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Impact evaluation and user acceptance of C-ITS IVI services

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Abstract

The InterCor project provides a C-ITS corridor for interoperable Day 1 services between Flanders (Belgium), the Netherlands, France, and the United Kingdom. Within this paper, we analysed in-vehicle signage (IVS showing speed limits) in the Flemish pilot, implemented using the available 4G cellular network. After conducting an extensive behavioural experiment, we concluded that in-vehicle communicated speed limits have no effect on driver's behaviour when the speed limits are also presented on the salient matrix signs above the road. Although IVI speed limits in addition to operational gantries did not add to behavioural compliance, drivers seemed to accept IVI technology as they obeyed the speed limits on the in-car devices. In order to further understand users' behaviour, we analysed their acceptance of the technology. 91% of the participants noticed the maximum speed indication on the HMI on multiple occasions. For the changes in behaviour, 64% of the participants indicated being more aware to exceeding the speed limit as a result of displayed speed limits on the HMI. However, only 36% of the participants indicated that they immediately reduced their speed after receiving a notification from the speed assistant.

Keywords:

Cooperative intelligent transport systems (C-ITS); in-vehicle signage (IVS); user acceptance

1. Introduction

Cooperative intelligent transport systems (C-ITS) are systems where information is exchanged between the road side (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:

- Wifi-p or ITS-G5: this is a variant of the wifi 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 network is used.

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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. Within this paper, we focus on the IVS service in Flanders over 4G, whereby the information currently provided by the traffic centre on variable message signs (VMS) is offered directly to the road user in the vehicle. The aim is to continuously inform users of the applicable speed limits and thus increase road safety. The remainder of the paper talks about assessing the perceived impact on user behaviour and user acceptance. For the technical evaluation we refer the reader to the relevant deliverable [1].

2. Location and deployment of the test infrastructure

The IVS service was piloted on the E313 and E34 motorways in Flanders, Belgium from February 2019 until late December 2019. Information about speed limits and lane deviations on the VMSs were replicated in in-vehicle information (IVI) messages, both sent using ITS-G5 and 4G cellular communication. The road-side and in-vehicle systems proved to be interoperable with pilot sites in other Member States in the InterCor project during previous elaborated tests. Technical evaluations proved the technical maturity of the road-side units and in-vehicle systems to provide the service to drivers. All services in Flanders were being broadcasted at the following locations (see Figure 1 for a geographical overview), with a total of 26 ITS-G5 RSUs installed at gantries, poles, or traffic lights.

- E313 motorway between the city Antwerp and the town of Ranst: 10 km of continuous coverage on the motorway equipped with dynamic lane signalling on VMSs, a peak-hour lane, and a bus lane.
- E34 motorway between the towns of Vorselaar and Ranst: 13 km of intermittent coverage.
- GLOSA test site: 2 intersections on the N12 local road in the town of Schilde.

3. Research questions and experimental setup

There are two societal valuable questions that we aim to answer within our experimental setup:

- The first one concerns road safety by IVS: *Is IVS increasing driver compliance towards road signs?*
- The second one concerns the efficiency of IVS: *Are road signs still needed when all conventional road signs are projected on the IVS display?*

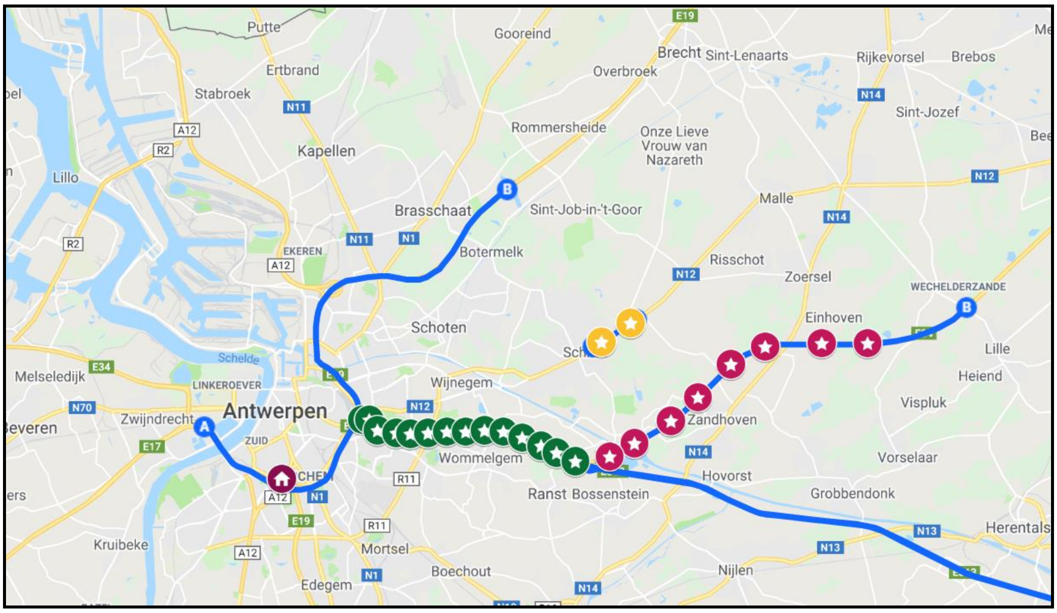

Figure 1: InterCor C-ITS pilot and testsite in Flanders and Belgium, indicating the locations of RSUs.

3.1 Research questions

3.1.1 First research question

In order to answer the first question, we created a scenario in which the IVS app repeats the signalling along the road. IVS might increase a driver's attention towards signalling and as a consequence driver's compliance of signs along the road.

This leads to the following more concrete research question of interest. **Are drivers more compliant with road signs along the road when in-car-signage is repeating these signs?** To test this research question, a use case with gantries was implemented signalling road works and a speed reduction towards 70 km/h. Such speed reductions are common on motorways for multiple reasons such as road works, traffic jams, obstructions, … The speed reduction was indicated on some of the gantries and these indications stayed on the gantries for the whole duration of the experiment.

3.1.2 Second research question

The second research question of interest reflects a greater ambition in which the future installation of full matrix displays, variable message signs, and other road signs are completely replaced by IVS. In this case the research question of interest is **whether drivers are compliant with the in-car-signalling, in absence of any road signs along the road**.

In order to test this latter hypothesis, a virtual IVS was created when passing some of the blacked-out gantries, projecting 110 km/h and 90 km/h, followed by the cancellation sign on the IVS display, respectively. These virtual IVS were also signalled at a second location, having 110 km/h, 90 km/h, and the cancellation sign when passing the blacked-out gantries in the same respective order. Note that closed bus or closed rush hour lanes were still able to be displayed on the gantries (and the HMI) if these settings were part of the actual safety situation during the experiment. In any case, the rush hour lane had to stay closed during the whole duration of the experiment. This setting with blacked-out gantries and HMI IVS is called a '*virtual implementation*'. We compared any reaction of the drivers in this condition to their behaviour in the control condition (no HMI) at the same locations.

3.2 Experimental setup and organisation

The aim of the setup was to minimise influences of time, location, or driver on the measurements aimed at investigating the effect of the IVS in-car service. Therefore we harmonised the timing and trajectory of the test itineraries. All itineraries were planned on the same trajectory within the same timeframe. In each time slot (TS) we planned for 33.3% of the drivers to use the in-car services G5, 33.3% to use 4G, and 33.3% not to use any in-car service. The app was always working in order to log tracked traces. However, in that case the tool was outside the visual and auditive observation area of the driver. There were two experimental conditions, 4G en G5, and one control condition: no in-car services but only the 4G app active to log a driver's trajectory. The control conditions were a reference for the experimental conditions.

For the first research question, the speed reductions were implemented in two phases as indicated in Figure 2. The speed of 90 km/h was indicated on gantries A04. The speed of 70 km/h was indicated on A03 and A02 just in front of the bus lane on which the truck mounted attenuator was installed. The second location for this use case was on gantries K04 and K05 for 90 km/h and 70 km/h, respectively, in the direction of the city of Luik. Note that we showed the same speed limits on the rush hour lane in case it was opened. Furthermore, because of legal reasons, the presence of (truck-mounted) attenuators was obligatory during the roll-out of the experiment.

For the experiment, we equipped 5 vehicles an OBU capable of ITS-G5 communication (with an exterior roof-mounted antenna); all other vehicles (we had a total of 11 participants) drove with an Android smartphone that displayed its information on a specifically-designed app for the 4G communication. The experiment was held on Monday 21 October 2019, with the time of day in the evening between 20h00 and 00h00 (the first drive started at 21h00, well after all congestion disappeared). Drivers left the parking lot with or without the in-car service, one driver each minute. For defining which of the drivers uses which service/app at which time, we devised a scheme that distributes and randomises this in a controlled fashion. Drivers who were using the service (experimental conditions) became part of the control group in another time slot and vice versa. In order to balance the possible confounding carryover effects (e.g., a driver provided with IVS in a first time slot will be aware of the hassle positions in another time slot), a Latin square determined the sequence of control and experimental conditions among the drivers. The successive distribution of time slots guaranteed that an equal amount of test users had a first experience with 4G as they would had have with G5. The drivers then drove in the test area E313-E34 as indicated in Figure 10. In each time slot, they made the same itinerary, starting at the car pool parking and arriving back at the same parking.

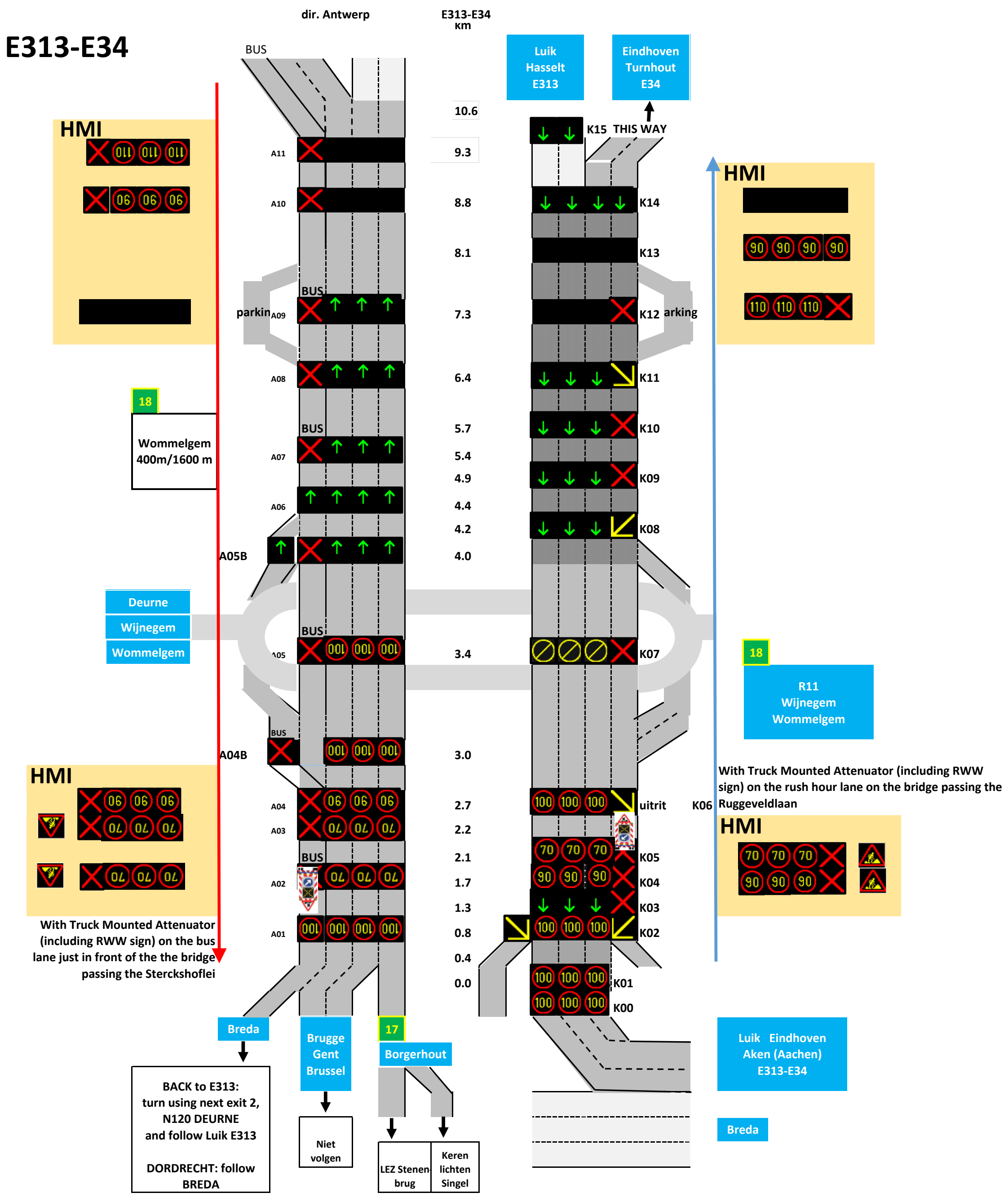

Figure 2: Detailed overview of the experimentally controlled conditions for the behavioural experiment on the E313 and E34 motorways.

The experimental organisers were present at this parking lot to take care of registration and swapping services. After receiving a short briefing, drivers filled in acceptability surveys, while the organisers installed the app(s) on their Android systems in addition to all other necessary equipment. The organisers provided holders for the drivers’ smartphones. Drivers also completed an attitude survey, and after each drive with ITS-G5 or 4G an acceptability survey on IVS and RWW. The organisers carried paper and pencil versions of the acceptability survey such that all participants were able to complete the test before leaving the parking lot.

3.2 Considerations for the experimental setup

The experimental setup had four locations in which something was induced to the drivers. At these four locations, a speed reduction was induced in two steps, first going from 120 km/h to 110 km/h and then to 90 km/h or going from 100 km/h to 90 km/h and then to 70km/h. On two of these locations were gantries and HMI giving the same message. On the two other locations, only the HMI gave a message and the gantries were switched off (black screen).

Truck-mounted attenuators were installed on the emergency lane or the rush hour lane in order to make the participants believe that the hazards were real. However, in order to retain a clean stimulus to the participants, the truck-mounted attenuators were installed outside the visual field of the drivers while passing the gantries with speed limits. This guaranteed that the visibility of the road sign was limited and hence interfered as little as possible with the IVS and the messages on the gantries. This was sufficient to let people believe that the stated speed reductions were not false. It was not unsafe in the virtual condition where test drivers got the message to reduce their speed to 90 km/h, while the rest of traffic keeps on driving at full speed. 90 km/h is an allowed speed on the motorway, and drivers could always drive on the rightmost lane. We also mentioned this at the briefing, i.e. that drivers best had to chose a lane in function of their current travel speed.

Within our experiment, we aimed at comparing the experimental groups 4G and G5 (gantries + HMI) against the control group (gantries + no HMI). This evaluation was a within-subject evaluation, comparing a driver's behaviour in the 4G and G5 conditions against his/her own behaviour in the control condition. This within-subject design reduced the error term with respect to interindividual differences.

4. Results of the impact assessment

4.1 Prevailing traffic conditions

In order to understand the possible influence the rest of the traffic stream (i.e. congestion) may have had on our experiment, we also analysed the total traffic behaviour during the entire evening the experiment took place, as well as during some other days for comparison. To this end, we looked at the measurements made by the available motorway detectors, and analysed these in a so-called Treiber-Helbing filtered time-space diagram [2], as shown in Figure 3. The colours in the diagram denote green for free-flow traffic (100 km/h – 120 km/h), yellow for moderate/synchronised traffic (80 km/h – 100 km/h), and red for congested/slow moving traffic (0 km/h – 80 km/h). As can be seen there was a congested bottleneck in the westbound direction towards Antwerp, with clearly backwards propagating congestion waves. The congestion lasted until after 19h00, which posed no problem for our experimental runs as these only started at 21h00. In addition, we can see how the lower speeds of 70 km/h indicated on the VMSs near the top of the diagram resulted in lower average traffic speeds (yellow-coloured regions in the black rectangle).

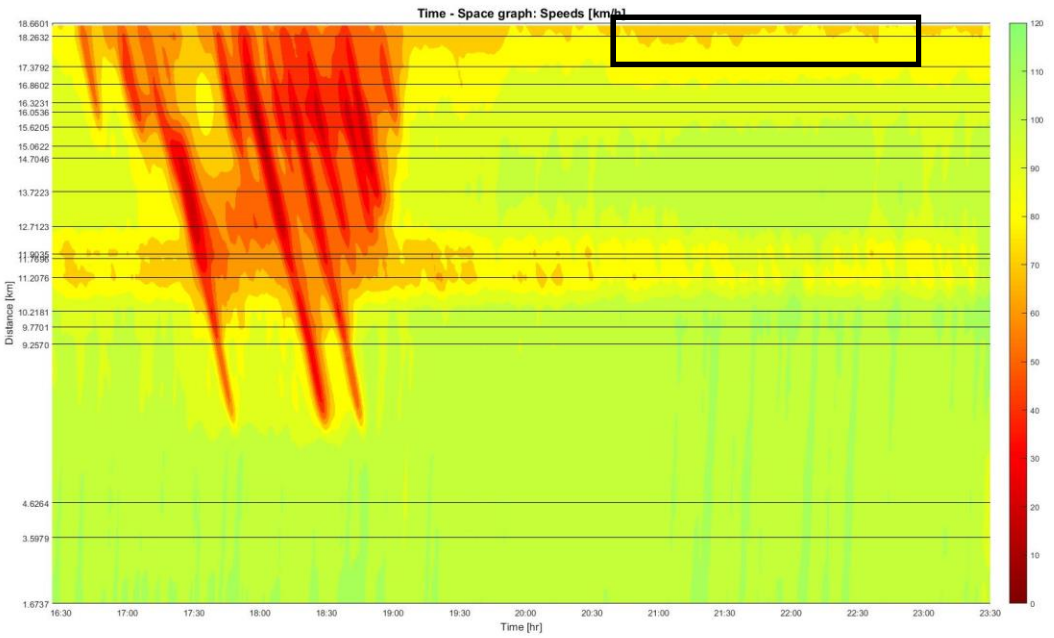

Figure 3: A time-space diagram of the speeds on the E313 (westbound direction) on 21 October 2019.

4.2 Comparison of speed trajectories with IVI reception

For each driver, we filtered his/her GPS trajectories and split these into four parts, as shown in Figure 4: one during which no HMI was active (blue lines), and one where the 4G/G5 HMI was active (red lines), and this for both the westbound and eastbound directions. The green lines are the locations of the IVI reception of speed limits. These speed limits were imposed by the experimental design. By analysing the speeds with and without the HMI stimulus, we could assess whether they had an impact on driving behaviour.

When looking at the graphs of the speed trajectories in the upper panel of Figure 4, we see from left to right the sampled speed driven by the car heading from the off-ramp at the town of Oelegem towards the city of Antwerp (similar results are observed in the lower panel). There are two locations on which the speed limits were experimentally manipulated.

At the first location we counted 4 vertical green lines, endorsing speed limits of 110 km/h and then 90 km/h (see black dashed lines). The gantries were blacked out on this location. Thus, there was no speed limit presented to the driver when no HMI was active (blue line). When the 4G/G5 HMI was active, the speed limits were visible in the car (red lines). Clearly, there is an impact of the 4G/G5 HMI demonstrated by the descend of the red speed samples towards 90 km/h when the respective IVI message appeared (green vertical lines). The blue speed line is not showing this deceleration. Comparing to other drivers, we noted that this impact seemed to be rather limited and some drivers seemed to hesitate while complying with the speed limits. Moreover, drivers seem to increase their speed shortly after the presentation of the speed limits on the HMI. The fact that the speed limits were not shown on the gantries might have raised hesitancy.

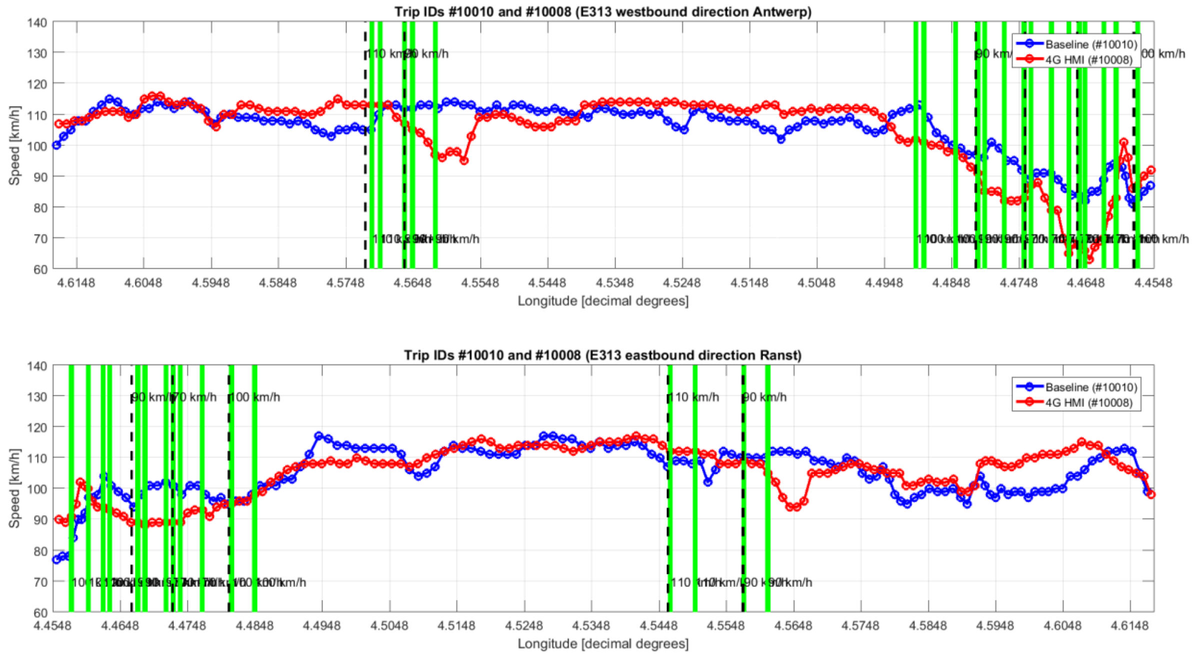

Figure 4: Example of speed trajectories of a single driver in the presence of IVIs communicated via 4G.

4.3 Results for the research questions

4.3.1 Is IVS increasing driver compliance towards road signs?

To answer this question, we must make an assumption on the profile of the distinctive behavioural pattern between the experimental and baseline condition. '*More compliant*' could mean that the driver will slow down faster in the experimental (4G/G5 HMI) condition reaching the speed limits earlier. Another possible pattern is that the driver is not fully compliant in the baseline condition. In that case, the driver might reduce more speed in the experimental condition. In the first case, the effect of IVS takes place in time while the extent by which the driver is slowing down might be the same. In the second case, the effect is related to the extent by which the driver is slowing down, not necessarily with a higher deceleration. This effect can only be displayed when the driver is not fully compliant in the baseline condition.

A robust measure that captures both possibilities is taking the median of velocities in a time period of *N* seconds before the first IVS (reference velocity) and *N* seconds following the IVI with the first lowest speed limit (reduced velocity). The difference between the medians before and after the IVS reception is a robust measure of speed reduction. This chosen time frame *N* should not be too long. The most distinctive effects can be expected in the first few seconds after the reception of the IVS. Taking time intervals that are too long will reduce statistical power as behavioural distinctive patterns are flatten out. We evaluated the reduction of speed for time windows $N = 10$ seconds (more or less 250 meters) and $N = 20$ seconds (more or less 500 meters). Because of the rather low number of participants and the data loss, we decided to use a paired Student *t*-test to verify our hypotheses. We condensed the statistical analysis to the essence with respect to the research question of interest.

Our results indicated that there was no statistically significant effect observed from having an IVI device indicating speed limits repeating the speed limits of the gantries that were positioned externally and above the lanes. This result might one wonder whether IVI has any effect at all on drivers' behaviour. The answer to this question is provided in the next section.

4.3.2 Are drivers compliant with the in-car-signalling, in absence of any road signs along the road?

The research question matters to the two sites with 4 vertical lines in Figure 4, i.e. the sites where the gantries were blacked out. A virtual IVI speed limit is created and appears on the display when passing the blacked-out gantries. We compared the experimental condition 4G HMI against a baseline without any speed limit information. This evaluation is capable to provide the real and pure effect of IVI as it will not be masked by any salient source like the gantries in the previous baseline. This evaluation can also be conceived as a control verification whether the IVI app is indeed able to influence sufficiently human behaviour. In different words this evaluation allows us to verify whether the absence of any effect in the previous research question is the result of an ineffectual in-car application. The statistical procedure is similar to the previous one. Once again, we use a paired sampled Student *t*-test to verify this hypothesis. The speed reduction is shown in Table 1. There are two locations per driver for the respective evaluation of the research question. A positive number is a reduction of speed, a negative number is an acceleration. As can be seen, in the condition with IVI, drivers reduced their speed on most occasions. This reduction in speed is consistent. When comparing the second with the third column, we do find strong evidence for an effective in-car application. The average improvement was 8.4 km/h (se = 2.346, t = 3.58, d = 14) for the 10 seconds-long timeframes and 9.633 km/h (se = 2.534, t = 3.80, d =14) for the 20 seconds-long timeframes. These improvements are both significant. It should be noted that the reduction of speed is the difference between the medians of the 10 or 20 second time window before the first IVI end after the lowest speed limit IVI. The effective speed reduction is considerably larger when one would compare the average speed before and the minimum speed after the IVI.

Table 1: Speed reduction between the 20 seconds before the first and highest received speed limit and 20 seconds after the first and lowest received respective speed limit in the 4G condition.

Driver #	Baseline condition No IVI (Δ km/h)	Experimental condition Effect IVI 4G (Δ km/h)		Driver #	Baseline condition No IVI (Δ km/h)	Experimental condition Effect IVI 4G (Δ km/h)
2	-8,0	6,0		6	0,0	2.5
2	2.5	9.5		6	0.5	11.5
3	-4.5	6.5		7	-6.5	3,0
3	9.5	8,0		7	7,0	0,0
4	0.5	6,0		8	-3.5	18,0
4	0,0	13.5		8	-	-
5	-0.5	12.5		9	0,0	17,0
5	0.5	-3,0		9	-3,0	28,0

5. Results of the user acceptance

In order to further understand users' behaviour, we conducted an *acceptability* survey beforehand stated to assess their stated preferences, combined with an *acceptance* survey afterwards to assess their revealed preferences (a full report of the user acceptance analysis can be found in [1]). These were then complemented with profiling and attitudinal surveys (this is a standardised instrument that was calibrated on a representative sample of the Flemish population, built on the framework of the theory of planned behaviour [3, 4]). These latter revealed that our group of participants were representative enough sample of the Flemish population, and individual drivers were not too much different from each other on the measured scales.

Examples of observations indicated that 91% of the participants noticed the maximum speed indication on the HMI on multiple occasions. While 64% of the participants indicated that they used the information during the test drive, 27% indicated not to use the information and the provided reason for not using the information was that the displayed information is not correct.

When considering the trip quality, most of the participants indicated a neutral position for the statement feeling more at ease while driving with the HMI showing the maximum speed, with two more disagreeing and two agreeing or totally agreeing positions to that statement. A large part of the participants was also neutral to statements regarding feeling more secure while driving with the HMI. These answers are more negative than the answers to the same question in the acceptability questionnaire. Furthermore, 91% of the participants indicated a neutral or disagreeing position on being distracted by the HMI. This is a positive result. For the changes in behaviour, 64% of the participants indicated being more aware to exceeding the speed limit as a result of displayed speed limits on the HMI. However, only 36% of the participants indicated that they immediately reduced their speed after receiving a notification from the speed assistant.

6. Conclusions and next steps

The InterCor project provides a C-ITS corridor for interoperable Day 1 services between Flanders (Belgium), the Netherlands, France, and the United Kingdom. The Flemish pilot deployed and tested IVS, RWW, PVD, and GLOSA, all of them implemented using dedicated ITS-G5 and 4G communication backbones.

After conducting an extensive behavioural experiment, we concluded that IVI speed limits (over 4G) have no effect on driver’s behaviour when the speed limits are also presented on the salient matrix signs above the road. We did find a strong behavioural influence of the app when it was the sole source of speed limit signalling. Drivers did follow the speed limits displayed by the app, but they equally well followed the speed limits displayed by the gantries. Using both sources did not intensify the compliance to speed limits. Furthermore, IVS seemed to be redundant when the same information was presented on the salient gantries. And although IVI speed limits in addition to operational gantries did not add to behavioural compliance, drivers seemed to accept IVI technology as they obeyed the speed limits on the in-car devices.

In order to further understand users’ behaviour, we conducted an *acceptability* survey beforehand, combined with an *acceptance* survey afterwards. Examples of observations indicated that 91% of the participants noticed the maximum speed indication on the HMI on multiple occasions. While 64% of the participants indicated that they used the information during the test drive, 27% indicated not to use the information and the provided reason for not using the information was that the displayed information is not correct. For the changes in behaviour, 64% of the participants indicated being more aware to exceeding the speed limit as a result of displayed speed limits on the HMI. However, only 36% of the participants indicated that they immediately reduced their speed after receiving a notification from the speed assistant.

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