User – centric approach for C-ITS solution proof of concept

Maria Gkemou¹, Katerina Touliou¹, Aristotelis Spiliotis², Evangelos Bekiaris³
¹ mgemou@certh.gr, Hellenic Institute of Transport (HIT), Centre for Research and Technology Hellas (CERTH), Greece
² touliouk@certh.gr, Hellenic Institute of Transport (HIT), Centre for Research and Technology Hellas (CERTH), Greece
³ aspiliotis@certh.gr, Hellenic Institute of Transport (HIT), Centre for Research and Technology Hellas (CERTH), Greece

Abstract
The current manuscript presents the iterative user-centric approach that has been followed for the prioritisation and full definition of the Use Cases of a highly innovative C-ITS integrated technological solution, newly introduced in the EU funded SAFE STRIP project (GA: n° 723211). This solution aims to shift intelligence from the vehicle to the road infrastructure, in a cost-efficient way, deploying I2X communication technologies and energy harvesting modules to support the micro/nano sensorial networks that will be embedded on the road pavement surface and will transmit real-time information (static and dynamic) about the road condition, the traffic and environmental conditions to the road users. In this way, a series of C-ITS applications can be supported with real-time, reliable, accurate and lane specific information, directly coming from the infrastructure. Next to the description of the overall approach followed, the key aggregated feedback coming from the stakeholders’ point of view is summarised.

Keywords:
Low cost C-ITS, intelligent infrastructure, traffic safety for all road users.

1. Introduction

The novel C-ITS (Cooperative Intelligent Transport Systems) solution, proposed in the context of the SAFE STRIP project (starting on 1st of May 2017; http://safestrip.eu/), aims to shift intelligence from the vehicle to the road infrastructure, in a cost-efficient way, deploying I2X communication technologies and energy harvesting modules to support the micro/nano sensorial networks that will be embedded on the road pavement surface in custom-made road markings/strip and will transmit real-time information (static and dynamic) about the road condition, the traffic and environmental conditions to the road users. In this way, a series of C-ITS applications can be supported with real-time, reliable, accurate and lane specific information, directly coming from the infrastructure, that will be further personalised and supported through a negotiations-based Human Machine Interface (HMI). 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 – Powered Two Wheelers, buses, trucks) are supported, while benefits for Vulnerable Road Users (VRU) are also essential. In the context of the SAFE STRIP project, the potential Use Cases of the project, reflecting applications clusters, that were intended to serve as the proof of concept of the integrated technological solution had been defined from the beginning.
Despite the fact that the potential of the envisaged system is not restricted to them, they comprise an efficient set of case studies that could reveal it.

Those case studies (nine in total) are as follows:

1. **Virtual Cooperative safety function** - Upgrade of two virtual safety functions that are already available in equipped vehicles and provision of them for non-equipped vehicles. The first one, named “Virtual VRU protection” is exploiting the ability of the strip to detect position and speed of vehicles and of VRU at zebra crossing, producing a warning to the driver when there is a potential collision. SAFE STRIP technology will provide for “VRU protection” application: 1) the position and speed, at lane level, of both equipped and not equipped vehicles in relation to pedestrian crossing location removing the need to use precise GPS positioning system, 2) the presence of VRU close to or on the zebra crossing, 3) information of the road surface conditions such as friction and wear. The second application, named “Wrong Way Driving” also matches a respective application for equipped vehicles. SAFE STRIP detects all vehicles (both equipped and not equipped) that are driving in the wrong direction (example taking the wrong exit from motorway rest area or gas station) and dispatches a warning to all other vehicles approaching the critical area.

2. **Enhanced Cooperative safety function** - Same as above, but for equipped vehicles. In this case, those two anticipated applications are being reflected in two distinct Use Cases (which is not the case for all the other Use Cases), as the implementation path differs significantly for equipped and non-equipped vehicles. In particular, non-equipped vehicles are receiving the information via the LTE (Long-Term Evolution) channel.

3. **Road wear level and predictive road maintenance** - By measuring pavement strains the motorway operator can evaluate pavement response and cracking performance. Remaining service life of pavements will be predicted using the present pavement condition and the latest rehabilitation action performed on that particular pavement. Survival curves will be developed to obtain remaining service life of a pavement family. The objectives are to determine the average service life of pavements and to predict their remaining service life. Also, the critical values and types of pavement damage (for road safety) will be defined so as to feed prompt mitigation from the infrastructure maintenance departments and in-time notification to drivers/riders through VMS (Variable Message Signs).

4. **Rail crossing and road works safety functions** - Road works and railway crossings, from the safety function perspective, can be considered as “hot spots” where constraints to vehicle speed or position in specific lanes must be enforced. The target safety application will suggest the proper deceleration and speed to be reached or the need to stop in a given distance. The applications for the two driving scenarios are based on the artificial co-driver concept which issues a warning when the driver’s estimated intention does not match the safest manoeuver. Specifically, road work safety function detects approaching vehicles (equipped and non-equipped) at lane level and provides a warning if the speed is not properly adapted or the vehicle will not stop in time in case of traffic jam in the road work area. Additionally, based on the vehicle’s lane position, lane change may be also suggested. SAFE STRIP will mainly provide 1) the position and speed at lane level of both equipped and non-equipped vehicles with respect to work zone starting point, 2) the available lanes or change in lane layout, 3) the speed limit in road work zone, and, secondarily, 4) the road surface conditions such as friction and wear, and 5) the presence of traffic jam. Similarly, for railway crossing safety function, especially when unprotected, the function will generate a warning when the estimated driver’s intention does not match the safest manoeuver to reduce the speed to the prescribed speed limit at the railway crossing or the vehicle will not be able to stop in case the train is approaching.

5. **Merging and Intersection Support: e2Call** - The application is an enhancement of the e2Call safety function developed by CRF for equipped vehicles. The original application is purely based on V2V (Vehicle to Vehicle) communication that exchanges vehicle position, speed and intended future paths. Additionally, the application relies on precise
GPS positioning and intersection, roundabout or road merging maps (for road layout and geometry). The output of the application is a warning to the driver when a potential conflict with other vehicles at intersection may happen or is imminent or when the driver is not going to respect give way right, stop sign or traffic light red signal. SAFE STRIP will improve the performance of e2Call function in many ways: 1) by providing with the position and speed at lane level of both equipped and non-equipped vehicles, 2) by removing the need to use precise GPS positioning system, 3) by providing with the local digital map close to the intersection, 4) by providing information of the road surface conditions such as friction and wear, and 5) by providing info about the traffic jam. The same application will be implemented for non-equipped vehicles as well (currently not existing). SAFE STRIP will provide the relevant information to non-equipped vehicles via LTE communication. Due to the expected delay in the LTE communication, the application will try to compensate for the delay and will not consider near potential collisions but only long range predictions (up to 5sec roughly).

6. **Personalised VMS/VDS (Variable Direction Sign) and Traffic Centre Information** - This application corresponds to the replacement of the current VMS/VDS infrastructure. Main objective of the application is to depict the VMS’s messages to the passing vehicles. The VMS’s message will be presented either through audio or visual channels or in both ways as informative or warning to the driver/rider. The message will be presented according to the driver’s profile (i.e. native language and preferred way of presentation).

7. **Autonomous vehicles support** - Improvement of automated functions for highway driving thanks to SAFE STRIP sensors data integration that is expected to lower the frequency of the driver having to take back control of the vehicle. Four (4) specific enhanced perception applications for automated vehicles will be supported, namely: *Dynamic trajectory estimation for automated vehicles; Definition of lane-level virtual corridors; Tollgates management and Work zones detection.*

8. **Virtual Toll Collection - for non-autonomous vehicles** - A virtual toll application for non-autonomous vehicles will be developed aiming to replace actual toll stations through the infrastructure provided by SAFE STRIP. The application will support toll station simulation enabling automatic passage as well as automatic payment. The infrastructure operator will be also acknowledged on the number and type of vehicles passing through the virtual toll station.

9. **Parking booking and charging** - The application optimises the use of available parking space. It provides information to the users about the availability and location of free parking lots. The application also includes payment capability through mobile application. Two scenarios are considered, parking with numbered places and street parking (free of charge parking and regulated parking).

The user-centric approach followed, as explained in the following section, had at this stage of the project as an upper goal the revision, prioritisation, filtering, enrichment, configuration and full definition of the Use Cases. Still, in the context of this process, and as made evident in section 3 of the current manuscript, a series of priorities, views, needs and attention points for the implementation and business path to be followed were also triggered and emerged. Though a part of them is not specifically focused on the specific Use Cases/target applications per se, they still constitute crucial feedback items for the way the associated applications (and consequently the overall integrated solution supporting and enabling them) should be developed and introduced in real-life.

2. **The Approach**

An iterative user-centric methodology has been defined aiming, finally, at the determination and full description of the use cases that will serve as proof of concept of the SAFE STRIP C-ITS solution [1]. The **starting point** has been the original goals of the project. That reference point, and specifically that part encompassing the target applications that will serve as proof of concept for the implementation approach towards the integrated solution as well...
as the need that led to the emergence of SAFE STRIP overall, have been investigated, revisited and analysed. More particularly, the revisiting groundwork relied on the consolidation of all relevant stakeholders’ needs, views and priorities, as those have been captured through on-line and in-depth surveys, the investigation of relevant accidents/incidents and gaps/priorities from the infrastructure point of view based on literature, the investigation on the legal/operational limitations on infrastructure end (as SAFE STRIP is mostly an infrastructure related solution) based on the study of relevant Directives and the Consortium experts’ views. The next step was the critical review and prioritisation of them in a Pan-European workshop held with external experts and during the first Scientific Advisory Board meeting of the Consortium with the respective experts.

Figure 1- Iterative user-centered approach followed for the development of Use Cases in SAFE STRIP.

The output has been an aggregated collection of gaps, restrictions, needs, views and priorities that has led to the full definition of the Use Cases. The Use Cases are described in detail and following such a format that will later serve as compliance checklists and key feedback pool for the system architecture and specifications work, the implementation work of the applications and the issue of pilot plans. In the context of planned validation activities of the project (technical validation and user trials), that will be conducted in 4 rounds, each iteration round will lead to an optimisation period that, in turn, may lead to use cases revisions according to the feedback collected. In this way, the Use Cases will take their final form before the final 4th pilot round of the project that will basically consist of trials with users trying the final solution through the applications delivered to them. However, the key functions and goals of each Use Case will be undoubtedly maintained as they have currently defined. Revisions and iterations will concern proven user needs during validation as well as adjustments of the technical details/specifications/Quality of Service (QoS) indicators thresholds given in the current document. Still, through the iterative process followed, SAFE STRIP will ensure that its goals, as those are reflected through its Use Cases, are fully respecting user needs and priorities.
One of the most crucial parts of the approach followed was the collection of the stakeholders’ needs and priorities, through the dedicated surveys that were put in place. The relevant stakeholder clusters are namely the drivers and riders, the Original Equipment Manufacturers (OEM’s), the road infrastructure operators, the road infrastructure integrators/constructors, the authorities, the Tier 1 (mostly) but also Tier 2 suppliers and the research/academia world. Both the on-line and in-depth surveys addressed all of them. The objective of the surveys was to collect the views, concerns, needs and priorities of all stakeholders’ clusters. Focus was on the originally intended applications (reflected through the project Use Cases); still, questions regarding the implementation approach and several aspects of it as well as about the future penetration and business cases of the project have been included to support the corresponding activities of the project later. Both surveys followed the same pattern, encompassing a General Section and Clusters specific sections targeting each stakeholder group. In both surveys, no personal information was collected and, hence, this report does not include gender, age, Socio-Economic Status (SES) and background information apart from the ones that are essential for clustering the users. The on-line survey was conducted through soscisurvey (https://www.soscisurvey.de). It was anonymised and promoted through SAFE STRIP social media, web site, Partners and User Forum members. The in-depth survey has been a superset of the on-line survey (meaning that it included all parts of the on-line survey plus additional more targeted questions) and was conducted with specifically selected representatives from each cluster. 326 respondents participated in the online survey and 67 interviews took place for the in-depth survey. Thus, overall, 393 respondents participated from 10 countries (Figure 2).

Data collected from the online and in-depth surveys has been analysed in the first place separately per user cluster addressed in the project and descriptive statistics (i.e. percentages, numbers and frequencies) have been used for the quantitative results. Average rankings were calculated for question items that respondents were asked to rank certain aspects and then based on average ranking, the relevant priorities were derived (this is applicable i.e., for impacts, applications, etc. where ranking was requested). In specific for the context of use priorities analysis, priority (first to show) scenarios have been selected, when collecting at least 75% of the responses, followed by those options collecting fewer responses (but not <30%). The same approach was followed for the analysis of results coming also from Consortium experts, SAB experts and experts participating in the Pan-European workshop.
Thus, analysis was performed first per user cluster and separate for each data source. Secondly, data was aggregated for all applicable data sources (i.e. common question items among different data sources). Both the consolidated qualitative and quantitative results have fed the project Use Cases, as described in the following section.

3. Aggregated Stakeholders’ Feedback

This section summarises the aggregated outcomes of the stakeholders’ surveys (on-line and in-depth). The key qualitative aspects which reflect the priorities given/stressed by the stakeholders (all clusters of them) are as follows:

- **The key legal/regulatory/operational barriers** were stated to be the data privacy issues, the liability issues in case of system malfunctioning, the lack of legal framework overall and the possibility that user acceptance is not strong and will not allow penetration of the system.

- **Conflicts** with existing road surveillance systems and regulations, as well as autonomous cars emerging technologies (via optical means) and existing intelligence (on-board systems) in equipped vehicles seem to be the key concerns of drivers. It was stressed several times, that compliance/harmonisation has to take place with regard to existing traffic management systems and processes, eCall regulation, current electronic toll collection and alternative toll charging methods underway, current research and development activity about road transportation and vehicle technologies that are yet to be fully integrated or standardized (i.e. IoT, C-ITS). Also, there might be an overlapping with “civil maps” and existing applications (i.e. Waze, Google) that already use vehicles or smartphones GPS data for traffic flow information.

- The most important advantages and benefits vs. relevant/comparable C-ITS solutions are considered to be the following:
  - Increased potential to enhance traffic safety, to reduce operating costs (less equipment, less unskilled personnel) and to increase quality of services provided to the road users.
  - Innovative technological solution, taking advantage of C-ITS.
  - The target to be a low-cost solution that requires only a communication module from the vehicle end and is also retrofitting older and all types of vehicles, promoting “equity” in roads.
  - Communication of accurate, real-time and personalised at the same time information (as it will come directly from the road and not through indirect sources, i.e. current surveillance systems and current time consuming means of pavement investigation surveys) which will be lane-specific.
  - The fact that the proposed solution will be the end-product of the cooperation of all types of involved parties (end-users, infrastructure operators, SME’s, industry and research/academia) gives an increased probability of exploitable application that will be accepted by all counterparts.
  - The “promise” that SAFE STRIP is likely to introduce new technologies that are “easier” and cheaper to spread in large scale while at the same time will require minimum or zero disruption of road infrastructure and of road operation during installation, increasing significantly drivers’ safety and services level through real time useful traffic information and necessary warnings.
  - Better integration of Connected Autonomous Vehicles (CAVs), which is the current key concern of operators.

- The most significant drawbacks/weaknesses/challenges/risks of SAFE STRIP are recognised as follows:
  - Standardisation process can be a drawback as it can restrict the availability in a short time and can also limit down interoperability.
  - The fact that wide penetration of the system will be rather challenging due to hinders imposed by the road authorities; at least until its standardised version is available.
  - The maintenance cost and effort that will be required for all strips installed in large scale; it is not yet clear how the replacement of strips will take place. In addition, the frequency
User-centric approach for C-ITS solution proof of concept

of road renovation in some countries is very slow; thus, implementation of the system can be very slow.

- The competitive market of OEM’s on-board systems.
- The market penetration could be slow due to lack of legal/operational framework.
- Insufficient communication means/network and potential security threats (i.e. hacking).
- Energy management of the ORU’s (On-Road Units) under a wide range of operational conditions (traffic loads, adverse weather conditions).
- By the time of the deployment phase, external to the Consortium third parties may invent something similar and competing, protect its knowledge or even interfere with SAFE STRIP planned invention (IPR issue).
- The likelihood of the system to be monopolised.
- Durability of the strip and validity of the overall system is not yet verified.

Key safety concerns encompass the following:
- Possible distraction of the drivers’ attention due to multiple incoming messages that may lead to road safety issues and non-acceptance of the system applications. This makes the HMI and personalisation work quite critical.
- “Overconfidence” to the system may also emerge, due to reduced attention and situation awareness of the driver due to "blind trust" in automation and warnings of C-ITS applications that may also lead to increase of driver reaction time.
- Increase of the traffic context complexity (especially in urban environments).

Key security concerns encompass the following:
- Risk of providing many services and pieces of information on the road environment which are not consistently merged.
- Hacking of personal information and cybersecurity of the overall system.
- Risk for erroneous information provision to the road users.

Key prerequisites/enablers recognised are as follows:
- Technologies are changing rapidly and SAFE STRIP should follow closely all relevant progress in the respective fields (communication technologies, C-ITS, energy management, etc.).
- The boost of the system relies a lot on its interoperable mandatory/standardized use.
- The final solution should be of low cost with clear benefits for road authorities. The cost should not surpass existing offered services/instrumentations, including any related maintenance costs.
- The system architecture should be open to allow for easy integration of different modules from different operators.
- Strips on the road should comply with current marking standards and restrictions.
- Most respondents agreed that SAFE STRIP requires a pilot application period before deployment. As a minimum, the system is expected to present robustness and reliability while working non-stop at all times and under every possible environmental condition. The driver/riders’ response to the imposed changes in mobility (distraction, acceptance, safety, driving behaviour, etc.) should be also evaluated.
- Intellectual Property Rights management and the development of a concise Exploitation Plan before the end of the project is a crucial enabler for success.
- More infrastructure stakeholders (even external ones) should be involved to promote SAFE STRIP to external third-parties for its effective exploitation and to evaluate external collaboration/partnerships. Interaction with the automotive world and major navigation/information actors can be a kernel issue as well.
- A legal framework covering SAFE STRIP should be established.

Overall:
- SAFE STRIP is expected by the vast majority of participants to bring positive impact in the daily mobility, increasing safety, allowing at the same time the road users to move in less congestion and get prepared for unexpected events.
- It seems to be an ambitious technological solution that aims to constitute a game changer in C-ITS; most of the respondents coming from all clusters (~82%) agree that SAFE STRIP should be included in the next C-ITS roadmap.
• **Recommendations/Extensions:**
  - The anticipated mobile applications use should conform with traffic safety regulations (regarding placement in the vehicle and use while driving), while it would be nice to provide a configuration of the system to the drivers/riders that combine all applications through one single interface in order to minimize driver workload. In the same context, HMI work should focus on prioritisation of the information/warning provided depending on their severity, in order to reduce the workload and, perhaps, give the driver the ability to choose which messages they want to receive.
  - If needed, different configurations of the system should be anticipated, such as basic to full range, covering different needs (driving in urban, highway, etc.).

Figure 3 - SAFE STRIP target applications prioritisation.

In the emerging prioritisation of SAFE STRIP target applications, reflected through the presented Use Cases (Figure 3), it seems that the cooperative safety applications (enhanced and virtual ADAS/ARAS) are considered of the highest priority, followed by the Road wear level and predictive road maintenance (which is intended for the road operators), while the Virtual Toll Collection and Parking booking and charging applications are the ones that have received the lowest (aggregated) ranking. The ranking that has emerged through the stakeholders’ surveys should be seen as a valid reference point for the project to be taken into account in case an irreversible failure in the development path is held or resources prove insufficient for some reason for full implementation of all.

Figure 4 - SAFE STRIP impacts coding.

The expected impacts of the project, that stakeholders prioritised, have been “coded” as shown in Figure 4. Their emerging prioritisation is seen in Figure 5 (top part). **Road safety**
and **mobility** are undoubtedly seen as the most significant impacts, followed by **traffic efficiency**, whereas the **boost of C-ITS penetration** is the last in the row (most probably because the envisaged solution is still at conceptualisation phase and its exploitation potential cannot yet be evident). The bottom part of the figure presents the emerged prioritised relevance of expected impacts vs. each target application/Use Case. It is evident that in most cases, road safety is the priority impact in most target applications, apart from the **Virtual Toll Collection** application, where operational support is first and the **Parking application**, where comfort is first (in both cases though, road safety is the least important). The outcome is considered quite natural and valid and confirms that the different external to the project stakeholders have understood the vision of SAFE STRIP.

<table>
<thead>
<tr>
<th>Expected SAFE STRIP impacts</th>
<th>Aggregated</th>
<th>Ranking</th>
</tr>
</thead>
</table>

**Figure 5 - SAFE STRIP target impacts prioritisation (top part) & target applications’ vs. impacts prioritization (bottom part) – [first is most important – last is the least important].**

Similarly, in Figure 6 (left part), the priority context (traffic context, vehicle clusters, info sensing) is given per target application (**the coding is attached in the right part of the figure**). It seems that **highway and urban traffic contexts** are the most popular in most cases. The rural context appears in the **Road workzones and unprotected railway crossing warnings** application. Passenger vehicles, PTW’s and trucks are seen as the priority vehicle cohorts for most of them (in the order they are mentioned), whereas several combinations of adverse weather conditions are appearing in each case. Road works are also present in some of them (i.e. “Virtual ADAS/ARAS”, “Advanced ADAS/ARAS”, “Autonomous vehicle support”, “Parking booking and charging”).
4. Conclusions and Further Steps

It is positive that SAFE STRIP has already convinced stakeholders for its ground-breaking vision; still, partially because of the stage it currently is, when no demonstration of the real solution was applicable, there has been a series of concerns expressed that will be certainly taken into consideration in the next stages of the project. Apart from the technical oriented ones (i.e., regarding the encapsulation and durability of the solution), a lot of concerns were expressed regarding the business potential and penetration approach to be followed by SAFE STRIP. Specifically those are valuable comments to be revisited in the core exploitation phase of the project (mostly in the last year). The needs captured from stakeholders’ surveys have been reflected in the final Use Cases [1]. All those needs that have been identified on secondary level and cannot be targeted by the project in its lifespan (due to limitation in resources or technical limitations, i.e., nature of available test sites in the Consortium) are being reflected in the potential extensions of the Use Cases, meaning that they are the first add-ons for the Consortium, within (if technical and resources limitations are solved) or beyond the project.

Acknowledgements

The work presented in this manuscript has been realised in SAFE STRIP (Safe and green sensor technologies for self-explaining and forgiving road interactive applications) project which has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (Grant Agreement n° 723211).

References

2. SAFE STRIP project web site - http://safestrip.eu