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Needs, restrictions and priorities for the development and installation of a multifunctional C-ITS solution on existing road pavement

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Abstract

The scope of this paper is to recognize the needs, restrictions and priorities in developing effort of a breaking through technology that will achieve to enable Cooperative Intelligent Transportation System (C-ITS) applications in existing road infrastructure, to make roads self-explanatory and forgiving for all road users and all vehicle generations with reduced maintenance cost, full recyclability and added value services, as well as supporting real-time predictive road maintenance functions. The enhanced broad functionality of the system on multiple levels imposes emerging needs and demands that will constitute the groundwork of the Use Cases for the implementation of the project, which are extracted through an iterative user-centered methodology approach and correspond to the target applications of the system. More particularly, the needs, views and priorities of all the relevant stakeholders have been captured through the outputs of 431 respondents participated from 10 countries in on-line and in-depth surveys. From the infrastructure point of view, the complementary investigation of relevant accident/incident and gaps/priorities was based on literature while the legal/operational limitations have been based on the study of relevant Directives and the view of experts. These sources provided important qualitative as well as quantitative outcomes, the aggregation of which led to the prioritisation of the target applications, two of which (last in ranking) are considered to be secondary in the sense that can be implemented with some flexibility.

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1. Introduction

The key results are presented as these have emerged after the application of the first phase of the user-centred approach that has been defined in the context of SAFE STRIP © project (Gemou, 2017), in order to collect stakeholders needs and identify gaps, restrictions and priorities. 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, 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/strips and will transmit real-time information (static and dynamic) about the road condition, the traffic and environmental conditions to the road users.This way, a series of C-ITS applications can be supported which 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 of 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, and trucks) are supported, while benefits for Vulnerable Road Users (VRU) are also essential. The Use Cases reflect the priority target applications of the project and have been developed to disclose its implementation objectives. As such, they constituted the key objective of the stakeholders and gaps survey that was conducted.

2. Materials and Methods

The various stakeholders' needs, concerns and priorities regarding the implementation goals have been captured through surveys held on-line, interviews and during a Pan-European workshop. Along with those, the view of the project Scientific Advisory Board (SAB) and Consortium experts has been collected, following a similar feedback format. Additionally, the literature on relevant accidents/ incidents and on gaps/ priorities as emerging from relevant C-ITS solutions deployment, but also from current mainstream infrastructure systems and processes was examined together with the relevant regulations concerning road pavement installations restrictions and prerequisites. All the relevant surveys/ workshops outcomes were aggregated to produce the consolidated results that consisted of a collection of gaps, restrictions, needs, views and priorities concerning the intended solution, leading, finally, to the full definition of the Use Cases. Those outcomes are interesting beyond SAFE STRIP, as it can turn useful and valid for other relevant initiatives dealing with C-ITS or infrastructure operations.

Obtaining the stakeholders' needs has been a vital part of the iterative user-centred methodology defined in the project. The participating stakeholders were divided into different clusters that constitute, in reality, the key value chain of the intended solution deployment (Fisher and Gemou, 2017). These are shown in Figure 1.

Survey forms – on-line and in-depth both - consisted of general and cluster specific sections. The on-line survey form that was a subgroup of the in-depth one, was anonymized and run through SoSci Survey software (SoSci Survey, 2017). The in-depth survey was conducted either face to face or throughout telephone. In addition, experts who attended the Pan-European and the SAB workshops were asked to give similar feedback by completing respective survey forms. 393 respondents from 10 countries participated in total in the on-line and in-depth surveys (67 in in-depth and 326 in on-line). In addition, feedback was collected from the 34 experts participated in the Pan-European stakeholders' workshop and the 3 experts, members of the SAB.

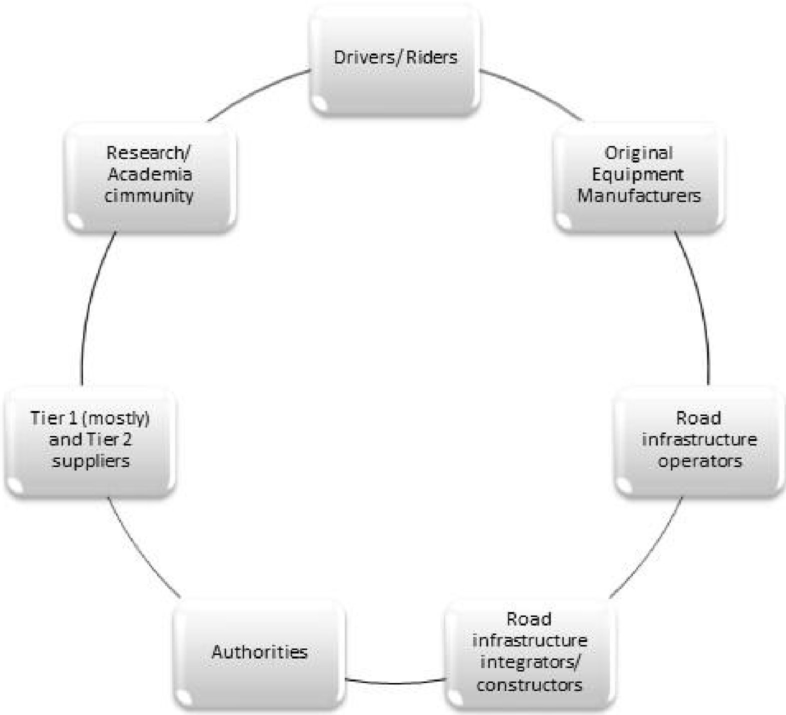

Fig. 1. Stakeholders clusters.

3. Use Cases

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 shown in Figure 2.

Case studies
Virtual Cooperative safety function
Intends to upgrade the two virtual safety functions "Virtual VRU protection" and "Wrong Way Driving", already available in equipped vehicles. The first one is exploiting the ability of the strip to detect position and speed of vehicles and of VRU at zebra crossing, providing application for a) the position and speed, at lane level, for all vehicles in relation to pedestrian crossing location removing the need to use precise GPS positioning system, b) the presence of VRU close or on the zebra crossing in term of magnitude and direction of speed and c) information of the road surface conditions such as friction and wear. The second application, matches a respective application for equipped vehicles. The system detects all vehicles that are driving in the wrong direction and dispatches a warning to all other vehicles approaching the critical area.
Enhanced Cooperative safety function
Same as above, but for equipped vehicles. The two anticipated applications are being reflected in two distinct Use Cases as the implementation path differs significantly for equipped and non-equipped vehicles.
Road wear level and predictive road maintenance
By measuring pavement strains the motorway operator can evaluate pavement response and cracking performance. Using the present pavement condition and the latest rehabilitation action performed the remaining service life and the average service life of pavements can be obtained. 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).
Rail crossing and road works safety functions
Road works and railway crossings are critical sections with regard to safety, where constraints to vehicle speed or position in specific lanes must be enforced. The applications for the two driving scenarios are based on the artificial co-driver concept which issues a warning when the estimated driver's intention does not match the safest manoeuver. Specifically, road work safety function detects at lane level approaching vehicles (equipped and non-equipped) 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 vehicle's lane position, lane change may be also suggested. 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.
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 which 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 going not 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 the position and speed at lane level for all vehicles, 2) by removing the need to use precise GPS positioning system, 3) by supplying 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.
Personalised VMS/VDS (Variable Direction Sign) and Traffic Centre Information
This application corresponds to the replacement of the current VMS/VDS infrastructure through audio or visual channel or both ways information or warning messages to the driver/ rider according to their profile (native language preferred way of presentation, etc.).
Autonomous vehicles support
Improvement of automated functions for highway driving thanks 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*.
Virtual Toll Collection - for non-autonomous vehicles
A vvirtual toll application for non-autonomous vehicles will be developed aiming to replace current toll stations. The application will support toll station simulation enabling automatic passage as well as automatic payment
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).

Fig. 2. Case studies.

4. Theory and Calculation

Answers collected from the stakeholders and experts were statistically processed and taken into account for the aggregated results. Descriptive statistics (i.e. percentages, numbers and frequencies) were provided 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). When prioritization was the objective, priority (first to show) scenarios have been selected when collecting at least 75% of the responses, followed by those options collecting less responses (but not <30%). Analysis was performed first on stakeholder cluster basis and separately for each data source. Secondly, data were aggregated for all applicable data sources (i.e. common question items among different data sources). The consolidated qualitative and quantitative results have led to the revisiting, prioritization and definition of several aspects of the Use Cases.

5. Results

5.1. Accidents – Incidents statistics

In 2014, 11733 car occupants were killed in road accidents in the EU which represents 45% of all road fatalities. 69% of fatalities occurred outside urban areas on non-motorways (CARE database, data available in May 2016). From the 26000 people killed in road accidents the same year throughout the EU about 13% of the links between causes are observed to be between 'faulty diagnosis' and 'information failure' (CARE database, data available in May 2016) which reflects the need for the development of cooperative safety functions as well as personalised VMS/VDS as presented in section 3 case studies. From the 26000 people killed in 2014, 5000 were killed at road junctions, 9923 inside urban areas and 3558 on motorways (CARE database, data available in May 2016). These numbers could be greatly limited if applications applicable to these sites are emerged, as the merging and intersection support function. Railway accidents occurring in level crossings comprise the second biggest cause of accidents with a 25% turnout (UNECE database, 2017) indicating the need to develop increased security measures. If all EU Member States currently performing above the current EU average (EU-28) could achieve a railway fatality risk equal to the EU-28, the overall fatality rate would drop by 40% to 0.16 fatalities per million train kilometres. This would bring a significant reduction in economic costs of accidents (€0.5 billion in terms of prevented casualties alone) and the convergence of safety performance levels (European Union Agency for Railways, 2016).

5.2. ITS impact on safety and traffic efficiency

A study conducted by National Cooperative Highway Research Program proved the correlation between the numbers of accidents occurred and the skid resistance value of the pavement (Hall et al., 2008). The study shows that as pavement friction levels decreases, there is a corresponding increase in crash rates. Another recent study (Mohammed et al., 2015) provides correlation between the Pavement Condition Score (PCS) as this has been proposed by (Owolabi et al., 2012) and number of crashes as well as PCS and number of people injured. Again in this study, as the PCS decreases the number of injured people is increased. A Road wear level and predictive road maintenance function as presented in section 3 can bring significant positive effects on safety while making the infrastructure maintenance more efficient and/or economic.

In addition, a detailed investigation showed that most drivers have a positive response and generally are positive towards the type and efficiency of information provided through Variable Message Sign (VMS) messages, with 47% of the drivers stating that they always change route when informed about an accident ahead, 45% doing the same for traffic congestion messages and 44% for roadwork activities (Ratrout and Issa, 2014). Still, a survey for the evaluation of six VMS in Trondheim, Norway, has shown that although re-routing information shown on VMS helps reducing travel times, this can lead to an increased number of crashes, as it can make drivers to brake or to change lane unexpectedly. In that case, no positive effects on traffic efficiency were recognized due to traffic congestion warnings, possibly because the VMS were not working as intended (Hoye et al., 2011). The above outcome is enhanced by results that show large speed reductions (reduction of more than 5%) and large proportions of vehicles braking while approaching a VMS if the sign is not understood (Guattari et al., 2012). That is another case where road safety and traffic efficiency can benefit from personalised VMS/VDS functions.

The toll collection plazas sites are critical sections of roads which present increased accident rates based on analysis and comparisons carried out between toll plazas and locations where Open Road Tolling (ORT) systems where deployed which shows a decrease by about 24% after the deployment (Yang et al., 2012). Also, based on data provided by AttikesDiadromes S.A. (the highway operator of AttikiOdos in Athens, Greece), these sites show increased rated of delinquency, having an estimated damage of about 3M€ since 2009 from more than 1 million non-conforming vehicles. In addition, the proper functionality of the road network relies on the quality/ quantity and speed of the incoming information collected by camera or other surveillance systems installed on the infrastructure. AttikesDiadromes S.A. has reported a mean current response time of 6.4m (for 2016). Hence a free-toll or Virtual Toll Collection scheme combined with more intelligent Traffic Centre Information is expected to have a positive impact on multiple levels.

5.3. Regulations and restrictions

The main field under investigation is road markings, as this is the infrastructure element that will finally host the on-road part of the integrated solution. The relevant directories are presented in Figure 3.

EN 1423 : 1997	Road marking materials – Wear simulators (CSN EN 1423, 2012)
EN 1871 : 2000	Road markings materials – Physical properties for paint, thermoplastic and cold plastic (CSN EN 1871, 2000)
EN 1790 : 1998	Road marking materials – Preformed road markings (CSN EN 1790, 2013)
EN 1436 : 1997	Road marking materials – Road marking performance for road users (CSN EN 1436+A1, 2008)
EN 1424 : 1997	Road marking materials – Premix glass breads (CSN EN 1424, 1997)
EN 1824 : 1998	Road Trials (CSN EN 1824, 2011)
EN 13197 : 2001	Wear simulators (CSN EN 13197+A1, 2014)
EN 13459 -1 : 1999	Road marking materials – Quality control – Part 1: Sampling from storage and testing (CSN EN 13459, 2011)
EN 13459 -2 : 1999	Road marking materials – Quality control – Part 2: Guidelines for preparing quality plans for materials application (CSN EN 13459, 2011)
EN 13459 -3 : 1999	Road marking materials – Quality control – Part 3: Performance in use

Fig. 3. Directories applied for road marking materials.

Ride quality strongly depends on the vibrations, as experienced by users and induced by road surface roughness. Two widely known quality indices which take into account ride comfort should be considered to establish a Pavement Management Report (PMR), the International Roughness Index (IRI) and the Pavement Condition Index (PCI). Finally, one of the key restrictions is imposed by the maximum allowed size/ thickness of road marking. European regulations do not explicitly state specific values/thresholds respectively. In a similar way, several national regulations and annexes do not define a maximum thickness. As it seems there is regulation gap (which has been also recognised by stakeholders), the restrictions imposed by the specific end-users participating in SAFE STRIP, namely A22 (in Italy) and AttikiOdos (in Greece), are investigated and to current knowledge, they vary from 3mm to 1cm from road pavement surface.

5.4. Stakeholders key outcomes

The aggregated outcome of the qualitative and quantitative data collected, together with the targeted accident analysis and investigation of operators needs from literature as well as the first investigation of relevant Directives imposing restrictions on infrastructure end produced the following prioritisation of the9 Use Cases presented in section 3 (Fig. 4).

The overall perception of the stakeholders is characterised by the expected positive impact in the daily mobility, the increased safety through better confrontation of unexpected events and the ambitious technological solution which should be included in the next C-ITS roadmap. However, the overall implementation and commercialization of the system bears some key issues. On the legal/ regulatory/ operational end, most respondents think there are barriers posed by privacy required on their data, any liability issues in case of system malfunctioning and the lack of legal framework. Conflictsare anticipated mainly with existing road surveillance systems and regulations, emerging technologies for autonomous cars (via optical means) and existing intelligence (on-board systems) in equipped vehicles.

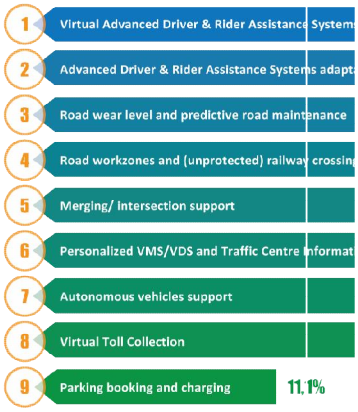

Fig. 4. Use Cases - Target applications prioritization.

Stakeholders think that the increased potential to enhance traffic safety together with the revolutionary technological solution which takes advantage of C-ITS and the target to be low-cost, communication accurate and real-time personalised constitute the main advantages and benefits of the system against relevant C-ITS solutions.

On the other hand, biggest drawbacks/ weaknesses are the standardization process which will be required before commercialisation, possible hinders imposed by the road authorities to penetration and the competitive market of Original Equipment Manufacturers on-board system.

Probable driver's distraction and the increased traffic context complexity combined with an ''overconfidence'' to the system are the most indicated safety related concerns. In the same vein biggest security concerns are the many services which may not consistently merge and the risk of hacking user's personal information. Last, the key prerequisites of this technology lie within the anticipated change that this technology will bring about, the interoperability of the system and the effort to present a low-cost solution for the users.

6. Discussion

SAFE STRIP seems to have a big potential which applies to modern and future transportation needs presented in this paper in terms of safety, comfort, added value services and technological development in the field of transportation. Research has shown that there are many challenging issues to be addressed before a wide deployment that have to do with the understanding of the users special needs and concerns as well as with the regulatory restrictions. Even with the resolution of the above, the lack of legal framework and the estimated time to generate one by the authorities, could conditionally trammel the rapid growth of the system.

7. Conclusions

The needs, views and priorities as recognised through interview and literature surveys and workshops in the context of the iterative user-centred methodology applied in the SAFE STRIP project together with the Use Cases that have fed respectively, will serve as a basis for the specification and development work that will follow. Upon the iterativeness of the approach defined, the consequent emerging versions of the integrated solution and the applications to be developed - that aim to serve as a proof of concept of the latest - will be tested in 4 evaluation rounds that will encompass technical validation and user tests in real traffic conditions (in A22 and ATTIKI ODOS highways), leading to the revision – if needed – of the initial Use Cases as well as the system architecture and topologies of the SAFE STRIP system.

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