Building up the Use Cases for an in-pavement C-ITS system taking into account key influencing factors and parameters

Michael Gogas[1a*], Mary Panou[1b], Maria Gkemou[1c], Aristotelis Spiliotis[1d]

[1]Centre for Research and Technology Hellas, Hellenic Institute of Transport
[2]Centre for Research and Technology Hellas, Information Technologies Institute
[a]mikegogas@certh.gr, [b]mpanou@certh.gr, [c]mgemou@certh.gr, [d]aspiliotis@certh.gr

Abstract

Within the frame of the ODOS 2020 (Intelligent cooperative integrated system for road safety and road infrastructure maintenance towards 2020) Greek national project, a breakthrough technological solution will be developed in order to achieve the implementation of Cooperative ITS (C-ITS) applications, deploying Infrastructure to Vehicle (I2V) and cellular technologies, without requiring costly interventions in the infrastructure, contributing to the increase of road safety, traffic efficiency and timely prognosis of road infrastructure critical deficiencies leading to predictive maintenance of the infrastructure. The integrated low cost technological solution relies on strips installed on the road pavement incorporating an arrangement of micro and nano-sensors and other communication and energy harvesting modules. In the current manuscript, a multi view approach method is presented in which the requirements of all the involved stakeholders along with the existing related transportation data are identified in the bases of the initial goals of the project, resulting in the formation of the Use Case scenarios which will serve as both a road map for the development of the system and a "Proof of Concept" for its inherent objectives.

Keywords: *in-pavement micro-nano sensors, monitoring and prevention of road pavement fatigue behaviour, C-ITS, road safety*

Περίληψη

Στο πλαίσιο του εθνικού έργου ΟΔΟΣ 2020 (Ευφυές ολοκληρωμένο συνεργατικό σύστημα ΟΔικής ασφάλειας και συντήρησης Οδικών υποδομών προΣ το2020), στοχεύει στην εισαγωγή μίας καινοτόμου τεχνολογικής λύσης που μέσω της χρήσης ψηφιακών τεχνολογιών επικοινωνίας υποδομής – οχήματος (Infrastructure to Vehicle – I2V), θα υλοποιήσει συνεργατικές εφαρμογές στο πεδίο των Ευφυών Συστημάτων Μεταφορών (Cooperative Intelligent Transportation Systems, C-ITS), χωρίς ουσιαστικές και δαπανηρές παρεμβάσεις στο οδόστρωμα συνεισφέροντας σημαντικά αφενός μεν στην αναβάθμιση του επιπέδου οδικής ασφάλειας και της διαχείρισης της οδικής κυκλοφορίας και αφετέρου στην έγκαιρη πρόβλεψη της φθοράς του οδοστρώματος οδηγώντας στην προληπτική συντήρηση της υποδομής. Η ολοκληρωμένη χαμηλού κόστους τεχνολογική λύση στηρίζεται στην ενσωμάτωση δικτύου μίκρο και νάνο αισθητήρων σε ειδικά στοιχεία υποδομής που τοποθετούνται επί του οδοστρώματος. Στην παρούσα εργασία, παρουσιάζεται μία πολυπαραμετρική προσέγγιση στην οποία οι ανάγκες των εμπλεκομένων και τα υφιστάμενα κυκλοφοριακά δεδομένα, σύμφωνα και με τους στόχους του έργου ΟΔΟΣ 2020, οδηγούν στη δημιουργία σεναρίων χρήσης του συστήματος (Use Case Senarios) συμβάλλοντας τόσο στην περαιτέρω ανάπτυξη του συστήματος όσο και στην επικύρωση της χρησιμότητάς του.

Λέξεις – Κλειδιά: *μίκρο και νάνο αισθητήρες οδοστρώματος, παρακολούθηση και πρόληψη κόπωσης οδοστρώματος, συνεργατικά ευφυή συστήματα μεταφορών (Cooperative Intelligent Transportation Systems, C-ITS), οδική ασφάλεια*

1. Introduction

According to EUROSTAT's (EU statistics office) database, the annual number of deaths in road accidents in the EU has been diminished from 55.000 in 2000 to 25.000 in 2018, but there is still a long way to meet the EU's Vision Zero (close to zero deaths) target for the year 2050. Human factor is responsible for the majority (90-93%) of road accidents. Almost one third (30%) of road deaths are attributed to high and inappropriate speed level, 10-30% of fatal accidents are caused by distraction of the driver, while another 25% of road fatalities in EU are alcohol related. The greatest share of accidents occurs in rural roads (54%) and built-up areas (38%) and only 8% of them take place in motorways. Half of those involve "vulnerable road users": pedestrians, cyclists and motorcyclists. Traffic accidents are the leading cause of death among people aged 15–29 years.

It is estimated that motor vehicle collisions caused the death of around 60 million people during the 20th century, around the same casualties of World War II. 91% of the world's road fatalities occur in low and middle income countries, although these countries have approximately half of the world's vehicles. Only 28 countries, representing 416 million people (7% of the world's population) have adequate laws that address all top-five risk factors (speed, drink-driving, helmets, seat-belts and child restraints). It has been pinpointed that without action, road traffic accidents are predicted to result in the death of around 1.9 million people annually by 2020 (World Bank, 2003; UN, 2010; WHO, 2010 and 2014; OECD, 2011 and 2015; Gogas, 2019).

In Greece, the accidents are recorded by both the Hellenic Police and the Greek Statistics Office (ELSTAT) databases. According to those facts and figures for year 2017 (2018 data still under processing), the most important factors causing road accident occurrence and related impacts are briefed in the below list:

- The most common causes of accident occurrence are correlated with speeding and aggressive driving, driving in the wrong / opposite direction, not complying with the right of way (STOP sign and / or red traffic light), distraction, alcohol / medicine / drug use and in the vicinity of crossroads (especially with rails)[1]. Those factors become even worse when taking into consideration their combination with the existence of fatigue, heavy traffic, hard weather conditions and pavement slipperiness or damage.
- 18,5% of persons involved in road accident are killed due to wrong way / lane changing.
- 9,1% of road accidents take place along the infrastructure of the newly built national road network, 17,8% along the old one, while the 73,1% of the accidents occur along the rest road network of the country.
- 15,2% of road accidents are due to the non-compliance with the STOP sign and right of way.

[1] At points where there is sharp differentiation in geometrical and / or operational characteristics of road (surface) transportation network

- 25% of road accidents occur near rail crossings.
- 20% of road accidents occur near or in crossroads.

In this paper, the focus is set on the Greek highways, since the initial demo pilot site and test bed of ODOS2020 integrated road safety system will be in Attiki Odos highway. The current situation concerning road safety facts and figures in Greek highways is depicted in Tables 1 & 2.

In Table 1, the aggregated road safety data (fatal accidents, deaths, injuries, material damages and their rates) per year from 2014 (establishment of Greek motorways association "HELLASTRON") until 2017 (2018 data still under processing) are presented.

Table 1. *Aggregated road safety data in Greek highways per year*

Index	2014	2015	2016	2017
Fatal accidents	38	40	40	39
Deaths	46	49	46	45
Death rate (fatalities / 1 billion of veh – km)	6,1	6,3	5,5	4,62
Accidents with injuries	293	327	364	365
Injured persons	301	319	550	539
Injury index (injured persons / 1 billion of veh – km)	39,8	40,7	65,4	55,32
Accidents with only material damage	3462	3800	4398	4.602
Material damage index (accidents with only material damage / 1 billion of veh – km	457,9	484,9	523,2	472,3

In Table 2, the detailed information on road safety data (fatal accidents, deaths, injuries, material damages and their rates) presented per Greek highway refers to year 2017 (2018 data still under processing).

Within the 2nd column, the respective data concerning Attiki Odos are depicted.

Table 2. *Road safety per Greek highway section*

Index	EGNATIA ODOS	ATTIKI ODOS	OLYMPIA ODOS	MOREAS	AEGEAN MOTOR-WAY	KENTRIKI ODOS	NEA ODOS	GEFYRA
Fatal accidents	11	4	8	2	5	0	9	0
Deaths	11	4	8	3	5	0	14	0
Death rate (fatalities / 1 billion of veh – km)	3,50	3,05	4,76	5,50	5,56	0,00	7,15	0,00
Accidents with injuries	143	44	28	25	30	6	89	0
Injured persons	198	56	54	48	52	7	124	0
Injury index (injured persons / 1 billion of veh – km)	63,06	42,72	32,15	88,05	57,84	35,53	63,33	0,00
Accidents with only material damage	559	539	1.114	314	716	84	1.260	16
Material damage index (accidents with only material damage / 1 billion of veh – km	178,02	411,14	663,16	576,02	796,44	426,40	643,51	1203,01

For the highways, where a balanced share of 11% of all the (fatal) accidents occur and especially for Attiki Odos highway, it seems that the imposed mortality rate is not very high but definitely not insignificant, while the same applies also for the injury and damage indications. In addition, the consolidated values of all the related indices do not appear to have a considerable fluctuation throughout the years. In any case, the enhancement of road safety is a priority for all infrastructure operators.

In this direction, the EU and the automobile industry seem determined by providing incentives for the incorporation of C-ITS as standard equipment in the fleet of new vehicles. However, this is not enough, as three important issues are not addressed:

1. There is no provision of integrating the C-ITS in the currently non-equipped vehicles which will continue to circulate on the streets for at least another decade jeopardizing road safety performance.
2. The need to implement an integrated strategic plan on the enhancement of road safety level on the side of the infrastructure in order for it to progressively become intelligent

and promote responsive, personalised and real-time communication with the road users (Europe on the move, 2018).

3. The current information provision systems in highways and motorways involve high enough costs for both their establishment and operation which, in most cases, neither comply with nor are justified by the quantity and quality level of information conveyed to the road users.

In particular, the typical C-ITS technological solutions most of the time provide a satisfactory level of support e.g. the VMS on dynamic adaptive speeding according to traffic and environmental conditions has proven to result in a reduction of road accidents' cost by 30-40%2), even though in many cases, the necessary "locality" of the real time information is either modified / adapted or completely neglected due to the generality and the universality of the provided information. In any case, those systems' most important weakness constitutes their cost of installation. For example, pertaining to a typical Variable Message Sign – VMS installation, the cost reaches the 24-90K€, while for the installation of a toll station the respective cost ranges around the 7,5M€. Those costs are extremely high not only for a country like Greece suffering from the last decade socio-economic recession, but for many other EU countries as well. In part, this fact explains the low penetration of C-ITS despite their considerable benefits.

To tackle the above, the proposed solution aims to early detect and continuously monitor in real-time on infrastructure level, events tackling with the road, environmental and traffic conditions and acknowledge the information directly to the road users preventing potential incidents / accidents. The novelty lies in the fact that the information provided will be:

- ✓ more reliable in content, as it will be directly detected by sensorial systems installed directly on the infrastructure and not by indirect surveillance systems and / or on-board systems
- ✓ lane specific, and as such, specific to events occurring on lane level,
- ✓ personalised, as it will take into account in a dynamic way the driver position and intention as well as their profile and
- ✓ more direct, as will be provided directly from the infrastructure, when they are spotted to the road users terminals.

Last but not least, all this potential is offered through a cost-efficient solution that is by order of magnitude of lower cost in comparison to typical infrastructure inspection and surveillance systems. Other than that, making it possible to offer support to all types of road users (driving equipped or non-equipped vehicles), surpasses the un-equity of on-board systems (of similar; still not better in terms of reliability functions) availability.

ODOS 2020 integrated infrastructure system will be experienced by the road users through four discrete applications for drivers / riders that will be developed. Those are the following:

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[2] New Market Research on Global & China Advanced Driver Assist Systems (ADAS) Industry-2015, Chisult Insight-2015

- Driver / rider road safety assistance application
- Monitoring the structural integrity of the road pavement
- Personalised (i.e. with personalised information provided in real-time to drivers/ riders) in-vehicle messages in replacement of current Variable Message Signs (VMS).
- Virtual toll collection system, replacing current infrastructure.

In this direction, ODOS2020 aims to design the system taking into account the national context specificities and its value chain stakeholders' needs, expectations and priorities, resulting, as a first step, into the system use cases that will drive further development and testing. Next to them, the technological readiness, across all types of technologies that need to collaborate for such a system as well as the requirements and restrictions imposed by the regulatory/legislative framework have also been considered.

Pertaining to the layout, including the first introductory one, the paper is structured within 6 sections. Within the second section, the methodological framework adopted in order to proceed with the data collection and compilation pertaining to ODOS 2020 system users and their needs and expectations is depicted. The results and findings produced upon the deployment of the afore mentioned methodological framework steps are provided in section 3. In sections 4 and 5 the scenario building and the final use cases are provided in detail taking into consideration the system users' needs and requirements, as well as the respective technological background and the legislative and regulatory framework. Any conclusions, as well as future research, implementation and exploitation plans are described in the frame of the last section.

2. Methodology

A five – step multi view methodology has been adopted for the development of the project Use Cases.

The **1st step** includes the identification of the relevant value chain stakeholders:

- Road users with emphasis on drivers and riders of all typesof vehicles (private cars, two wheelers, buses, trucks, etc.).
- Road/Traffic Management Centres (TMC) operators.
- Transport policy decision bodies in Greece and the EU.
- Road infrastructure construction and maintenance industry's stakeholders.
- Original Equipment Manufacturers (OEMs) dealing with the development and integration of Advanced Driver / Rider Assistance Systems – ADAS / ARAS and ITS (Intelligent Transportation Systems), Tier1 suppliers and other technology providers.
- Academia and research community on related technological fields.

The **2nd step** of the methodology involves the identification of the relevant stakeholders' needs, requirements and priorities which was accomplished by conducting both a personal interview survey and an on-line experts' survey amongst the participants of the 1st project workshop, resulting in qualitative and quantitative results. The questionnaires were addressed to all the identified stakeholder clusters.

The **3rd methodological step** incorporates the identification of the current technology, methodologies and tools to be implemented in ODOS2020 project together with their geometrical, technical and operational specifications/ characteristics. Inthis direction, a state of the art review of existing technological components and practices was elaborated with the assistance of the Consortium experts. At the end, a benchmarking database of technologies, methodologies and tools was formed to serve as a detailed and dynamically updating pool of technological resources, through the project's lifespan development phases. There is an interrelation between the system architecture layout and the available technology in the way that the former sets the requirements which are updated based on the availability of the latter.

Next, within the **4th step**, the related regulation, legislation, technical standards, guidelines and also constraints were reviewed, defining the borders of application.

In **step 5**, an accident analysis review in the EU and Greece in particular with focus on highways and especially on Attiki Odos (testbed of ODOS2020 project) took place.

The results and findings produced upon the deployment of the methodological framework steps are provided in section 3.

3. Results and findings

This section is divided in three parts. In the first one, the surveying aggregated answers are presented. In the second, the participating technologies are identified and, in the third, the current regulatory framework on road markings and identical elements which are likely to encapsulate the system both on and to the side of the road pavement are depicted.

3.1 Questionnaire survey

A total of **41** representatives from all target groups have corresponded. Their background and respective feedback lies in the following categories:

- ✓ Experts in road safety, infrastructure maintenance and communication technologies answering special questionnaire: 16 representatives.
- ✓ Rest of the core group of stakeholders incorporating the categories shown in Figure 1 answered the following qualitative and quantitative analysis questionnaires:
  - Drivers/ riders of all types of vehicles (private car, two wheel, bus, truck etc.): 7 representatives or 28 % of total.
  - Traffic and infrastructure operators: 2 representatives or 8% of total.
  - Infrastructure integrators: 3 representatives or 12% of total.
  - Legislation authorities (public bodies): 2 representatives or 8% of total.
  - OEMs & Tier 1 suppliers: 4 representatives or 16% of total.
  - Research community and academia: 7 representatives or 28% of total.

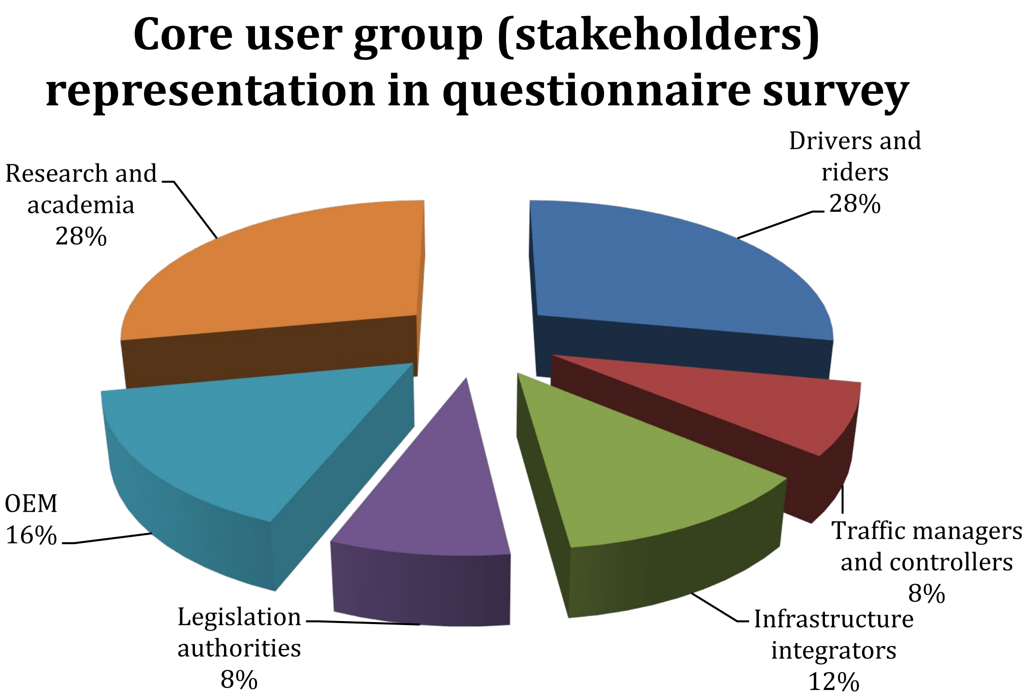

Figure 1. *Core user group representation during thesurveyThe experts' input has been received during the project's first workshop elaborated in Athens, Greece, (22.02.2019).*

The key findings of the stakeholders' aggregated input are listed below (Gkemou et al, 2019; Gogas, 2019). In specific, concerning the user requirements on the techno-economical characteristics of the system and its implementation:

- Out of the four target applications, full priority should be given to road safety functions (see application prioritization within Figure 2).
- The system should apply to all types of vehicles (private cars, buses, trucks, etc.), new, equipped and non-equipped, requiring a budget of no more than 1.000 – 2.000€ per vehicle and 3.000 – 6.000€ per critical spot for the cost of the infrastructure (see willingness to pay from the part of the users and the operators in Figure 3, a & b).
- The timeframe for implementing the road safety, wear monitoring and predictive maintenance parts are expected in due course (short-term), while the personalised VMS and the virtual toll collection plaza are due for later (mid-term or long-term).

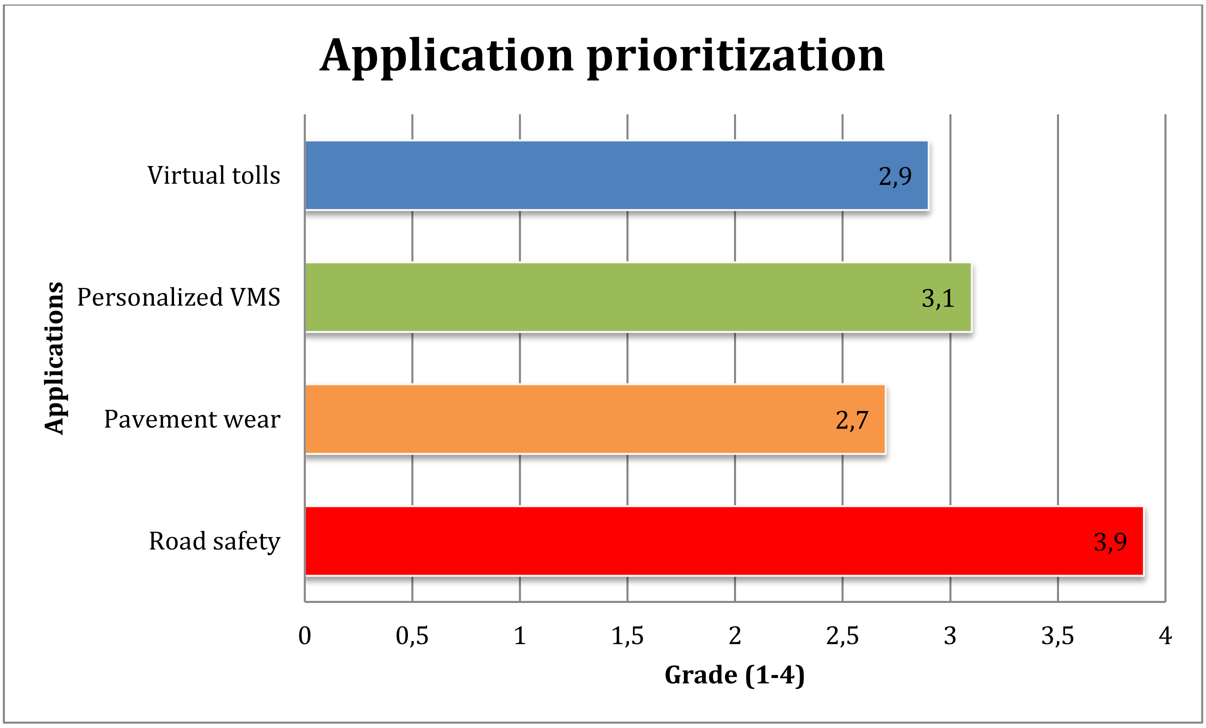

Figure 2. *ODOS 2020 application prioritization*

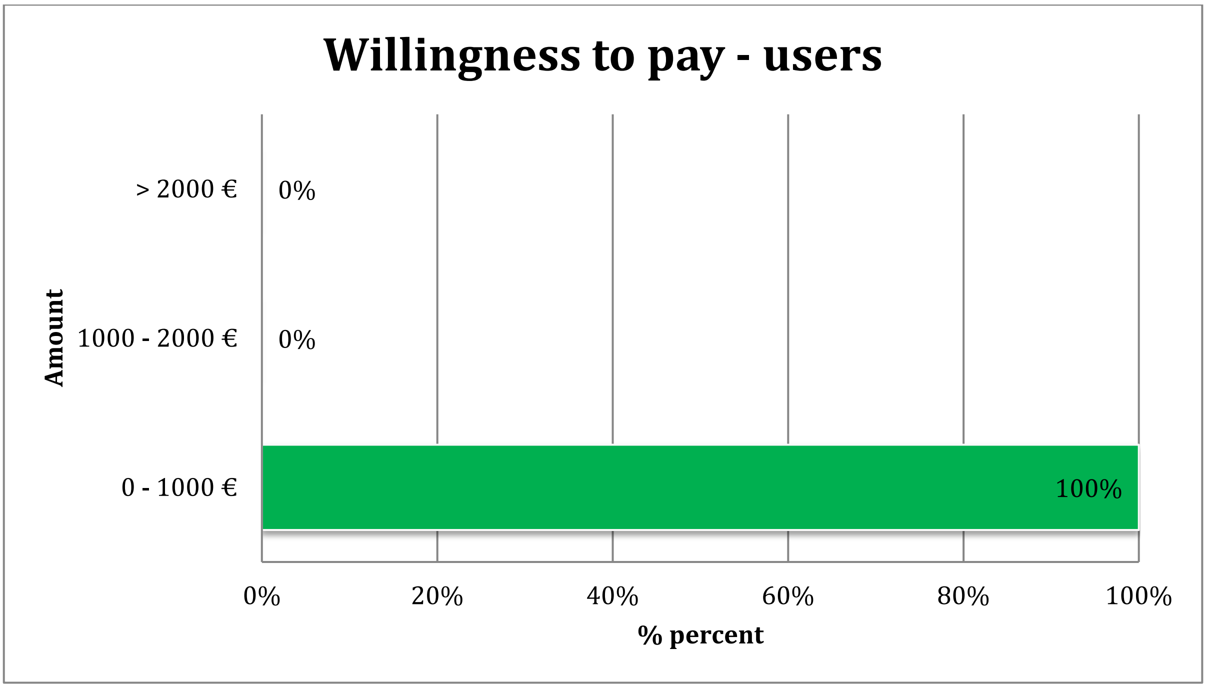

Figure 3a. *ODOS 2020 willingness to pay – users versus operators*

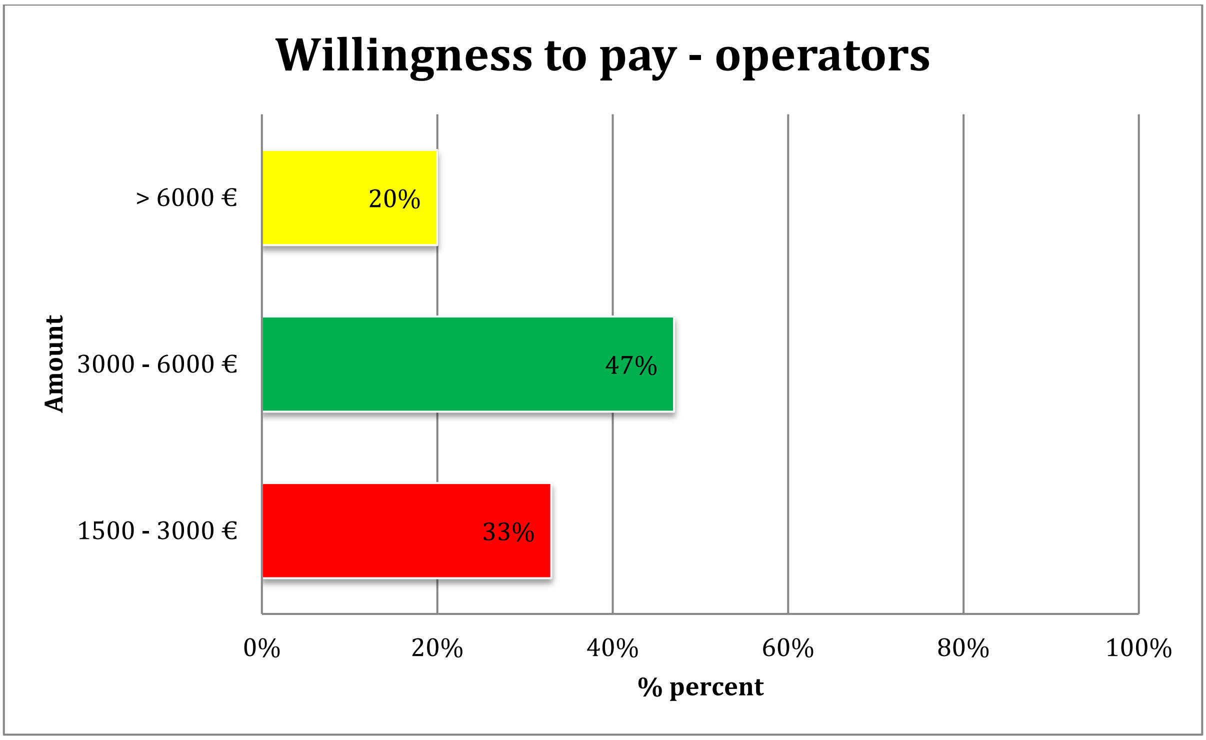

***Figure 3b.** ODOS 2020 willingness to pay – users versus operators*

The most important concerns from the part of the stakeholders focus on (Figure 4):

- Road safety risks in combination with the level of provided services.
- The system requirement for maintenance (frequency, type of work, legal responsibilities), in order for the system to provide reliability, seamless operation and provision of high level services.
- Whether and under which conditions energy autonomy is feasible and other energy sustainability lifetime issues.
- Sustainability and viability of the system (cost for maintenance and / or upgrading, use of alternative renewable energy sources, etc.).
- Collaboration framework with public organizations and bodies (legislative / regulatory framework and cooperation conditions).
- Privacy rules and requirements during personal information exchange (GDPR).
- Involved costs for purchasing and replacing the equipment.
- Ability to serve a high number of passing vehicles at high speeds through the toll station.
- Level of responsibility of each involved stakeholder especially in the case of insufficient fidelity and updating of the personalised messages sent towards the road users, including delays in processing, entailing the occurrence of a respective road traffic accident.

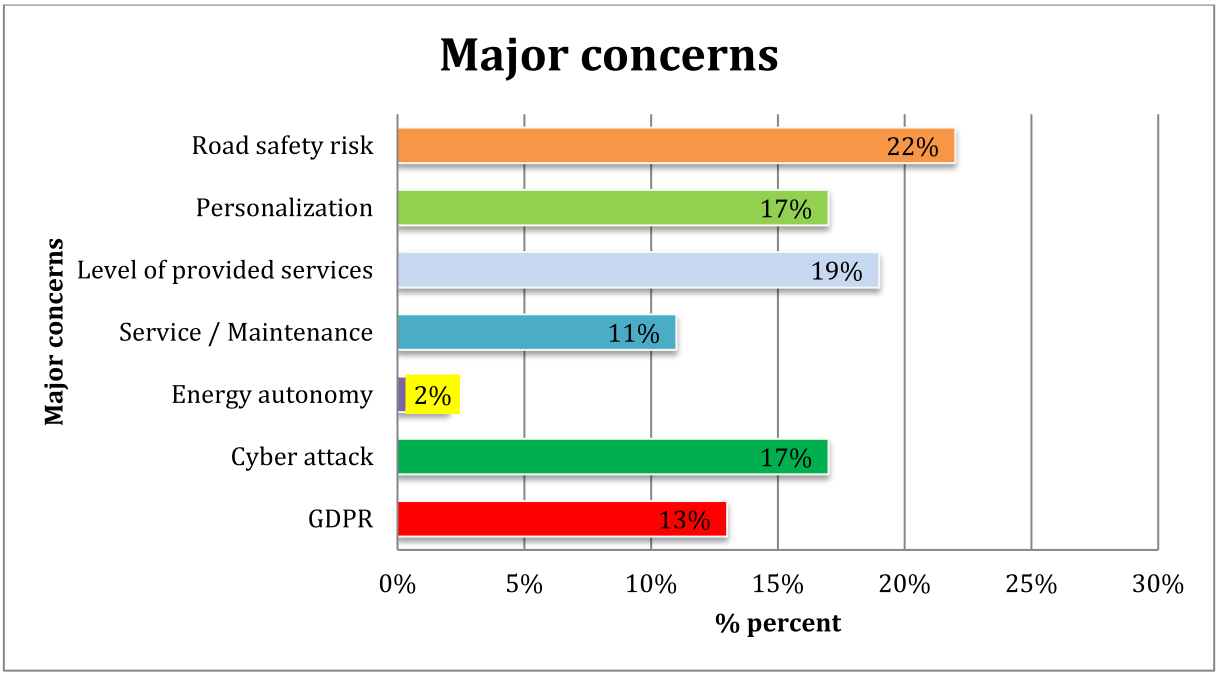

Figure 4. *ODOS 2020 most important concerns – users & operators*

In particular, drivers are concerned mostly about road safety issues, such as the stability of riders passing over the strips, driver / rider distraction using pads and smart-phones while driving, as well as GDPR compliance.

Legislation authorities express the need for the innovative technological solution to be compatible with current operational and technological standards and regulations (dimensions, colours, degree of flexibility, slipperiness etc.).

Infrastructure integrators, OEMs, suppliers, technology providers and road operators are mostly worried about potential failures due to everyday use, environmental conditions, natural disasters and cyber-attacks, expressing concerns involving the respective costs of maintenance, repair and replacement of the system components, etc.

The academia focuses on the technical and interoperability precautions and conditions, respectively, concerning the interrelation and adaptability of the new solution with the already set technological and communication standards, protocols, methodologies, services and methods.

The road operators are interested in the provision and maintenance of a reliable, up to date and real time I2V communication function, promoting collaboration and cooperative which does not conflict with other current market solutions in place.

All the involved stakeholders are in favour of a seamless operational system, eliminating failures, delays and interruptions, even during the replacement of the obsolete equipment with new one which entails the pausing of provided services and the engagement of road lanes for the installation / uninstallation of the strips and the associated equipment components (Gkemou et al, 2019).

Pertaining to the impact prioritization, the users and operators converge to road safety, traffic management, driving attitude and mobility issues and their enhancement and upgrading (Figure 5).

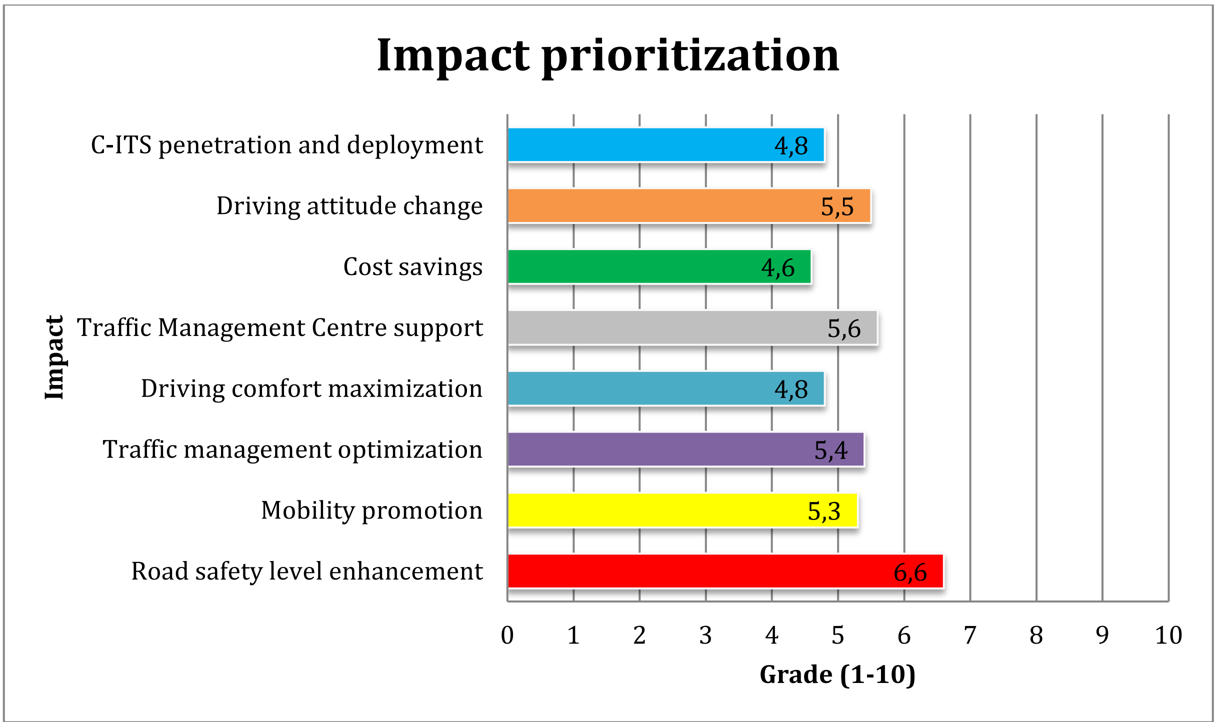

***Figure 5.** ODOS 2020 impact prioritization*

Finally, the most critical transportation scenarios for which the road users would require support, assistance and guidance through personalised information according to emerging needs are as follows (Gkemou et al, 2019). They all have to do with critical environmental and traffic information and warnings that have to be provided to drivers (Figure 6):

- Approaching crossroads, road / rail crossings and points where there is sharp differentiation in geometrical and / or operational characteristics of road (i.e. change in number of lanes).
- Approaching black spots.
- Approaching zone with road works.
- Before entering into the road shoulder (emergency stopping lane).
- Before entering into incoming traffic.
- Forecasting and warning on the expected pavement performance degradation (pavement health monitoring).

- Concerning the improvement of existing preservation schemes on current highways (optimal pavement preservation).
- Provision of personalized information on road safety and navigation (including PoIs3) based on user preferences and needs.
- Warning on upcoming tolls and respective tariffs, as well as provision of virtual electronic transactions opportunity.

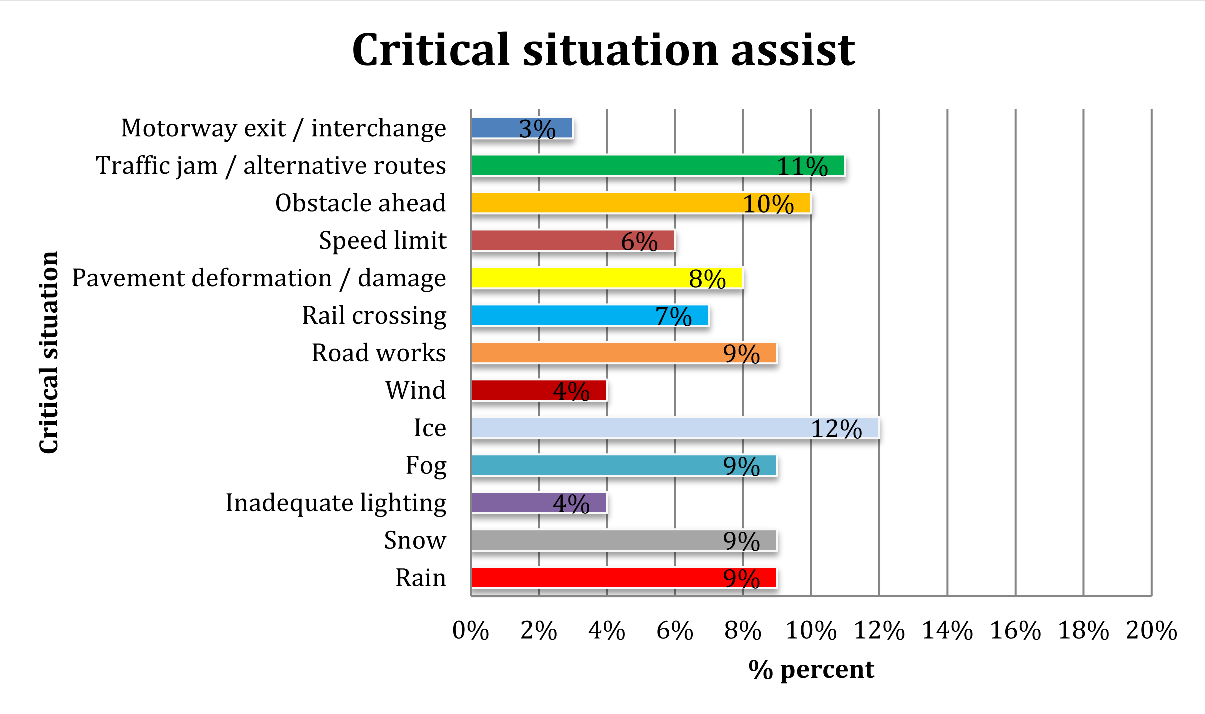

***Figure 6.** ODOS 2020 critical transportation scenarios' warnings to drivers*

3.2 Participating technologies

According to the user needs and expectations in relation to the objectives of ODOS 2020 project and its targeted applications, a pool of technology tools, methodologies and techniques was identified through the elaboration of an extended and exhausting state of the art review on the available alternative innovative but also applicable technological solutions. Within the context of ODOS 2020 EEA1 deliverable on "Benchmarking technology database", several categories were identified and assessed as per their matching to the project scope as listed below (Gkemou et al, 2018) and provided on-line at https://odos2020.iti.gr/benchmarking-database/:

- Sensors
- Energy Harvesting and management modules
- Batteries
- Microcontrollers

[3] Points of Interest

- Infrastructure materials / solutions
- Encapsulation techniques
- C-ITS for transport applications and technologies (of relevance to ODOS 2020)
- Algorithms, mathematical equations, applications, etc.
- Communication mechanisms and units
- Vehicle detector stations and traffic monitoring units
- Business models and exploitation plan of the final product

3.3 Legislative and regulatory framework

The focus was also set on the legislative and regulatory framework, given that the significance of the horizontal signing is fundamental in the delineation of areas of different traffic uses on the road pavement, such as road lanes and parking areas, bus lanes, prohibited areas, areas for walking and / or cycling, direction and / or warning signs etc. (Gkemou et.al, 2019). The strip and all the related equipment that is going to be encapsulated in and / or established near the road pavement in the context of ODOS 2020 demo pilot deployment are incorporated in the generic category of road signs and road markings. So, they fall under the Greek and European regulations and technical specifications as per their colour, dimensions, friction, contrast, retro-reflectivity and applied materials.

As per the most common materials used in horizontal signing, the best alternatives are:

1. the epoxy light reflective resins that are sprayed on the road pavement with use of specialised machinery equipment, and
2. the thermoplastics with hydrocarbons which need to be heated up to 160°C - 220°C with the view to be more flexible and easy to use.

Pertaining to the strips put on the road pavement, the tapes are prefabricated cut into desirable shapes ready to be positioned on the road. Those materials are defined and their physical properties should comply with EN 1871. In addition, they should follow the technical specs concerning equipment featured above the road pavement surface with special focus on limiting the total height below 1cm in highways and interurban road network (equal for "cat's eye" reflectors as well) and 2,5cm in the rural environment (equal for rumble strips and road bumbs) (Faheem, 2011; Mahmoud, 2014).

4. Use case scenario building

The paper aims to present the use case scenarios that will drive the development and testing of a low cost C-ITS technological solution deploying I2V and cellular technologies. The proposed solution aims to early identify, on infrastructure level, events tackling with the road and environmental conditions and acknowledge the information to the road users preventing potential incidents/ accidents. Upon the stakeholders' recognised needs and priorities, each Use Case Scenario has been described in a consistent manner across the following fields:

- ✓ Scenario name andend user-oriented functional description.
- ✓ Involved technological components.
- ✓ Technical and operational specifications and standards to be met.

- ✓ Technical and operational constraints to be taken into consideration.
- ✓ Target stakeholder groups the system is addressed to.
- ✓ Potential extension, replication, transferability and adaptability of provided services incorporating different users' categories, driving environment and / or transportation means.

Based on accident statistics analysis, involved stakeholders' and users' needs, available technology, as well as technical specifications, standards, regulations and guidelines on horizontal markings and the dimensions and way of establishment of equipment on road pavement, the particular critical situations that would be applicable for each one of the four applications of the system are briefly depicted within the list below:

1. Pertaining to "Driver/rider road safety assistance" app, the critical points incorporate:
    - i. Prevention of imminent danger (road works ahead, proximity to crossroads/ rail crossings, exceeding speed threshold in dangerous road sections, etc.)
    - ii. Entry into the road shoulder (emergency stopping lane).
    - iii. Strong wind gusts (especially after exiting a tunnel of while crossing a bridge).
    - iv. Entrance to oncoming traffic.
    - v. Adverse environmental conditions on road pavement (snow, fog, low ambient light, humidity).
2. As per "Monitoring the structural integrity of the road pavement" app, the critical points include:
    - i. Detection of sections with considerable road wear damage reported to the Traffic Management Centre (TMC) or the responsible infrastructure manager.
    - ii. Cases of infrastructure (and equipment) failure (e.g. bridge joints with road, tunnels, etc.) where the TMC needs to engage and correspond.
    - iii. Applying a health monitoring system in road sections where no other monitoring means are available or improve existing health monitoring plans by using the additional real time data provided by the system.
3. Concerning the "personalised VMS" application, the critical situation is located in Human Machine Interface principles, as poor perception of the provided information can lead to bad decision making.
4. As far as the "virtual toll collection system" is concerned, the critical circumstances have to do with the vehicle identification at high speeds and of many vehicles simultaneously, the type and dimensions of the vehicle, the distance travelled, the load factor, the time delays, the near future regulations that are subject to enter the field, etc.

Finally, as per the use case scenario building, for each system's application, the critical points where the system is planned to be installed:

1. Driver/rider road safety assistance application:
    - i. Crossroads and junctions (including also entries into / exits from highways), as well as critical points where there is a geometrical and operational characteristics differentiation of the transport network (i.e. change of number of lanes).

ii. Black spots (due to road infrastructure topography) based on statistics and real evidence.
iii. Carriageways where road works take place ahead.
iv. Entry into the road shoulder.
v. Entry into oncoming traffic.

2. As per the monitoring of the structural integrity of the road pavement application, this applies:
   i. To timely forecast the road pavement condition and determine an optimal maintenance plan.
   ii. To optimize existing maintenance plans on the basis of contractual obligations of the infrastructure manager using real time data collected by the system.
3. Personalised VMS application is applicable overall wherever VMS infrastructure is currently installed with the provision to be more frequent covering also rural, urban and periurban contexts not currently covered.
4. Concerning virtual toll collection, it is considered especially valuable in cases when the collection of toll tokens has to be elaborated faster due to high speed or dense traffic conditions, rationally to the distance travelled and according to the vehicle type.

5. Use cases

ODOS 2020 intends to develop, deploy, demonstrate and assess a total of four (4) applications related to road safety, pavement predictive maintenance management, personalized VMS and virtual tolls. At this stage, ODOS 2020 project consortium has set a number of potential impacts which is listed below:

- ✓ Upgrading current road infrastructures to «smart» ones, adopting low cost solutions without making any substantial interventions on the road pavement.
- ✓ Reducing (operational) cost of infrastructure by 50-95% as compared to the current situation (using traditional methods exclusively), also avoiding any additional cost for vehicle equipment in the case of smart mobile device usage (e.g. pad or phone).
- ✓ Guaranteeing the maximum possible energy autonomy, durability, resistance and resilience of the road pavement sensors and other equipment in all environmental and traffic conditions and srtesses.
- ✓ Aiming at the provision of focused, real time updated, punctual and personalized information to road users (e.g. for specific point of specific road lane).
- ✓ Developing smart apps for smart pads using Android / iOS, acquiring the potential to provide other added value services as well.

Based on the aforementioned, the preliminary use cases are briefly depicted within Table 3 below (Gkemou et al, 2019). For each application (Column 1), with respective priority level (Column 2), the use cases, the involved stakeholders in information exchange and the basic functions enabled are depicted and analysed within the 3rd, 4th, 5thand 6th Columns of the Table respectively. Within the 7th Column, the final scenario building per application is depicted.

Table 3.*Preliminary use cases*

Application	Priority	Use case	Details / Scenarios	Involved stakeholders	Basic functions of the app
Driver/rider road safety assistance	Top	Crossroads, road / rail crossings and points where there is sharp differentiation in geometrical and / or operational characteristics of road (i.e. change in number of lanes)	Crossroads with or without traffic lights and points where the stopping or change of trajectory of moving vehicles is necessary to avoid danger. Rail crossing warning. Warning for foreseen obstacles (e.g. parked vehicle on road side, accident on the road, pedestrian in crossing etc.) Adverse weather conditions	• Drivers / Riders, buses, trucks and trains • TMC • Train operators	✓ Ensures communication among vehicle sand the TMC ✓ Records and monitors kinetics(the longitudinal and transverse position and speed) of each vehicle on road ✓ Vehicle identification
	Top	Black spots	Sharp turns/ slippery pavement / reduced visibility Statistically dangerous sections		
	Top	Road works ahead warning	Construction work zone ahead involving speed and manoeuvring recommendations		
	Top	Entry into the road shoulder (emergency stopping lane)	Clear indication when a vehicle is travelling on the emergency stopping lane		
	Top	Entry into oncoming traffic	Includes the entry into oncoming traffic into a highway and the use of a counter current section of lanes which at steep turning		
Monitoring the structural integrity of the road pavement	Secondary/ Complementary	Health monitoring system	Forecasting the expected pavement performance degradation	• TMC operators • Legislation and regulatory compliance	✓ Monitoring the strains caused by static and dynamic imposed traffic loads
	Secondary/ Complementary	Optimal pavement preservation scheme	Improve existing preservation schemes on current highways		
Personalised VMS	Secondary/ Complementary	Provision of personalised pushed up information based on user preferences and needs	Will take into account the preferences and needs of the user (customised options), his/her profile (i.e. age, gender, disabilities, ethnicity) and the driving profile (i.e. relaxed, economic, performance)	• Road users • TMC operators • Legislation and regulatory compliance and enforcement authorities	✓ Communication between vehicles and TMC ✓ Recording of vehicle kinetics (speed, position, trajectory etc.) ✓ Vehicle identification ✓ Operator identification
Virtual tolls	Secondary/ Complementary	Replacement of existing toll collection plazas with virtual electronic transactions	Will be placed on each entry and exit of the highway and apply mileage charge with no need for the vehicle to perform a stop	• TMC operators • Highway users	✓ Detection of vehicle position ✓ Determination of distance travelled ✓ Identification of vehicle ✓ Complete transaction

Through the development and testing of ODOS 2020 applications, the consortium estimates that considerable benefits will be produced for both road safety and economy. In particular, concerning road safety the benefits are related to:

- Reduction of road accidents by 5% - 8% due to respective early and real time updated personalized warnings, as well as enhanced pavement maintenance management.
- Diminishing by 10% of road accidents with fatalities occurrence attributed to wrong way vehicle movement.
- Elimination of road accidents whose causes are classified in databases as "under investigation" from 25**%** to 5**%**.
- Cut down by 30% - 40% of accidents caused by insufficient information provision through VMS.

Finally, pertaining to economy, the benefits are related to:

- Energy savings of at least 20% through the use of energy harvesters, under all different types of environmental conditions.
- Considerable cut down of VMS establishment costs reaching approximately the 24.000€ - 90.000€ per installation.
- Avoidance of annual VMS maintenance costs reaching approximately the 3.500€ - 11.000€ per installed unit.
- Cost savings reaching approximately the 7,5M € associated to the establishment, installation and setting to operation of a toll station facility.

6. Conclusion

This paper presents an innovative integrated low cost technological solution introduced in order to enhance road safety level and replacement of costly road infrastructure elements that are being used on everyday basis, by focusing mostly on the intelligent advancement of the infrastructure and the personalised real time communication among users of the road network with use of IoT and C-ITS. The generic concept, aims to shift technology from the vehicle to the infrastructure in order to minimise the cost for the drivers and provide equal service to all road users ODOS2020 integrated road safety system promises equal opportunities in technology and C-ITS system applications, as the establishment and operational costs will be undertaken mainly from the infrastructure provider (which also benefits greatly from the use in terms of service quality and cost).

The innovation stands both on the integration of all relevant technologies to make this a reality, but also in the fact that it is the first time an integrated and innovative solution introduces new rules pertaining to socio-economic factors that provide equal technological access – and, thus, Quality of Life - for all types of users (and vehicles) and its applicability and compatibility to any type of infrastructure. Relevant future expansion incorporates the testing and application of the system to other surface transportation means, such as trains, in order to establish a common interface towards the enhancement of road safety level.

7. Acknowledgment

The work presented in this paper was held in the context of ODOS 2020 project (https://odos2020.iti.gr/), which has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code:T1EDK-03081).

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