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Development of an HMI for a virtual co-driver based on data collected by intelligent road markings

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Abstract

Traditional in-vehicle human machine interaction (HMI) systems are based on warnings used to alert the driver and inform him/her to properly react to an unexpected event. However, new driver vehicle interaction patterns are needed to leverage on the added value of disruptive C-ITS mobility paradigms. The SAFE STRIP project has developed a road marking system that includes smart sensors and V2I technologies. Based on the sensor information, a virtual co driver aids drivers and riders to cope with issues detected by the sensors, such as slippery road, roadworks, or possible collisions with other road users. The virtual co drive r negotiates with the driver/rider through an HMI, the development of which is presented here. In this paper the HMI development process and the results of 3 simulator-based studies are reported, concluding with the lessons learned for the design of co-driver HMIs.

Keywords:

Human-Machine-Interface (HMI), Co-driver, Cooperative Intelligent Transport System (C-ITS)

Introduction

Modern vehicles equipped with driver assistance systems can “feel” (e.g. by on board sensors) sensors), can “see” (e.g. by cameras) and potentially “speak” (e.g. by communication [1]. The term Intelligent Transportation Systems (ITS) was coined over two decades ago to designate applications of information and communication technologies to the operational management of transportation networks. The technology of Cooperative ITS (C ITS) enables the communication processes of vehicles among each other (V2V) and with traffic infrastructure (V2I). It is based on the principle that all cooperative parties (e.g. in vehicle or roadside processing and communication units) exchange information in an ad hoc network using wireless communication. Every receiver evaluates the data received and considers the information for its data analysis, resulting in strategic warning, tactical advice and information provided to the driver. The availability of data collected in real time from different sources can enable better traffic information, management, and planning. C-ITS offers relevant benefits for cities and infrastructure owners in collecting traffic data, providing mobility information and optimizing traffic flows, in a wide range of use cases including intersections, roundabouts and railway crossing, taking into account all modes of mobility, such as private vehicles, public transport, emergency vehicles, cyclists and pedestrians. This innovation can promote adaptive added value services to make the overall transport system more intelligent, with a significant impact on safety and the added value provided to the final users [1].

The work reported in this article was done in the R&D project SAFE STRIP, funded by the H2020 research framework. SAFE STRIP enables C ITS applications through developments in existing road infrastructure (integrated strips markers), deploying I2V and V2I, among others. The purpose of this is to make roads self-explanatory and forgiving for all road users (trucks, cars, and vulnerable road users, such as Powered Two-Wheeler riders) and all vehicle generations (non-equipped, C ITS equipped, autonomous), with reduced maintenance cost, full recyclability and added value services, as well as to support real time predictive road maintenance functions. The strips will support ITS services and apps as they provide personalised in vehicle messages for all road users (trucks, cars and vulnerable road users, such as PTWs riders) and all vehicle generations (including future automated vehicles), at a reduced maintenance cost, fully recyclability and containing added value services, as well as supporting real time predictive road maintenance functions [2].

Either through on-board Human Machine Interface (HMI), for vehicles provided with connected information systems, or mobile terminals the drivers/riders get feedback and warnings that support a series of C-ITS safety and added value functions. Warnings and notifications are issued by an intelligent decision system (that relies on fusion of infrastructure, tyre s and vehicle data) and following a tailored HMI strategy, are provided through distributed interfaces.

Related works

One of the most recent and effective measures to prevent collisions and mitigate their impact (e.g. in terms of fatalities and injuries) relies on vehicle and infrastructure cooperation for the deployment of C-ITS applications. The cooperation at perceptual level is used to collect data from heterogeneous sensor systems (e.g. V2V and V2I communication) while the control level is applied to implement strategies to optimize safety, traffic and energy efficiency, and comfort [3][4][5].

Even though all methods require exchange of information, some of them (e.g. [6]) do not consider the driver behaviour. Most driver-centred approaches are based on classification of intentions by means of pattern recognition [7][8]. A review of methods for classification of incoming vehicles is provided in [9]. Moreover, most of these optimization algorithms are based on the measurement of the Time-to-Collision (TTC). TTC is the ratio of instantaneous range to range rate. If both vehicles continued traveling at the same constant speeds they were traveling when TTC is measured, the collision would occur after a time of TTC [10].

However, these methods make several simplifying kinematic assumptions to estimate TTC. First, the driver braking is assumed to be constant throughout the braking period. Second, the lead vehicle is assumed to be still for the entire approach and braking period. In practice, these scenarios often can involve traffic that is slowing ahead of the striking vehicle. Although the struck vehicle may have been stopped when the collision occurred, it could have been moving during the approach period, which would affect TTC estimation.

In recent years, in-vehicle information systems are experiencing an essential transformation. Traditionally, HMIs for automotive domain are designed to minimize the impact on the driver. As specified by the National Highway Traffic Safety Administration [11], the US authority on traffic safety, the primary requirement of in-vehicle HMI is to deliver timely needed or desired information while minimizing driver distraction. In order to achieve this objective, the interfaces should take into account characteristics such as legibility, interpretability and accessibility [12]. Besides these general features, new requirements are emerging due to the ever-growing complex cooperative traffic systems. The term Cooperative HMI describes those interface systems distributed among several vehicles [13]. The information displayed by these systems is built and dynamically adjusted considering the overall situation of each car that made up the cooperative system [14]. Cooperative HMIs provide all the needed parameters through Vehicle-to-everything (V2X) communication and their architecture is cloud-based and enabled by a robust, reliable and fast connectivity. Guidelines to design HMI for C-ITS, although rather generic, suggest a focus on timing of alerts: the users should be able to timely recognize the warnings and properly react in a reasonable time frame. In order to ensure the fulfilment of these requirements and improve the overall on-board interaction, new trends are recently emerging. A relevant trend is represented by the progressive introduction of multimodal functionalities, to exploit sensory channels other than the visual one. Moreover, in recent years, several researches have been performed about the use of nomadic devices, e.g. smartphones, as appendixes of in-vehicle interaction systems [15]. However, the vehicle-related information, including suggestions on driving style, cannot be not displayed on smartphones in the aforementioned approaches, mostly for architectural reasons.

Cooperative Co-driver

The cooperative co-driver developed in SAFE STRIP takes advantage of the data provided by the SAFE STRIP infrastructure to enhance the safety by improving the driving behaviour both at a tactical and operational level. The co-driver is implemented as part of a novel C-ITS distributed architecture where heterogeneous modules (i.e. sensors and applications) share data through an MQTT broker. The aim of the co-driver is to assess the existence of safe manoeuvres within all possible manoeuvres rather than discovering the exact one the driver intends to perform. It considers 2 types of longitudinal manoeuvres, that are called “motion primitives”:

- Stop manoeuvres i.e. stop before the conflict area
- Pass manoeuvres, i.e. reach the intersection at a given time T.

The co-driver uses human-like motion primitives to explore feasible goal-directed actions or manoeuvres [16] and the bio-inspired concept of mirroring to evaluate and discover the human intention [17] to be able to deal with complex multi-vehicle intersection scenarios, as the one represented in Figure 1.

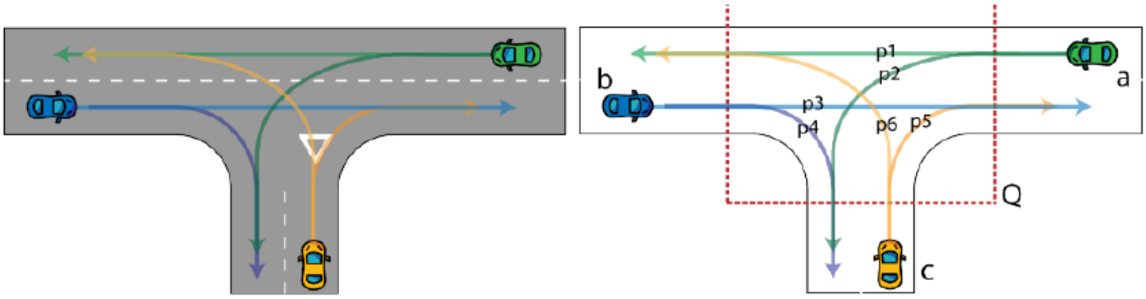

Figure 1 - Intersection scenario

In Figure 1, the three vehicles are labelled *a*, *b*, *c* respectively, one for all incoming lanes. For each vehicle, all possible paths are considered by applying traffic rules, and they are labelled with *p* (path) and numbered from *1* to *6*. The red square *Q* is the conflict area. This area cannot be occupied by two or more vehicles if they have intersecting trajectories.

For each vehicle approaching the intersection, all feasible trajectories are instantiated. Once the trajectories are defined, the computation of the sets of possible longitudinal manoeuvres to approach the intersection and the time slots is performed, based on all other vehicles, the right of way order, the conflict between all their trajectories. To resolve vehicles conflicts and inhibit overlapping time slots, all possible intersections of all trajectories are calculated, and then the right of way order is taken into account to establish the order of passing for each conflict.

The time slots are used for the computation of the manoeuvres and the warnings. For this computation, the co-driver uses the principle of reducing neural motor noise effects [18] to construct the motor primitives that resemble human motor primitives, which is well approximated by minimum square jerk criterion. Therefore, instead of using a traditional TTC-based approach, it calculates the safest maneuver as a function of the jerk, i.e. the rate of change of the acceleration.

The initial jerk is taken as a measure of the effort to pursue the maneuver. The jerk is not only a measure of safety, but also of comfort. To avoid drivers/passengers losing control over their body motion, it is important to limit the maximum acceleration(i.e. the force they can safely be exposed to) and also the maximum jerk: in fact, they need time to adapt to even limited stress changes by adjusting their muscle tension. Even where occupant safety is not an issue, excessive jerk may result in an uncomfortable ride.

Development of a Human Machine Interface for C-ITS: key principles and criteria

The use of warnings in a mobility context includes a certain number of ergonomics issues, such as workload and distraction, intelligibility of each warning to understand the correct action to be performed in a short time, or combination of contemporary warnings (with different severities) provided by coexisting applications. The warning-based interaction paradigm involves a real-time driver-vehicle communication, acting on the imminent request of reaction by the human user. This implies a focus on the effectiveness of communication and efficiency in terms of reaction times.

In a C-ITS framework, where the vehicles are connected to each other and/or with the infrastructure and share data (e.g., position and speed of all vehicles), the number of unexpected events is drastically reduced or even set to zero . In a fully connected scenario, a warning-based HMI strategy should be replaced with a more sophisticated HMI strategy [19] able to exploit the potential of C-ITS.

The SAFE STRIP HMI has been designed in a way so as to offer the same user experience across different contexts, different level and way of cooperativeness, different profiles of drivers, different vehicle contexts drivers/riders, different applications (responding to different road scenarios) and different types of vehicles (equipped, non-equipped).

To meet those requirements in the C-ITS context, there are five key principles that the HMI of SAFE STRIP should fulfil from an implementation point of view:

- Reflect a distributed C-ITS architecture, i.e. exploit and replicate the distributed configuration, in order to allow more reliability, less energy and calculation power consumption
- Support a layered (negotiation-upon-warning) Driver Assistance strategy, i.e. adapt the tone of the message according to the level of urgency
- Be ubiquitous, in order to be shared among the traffic actors
- Be unobtrusive, i.e. avoid overload of information to the users
- Support personalization i.e. be adapted to drivers/riders' preferences and characteristics.

HMI strategy and implementation

Figure 2 - Example of SAFE STRIP HMI

During the project, an iterative design and validation path has been adopted. The HMI activity has foreseen a "human-in-the-loop" approach, in order to involve the users from the very preliminary design phases. The involvement of the users happened both for design and validation phase: to validate the HMI, in fact, we developed simulation scenarios based on the communication of the elements in the driving environment.

To avoid increasing the cognitive workload of the driver, the graphical layout has been designed to provide only the information that is necessary to support the driver:

- WHY: brief explanation of the situation the driver is requested to deal with
- WHAT: representation of the most appropriate action to be undertaken

Each information displayed in the HMI was directly linked to the co-driver. In this way, the HMI was completely handled by the cloud-based decision system. The HMI strategy was composed of 3 levels of urgency: low and medium urgency (i.e. Level 1 and 2) are, if possible, handled with a negotiation-based approach. This means that the system suggests to the driver the optimal behaviour to reach his/her target in the most effective way, without and before proceeding to creating critical warnings. High urgency, representing highly critical situations, is handled with a warning. The Warning Levels, determined by the jerk, are different among the road scenario in which the user is driving/riding.

Figure 2 shows an example of the SAFE STRIP HMI. The yellow frame indicates the medium urgency of the warning/negotiation; the icon and the label ("Front") indicate the type, the direction and the distance of obstacle/road actor; in the lower part of the screen, the action to be taken is displayed, with a graphical representation and a label. Consistently with the principles of negotiation-based approach, an analogue approach has been used in the pictogram design. Same "look and feel" has been followed for all applications of SAFE STRIP that share the same concept (i.e. all apart from those addressing autonomous vehicles), namely cooperative safety applications, virtual toll and parking applications and Variable Message Signs (VMS) application.

Methodology

The studies presented here were aimed at finding out whether the HMI developed in the project could be expected to be useful to real drivers and riders, specifically in helping them avoid dangerous situations or collisions. The situation awareness test ("Study 1") was aimed at finding out whether the HMI was able to produce the required situation awareness in drivers, so that a compliant driver would be able to avoid a dangerous situation or collision. The effectiveness tests for car drivers and powered two-wheeler (PTW) riders (combined, and reported as "Study 2") were aimed at finding out if the use of the system would –at least in a simulated environment –lead to the users successfully avoiding dangerous situations or collisions. The SAFE STRIP HMI has been tested upon the use cases reported in Table 1.

Table 1- Test Scenarios

Name	Description	Studies
T-intersection	In an urban scenario, the ego vehicle approaches a T-intersection from the stem of the T. Another car, which has preference at the intersection, is approaching from the left branch of the T, invisible to the driver until shortly before entering the intersection.	1
Pedestrian detection	In an urban scenario, a pedestrian is approaching at a pedestrians' crossing. The pedestrian is not visible to the ego driver, due to a parked vehicle in front of the crossing. The pedestrian eventually starts crossing the road.	1, 2
Wrong-way driving	In an extra-urban (motorway) scenario, the ego driver is about to use an exit lane in order to leave the motorway. A wrong-way driver is approaching the ego vehicle on this exit lane but is out of sight until shortly before the possible collision.	1, 2

In all 3 scenarios, the ego driver would need to slow down or brake to avoid a collision.

Study 1: "Awareness Test"

Study 1 was conducted at the Vehicle Interaction Lab at Fraunhofer IAO (Stuttgart, Germany), which comprises a real car. The simulation of the surrounding environment was realized with the software SILAB by the Würzburg Institute for Traffic Sciences. Three back projections on three planar screens in front of the car enabled a frontal view of 180 degree. Three additional projections simulated the two side-view mirrors and the rear-view mirror. The interior of the vehicle mock-up was equivalent toa standard car. The visual and audio HMI elements were displayed on a smartphone (Samsung Galaxy A6 5 inch) at the right-hand side of the driver, right above the centre console. The respective sounds were also emitted by the smartphone

We used an on-line freeze probe technique (SAGAT). The SAGAT is one of the most widely known measurements for Situation Awareness [20].It is a freeze on-line probe technique for human in the loop simulations, and it provides diagnostic information regarding how well the system in question supports the operator's situation awareness requirements. The simulation freezes at randomly or pre-defined points in time and subjects are queried to their perception of the situation.

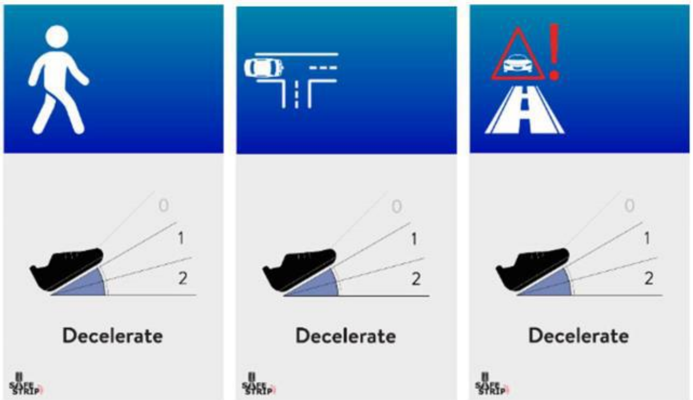

Figure 3 - Icons in the Level 1 messages (left to right: pedestrian scenario, T-intersection scenario, wrong-way driver scenario)

The drivers drove the scenarios for approximately3 minutes before the safety-critical situation appeared. Drivers were instructed to keep a speed of 50 km/h in urban areas and of 100 km/hon extra-urban roads/motorways. They were told they should pay attention to the driver assistance system on the smartphone but keep their speed constant.

At a pre-defined distance before the safety-critical event (ca.2 seconds after the display of the level 2message), the screens around the driving simulator blanked out and the simulation stopped. This ensured that the driver could perceive with the 2ndmessage, and then could evaluate the urgency of both warning levels. All messages on the mobile device were displayed in German language, as the participants were all native German speakers. Figure 3shows an example of a level 1message (blue).

Study 2: "Effectiveness test"

The "Study 2" was conducted as a combination of tests at CERTH/HIT riding simulator and RE:Lab driving simulator. 20 users in total participated in the test. The only requirement for all was to own a valid driving license for passenger cars/motorcycles. All subjects at CERTH trials were male, six of which participated in both experiments, whereas 3 of them were between 27-36 years old and 37-46 years old. At RE:Lab, 7 females and 3 males participated, whereas the average age was ≈29 years. All drivers or riders tested the same scenarios (i.e. 4 scenarios per driver/rider). The same dependent variables and protocol were followed for each test site. Riders were also provided with headsets, since the mobile application included a Text-to-Speech function to verbally present the warning avoid excessive distraction to riders.

The experimental process followed consisted of the following steps:

1. The driver/rider was given 10 minutes to drive freely with the simulator.
2. The driver/rider was explained the overall scope of the test. S/he was stressed that the goal was to drive in the safest possible manner according to his/her understanding and experience.
3. The driver/rider was requested to drive all scenarios in the row in random but mixed in the sense of road condition.
4. The driver should run and complete the scenario, without being interrupted by the instructor unless s/he had a query.
5. At the end, the driver was asked to complete the Van der Laan user acceptance scale and the few open questions and add any free comments, while the test instructor made free observation notes(e.g. near-end collisions, collisions or significant abrupt manoeuvres).
6. The key dependent variables were reaction time, speed adaptation, steering angle change.

Results

Awareness test results

The results of Study 1 confirmed the hypothesis that the system is able to raise attention to upcoming hazards and alarm the driver about critical events. Regarding the awareness criteria, the results are depicted in Table 2. In the pedestrian detection scenario, all participants and the wrong way driving scenario, all participants identified the source of danger. In the T-intersection scenario, the participants did not identify the source as easily. Some users considered the icon “too complex”; it could not be understood without watching the screen too long and thus diverting too much attention from the road. In case of the wrong-way driver, participants noted that apart from the icon, the wording (German: “Geisterfahrer”) helped them to understand the situation. The instruction of what to do (lower part of the screen) was less-well understood in all scenarios. Most of the time, drivers perceived the source of danger and then paid attention to the road, ready to react or break (which would have been the correct reaction in reality). The levels of urgency were understood correctly; sometimes, blue and yellow were regarded as equally urgent but never in reversed order (Figure 2).

Table 2 - Main SAGAT results

Number of participants who…	Pedestrian detection	Intersection support	Wrong-way driving
… named the source of danger correctly	11 (100%)	6 (55%)	11 (100%)
… were aware of the distance to the upcoming hazard	8 (73%)	7 (64%)	7 (64%)
… could name the recommended action	5 (45%)	6 (55%)	5 (45%)

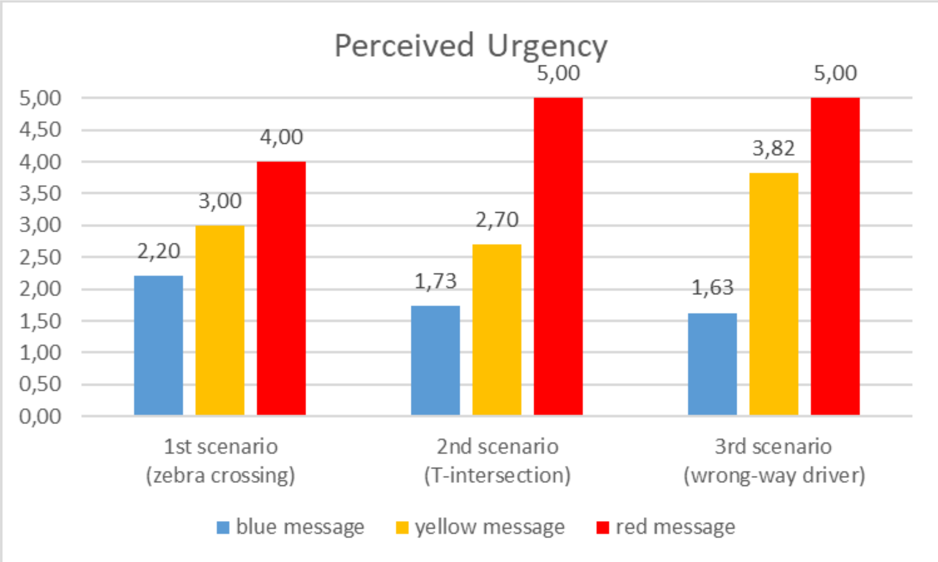

Figure 4 - Perceived urgency of the messages (1 = lowest urgency; 5 = highest urgency).

In summary, the (yellow) level 2 message showed a great potential to make drivers slow down. The messages that were effective in showing the source of danger / type of danger quickly were the most effective ones also in producing motivation to slow down.

Effectiveness test results

The analysis that follows utilizes the traditional [-2 to 2] scoring for estimating the acceptance dimensions.

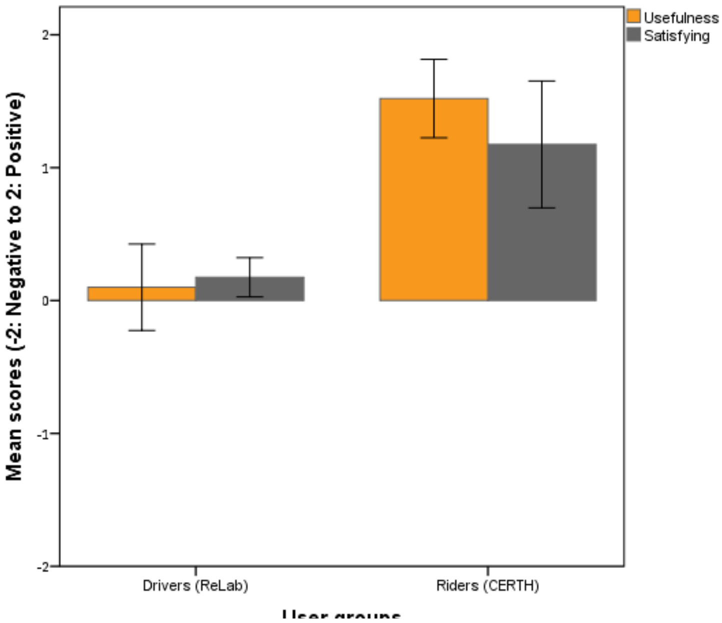

Figure 5 - Mean acceptance scores per pilot site and overall

Two composite scores were estimated based on the pragmatic (i.e. usefulness question items: 1, 3, 7, 9) and hedonic/aesthetic (i.e. satisfying related question items: 2, 5, 6, 8) dimensions of user acceptance, as defined by the authors of the Van Der Laan scale. As shown in the above bar chart, acceptance was average for the drivers (.1±.45) in but good for the riders (1.17±.67). Overall, it appears that the pragmatic value of elements (Usefulness: .81±.42 and Satisfaction was better accepted than the aesthetic aspects. Overall, usefulness (.81±) and satisfaction (.67±,71) mean scores were above average. Further improvements were deemed necessary in both the design and functional specifications to achieve acceptance regardless the user type. Another reason that could explain this discrepancy could be the fact that drivers are already mature and accustomed to smart systems warning and information HMI elements and features, which is not the case for riders. Concerning the qualitative results, the users appreciated the HMI, and in particular the possibility of receiving safety-related information well in advance. The extra-urban scenario was considered as more effective, even if the icon used to represent the vehicle in wrong way was considered more "abstract" and needed more reasoning to be understood. A recurring comment was represented by some text dimensions: the labels describing the object/road actors has been considered as too small and difficult to read. Regarding the objective results, the analysis focused on the evaluation of the reaction times, the type of reaction and the behaviour of the subject after the subject received the warning message. In the riding simulator setup, a local "cloud" server and a smartphone were used. The cloud server was running the MQTT broker, the co-driver and the Decision Support System program. The smartphone was running the application for the non-equipped vehicles. The mobile application functioned as virtual Road-Side Unit and also as the smartphone for non-equipped vehicles both.

The type of reaction for each participant was more or less constant across the test with most common being the throttle reduction. The speed adaptation 5s after the HMI warning was issued was analysed for all scenarios and all volunteers. The highest speed reduction was recorded at the Dry road / Pedestrian crossing scenario [-22.29 km/h (StDev: 13.43)]. The steering angle after the warning did not have any important difference. The experiment at driving simulator focused on the analysis of the reaction times, the type of reaction and the behaviour of the subject after the subject received the warning message. Four simulator setups were used for the two scenarios and the two road conditions.

Table 3 – Reaction times (mean and standard deviation).

	Setup 1		Setup 2	
Road condition	Dry road		Wet road	
Scenario	Pedestrian	Wrong way driving	Pedestrian	Wrong way driving
Average reaction time/ s (with std)	1.534 (0.481)	1.239(0.663)	1.613 (0.661)	1.153 (0.499)

As reported in Table 3, at driving simulator, the lowest reaction time was measured in the Wrong Way driving scenarios. To confirm this, subjects' comments remark that this scenario (and the related HMI) was considered the most clear and effective. It is important to highlight that, in every condition, the reaction time with the SAFE STRIP HMI was considerably low. This is also confirmed by the fact that non accidents and no real misses occurred in the test sessions. From the performance results it is clear that the system was effective in warning the drivers and the riders on time and they were able to adapt their speed in order to avoid an accident, even though almost all riders and all the drivers complied with the speed limit. It is important to note that since the screen of the smartphone is outside the field of view of the rider, the riders were reacting to the audio warnings and not to the warnings displayed on the smartphone screen.

Conclusions and next steps

This paper described an innovative HMI approach to exploit the potential of the C-ITS. A Human Machine Interface implemented as a mobile application has been developed, in order to inform the driver about possible danger, and to foster an optimized driving behaviour. The HMI relies on a virtual co-driver aimed at suggesting the timing and the intensity of certain given manoeuvres, e.g. the braking. The HMI has been developed with a negotiation-based approach, in order to allow a smooth, easy and pleasant interaction. It has been iteratively tested in riding and driving simulators in Germany, Greece and Italy with 31 users in total. The remarks made during the tests, along with the subjective results, have been taken into account for the fine-tuning of the HMI and of the co-driver decision making before moving to trials. Based on the results of the experiments, we identified four aspects of the HMI that could be improved: (1) the symbol depicting the imminent collision at the T-intersection, (2) the symbol indicating an approaching wrong-way-driver, (3) the second symbol telling the drivers to decelerate or break, (4)the thresholds of the co-driver in urban scenarios, in order to avoid early warnings that could be considered as misleading. These modifications have been included in the final version of the HMI and will be tested in the project's pilots with users on real equipped and non-equipped vehicles.

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