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Intelligent Road Marking Systems enabling future connected mobility

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Abstract

Cooperative Intelligent Transport Systems (C-ITS) will pave the way towards automation and better traffic management. However, the deployment of these technologies is slowed down also due to the high cost of applying the V2I/I2V infrastructure required. The integration of low-cost micro/nano sensors into road elements (i.e. road pavement tapes/markers) would avoid the need for costly infrastructural elements and support the development of a more intelligent and cost-effective road infrastructure. This paper proposes a new generation of intelligent road markings that will boost the uptake of cooperative system applications. The document describes the added value of the intelligent road marking system to be developed within the SAFE STRIP project, meant to make roads self-explanatory for all road users and all vehicle generations. Key features derived from this disruptive innovation are: (i) support real-time predictive road maintenance functions through dynamic road embedded sensors inputs, (ii) reduce the overall the infrastructure operational installation and maintenance costs supporting at the same time a broad series of C-ITS applications and (iii) allow faster, more position specific and context oriented communication and data sharing between vehicle and infrastructure.

Keywords:

Cooperative intelligent transport systems, Intelligent road marking systems, Embedded sensing system

Introduction

The development of Cooperative Intelligent Transport Systems (C-ITS) has the potential to play a significant role in tackling the increasing problems of congestion, transport energy consumption and emissions in Europe. Indeed, C-ITS enables an efficient traffic state estimation and traffic control, and makes it possible to go a step further in providing real time information and tailored control strategies to specific drivers. C-ITS typically involves communication between vehicles (V2V), between vehicles and infrastructure (V2I) and/or infrastructure-to-infrastructure (I2I). The benefits span a range of areas, including improving road safety, reducing congestion, optimising transport efficiency, enhancing mobility, increasing service reliability, reducing energy use and environmental impacts, and supporting economic development. [1]

Even though the penetration rate of these systems is expected to increase fast, currently, studies estimate that, for instance, penetration rate of new vehicles equipped with Advanced Driver Assistance System (ADAS) in developed countries – Europe and America – is nearly 8%, while in emerging markets is about 2%. [2] This is also due to pricing, including the high cost of applying the V2I/I2V infrastructure required in many cases for cooperative applications and to support the automated driving functions of tomorrow. SAFE STRIP project aims at boosting the uptake of cooperative system applications by increasing their functionalities through low-cost micro/nano sensor communities embedded in road elements (i.e. road pavement tapes/markers). This would avoid the need for costly sensors or infrastructural elements and make road markings key elements in the development of more intelligent and cost-effective road infrastructure.

This document is organized as follows: a first part is dedicated to the description of the evolution of Road Marking Systems (RMS), including a short description of the current available options (both on the market and for the project). A second part introduces the SAFE STRIP project concept and highlights the added value of the collaboration between RMS and Intelligent Transport Systems (ITS). Finally, some considerations are made on related business insights. The conclusions close the paper.

Evolution of RMS towards integrated solutions

Road markings started being ordinary paint to divide roads in defined traffic lanes. In the last 100 years, numerous properties have been added, making roads increasingly important for road safety: retroreflective properties, thanks to the incorporation of micro-lenses (i.e. glass beads), increased night visibility; the development of Type II Markings increased visibility under bad weather conditions. Road markings currently have fast-drying systems, high visibility and lower installation cost. They fulfil different functions, for both drivers and pedestrians, not only related to traffic guidance, but also for information, indicating for example regulations. They provide drivers with guidance as to where their vehicle should be positioned; indicate the direction of the road ahead; provide information about appropriate speed, parking and directions, and some can even provide tactile and auditory feedback to a driver. Road markings have also become more environmentally friendly, avoiding the use of solvents or harmful components.

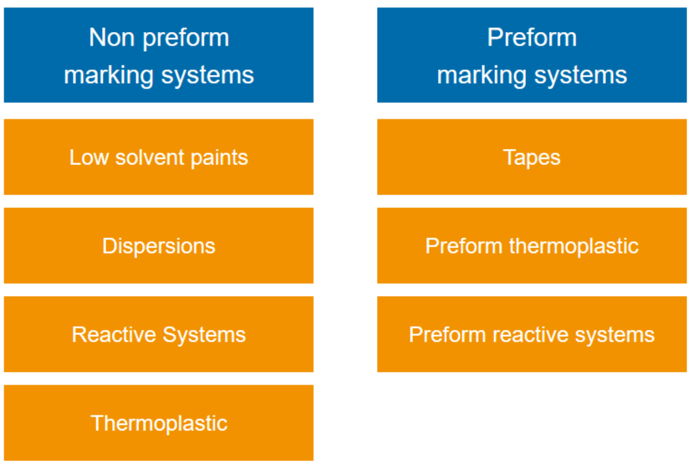

Figure 1: Types of Road Marking Systems

Different types of Road Marking Systems (RMS) exist: non-preformed or preformed markings systems (example of types provided in Figure 1); thin film or thick film systems. RMS can be made of single-component paints and dispersions, plural component plastics and paints, thermoplastic compounds and polymer tapes.

Within the SAFE STRIP project, road markings materials have been studied to identify the most suitable material to use for sensor integration. The best option proved to be the acrylic cold plastic. It belongs to the group of solvent-free, multi-component, reactive systems and consists of two or more components which – through chemical interaction – form a duroplastic compound that cannot be thermally plasticized thereafter. This material is suitable for bituminous surfaces (e.g. mastic asphalt, asphaltic concrete) and concrete pavements (priming required) and it can be applied with common application machinery for coldplastic markings (extruder / dispensing shoe) equipped with special adapter kits for profiles. It is abrasion resistant, and has no length, width or colour restrictions, while it has a height restriction of approximately 12 mm. This material fulfils the requirement of the German road institute BASt as type I and type II marking and has a homologation in several European countries. An example of material application and profile stripe is provided in Figure 2 and Figure 3.

Figure 2: Application with screed box

Figure 3: Finished profile stripes[1]

The potentialities of integrating ITS solutions into Road Marking Systems

The brief description of the evolution of the RMS proves the continuous effort to improve

[1] The shape of the profile for the SAFE STRIP project still needs to be designed.

performance and functionalities, with technological breakthroughs that include adding retroreflectivity, increasing longevity, and lowering installation cost.

Today, great potentialities for road markings lie in conveying a range of information to the driver, improving road environment understanding for advanced driver-assistance systems and for future use in autonomous road vehicles. The use of road markings for lane guidance has already been around for many years. Lane assist technologies are now relatively commonplace in vehicles. These driver assistance features provide safety and comfort to drivers, many of whom have come to depend on this technology. [3]

The objective of the SAFE STRIP project is to go further, with the integration of C-ITS enabling sensorial and communication units into the existing road infrastructure, aiming to upgrade localisation for vehicles. The collaboration of RMS and ITS aims at developing new road marking materials and designs with embedded micro/nano sensor to support V2I/I2V communication.

RMS and ITS in SAFE STRIP project

The concept

The disruptive technology to be introduced by the SAFE STRIP project will achieve to embed C-ITS applications into the existing road infrastructure. Novel I2V and V2I, as well as Variable Message Signs (VMS) and Variable Speed Limits (VSL) functions, will be integrated into low-cost, strips markers on the road, and will be complementary to the available, conventional signage in a coherent manner. Roads will be made self-explanatory, with personalised in-vehicle messages, due to advanced cooperative functions, for all road users (e.g. 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.

The encapsulation of micro-, nano-sensors, energy harvesting modules and microchips in the road marking is developed to be very resistant to wear by traffic loads and weather influences. All existing norms are fulfilled to guarantee the safety of the road user. For that a special cover for the electronics is developed and optimized to have a high adhesion to the existing road marking materials. The sizing of the electronics is tailored to the allowed sizes of road markings from road operators' point of view[2].

The data exchanged among the Traffic Management Centre (TMC), the cloud, vehicles and the infrastructure will be collected and processed, providing several services to drivers and road authorities. SAFE STRIP aims to embed static info (i.e. enhanced map data, speed limit, curvature, asphalt characteristics, etc.) to be transmitted to the vehicle, programmed after deployment and reprogrammed when the use of the road changes or during road works. Dynamic info will be received directly from the TMC, processed and transmitted to the passing vehicles in a personalised manner.

[2] The SAFE STRIP project investigated the restrictions imposed by the end-users of the Consortium, namely Attica Tollway Operations Authority and Autostrada A22. In particular, current restrictions for A22 in Italy require additional elements on road surface not higher than 3-5mm from the pavement surface.

The sensors embedded will also allow the dynamic measurement of environmental parameters (like temperature, humidity, water, ice, oil, smoke), while road sensors data fusion with vehicles' intelligent tyres' info will be used to accurately estimate each vehicle's friction coefficient.

Further data exchanged with the TMC will come from the passing vehicles, including non-equipped ones, and from work zones, railway crossings and other critical zones/spots. These will improve the measurement of the transit time, speed and lateral position in the lane, thus, offering key road load and circulation data and warn the driver/rider of critical areas and incidents well ahead. Additional applications will enable high accuracy and low cost automatic parking/tolling/insurance policies, as well as the definition and management of lane-level virtual corridors for automated driving.

The SAFE STRIP architecture and communication solutions for C-ITS equipped and non-equipped vehicles is provided in Figure 4.

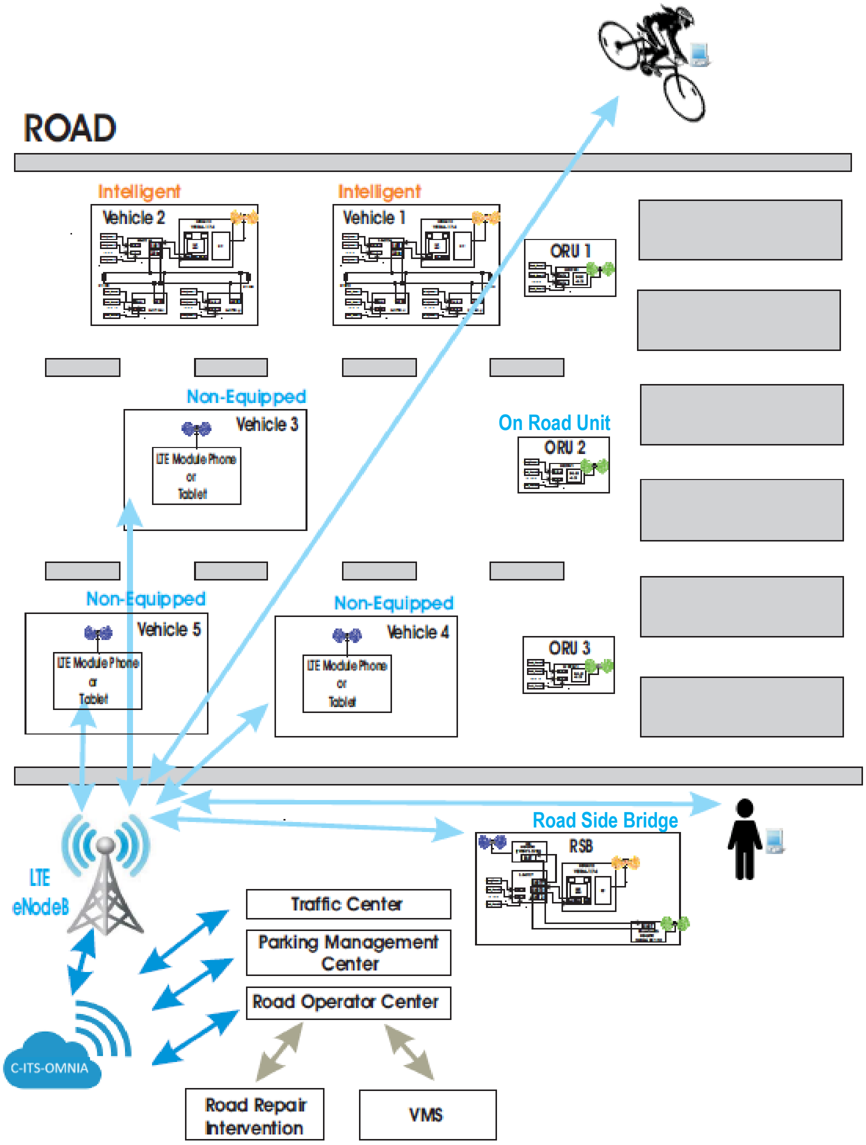

Figure 4 – SAFE STRIP architecture for C-ITS equipped and non-equipped vehicles.

More specifically, the communication between equipped vehicles and the SAFE STRIP components (i.e. Roadside Bridge – RSB) will follow IEEE 802.11p and ETSI ITSG5 standard. In the case of the non-equipped vehicles and Powered Two Wheelers (PTW), instead, the RSB will communicate all information from the road to the SAFE STRIP cloud (C-ITS-S based on OMNIA platform[3] - C-ITS-OMNIA) via LTE connectivity. Finally, warnings and other information will be sent by the cloud to the non-equipped vehicles. Both channels, V2X and LTE will be properly tested, evaluating the average communication time and the maximum latency time

Directives and restrictions

Road surface marking is probably the most important part of road signs as it is used to delineate areas for different traffic uses and to denote traffic rules (e.g. Separation of traffic lanes, distinction of bicycle/ pedestrian zones, provision of warning lines, stop lines, traffic messages, notation of parking spaces, etc.). Therefore, the use and placement of any sign or similar on the road pavement surface needs to be governed by crucial technical and legal requirements and restrictions [4].

The key restriction for the integration of the micro and nano-sensors into road markings is the allowed size. Apart from this, whichever type of surface road marking will be used in the project – commercially available or customised - its application should adhere to the respective European standards. An overall list of the European standards is provided in Table 1. Standards regulate also qualitative criteria, which stand for any local configuration on road's surface that may bring changes in the overall comfort of the road users. 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, are the International Roughness Index, IRI and the Pavement Condition Index, PCI to establish a Pavement Management Report (PMR).

Table 1 - European Standards

Standard No	Title
EN 1423: 1997	Road marking materials – Wear simulators
EN 1871: 2000	Road markings materials – Physical properties for paint, thermoplastic and cold plastic
EN 1790: 1998	Road marking materials – Preformed road markings
EN 1436: 1997	Road marking materials – Road marking performance for road users
EN 1424: 1997	Road marking materials – Premix glass breads
EN 1824: 1998	Road Trials
EN 13197: 2001	Wear simulators
EN 13459 -1: 1999	Road marking materials – Quality control – Part 1: Sampling from storage and testing
EN 13459 -2: 1999	Road marking materials – Quality control – Part 2: Guidelines for preparing quality plans for materials application

[3] The OMNIA Platform is a road transport environment, able to integrate several ITS applications (e.g. Urban Traffic Control, Public Transport, Parking, Streetlights, VMS, etc.), independently of the supplier or technology. Within the SAFE STRIP project, the platform (C-ITS-OMNIA) will be connected with different mobility management centres, elaborating data coming from the road and providing Cooperative ITS services.

Standard No	Title
EN 13459 -3: 1999	Road marking materials – Quality control – Part 3: Performance in use

SAFE STRIP added value

The physical road infrastructure (road pavement and road marking) is subject to wear and tear caused by traffic and environmental conditions. The constantly changing condition means it is often difficult and time-consuming to monitor their quality. To maintain accurate maps of road-marking quality requires road authorities and road maintenance companies to perform regular periodic surveys, perhaps several times a year. [5]

SAFE STRIP integrated road strips will bring significant added value to these stakeholders, support real-time predictive road maintenance functions and reducing maintenance cost. As a matter of fact, the embedded V2I/I2V interfaced sensors allow faster, more position specific and context oriented communication (e.g. vehicle localisation, road geometry, sense pedestrian crossing, etc.) and data sharing between vehicle and infrastructure. Direct benefits of their application include, in addition to the reduced maintenance costs, the increase of road safety and reduced costs of the overall road infrastructure. SAFE STRIP technology also aims to replace (partly and fully) costly infrastructure elements, such as toll stations and Variable Message Signs (VMS), reducing installation maintenance and life cycle cost and time by levels of magnitude.

SAFE STRIP concept and road strips have also the potential to bring key benefits to the intelligent transport system providers, who will be able to access real-time accurate data regarding both environmental conditions as well as road maintenance related information, with an increased level of granularity. This could enable them to provide additional valuable functionalities (i.e. real-time monitoring at pavement level, continuous monitoring capabilities, real time environmental information). Indeed, the road network performance relies on the quality, quantity and speed of the incoming information collected by systems installed on the infrastructure (e.g. camera or other surveillance). The current response time[4] can be greatly enhanced through SAFE STRIP, allowing the provision of more reliable and in-time information to the drivers and operators.

Building on these concepts, within SAFE STRIP, the TMC monitors extra-urban roads and recognizes incidents or special events. This application is based on the information exchange between the vehicles, the road as a monitoring sensor and the proactive Traffic Management Centre through V2I communication. Being able to receive data from various other data sources than the traditional ones enables the application of algorithms for more accurate status forecasts and for advanced maintenance alarm management. The dynamic information can be used in real-time to coordinate corrective actions, to promote collaborative traffic control and increase safety.

[4] Attikes Diadromes S.A. (Attica Tollway Operations Authority) has reported a mean current response time of 6.4m (for 2016)

Hypothesis of use case scenarios

The vast potential of SAFE STRIP will be demonstrated through the application of 9 Use cases (illustrated in Figure 5), carefully selected analysing both the current relevant market needs, through factual reports of road authorities on accidents/incidents and stakeholders' surveys, and the restrictions imposed by the infrastructure as well as by the Consortium and SAB experts.

These Use Cases correspond to the target applications of SAFE STRIP that will serve as proof of concept of the integrated solution. The 9 Use Cases include: 1) Virtual Cooperative safety function; 2) Enhanced Cooperative safety function; 3) Road wear level and predictive road maintenance; 4) Rail crossing and road works safety functions; 5) Merging and Intersection Support: e2Call; 6) Personalised VMS & Variable Direction Signs (VDS) and Traffic Centre Information; 7) Autonomous vehicles support; 8) Virtual Toll Collection - for non-autonomous vehicles; 9) Parking booking and charging. All of them include different scenarios, to support both equipped and non-equipped vehicles.

These application scenarios will be the starting point of the technical and user validation. The planned validation activities of the project will be conducted in 4 rounds, and each iteration round will lead to an optimisation period, where the Use Cases will be revised. The key functions and goals of each Use Case will be maintained; revisions and iterations will concern proven user needs during validation as well as adjustments of the technical details and specifications. The Use Cases will take their final form before the final 4th round of the project that will consist of trials with users. The final user trials will assess the impacts of SAFE STRIP in safety, driving behaviour, traffic efficiency and cost sustainability, as well as its technical performance, acceptance and usefulness and its penetration potential for different user groups.

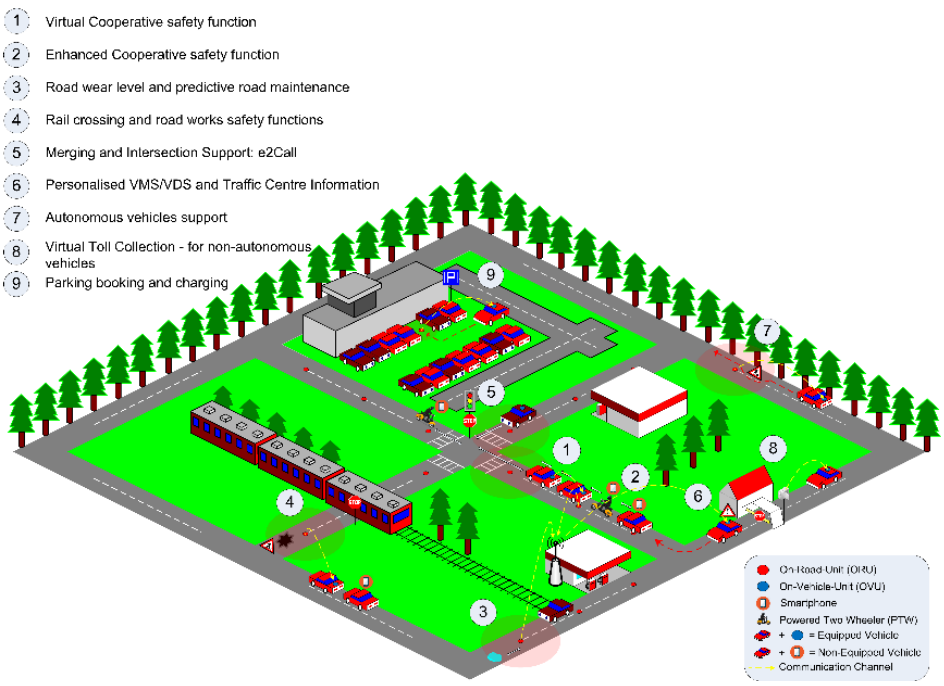

Figure 5 - SAFE STRIP Use Cases overview

Business-related insights

Intelligent road markings like SAFE STRIP represent a step further towards the digitalisation of the transportation sector. As a matter of fact, in addition to the development of more environmentally friendly materials and formulations and of new application methods, the development of intelligent road markings systems is a key innovation for mastering the future challenges of the mobility sector and the increasing road safety requirements.

The combination and integration of intelligent road markings and ITS applications changes the industry business model, leading the shift from a typical manufacturer and system provider to a more service orientated business model. More specifically, as described above, the SAFE STRIP technology helps delivering additional services to the road operators and drivers. For example, a real-time wear measurement of the road marking allows delivering a new maintenance service that guarantees a defined quality of the road markings; while the data provided by the intelligent road strips, properly processed and transmitted by the traffic management centres, will allow to provide personalised, accurate and real-time information to the vehicles, at the same time completing/replacing current signage infrastructure as well as Toll stations and therefore leading to an improved driving experience and an important saving of resources in long term for the road operators.

Such a model enables road authorities and other customers to better manage mobility, increasing road safety with high-level quality and in significantly lower cost and, at the same time, adopting environmentally friendly solutions, providing a sustainable return.

Conclusions

SAFE STRIP is developing a revolutionary technological solution that integrates low-cost micro/nano sensors into road elements (i.e. road pavement tapes/markers). The aim is to enable C-ITS applications through the existing road infrastructure with only minimum interventions, leading the development of a more intelligent and cost-effective infrastructure. The communication of accurate, real-time and personalised information will come directly from the road and not through indirect sources (i.e. current surveillance systems and time and resource-consuming means of pavement investigation surveys). This technology has the potential to enhance traffic safety, to reduce operating costs and to increase quality of services provided to the road users and operators.

This new generation of intelligent road markings will boost the uptake of cooperative system applications, at the same time creating new business opportunities.

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