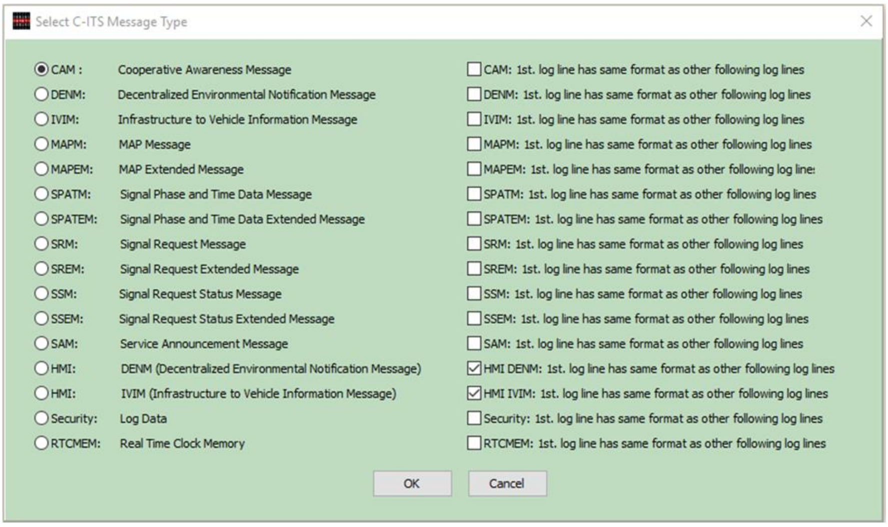

Figure 2: Screenshot of the data tool: selection of data type.

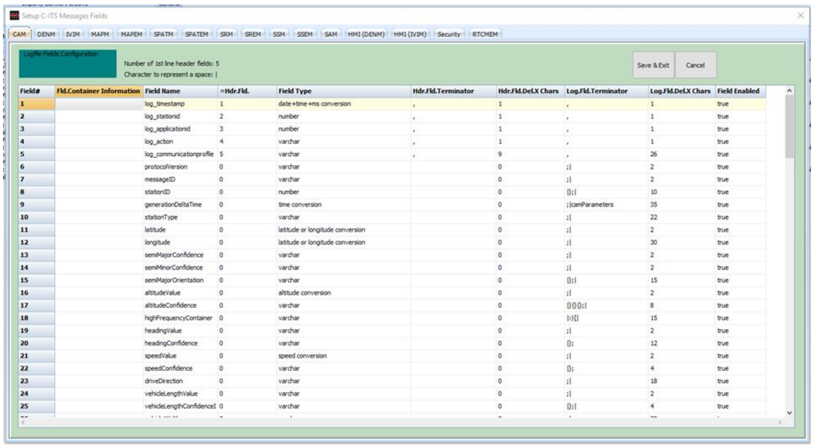

Figure 3: Screenshot of the data tool: structure of data-base.

3.3 Data-analysis

The evaluation is based on the events and trips that were made during the pilot test-day on 21 October 2019. In that way we had a controlled environment not only for the impact evaluation, but also for the technical analysis.

Remarks on the data are:

- The OBU analysis are based on 11 to 12 trips, a log problem was noticed (some PCAP data was not converted to JSON format).
- A clock issue occur between RSU and OBU: this was corrected afterwards to define PDR and ECR. The communication delay is based on a new measurement after correction of the clock data in January.
- FOR ECR we predefined certain distances: 25 m, 50 m, 75 m, … As ECR value we took the first distance wherein the 75% PDR could occur. If the PDR was higher than 75% at a certain

distance, we took the first distance wherein the PDR was lower as effective communication range.

Analysis were made per RSU and overall.

4. Results

4.1 ITS-G5 communication performance to vehicle applications

The median for communication delay was defined for CAM, RWW, and IVS. The delay for IVS was 48 ms, for DENM 55 ms and for CAM 5 ms.

The overall communication range at 75% is 350 m. There were differences found between the RSU:

Table 2: PDR and ECR of RSU.

	IVI	
	PDR	**ECR**
RSU1	10,12%	300
RSU2	32,27%	275
RSU3	12,17%	325
RSU4	42,49%	325
RSU5	7,49%	350
RSU6	19,38%	325
RSU8	72,85%	450
RSU9	77,47%	525
RSU10	44,05%	275
RSU11	80,36%	550
RSU12	72,99%	475
RSU13	73,51%	450
RSU14	63,95%	350
RSU15	69,27%	400
RSU15b	64,84%	250
RSU16	63,07%	475
RSU28	91,82%	650

We found that the communication performances of RSU1 to RSU6 were worse compared to the others. RSU1 to RSU6 were placed in a curved stretch of road, where at one side sound barriers were installed and at the other side there were (high) trees. We assume that these conditions have an influence on the communication performance.

The performance of RSU10 was also lower. This RSU was placed very near (around 40 m) a bridge. We also assume that bridges will have an influence on the performance of the RSU. The same influence of obstacles severely limiting line of sight is seen in RSU15b.

The overall Packet Delivery Ratio (PDR) was 45% for DENM and IVS. As described above, we also found differences between the RSUs.

The vehicle-to-infrastructure communication delay was 4 ms. The overall V2I effective communication range for PVD was 225 m. At 500 m distance there was no PDR. In the graph below we noticed that at a distance higher than 250 m, the RSU only received a very small amount of messages (between 9 and 37 messages).

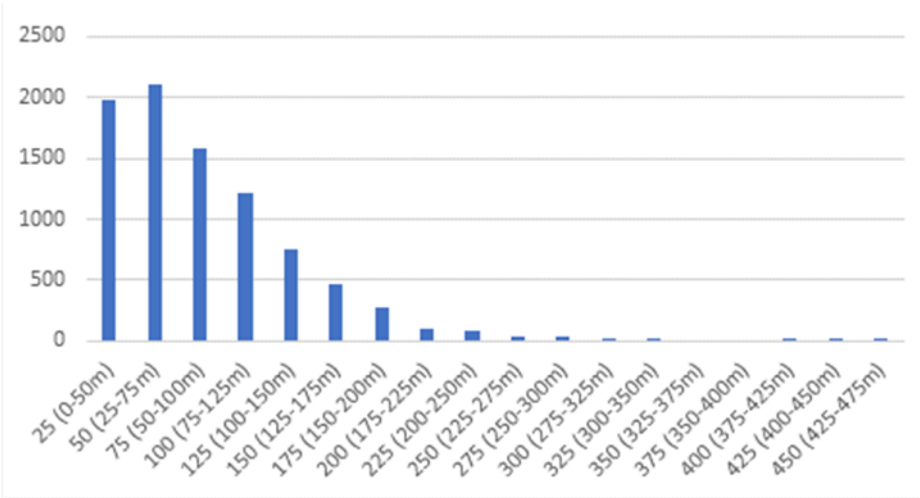

Figure 4: Messages received by RSU.

4.2 4G communication performance to vehicle applications

The communication delay for 4G was less than 1 second. There was no data available to define this more into detail. The test site was fully covered by LTE, with strong signal quality on the entire pilot site. Depending on the density of the road-side foliage, GNSS position quality might be affected. This was counteracted with intelligent map matching in the client solution. Tunnels may cause a drop or lack in GSM network signal and will certainly cause issues with GNSS reception. Pertaining to other structures, the impact is largely dependent on the degree by which the ‘view of the sky’ is obstructed. An underlying condition caused by dense volumes of connected vehicles may be cell network saturation. However during testing in peak traffic conditions, we were not able to detect a noticeable impact on the connection. Additionally, heavy goods vehicles in the form of trucks may cause minor GNSS signal reflection, which may negatively impact the quality of the GNSS fix. However, in recent GNSS receivers, reflection is mitigated to some degree. Interruptions between 4 to 6 minutes were encountered when crossing borders. This lost connection was due to service discovery and time for connecting to the foreign mobile network. InterCor did not investigate mitigation of this connection loss, since it should be done at mobile network operator (MNO) level.

4.3 Communication performance to back end servers

The delay between the original command to change the dynamic lane indicator sign (VMS) and the publishing of the message on the IF2 interface varied between 2 s and 5 s. The minimum 2 s delay was caused by the transfer through a “simulation system”, where we could inject test messages. Any additional delay was caused by the processing capacity on our C-ITS central server, which turned out to be 25 signs per second.

Exceptionally (only about 15 times a day), during peak moments, as much as 34 signs (out of 1500 signs) would change that second. The unprocessed changes would then be processed during the next one or two seconds.

A delay of 2 s would be acceptable, since there is also a similar update delay between the change command and the change of the physical lane indicator sign.

Table 3: Communication performance to back-end servers.

Direction Hasselt		**log archive**	**IF2**	**div IF2**	**RSU**	**div RSU**
90	**K04**	20:35:00	20:35:02	0:00:02		
70	**K05**	20:35:00	20:35:01	0:00:01	20:35:01	0:00:01
100	**K06**	20:35:00	20:35:01	0:00:01	20:35:01	0:00:01
	RWW	20:51:16	20:51:44			
Direction Antwerp		**log archive**	**IF2**	**div**		**div**
100	**A01**	20:36:32	20:36:32	0:00:00		
70	**A02**	20:36:32	20:36:32	0:00:00		
70	**A03**	20:36:32	20:36:32	0:00:00	20:36:32	0:00:00
90	**A04**	20:36:32	20:36:32	0:00:00	20:36:32	0:00:00
	RWW	20:43:14	20:42:42 20:43:24	0:00:20		

An average delay was found between less than one second and one second. For one case IF2 and RSU was not that good.

4.4 PKI-Security in ITS-G5 communication

All RSUs and OBUs were equipped with security. Almost all (99%) of messages are signed and verified successfully on the OBUs. Main causes of failures were due to validation, but the payload was delivered (non-strict verification). The additional processing time for successfully signing messages was not logged. The additional processing time for successfully validiating the messages was 5 ms. The maximum validation rate was 200 messages/s.

4.5 *Application functionality and performance*

The main purpose of applications is to inform and warn drivers in the relevance zone of events. The functionality and behaviour of applications is measured in several indicators for timeliness, reliability and accuracy of the presented information.

Events, relevance and the type of information may vary per service. A reference model for evaluating the functionality and behaviour is the zone model sketched in Figure 5 for IVI events. Similar zones apply to DENM (RWW) events.

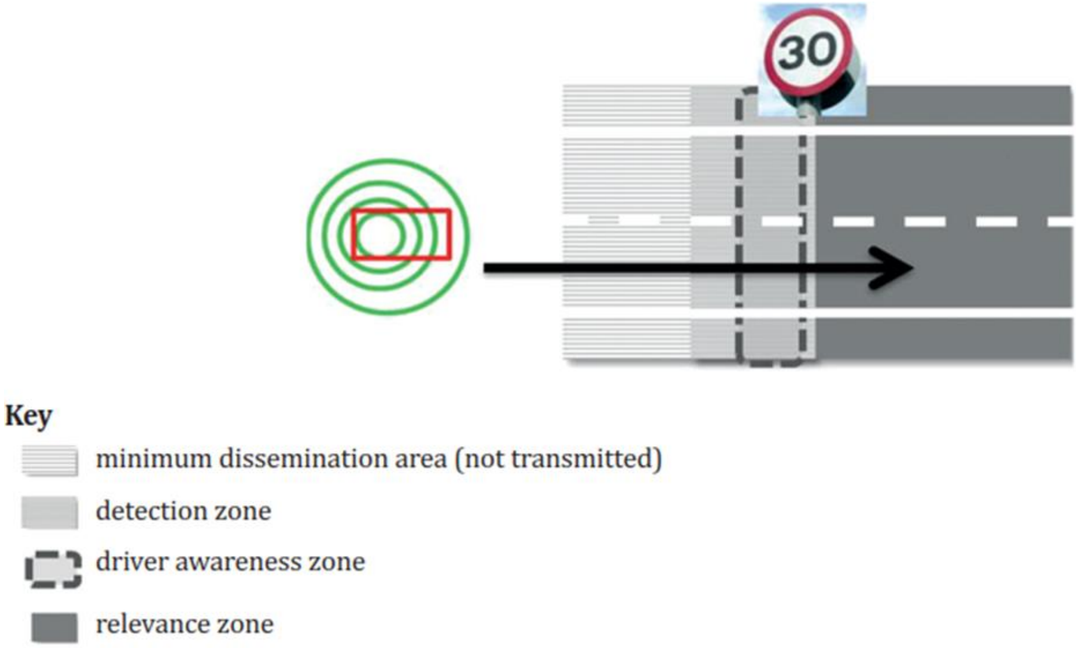

Figure 5: IVI Zone model.

The dissemination and detection areas define the area in which vehicles must receive the first C-ITS messages for an event, and the in-vehicle application must detect that event for the first time. The driver must be informed or warned in the awareness and relevance zones.

This model is simplified for evaluation purposes here. The relevance zone is defined for:

- RWW events as the event history in DEN messages.
- IVS events as the relevance zones of IVI messages.

The end-to-end communication delay is around 50 ms on the Flanders test site from RSU to OBU. The median end-to-end communication delay is less than 1 second, but it can go up to 2 to 3 seconds. The cause was mainly the 1 Hz update frequency of the client app. The delay increases when using 4G communication compared to ITS-G5.

The IVI and DENM events on the E313 and 75% of the E34 motorway*[1] in Flanders are fully covered on the relevance areas. First warnings are presented on the HMI and mostly in the beginning of the relevance zones (0.5 s). The HMI information was not displayed anymore shortly (-1.5 s) before the end of the relevance zone.
Messages are received over the complete relevance area.

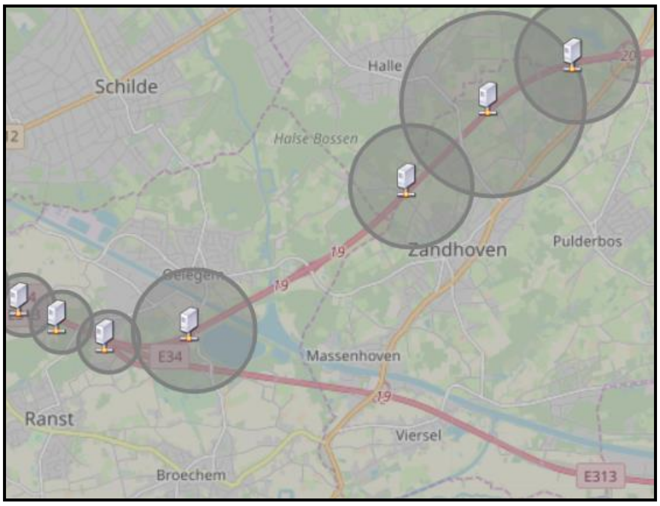

Figure 6: Area with no coverage of RSU on E34.

The coverage of the relevance zones for 4G communication is similar to that for ITS-G5. First messages are presented in-between 1 to 3 seconds when entering the relevance zone.

The reliability of applications is evaluated for two criteria: the HMI activation ratios and the percentage of time that advices were actually provided in the relevance zones (see previous section). An HMI activation is a trigger or presentation of information on the HMI to inform or warn a driver of an event. An application is reliable in the perception of the driver if an activation is given in the relevance zone of every event, while no activations are given outside events.
Reliability is measured for the following ratios, where an activation is measured if it is given during any part of the relevance zone, the accuracy of such activations is measured in the next section.

True Positive Valid activation that is correct in time, location and contents, as the application is specified to activate.

False Negative Missed activation, i.e. no single activation action is recorded throughout the time period and relevance area of an event.

False Positive Invalid activation on the HMI when no event is relevant in the vicinity or driving direction, i.e. the application does not behave as specified or expected.

[1] A stretch of road between the “Kapelbeek” and “hof van Liere” is not covered by an RSU.

The true positive activation was 97% for DENM during the test day. 3% of the messages were missed. This could be caused by the use of a non-updated application during the test day. The RWW services gave a warning when entering the zone and stopped displaying the warning when passing the event location.

The true positive activation of IVI is 97.6%. Both speed and lane advice are presented for over 94%. Loss of coverage can also be related to the battery performance of the users. It was noted that when the battery was lower than 30%, the update frequency or data provisions was lower (dropping to once every three seconds). IVS warning were received when entering the relevance zone and stopped displaying near the end or after leaving the relevance zone (1.5 s).

5. Conclusions

The C-ITS service was made available in Flanders during one year and included technical and user tests. The ITS-G5 services with security and the IF2 service through cellular communication were piloted. The C-ITS services successfully provided variable message sign information and road works warnings to drivers.

5.1 Communication performance

The end-to-end communication performance of ITS-G5 was evaluated as well as the communication delay from back-end server to RSU. The performance of the I2V communication is pre-measured during the pilot period and measured during the user-testing:

- The end-to-end delay is the delay to send messages from road side applications to in-vehicle applications. The average delay when using ITS-G5 is around 50 ms. The median delay for 4G cellular communication is less than 1 second.
- The I2V effective communication range for ITS-G5 is about 350 m, meaning that 75% of the messages sent by RSUs are received by OBUs within this range. The packet delivery ratio at 500 m distance is 45% this proved to be sufficient to cover all RWW and IVS events on the E34 and E313.
- The 4G cellular communication network covered the complete pilot sites and all events.
- The PKI signing rate was not logged during the pilot. The validation & verification success rate was 99%. The processing time for verification and validation is 5 ms.
- The back-end communication delay was investigated by comparing the IF2 and RSU logged data with the vent logs of the traffic center. An average delay of 2 s was found which can be considered as acceptable.

5.2 Applications and services

The functionality and performance of in-vehicle applications is evaluated in terms of the accuracy and reliability of services provided to users. In-vehicle systems inform the user correctly in more than 92% of the road works (RWW) events and in 95% of the dynamic speed limits and lane (IVS) events on the E313 motorway. Speed Advice and Lane advice was respectively shown for 96% and 94% in the relevance zone to users.

5.3 Cross-border interoperability

For the pilot on the E313 and E34 motorway, the cross-border interoperability tests were performed during the TESTFEST. Cross-border interoperability has been tested; some issues were detected and resolved. More detailed information has been reported in the InterCor Milestone M7. As a main conclusion, based on the findings of several participants during the cross-border interoperability TESTFEST were:

- **Overall**: the events that were transmitted by the Road Side Units were received: speed limits, road works, lane closures/opening, …
- **GLOSA worked**: participants received the status and predicted timing of upcoming traffic lights (red/green).
- **ITS-G5 and cellular data are consistent**: the information received through both channels is consistent and generally received synchronously.
- **PKI**: generally worked well.

➔ Cross-border interoperability was achieved! Problems that were encountered were mainly programming issues and not directly related to interoperability.