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Validation Approach of an C-ITS infrastructure – based solution

Andrea Steccanella[a], Maria Gkemou[b]*

[a]*Electrical / Electronics – Safety & Driver Assistance Systems, CRF S.C.p.A., Via Sommarive, 18, 38123,Trento (TN) - Italy,*
[b]*Hellenic Institute of Transport, Centre for Research and Technology Hellas, Egialias 52, Marousi 15125, Athens, Greece*

Abstract

SAFE STRIP (SAFE and green Sensor Technologies for self-explaining and forgiving Road Interactive aPplications) EU funded project aims to develop a low-cost integrated solution, installed directly on the road surface, able to collect the information of forthcoming dangers that the vehicles cannot evaluate on their own through state-of-the-art sensors. Reliable and punctual data, with lane level accuracy, are gathered and specific warnings (like low grip surface due to ice) are disseminated through Infrastructure to Vehicle (I2V) communication. All the vehicles benefit from the solution: modern vehicles equipped with ADAS functionalities but also private users connected to the infrastructure through smartphone applications. The current manuscript presents in short the technological solution towards evaluation, the multi-layered validation approach anticipated by the Consortium for delivering a prototype of an as much as possible high technological readiness and the technical validation results in hand evidencing its robustness prior being tested with users.

Keywords: C-ITS; smart infrastructure; I2V (Infrastructure to Vehicle); validation

1.1.1. Nomenclature

ADAS Advanced Driver Assistance Systems
BLE Bluetooth Low Energy
C-ITS Cooperative Intelligent Transport Systems
DSS Decision Support System
HMI Human Machine Interface
I2V Infrastructure to Vehicle
ITS Intelligent Transport Systems
LTE Long Term Evolution
MAIDS Motorcycle Accident In-Depth Study
MQTT Message Queuing Telemetry Transport
OBU On-Board Unit
OEMs Original Equipment Manufacturers
ORU On Road Unit
PTW Powered Two Wheelers
RSB Road Side Bridge
RSSI Received Signal Strength Indicator
V2I Vehicle to Infrastructure
VDIS Vehicle Detection and Identification System
VMS Variable Message Signs
VRU Vulnerable Road Users

2. Introduction

Although C-ITS may have a great impact on road safety, traffic efficiency and comfort, their extremely small penetration - the maximum penetration rates of ADAS in Europe did not surpass 9.86% in [1] - practically nullifies their impact. That, among other, relates to the high cost of applying the infrastructure required, in many cases, for cooperative applications functioning. Still, critical infrastructure situations (such as night and bad weather) represent 35% of the root causes for road injury accidents in EU (TRACE 2015). Also, according to the

*Andrea Steccanella, Tel.: +39 0461312617; *E-mail address:* andrea.steccanella@crf.it, Maria Gkemou, Tel.: +30 2111069553; *E-mail address:* mgemou@certh.gr

MAIDS, 4.2% of the investigated PTW accidents (Total n=921) occurred in a motorway and in 7.9% of the cases, road condition was described as "wet". Water was coded as a roadway contamination, because of the negative effect that it could have upon PTW handling and braking capabilities. Ice, snow and mud were reported in 2.5% of all cases. In parallel, surface deterioration or damaged bitumen (i.e. broken or separated asphalt) was found on 26% of all roadways. It is thus implied that road conditions and wear should be clearly considered and known by driver advanced road safety systems. In order to meet the aforementioned challenges, a revolutionary C-ITS technological solution is introduced in the context of the SAFE STRIP H2020 EU funded project (GA: 723211; starting on 1st of May 2017; http://safestrip.eu/), that shifts intelligence from the vehicle to the road infrastructure, in a cost-efficient way, deploying micro/nano sensorial frameworks, I2V/V2I communication technologies as well as energy harvesting to support the implementation of custom low-cost on-road strips that will be installed in each lane of the road pavement and will finally be painted (following industrial road marking systems requirements), reaching a height of 9[mm] from the pavement surface. The on-road strips, through a communication gateway, is capable of transmitting real-time information (static and dynamic) about the road condition, the traffic and the environmental conditions to vehicles supporting a series of C-ITS safety/informative services but also functions for autonomous vehicles with reliable, accurate and lane specific information, directly coming from the infrastructure, that will be further personalised and supported through a negotiation-based HMI. The vision is to make roads self-explanatory (with personalised in-vehicle messages) and forgiving (due to advanced cooperative functions) for all road users (trucks, cars and vulnerable road users, such as PTWs riders) and all vehicle generations (non-equipped, C-ITS equipped, autonomous), with reduced maintenance cost, full recyclability and added value services, as well as supporting real-time predictive road maintenance functions. All vehicles generations will benefit; C-ITS equipped vehicles through upgrade of their intelligence, non-equipped vehicles will benefit from intelligent functions that lacked before and autonomous vehicles will acquire lane localization data that will assist them fulfilling the gaps of on-board systems for the creation of virtual lanes, corridors, etc. that are essential to them. Infrastructure operators as well as all road users (passenger cars, PTW's, buses, and trucks) are supported, while benefits for VRU are also essential. Most importantly, however, the greatest contribution of SAFE STRIP lies in the vision to replace mainstream surveillance systems, VMS and toll stations through its proposed solution, which implies a radical reduction of installation and maintenance costs with a parallel increase of traffic safety. The current manuscript describes in short the technological solution under validation (section 3), the iterative evaluation methodology (section 4) and the results emerging as of the multi-layered technical validation part preceding the trials with users in real traffic conditions (section 5) that provide evidence on the proof of this novel concept.

3. Solution under validation

The basic part of the SAFE STRIP miniaturised road platform is an integrated ORU platform, which corresponds to a custom so-called "strip" that will be placed at specific points on the traffic lanes, as well as on the road pavement next to a zebra crossing area. The role of the strip is to detect and transmit all intended data (vehicle/pedestrian detection, road condition, environmental data including traffic data, etc.) to a RSB that serves as the communication gateway to the road users by means of alternative communication channels and protocols. The strip contains all necessary sensors requiring close-to-road or lane-specific measurements. It is based on a central unit, which drives several sensors, some of which being external to the main ORU board, such as the VDIS for vehicle detection and VRU detection that has been custom-developed in the project utilising ribbon switches and RFID technology as well as the strain gauges module (consisting of two strain gauges per lane, placed at right angle to each other) that is responsible for measuring strain profile of the pavement. The basic communication between the ORU and the RSB is realised wirelessly over BLE. The RSB is able to communicate wirelessly through ETSI ITS-G5 with the equipped vehicles and through LTE network to the non-equipped vehicles respectively. Additionally, for low-speed scenarios (e.g. in the urban traffic environment), the RSB utilises BLE technology in order to communicate with both the equipped and non-equipped vehicles and exploits the LTE network to communicate with the Central ITS Station (C-ITS-S) of SAFE STRIP sending modified ITS messages. Upon the decision making process, a warning message is produced and sent as a MQTT message to the end-user mobile application that is specifically built for the non-equipped vehicle users. C-ITS-S stands for the SAFE STIRIP sub-system being responsible for the provisioning of C-ITS services. It communicates with connected third parties, representing, for example, the road, traffic management and parking operator centres. The ORU platform is powered by a global energy unit utilising rechargeable and non-rechargeable batteries and micro harvesters. For powering the RSB, two approaches have been applied (and validated): one based on 100% powering from renewable energy sources with no need to be connected to the electrical grid. In this approach, the main challenge is to design the RSB in a way that the system does not run out of energy. In the second design approach, the RSB is powered at least 20% from renewable energy sources whilst another 80% from the electrical grid. In the latest approach, the RSB is smaller and less expensive but it has to be connected to the electrical grid to charge its battery when it is not possible from the renewable sources. The validation of both approaches is one of the objectives of the technical validation of the system. The vehicle demonstrators of the project are equipped with an OBU which integrates all the necessary communication modules and software stack for the realisation of V2X communications and the required interfaces for the interconnection with vehicle's CAN bus system and sensors. The OBU implements a DSS responsible to prioritise warnings originated from different sources and shown on the driver OBU. In the case of non-equipped vehicles, decision making runs on the C-ITS-S, with the prioritised warnings shown on mobile terminals.

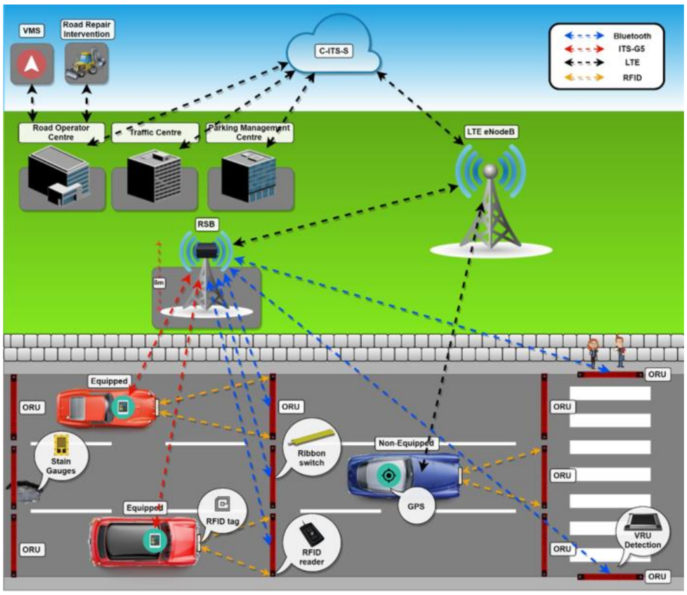


Fig.1 SAFE STRIP functional architecture.

4. Evaluation Methodology

4.1. Iterative evaluation

SAFE STRIP system has been evaluated in controlled environments (test beds in Spain and in France and in one closed test tracks in Italy) and will be also tested in real life conditions in two test sites (A22 highway in Italy and ATTIKI ODOS in Greece) with six vehicle demonstrators in order to validate its performance, user experience and acceptance aspects and, finally assess its impacts to safety, mobility, the environment and European industrial competitiveness among other. An iterative implementation and validation plan is developed covering all types and phases of anticipated testing as explained in [3].

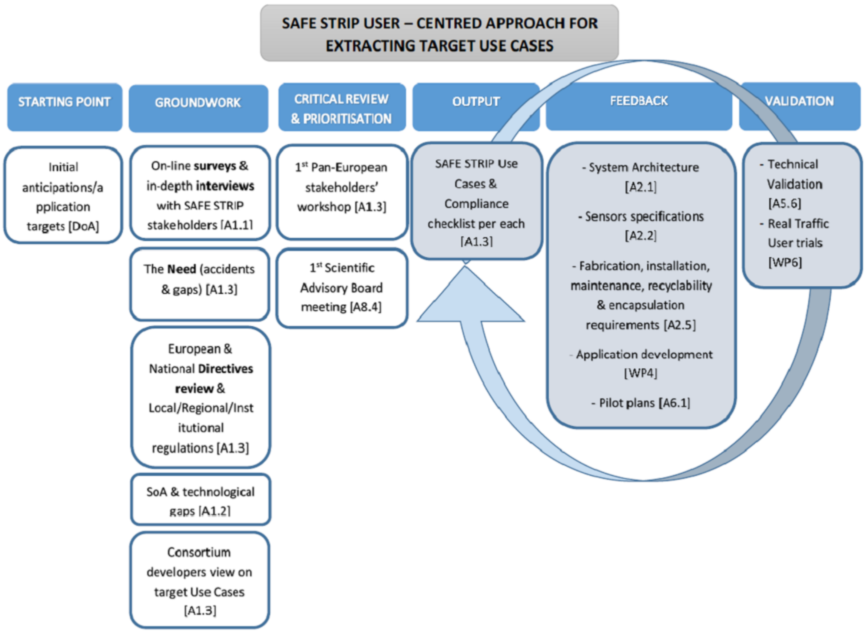


Fig. 2 SAFE STRIP User – Centred Iterative Approach.

The starting, and reference point, has been the goals of the project, more specifically, the part encompassing the target applications that has served as proof of concept of the implementation approach towards the integrated solution as well as the need that led to the emergence of SAFE STRIP overall. The next step was the critical review and prioritisation of them by experts participating in a Pan-European workshop and the Scientific Advisory Board of the project. The output has been an aggregated collection of gaps, restrictions, needs, views and priorities that has led to the extraction of the UCs. The UCs were described in such a detail to serve as functional requirements checklist feeding the system architecture and specifications work, the implementation work and the issue of pilot plans and validation approach. In the context of planned validation activities of the project (technical validation and user trials), conducted in 4 rounds, each iteration round leads to an optimisation period that, in turn, leads to system and UCs revision. As mentioned above four testing validation rounds have been planned in order to iteratively test and optimise the final solution. First validation round focus was the testing of the first version of the core ORU of the strip. At second stage – on top of the upgraded ORU's elements – the communication channels have been tested (i.e. how the information originating from the ORUs can reach the vehicles and the backend services). RSB is tested to allow the communication between ORUs, equipped vehicles (i.e. vehicles with ETSI ITS-G5 transceiver), non-equipped vehicles (i.e. vehicles connected to SAFE STRIP service via LTE cellular connectivity) and back-end services (C-ITS-S platform available as cloud service). During this iteration the first tests of the HMI strategy and the 1st stage of the friction coefficient benchmarking tests took place. At the time of writing we are close to the third iteration where preliminary user-trials will be performed, after an overall walkthrough of the applications. In this iteration all the information gathered from the infrastructure and the vehicles will be fused and tested in the context of the SAFE STRIP demonstration cases [4]. The aim of the project is to spread SAFE STRIP solution as much as possible; therefore, the project tackles different type of demonstrators: cars and motorcycles equipped with ETSI ITS-G5, non-equipped cars and motorcycles where cellular connectivity is available to retrieve information from cloud services, autonomous cars and finally drivers with only smartphone applications available. Iteration 3 is dedicated to the assessment of the applications into these demonstrators in a homogenous way. This iteration is split into two sessions: the first one runs the final technical validation of the integrated system on all ends – infrastructure, application, communication and demonstrator ends– while the second one serves as the first round of user trials. The 1st round of user trials (to be conducted in the context of the 3rd validation round of SAFE STRIP) will run in each participating test site with ten drivers, who will test the in-vehicle and mobile functions for passenger cars, 3 (different to the previous) drivers, who will evaluate the autonomous functions (a different driver will be "in control" and the other two will be passengers), ten riders, who will test the in-vehicle and mobile functions for motorcycles and 3 representatives from operators (motorway and parking). Finally, the fourth round encompasses the final real-life trials of the project. SAFE STRIP will be deployed in the anticipated test sites. The strips will be encapsulated, painted and installed on-site emulating the anticipated real-life deployment of the system. An intense testing campaign with drivers and riders will run in test tracks and highways to validate the performance of the system, the overall customer acceptance, the expected impact and potential of SAFE STRIP. Twenty drivers and twenty rides, ten representatives from operators and three (different) drivers, as in the first round, to evaluate the autonomous functions will participate. The user trials of the 4th round will be complemented and concluded with focus groups at each test site where key stakeholder representatives from all the SAFE STRIP value chain will participate: drivers, riders, infrastructure operators, parking operators, authorities, Tier 1 suppliers, OEMs.

4.2. Incremental multi-layered technical validation

Technical validation, anticipated prior to real life user testing, is multi-layered and incremental. The testing iterations have been considered in such a way so that the system grows in complexity iteration by iteration in a controlled way. At high level all the components are structured in two layers: "Single module" and "Application module". Four different actors have been identified in the project: ORU, RSB, Demonstrators (divided into equipped-vehicles and non-equipped vehicles) and the Backend services. Each of them is composed by single components (or basic functionalities) which are being fused to develop the SAFE STRIP applications and services (advanced functionalities): generate warnings or collect statistical data for the backend services.

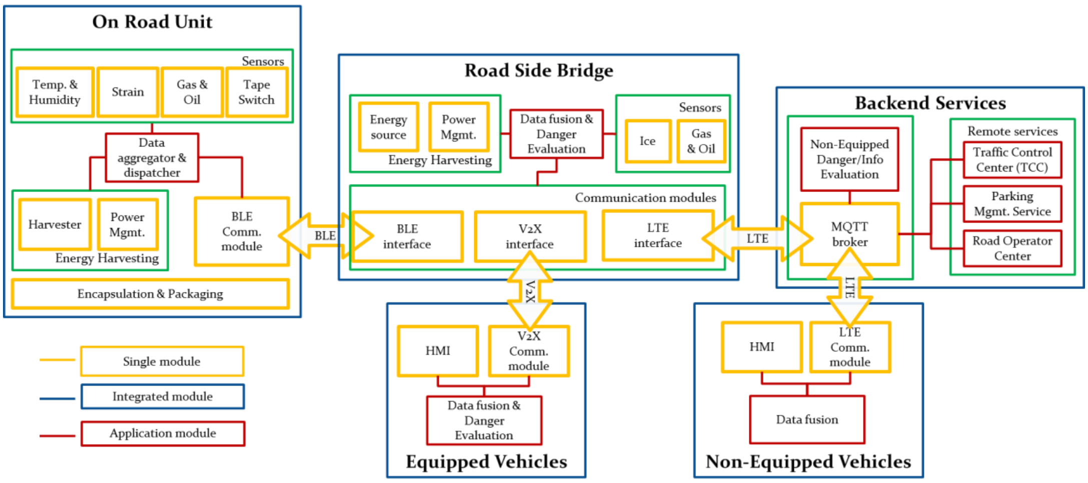
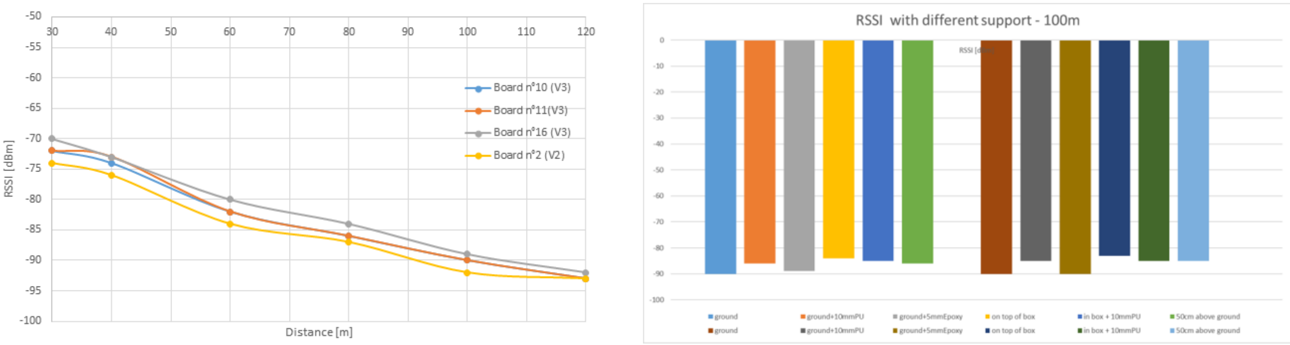


Fig. 3 SAFE STRIP incremental technical validation process

In Figure 3 the layers of each actor are distinguished: yellow containers represent the single modules, modules that shall be tested as independent components, while the red ones represent the application layer (the advanced functionalities of the specific actor). ORU and RSB are totally new components; therefore an assessment phase was deemed necessary to be performed to validate the proper operation in real-life conditions. During the first iteration the technology limitations of the selected sensors and the quality/reliability of the retrieved data have been assessed. The energy constraint was an additional complexity; as ORUs should be able to operate without external power supply for at least one year operation (similarly the RSB should be able to minimise the energy requested from the power grid in the optimum case). To protect the strips from extremely high or low temperature, presence of corrosive materials, heavy vehicles passing over, a specific encapsulation has been developed. The encapsulation module has been tested during the first iteration without electronic components inside while in the second one, there has been proved that no damage occurs to the electronic when vehicles drive upon the strip.

5. Results

The availability of sensors installed on the road surface brings several advantages: first of all the possibility to collect direct and continuous measurements, with lane level accuracy, enabling to monitor the road status and allowing to foresee road failures and almost instantaneous detection of anomalies in the normal environmental conditions. From SAFE STRIP analysis four sensors have been identified as the most relevant to enhance the vehicle safety system: temperature and humidity sensor, gasoline and oil spill on the road, vehicle detection and identification system (detection of position, speed and driving detection of the vehicles driving upon the strip as well as vehicle identification that allows personalisation of services received). Several strips contribute to collect the information necessary to trigger an application warning or a notification message. In SAFE STRIP project up to 7 strips are necessary to support all the SAFE STRIP use-cases: VRU protection, Wrong Way Driving, Work Zone detection, Railway crossing detection, Intersection collision warning, Queue at motorway exit, Virtual corridors for automated vehicle, Virtual Toll Collection, Parking availability, In-Vehicle VMS. All the ORU stations are connected via BLE to a side station, the Road Side Bridge (RSB); the optimum number of ORU stations as well as the maximum communication distance is one of the outcomes of SAFE STRIP project; a trade-off is occurring between the resolution of the measurements (how frequently updates are necessary and how many sensors shall be installed to reach the use-case granularity) and the production and installation cost of the SAFE STRIP system. Another parameter to take into account is the energy availability: the ORUs are not connected to the power grid to minimize the installation effort but, as mentioned above, the need is to keep the strips operational for one year activity. Depending on the application the information gathered from the sensors is collected periodically or triggered based on specific event, the duty cycle and the power required to collect and send the information to the RSB are part of the budget equation of the SAFE STRIP system. From the results of the 1st testing iteration evaluation, performed simulating the overall power consumption of the single components, the ORU harvester module is able to support the SAFE STRIP application for one year operability. In the 2nd testing iteration the prototype has been intensively tested in real environment conditions: no faults have been detected during the two weeks trials. The energy module was able to power up the system relying only on the rechargeable batteries and the solar panels. During the two iterations BLE ranging measurements were also performed in real environmental conditions. The ORU was placed on the ground while the RSB was installed at 8 meters above the ground. During the first trial, conducted in the Spanish test site, the ORU where able to communicate with the RSB at 60 meters distance. Our goal is to reach 100 meters so optimization was deemed necessary to the ORU. For the second testing iteration the new ORU has been equipped with a new antenna and different layout. The ORUs were able to successfully communicate to up 120[m] in Line of Sight conditions and open space environment. Ranging measurements have been also conducted in a real-life environment where obstacles were present in order to check the performance drop. During this testing campaign the strips were able to communicate at maximum distance of 70 meters. Several configuration were tested to check the communication performances varying the position of the ORUs: they were installed changing the orientation and the antenna height from the ground. From the analysis it turned out that significant variations in the channel quality were presence at distances included among 60 and 100 meters, see Figure 4(b). Further optimization to the communication protocol and the ORU enclosure will be performed in order to improve the range and reliability of the BLE channel for the third validation.



(a) (b)

Fig. 4 (a) Ranging measurament of BLE channel during the 2nd testing iteration. The ORUs were placed on the road surface while the RSB is installed on the building (8 meters above the ground), (b) RSSI of the BLE packets placing the ORU at different heights from the ground.

The RSB is responsible to collect the data from the strips and forward periodic updates or danger notifications to the traffic control centre and the vehicles for specific use cases (see Figure 3). The mean latency time required by the system from the detection of an anomaly to the reception of the danger has been measured during the 2nd testing iteration campaign. Two different channels are available in SAFE STRIP: the Equipped Vehicles channel (wireless IEEE 802.11p ETSI ITS-G5) with target latency <300[ms] and the Non-Equipped Vehicles channel (cellular LTE connectivity) where <3[s] delay is accepted. The results have proved that the RSB is able to detect and forward the information coming from the strips within the expected latency; more specifically the latency time for the ETSI ITS-G5 channel is <150[ms] while the deviation for the LTE communication channel is <1[s]. The key objective of the third iteration will be the measurement of the overall latency time necessary to complete the entire communication chain: from anomaly detection to the trigger of the application warning. Finally, after completion of all the technical validation rounds, the entire system will be assessed by external drivers in order to identify the user acceptance of the SAFE STRIP solution from people outside the project. Two user trials rounds are foreseen: a preliminary one (November 2019), where feedback and suggestions will be collected from the users, and a final event (February 2020) where the final configuration will be extensively tested.

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