MEMORIA CIENTÍFICO-TÉCNICA DE PROYECTOS COORDINADOS

Convocatoria 2021 - «Proyectos Pruebas de Concepto»

AVISO IMPORTANTE - La memoria no podrá exceder de 35 páginas. Para rellenar correctamente esta memoria, lea detenidamente la descripción del contenido disponible en la web de la convocatoria.

IMPORTANT – The research proposal cannot exceed 35 pages. A document describing the contents of the proposal is available at the website.

1. Portada

Título del proyecto coordinado (Acrónimo): Sistema Integrado para monitorización de tráfico y supervisión del estado de carreteras utilizando sensores de fibra óptica

Title of the coordinated project (Acronym): INteGratEd System for TrafflC and road condition monitoring using fiber Optic seNsors (INGESTION)

Datos de los subproyectos - *Subprojects data*

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Título - *Title*: INteGratEd System for TrafflC and road condition monitoring using fiber Optic seNsors (INGESTION) I

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Título - *Title*: INteGratEd System for TrafflC and road condition monitoring using fiber Optic seNsors (INGESTION) II

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3. State of the art, current knowledge, and justification of the proposal

The INGESTION project focuses on the exploitation of research results from our previous coordinated project TEC2016-76021-C2-1-R, "Photonics sensors for safety and security" (SENSA), where fiber optic sensors capable of monitoring asphalt structures were developed. In this project, these results are leveraged to demonstrate two technologies for road traffic and condition monitoring at high technology readiness level (TRL) and take the initial steps to proceed to their commercialization via the creation of a new spin-off company from the university.

Background

The main topic of the SENSA project was the investigation of photonic sensors for new solutions within the security and protection challenge. Various research results from the project exhibited a high potential to be developed towards the potential transfer to society. The outcomes that we use in the INGESTION project are related to road traffic and condition monitoring using fiber optics solutions, both point and distributed. These outcomes are linked to the following specific tasks developed in SENSA:

Task 3.2: Fiber optic sensors for traffic monitoring, whose objectives were to develop methods to instrument road pavement degradation using fiber optic sensors. Issues of interest in pavement monitoring are detecting cracks, ground displacement, and impacts of heavy truck traffic, vehicle detection, and weight-in-motion systems were also investigated in the tasks. As a result of the task, a novel method to monitor traffic using point optical sensors was developed and tested in the field achieving TRL4-TRL5 (interrogator-transductor).

Task 2.1: Distributed sensing systems, aimed to develop methods to improve the performance and implement novel measurement functions using Rayleigh and Brillouin distributed sensors. As a result of this task, we developed novel enhanced-performance distributed vibration sensors based on Rayleigh backscattering that were demonstrated in the lab at TRL4.

In the following, we identify the problem that we are addressing, road traffic and condition monitoring, and how a system derived from the results of the SENSA project can tackle it.

Road monitoring: an increasing need

The development of an efficient, sustainable transport system is a major concern nowadays due to the repercussion it has on the quality of life of the population and because of its important economic and environmental impacts. In urban areas, the rapid population increase, together with outdated mobility schemes, results in an unprecedented amount of urban traffic, from personal vehicles to heavy freight. This implies more traffic congestions, air and noise pollution, accidents, infrastructure degradation, etc., all of which have a detrimental impact on the wellbeing of the citizens.

Moreover, urban mobility is not the only concern in road transportation systems. Interurban freight transportation has experienced constant growth as well. For example, the total road freight shipped in Spain in 2019 was 1,542 million tons, which is more than a 4% increase compared to 2018 [Min20]. This increment has a harmful effect on the durability of the infrastructures, particularly bridges and pavement [Eur07]. Besides environmental and safety aspects, the increasing degradation has a negative economic impact, considering that the recent years, almost 1% of the GDP in Europe was spent on transport networks. A 60% of this amount was directly used in road infrastructures [Eur21].

Intelligent Transport Systems (ITS) are advanced applications to provide innovative services relating to different modes of transport and traffic management and enable users to be better informed and make safer, more coordinated, and smarter use of transport networks [Eur10]. ITS integrate telecommunications, electronics, and information technologies with transport engineering in order to plan, design, operate, maintain and manage transport systems. The success of ITS largely depends on how the devices collect and process the information retrieved from the environment. The impact of ITS is directly linked to the accuracy, reliability, and quantity of retrieved data. Consequently, to get the full potential of ITS devices, the development of communications, decision-making processes, and sensors must be paired [Gue18].

In order to contribute to the creation of new smart and efficient transport systems, this project proposes the development of a new fiber optic solution for alleviating the lack of high-quality cost-effective information in transport-related applications. The project will focus on two development lines to monitor the state and use of roads with fiber optic sensors. These systems are based on results obtained within project SENSA linked to road traffic monitoring using localized fiber optic sensors and distributed fiber-optic vibration sensors. Both approaches are complementary and together show high potential to solve problems related to the information about the traffic and road condition.

Traffic monitoring

The first and most evident interest regarding road sensing is the monitorization of traffic. This implies the detection of many parameters of interest: traffic flow, speed, routes, occupancy, type of vehicles, or weight per axle, among others. Together, these aspects can create a precise picture of road use and its role within the road network. Depending on the quantity, quality, and frequency of the data obtained, numerous actions and applications can be used to improve the general efficiency of roads from different points of view. Indeed, there is a wide range of ITS applications that can exploit the data provided by traffic sensors. Dynamic signaling is a straightforward application by which elements such as traffic lights or speed limitations vary depending on the occupancy and road conditions. For example, at a basic level, traffic lights turn green with the detection of a vehicle. This can be improved by synchronizing several traffic lights within the vicinity to optimize the transit time depending on the information provided by a set of traffic sensors, considering occupancy, but also speed, and other parameters. This enhancement implies that the sensor capacities must feature extra abilities besides vehicle detection. In general, dynamic applications will require real-time operation and communication between nodes.

Also, analysis and prediction applications are highly dependent on the quality and quantity of information. Parameters that might appear secondary, as acceleration or noise, play an important role in the estimation of air and acoustic pollution and allow a better characterization of the drivers' behavior [Sae96]. This, correlated with other elements (e.g., weather conditions), facilitates the prediction and identification of congestion problems that might be mitigated with the appropriate planning, promoting the efficient use of the resources. This set of applications based on prediction and mobility models have an important role in the design of new roads and the planning of their repair and maintenance. In this context, it is especially valuable the information about the type and weight of the vehicles using the roads.

The most extended traffic sensors nowadays are inductive loops and pneumatic tube counters, which in most cases offer just flow measurements and occupancy. New solutions have been emerging, based on magnetometers, radar, traffic cameras, etc., but none of them offer real-time multiparameter sensing (flow, speed, direction, vehicle type, weight-per-axle estimation) at a low cost. Most advanced solutions are expensive, limiting the creation of massive sensor networks that would allow the implementation of advanced applications for smart mobility. Consequently, in the context of traffic monitoring, there is an increasing need for low-maintenance reliable devices that offer real-time multiparameter information, but a reduced cost.

Condition monitoring

Another important aspect of the road network that is tackled in this project is condition monitoring. The road network of a country is a basic economical and societal infrastructure. This network requires regular maintenance to provide for and preserve users' usability, accessibility, and safety. For instance, the annual maintenance cost per kilometer of highway in Spain is around 80,000€ and 38,000€ per km of conventional roads. Considering the total national networks this amounts to 1,300 million euros per year. The main costs come from maintenance associated with the degradation of the pavement of the road.

Road pavement is a mixture of gravel, aggregate, and asphalt or concrete laid down on a specific route for vehicular traffic. Pavement undergoes a process of deterioration resulting from repeated traffic and environmental loading. By detecting pavement distress and damage early enough, it is possible to develop more effective pavement maintenance and rehabilitation programs and thereby produce significant cost and time savings. Furthermore, pavement condition is a fundamental factor to maintain the best infrastructure performance in cities and to provide safety for road users.

Hence, pavement monitoring is needed to achieve roadway satisfaction and comfort for users during their movements. It is also needed to satisfy safety conditions on roadways and avert accidents caused by pavement distresses and roadway anomalies. Traditional methods of inspection of the state of road pavement, based mainly on manual labor, are inefficient and costly. Recently, new technologies have started to be applied to improve pavement monitoring processes such as image acquisition systems, vibration detection in vehicles using accelerometers, penetrated geophones, embedding of point strain sensors, or ground-penetrating radar [Sht20]. However, these systems still have serious limitations, and they are difficult to install and use to provide either continuous long-term monitoring for pavement structural behavior changes or real-time warning for in-service pavement failure.

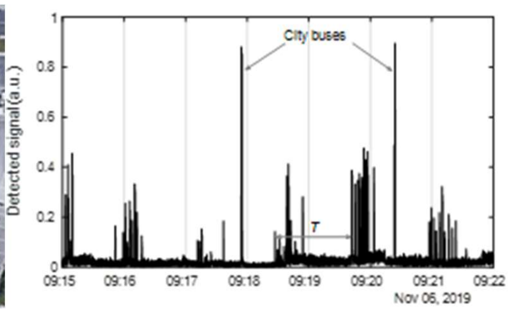
The systems that we are going to implement in the INGESTION project, both those based on point and distributed fiber-optic sensors can provide precise information for the two aspects of the road network monitoring that we have just discussed: traffic and road condition monitoring. We are going to work in both in parallel, but at this stage, we consider that the point-based solution is closer to the market and simpler from an entrepreneurial point of view to launch. Therefore, it will be taken to a higher TRL, at least TRL7, during INGESTION. Nevertheless, the distributed vibration sensor solution is going to be taken all the way to validation in a real operational environment at TRL7. Therefore, it will be ready for final business case evaluation and commercialization at a later stage, possibly as a more advanced product offering of the start-up company that we intend to promote.

Traffic-monitor based on point fiber optic sensors

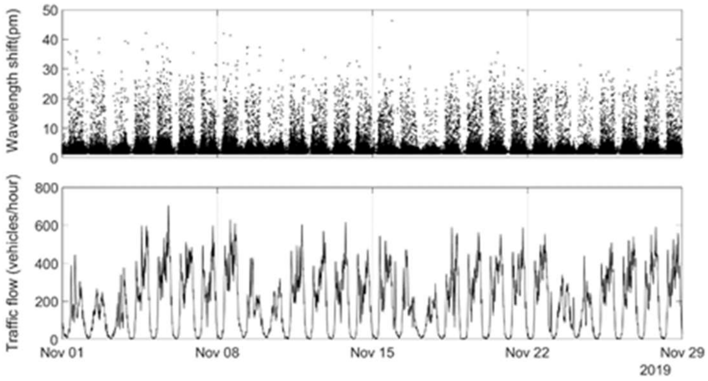
Despite of the many advantages of fiber-optic sensors, their use is still mainly limited to 'niche' applications. One of the main reasons for this limited use is the higher cost compared to mature and well-established technologies. During the INGESTION project, we will work to break this trend. During the SENSA project, we demonstrated at TRL4 a new type of point fiber optic sensor with a low-cost transducer and interrogator. In the INGESTION project, we will merge the know-how in asphalt monitoring from the SENSA project with the broad experience of the Public University of Navarre (UPNA) and the University of Cantabria (UC) in fiber optic sensors to develop a specific low-cost system able to monitor mechanical vibrations in asphalt structures. These vibrations, after an analysis, can be directly translated into flow, speed, acceleration, lane, direction, vehicle type, and it can even offer a rough weight estimation of the vehicles driving over the sensors.

During SENSA, the Pamplona City Council and UPNA signed a collaboration agreement that allowed us to install fiber optic sensors on a public road. The location selected was Calle Cataluña (Pamplona), close to the Photonics Lab on campus. In this installation, several types of sensors were tested, being the most significant the results obtained using arrays of fiber Bragg gratings (FBGs) interrogated using a commercial interrogator. The results were presented in different conferences [Bra16] [Bra19] [Bra21], focusing on different findings, such as the robustness of the sensors and the high survivability during the installation, even in already degraded asphalt (they are operational after +4 years).

Due to the interest shown by possible end-users of the system, such as the Pamplona City Council, we continued the research, focusing on overcoming the main barrier for possible commercialization: the high cost of FBGs and the interrogator. Consequently, we started the development of a new solution that could offer equivalent information at a reduced cost.

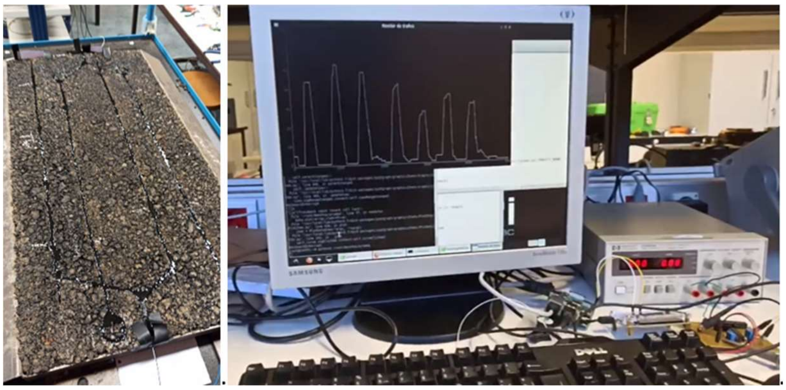


Location of the first proof-of-concept in C/ Cataluña and initial measurements showing the detected traffic signal vs time.



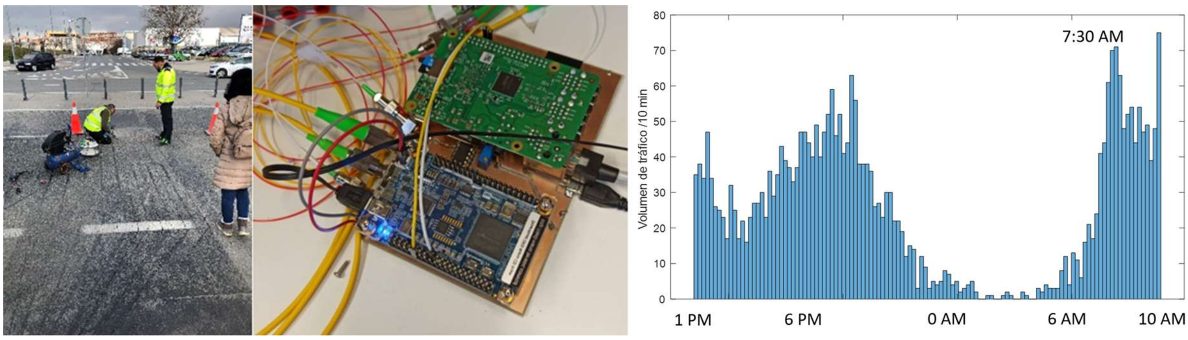
Results retrieved during November 2019, showing clear daily and weekly traffic patterns.

This new approach was based on an interferometric solution by which the light injected into the sensors is split between different branches. Then it is reflected and mixed again before being processed. The resulting signal includes visibility fringes that, after a proper analysis, reflect the stimulus applied to the sensors. We developed and tested the system in the laboratory using research equipment and asphalt specimens.



Asphalt specimen used for the validation and initial impact tests.

Both the new interrogation method and sensors worked successfully in the laboratory, so we proceed to test them in a relevant scenario: the test site at Calle Cataluña. Again, the sensors operated successfully, and the effective detection of vehicles was achieved. In this installation, the interrogator was located in the Photonics Lab and it was connected to the remote sensor test zone using a fiber optic cable.



Images of the installation process, the prototype, and first measurements of the low-cost approach.

At that point, the potential of the system for traffic monitoring became clear. The performance of both sensor and interrogator matched the requirements of the application so the next step was towards the evaluation of the possible commercial interest in the system. In this regard, we initiated the promotion of a business idea in the form of a new spin-off company for commercializing these products. This idea, with the name "Menditech" (initially "Asphaltoptics") has already received several entrepreneurship awards:

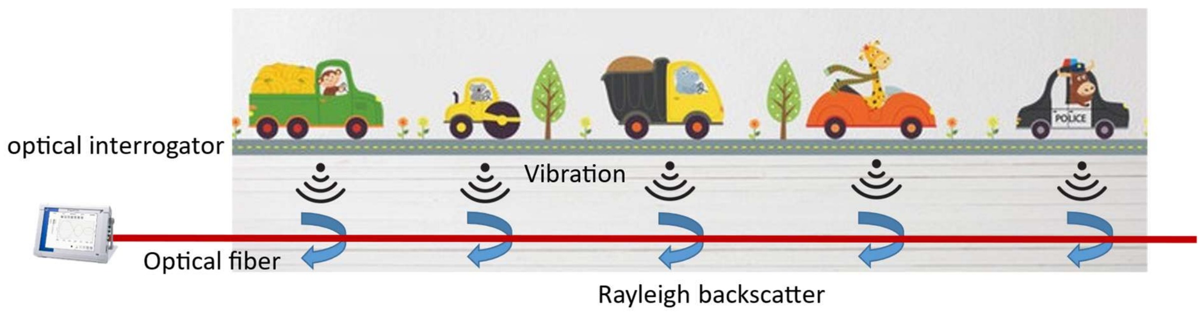
- Selected in the "Impulso Emprendedor" call for innovative business ideas organized by the government of Navarra and CEIN, which Included a 6-month course on entrepreneurship.
- 1st prize in the "VII Premios IBERUS" call for the best innovative idea organized by the University of Zaragoza, the Public University of Navarra, the University of La Rioja, and the University of Lérida.
- 2nd prize in the "Premios Iníciate" call for the best innovative projects organized by the government of Navarra and CEIN.
- Selected for the *Smart Pamplona Lab program*, by which a new collaboration agreement was signed to establish new sensing points in Pamplona. These new installations will allow testing and developing future versions of the system, specifically for in-situ monitoring.

At this point, the potential for transference and commercial exploitation of our point sensor system for traffic monitoring has become clear. Also, the technological base has been validated and developed: the sensors have been tested in real conditions and the interrogator performed successfully in the laboratory (TRL4). Thus, the INGESTION project will focus on the further development of the system that is required to reach a commercial stage. This will involve the testing of the system in a real operational environment. In particular, the sensor devices should be further developed to increase their sensitivity and robustness so non-specialized personnel can install them in the future. Regarding the interrogator, work on optoelectronics, software, signal processing, and packaging must be done to validate the device in a real environment.

A patent application is being considered, in particular regarding the sensor design. Nevertheless, the most valuable resource up to date is the know-how gathered by the research group in FOS installation in asphalt, protection, state of the art, etc.

Road traffic and condition monitoring system using distributed vibration sensors

The other development of our global technology transfer effort is the demonstration of a system to monitor road traffic and condition monitoring based on the use of so-called distributed acoustic/vibration sensors (DVS). These are fiber optic sensors based on the Rayleigh backscattering in the fiber. There are different varieties of these sensors, but the one we developed in project SENSA and that we are going to deploy in this project is based on launching pulses or sequences of pulses in the fiber and detecting the optical phase of the backscattered optical field from each position in the fiber. From the variation of this optical phase is it possible to detect elongation and compression of the fiber associated with vibrations in the nanostrain and even tens of picostrain range [Sag21] [Mom19] [Mom18].

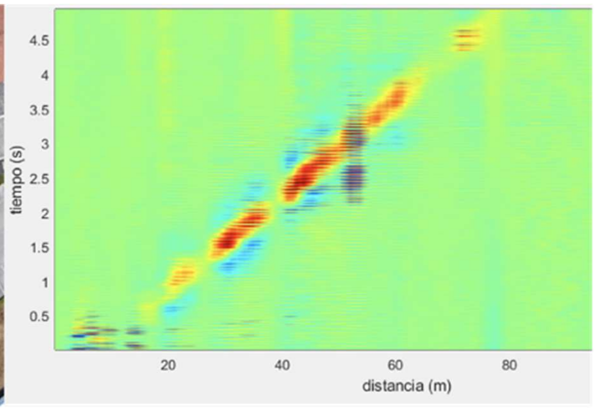


Distributed vibration sensing for road traffic and condition monitoring

In the literature, DVS sensors have already been demonstrated to monitor road traffic [Hall19]. This is based on using the DVS to detect the vibrations that the transit of vehicles induces on the road. The origin of this vibration is twofold: lower frequency forces associated with vehicle's suspension dynamics and higher frequency repetitive forces associated with tire treads or wheels rolling over individual track blocks [Ket05]. The fundamental advantage of the use of the DVS system compared to other options is that it leverages already installed fiber optic cable that can be used directly as a transducer. Typically, telecom operators, governments, and municipalities install optical fiber cables along streets, roads, and highways, taking advantage of the rights of way associated with these infrastructures. These optical fiber cables are installed in conduits with direct burial or with other methods, but they are typically close enough to detect the vibration induced by cars. Therefore, in order to use this already-available optical fiber network and convert it to road traffic monitoring, it is sufficient to connect it to a so-called interrogator instrument that generates the necessary optical signals and detects and interprets the backscattering.

Within task 2.1 of the project SENSA, we developed novel distributed acoustic sensors based on Rayleigh backscattering [Sag21] [Mom19] [Mom18]. These sensors make use of pulse compression techniques to achieve long measurement lengths, high spatial resolution, and extremely high vibration sensitivity. The operation of these sensors was demonstrated in laboratory settings at TRL 4 (technology validated in the lab) level. This sensor can be used to monitor road traffic and condition by detecting the vibration patterns generated by vehicles on the pavement and also in their interaction with potholes, cracks, and pavement surface degradation in roads and city streets.

We already have (unpublished) preliminary results of the monitoring of road traffic using our TRL4 DVS sensors. The figure below depicts the detection of a single-car traveling along the Av. Cataluña, at the UPNA campus, where we have installed around 100m of cable in one of the conduits used for street lighting that is buried below the sidewalk at around 1-m depth. In the 2-D graph on the right, the optical phase perturbation associated with the passing of the car is clearly noticed. Yet, there is even more information in the measurement, the rapid variations in phase are the vibration waves (seismic waves) generated by the car (mainly the so-called surface Rayleigh vibration waves). We have found that there is a clear dependency on the intensity of the generated waves and the rugosity and irregularity on the pavement surface. Moreover, an isolated strong vibration is generated around the 55-m location that coincides with a pothole on the road.

Preliminary results on traffic monitoring using DVS

We are currently involved in a technology transfer and exploitation effort to take the DVS technology developed in the SENSA project all the way to the TRL7 level with its demonstration for the specific task of road traffic and condition monitoring. As part of this effort, we have recently initiated (in December 2020) a development project supported by the regional Navarra Government called FIBRATRAFIC that is going to run till November 2022 and is going to contribute to our DVS technology valorization effort. However, notice that there is no overlap of activities with the current INGESTION project because the regional project is focused on the basic demonstration of vehicle location detection. In contrast, the INGESTION project is going to run for an extra year to FIBRATRAFIC and is going to focus on the use of an improved DVS configuration with enhanced precision to be able to not merely detect cars but also be able to measure the higher frequency seismic waves that are associated to the vehicles and their interaction with the pavement degradation in the form of rugosity, potholes, cracks, deformations, etc. In addition, in INGESTION we only require resources from the global project budget for the distributed vibration sensing line for the final year when the FIBRATRAFIC project will be already over.

It is necessary to point out, that what we are proposing in the INGESTION project is not to conduct new basic research on distributed vibration sensors, but to take the steps to industrialize our already available fundamental developments, as it is highlighted in the Implementation Plan section below. No additional research is necessary to be able to monitor road traffic with DVS sensors, we have already demonstrated that it is feasible with our lab setups. Furthermore, there are already multiple demonstrations of this principle in the literature and even some commercial products are starting to become available. Likewise, we have already demonstrated the capabilities of these sensors for pavement condition monitoring in proof-of-concept experiments. Even more advanced research on this subject can be found in the scientific literature, with experiments that have demonstrated the use of the vibration (seismic) waves generated by passing cars to perform a velocity inversion process that provides detailed profiling of the soil layers that constitute the pavement [Dou17] [Yua20]. Our system demonstration for this project is not as ambitious at the moment, although a commercial product based on our developments could later incorporate these principles as they are further investigated by the research community.

Another technology that plays a fundamental role in traffic and road condition monitoring using DVS sensors apart from photonics is machine learning [Shi18][Wu21] [Var19]. This is fundamental to obtain actionable information from the raw measurement data provided by the DVS. The problem of determining which event is associated with a perturbation in the fiber constitutes a time series classification problem for which there are literally hundreds of available machine learning algorithms. In our previous developments, we have started to work on applying machine learning algorithms for vehicle detection. During this project, with the expertise of the UC team on machine learning (in particular, deep learning approaches), we will work to improve these algorithms and also extend them to the application of road condition monitoring. We plan to evaluate new developments, such as transformer, for data-sequences classification and anomaly detection, with the aim to offer valuable insights about the vehicles and traffic conditions to the final user.

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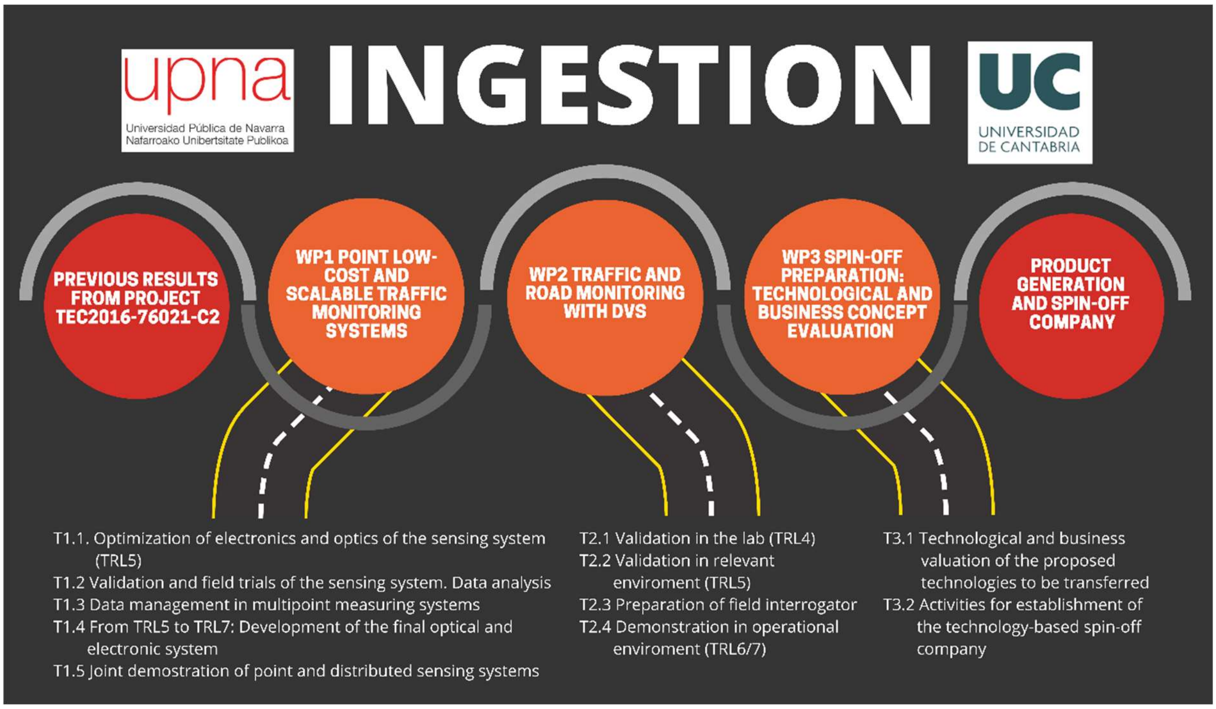
4. Objectives

The general aim of the Ingestion project is to generate innovative hi-tech products on an application with significant market opportunities: road maintenance and traffic monitoring. To increase the feasibility of transfer of previously developed technology in project TEC2016 –76021 to the industrial sector, both research groups of the former coordinated project are going to collaborate again in this proposal. Three main technological objectives have been established that correspond with 3 work packages detailed in section 6 and shown in the next figure:



General Overview of the Ingestion project

1- **Development of point low-cost and scalable traffic monitoring systems**

The first objective of this project consists of boosting the technology developed for traffic monitoring in project TEC2016-76021-C2-1-R "Photonic Sensors for Safety and Security (SENSA)" to obtain pre-commercial products that can be transferred to companies, initially to a technological-based start-up company from UPNA. The demonstration of the system will be conducted with a real deployment on the streets of Pamplona City. In order to achieve this first objective, 5 sub-objectives are planned along the 2 years of extension of the project:

I) Optimization of electronics and optics of the sensing system (TRL5)

II) Validation and field trials of the sensing system. Data analysis

III) Data management in multipoint measuring systems

IV)From TRL5 to TRL7: Development of the final optical and electronic system

V) Joint demonstration of point and distributed sensing systems

2- **Development of a sensing system for road condition monitoring using distributed fiber optic vibration sensors**

This objective is intended to leverage the Distributed Vibration Sensor techniques developed during project TEC2016-76021-C2-1-R "Photonic Sensors for Safety and Security (SENSA)" to demonstrate in an operational environment a system for monitorization of traffic and road condition monitoring. The demonstration of the system will be conducted with real deployment on the streets of Pamplona City and also on the roads of the Comunidad Foral de Navarra**.** In order to get this second objective, 4 sub-objectives are planned along the 2 years of extension of the project:

I) Validation in the laboratory of the developed system (TRL4)

II) Validation in relevant environment (TRL5)

III) Preparation of field interrogator

IV) Demonstration in operational environment (TRL6/7)

3- **Preparation of a new spin-off company: technological and business concepts evaluation**

Finally, this objective intends to pave the way for the creation of a technological base spin-off company from UPNA that would transfer research results from former project “SENSA” to market. In order to achieve this goal, we will carry out the technological and business valuation of the proposed technologies to be transferred and, also, we will start the activities for the establishment of the technology-based spin-off company.

These 3 objectives will be carried out along the two years of the project and correspond with 3 working packages that are fully detailed in section 6 of this proposal.

In this project, all hardware tasks will be led by Universidad Pública de Navarra (UPNA) researchers and the software tasks will be led by Universidad de Cantabria (UC). Because the application and hardware development has been carried out by UPNA researchers in former project TEC2016 –76021, the leadership of most part of the tasks will be driven by UPNA researchers. Thus, IP1 from UPNA will lead objectives 1 and 3 and IP2 from UPNA will lead objective 2.

Key aspects and possible products

This project aims to promote and accelerate the creation of technological products and applications for traffic and road condition monitoring. One of the <u>key aspects of this proof-of-concept</u> is the technology validation; particularly in-field. In this aspect, previous results have shown that the technology can match and even surpass the requirements for road monitoring. However, these results must be consistent and proved during longer time lapses; particularly to evaluate the impact of temperature and weather in the measurements. Another key aspect, with an associated challenge, would be the obtention of robust devices able to operate in harsh environments such as street manholes. Finally, the transfer of the technology is a crucial element of the proposal. We are planning the creation of a spin-off, which is a challenging task by itself and we expect many difficulties during the process, being the most critical the validation of the business idea.

A first product for traffic monitoring based on point-sensors is expected to reach a precommercial stage and to be validated in real conditions with potential users such as the Pamplona City Council or even private IT & system integration companies. A second product, based on distributed vibration sensors will be scaled to TRL7 and evaluated in-field using already deployed fiber optic network. This product will be capable of monitoring traffic along several kilometers, but also to evaluate the road condition.

To evaluate the commercialization potential of the products, the creation of a spin-off from the UPNA is planned. The activity sector of the spin-off will be technology and telecommunications, more specifically the market of traffic and road sensors. This market is rising abruptly during the last years, and it is predicted that it doubles its economic impact in five years. The potential users of the products will be public entities in charge of the road network management, both urban and interurban. Different areas of these agents will be interested in the products: areas of mobility, conservation, citizen security and signaling. Within the private sector besides motorway or signaling managers, private IT & system integration companies are targeted to integrate our products into their integral solutions. More details about the business idea and impact can be found in the social and economic impact section.

Gender dimension

There are no issues of gender related to this project; however, the UPNA is deeply committed to gender equality. The Statute of UPNA clearly states the principles of non-discrimination against researchers, professors, employees or students in any way, especially because of gender, age, ethnic, national or social origin, religion or belief, sexual orientation, language, disability, political opinion, social or economic condition. There is a Gender Equality Unit and a Gender Action Plan included in the University's Strategic Plan. UPNA's Gender Equality (https://www.unavarra.es/unidad-igualdad/) and Social Action Units (http://www.unavarra.es/unidadaccionsocial/) will closely collaborate during the implementation of the project, by monitoring and making regular diagnosis that ensure the implementation and compliance with all the equality and non-discriminatory principles.

Justification of the coordination

About the teams of the INGESTION consortium: Universidad Pública de Navarra (UPNA) and Universidad de Cantabria (UC). The complementarity in both expertise and facilities of both groups, is justified by the long and sustained cooperation in a series of research projects. Since 1992, researchers from both groups have collaborated in 11 coordinated projects funded by the Spanish Government.

Both groups have also cooperated in European projects such as: the Fiber Optic Sensor European Network (FOS-EN), the EU Brite-EuRam ERB RRT-CT98-5074, European Cost action 299 (FIDES), European Cost action TD1001 "Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications (OFSeSa)", which was closely related to this DISFOS project proposal. Also, into the recent Cost Action MP1401 "Advanced fibre laser and coherent source as tools for society, manufacturing and life science".

Both groups have contributed substantially to the state of the art in the photonic/optical/ fiber optic sensing area. This fact is internationally recognized by being several of the researchers members of the international steering (ISC) or of the international technical program committees (TPC) of the more relevant international conferences in the field. It is worth mentioning that two IPs of this project are involved since 2002 into the steering and technical committees of the International Optical Fiber Sensor Conference (OFS) and the European Workshop on Optical Fiber Sensors (EWOFS). In 2014, UC´s group organized the 23th Optical Fiber Sensor Conference (OFS); being José Miguel López Higuera the General Chair of the meeting and Manuel López-Amo the chair of the technical committee. We are also members of several TPC committees of another prestigious conferences closely related to DISFOS topics such as OSA sensors or OSA BGPP or I3 sensors conference. Both groups, again, have joint their expertise, facilities and workforce (12 researchers-11 doctors) to reach the objectives of the INGESTION project.

In this project, UPNA´s team will carry out most of the research in the hardware development of the sensing systems and UC´s team will analyze and process raw data from the measuring systems and develop low-cost software solutions to store and display traffic information. These tasks are the evolution of the corresponding tasks carried out in former project TEC2016-76021-C2-1-R (SENSA), adapted to this new call of "*Pruebas de concepto*". Formally, most part of the tasks of the project will be leaded by UPNA´s researchers, but in general, in this project, UPNA will lead hardware and business valuation tasks and UC´s will lead all the activities related with software.

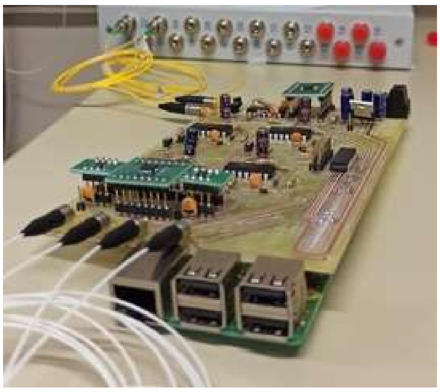
5. Methodology and implementation plan

In this section, we start by describing the methodology that we are going to follow to implement the three parallel development lines of the INGESTION project, which are directly related to its three main objectives. Then, we introduce the project's organizational structure and detailed work plan in which these three lines are linked to different work packages.

Development of low-cost scalable traffic monitoring systems based on point fiber optic sensors.

The success of the SENSA project allowed our teams to investigate how optical sensing technologies would drive innovative solutions on traffic monitoring by studying how these sensors perform in asphalt structures. One of the potential products obtained from this project was the "proto-design" of a low-cost traffic sensor, which was successfully demonstrated in the laboratory. Based on these advances, we intend to accelerate the transference of this research from the first demonstrations and basic prototypes to a pre-commercial product (TRL7 even 8) that promotes the creation of a spin-off company from UPNA. Starting from SENSA´s results, it will be necessary to optimize the optical fiber transducer and interrogator prototypes to be installed and operate correctly in real environments. Moreover, it is planned to create a demonstrative sensor network in the city of Pamplona by integrating the new sensing locations with the already installed ones. As presented in the background, the impact of new smart city applications is directly related to the amount of information employed. Thus, our objective is to create a proof-of-concept sensor network with at least 6 locations to demonstrate the operation of the sensors in the network and to develop a data management system. These locations will be decided together with Pamplona´s City Council to, besides, work on data processing algorithms that will facilitate advanced traffic control systems.

Specifically, to optimize the transducer and interrogator design (T1.1), it is necessary an electro-optic design engineer (EG1) that implements the proto-design obtained from SENSA into an MVP (minimum viable product) prototype to be tested in-field. Note that during SENSA, the prototype was only tested in the lab, using a fiber-optic connection to the test zone. These features include the optimization of the reception for multiple channels, the optimization of the laser drivers, the inclusion of a signal-processing unit and communications, and the optimization of the software for the data processing. On the other hand, to optimize the sensor design, it is necessary to perform an in-depth analysis of previous results obtained from the in-field test. This work will allow tuning the sensitivity of the sensor, sensing range, size, define the installation process and improve the robustness of the transducer.



Proto-design of the interrogation system obtained from SENSA

Next, it is necessary to demonstrate the correct performance of the system in a set of in-field tests (T1.2). To do this, we have a collaboration agreement with Pamplona´s City Hall –that will be still active during the project´s duration- outlining various actions to install our sensors. It is expected some iterations to polish the final design, hence, new installations will be done. Moreover, we plan to compare our technology with other popular solutions, such as magnetic coils, pneumatic tubes, radar, or magnetometers among others; by installing them in parallel or jointly. These installations will be planned together with the Pamplona City Council taking also into account (as it will be presented afterward) our product on road condition by DVS.

Once the system's design fulfills the targeted performance, all the sensors already installed in Pamplona, together with the new ones, will be merged into a common network to retrieve and process the data jointly. One of the purposes of the installed systems is to obtain enough data in a real scenario so task T1.3 could be carried out. Starting from the expertise of the UC group in data processing algorithms, UC will work in the data processing, software optimization, validation, and creation of a database with traffic information. An important and time-consuming step is the reliable classification of vehicles depending on the profile of the signals. This work will be performed mainly by the engineer to be hired, in collaboration with UC. A prototype of the processing algorithm will be implemented and then will be trained, including architecture and hyperparameter optimization. The result will be a trained model whose performance (in terms of precision and other metrics) will be validated. From this point, the possibility of embedding the model in an edge-computing device (such as Nvidia Jetson, Raspberry Pi 4, Google Coral TPU…) will be explored and validated. This last step is important to help the commercialization of smart mobility applications that add value to the final product.

Finally, at this point, we will have the designs of the MVP product: transducers, interrogator units, software for signal processing, and data management; together with a business model and plan to be developed in WP3. Therefore, task T1.4 for this work package is to climb the steps on the TRL ladder to our objective: TRL7, and even to escalate to 8. To achieve this, we will work towards a final product design ready to explore the commercial potential and to create a final interrogator unit development. For the latter, due to the need for professional advice for the final design in electronics, we will dedicate a specific budget to hire this service externally. In Addition, other aspects as packaging and certifications will be considered in this task.

Development of the system for traffic and road condition monitoring using distributed fiber optic vibration sensors.

For the second line of development in our technology transfer effort, the deployment of a system for traffic and road condition monitoring using distributed fiber optic vibration sensors, the methodology that we are going to follow is to gradually climb the TRL levels ladder to arrive at an operative pre-commercial system for traffic and road monitoring at TRL7. This will provide a validated system ready for transfer to a company so that they can undertake the final stages of building a fully qualified and validated commercial product.

As explained in section 3, we are already running another Navarra regional project, FIBRATRAFIC, that is focusing on the basic detection of the presence of vehicles on the road using distributed vibration sensors. However, in our current proposal, INGESTION, we are going to undertake complementary activities to go a step further. First, we are going to focus on not just detecting the presence of vehicles but also on assessing the condition of the road pavement, its degradation with deformations, peeling of superficial layers that leads to increase rugosity, and development of potholes and cracks. This requires the implementation of distributed vibration sensors with increased sensitivity and the development of additional machine learning algorithms to detect and classify those events.

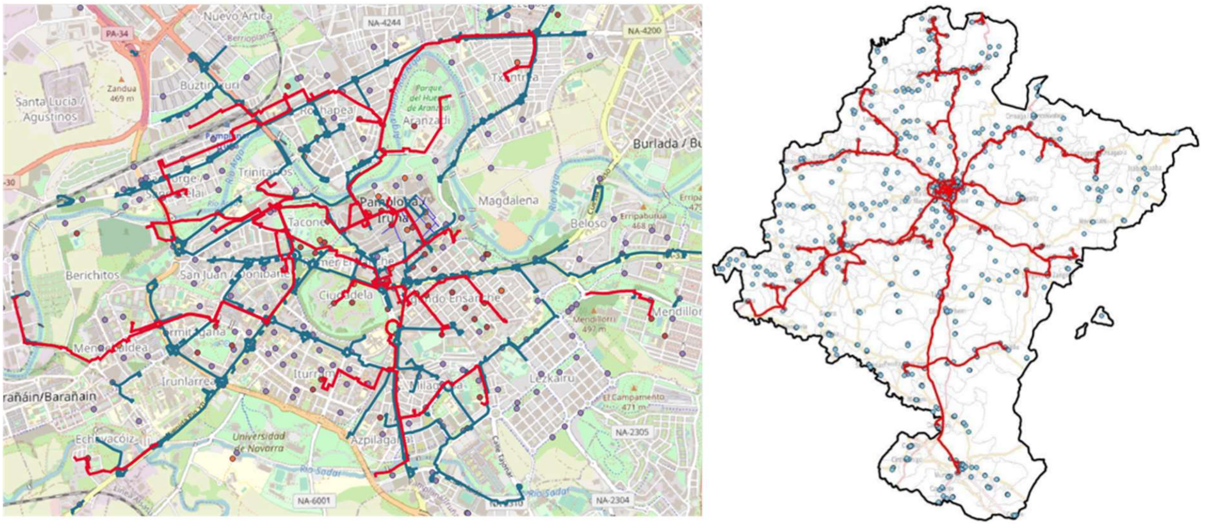
We will start with the results from the SENSA project, which constitute the fundamental underpinnings of our current proposal. As detailed in the state-of-the-art section, one of the results of this project was the development of distributed vibration sensors based on coherent optical time-domain analysis (COTDR) that deployed optical pulse compression to obtain long-range, in the tens of kilometers order, high spatial resolution, up to a few tens of centimeters, and measurement sensitivity in the nanostrain and tens of picostrain order. Therefore, the first task (T2.1) will be to assemble a table-top laboratory setup of the enhanced distributed vibration sensor that we are going to use throughout the project (at TRL4). We will fine-tune this setup to optimize it for the performance required in the system. All this experimental work will be done using fiber spools in the lab (not connected to anything) and using the strain sensitivity of the implemented system as the fundamental yardstick to assess that we are reaching the desired performance.

The second task (T2.2) will be to validate the technology in a relevant environment at TRL5. We will take advantage here of a connection that we already have in our lab to a fiber optic communication cable that runs along one of the avenues beside the Arrosadia UPNA Campus (Av. Cataluña). This connection was established also during the SENSA project to implement the road monitoring demonstration using point fiber optic sensors. The cable is a conventional armored fiber optic communication cable identical to the ones normally laid by telecom companies. The cable, which is around 100 meters long, is inserted in the corrugated conduits used for the street lighting system at a depth of approx. 1m as depicted in the next figure, which shows the cable termination in one of the street lighting manholes.

Connecting to this cable will provide access to real traffic measurements. This will give us the platform to start validating the technology in a real relevant environment. During this task, we will finish tweaking the DVS setup and, more importantly, we will carry out the all-important activities related to the development of the signal processing and machine learning required to make sense of the raw information obtained by the DVS. The UC group participate in this task with the development of deep learning algorithms for the automatic processing of the distributed signal. Using both the data collected in the lab (T2.1) and from the cable already installed near the Arrosadia UPNA campus, the data will be pre-processed, labeled, and used to train a deep learning network. The objective of the developed algorithm will be the automatic identification of perturbations in the fiber optic cable, so specific vehicles can be detected and classified. We expect to use recent developments in the field of time-series signals for classification and anomaly detection, such as LTSTM networks or transformers. In the same line of the contributions in WP1, the trained model will be embedded in portable hardware so its performance could be assessed in the planned in-field trials.

Once the final DVS configuration is determined, another task (T2.3) will start with the objective of having a transportable field prototype of our DVS interrogator that in previous stages was just a laboratory setup. This task will run in parallel to the other tasks. Given the short time frame of the project, our approach will be to introduce modifications in a field prototype of DVS that we are concurrently building, which should be available by the start of this task. This is a prototype that is not going to be optimized in terms of cost or footprint. The objective is to have an operational prototype that, regardless of costs, can operate unattended for long periods in the field to let us demonstrate our system in a real-world scenario. Therefore, we will adopt a modular design using OEM high-level components that we already have such as modular narrow-linewidth laser source, optical receivers, pulse modulators and EDFA, and arbitrary wave generator and digitizer cards. All these modules will be integrated into a 19''-rack box under the control of a rugged industrial PC. For the specific uses of this project, the prototype will be adapted to the enhanced setup that we determine during the previous tasks (T2.1).

The final task will be related to the demonstration of the technology and system prototype in a relevant and operational environment (T2.4). In this task, we will start working with the DVS setup in the lab until the field prototype becomes available. However, in this initial phase, we will move to a more relevant scenario for the demonstration of the technology. The idea is to connect our setup in the lab to a real fiber installation different from the small-scale one we have beside the university. For this, we will take advantage of the corporative fiber optic network of the Pamplona Municipality and also of the Navarra Government network. The figure below depicts the map of these two networks. Notice that the Pamplona municipality owns an extensive fiber-optic network that is used for the interconnection of municipal premises (in red) and also for the remote control of street lighting and traffic lights and interactive signals (blue lines). All this network runs parallel to the street and is also buried in conduits under the sidewalk as the fiber cable that we have been using beside the University. UPNA is already in the process of signing an agreement with the Pamplona City Council to have access to the dark fiber in this network. Besides, we are quite fortunate to have a Point of Presence (PoP) of the municipal network, i.e., an equipment room where fiber cables are terminated, at less than a hundred meters from the university. Hence, we can easily extend a cable from our lab to this PoP. This will give access to real traffic measurements in several Pamplona streets even before our field DVS interrogator prototype is fully available.



Fiber optic networks of the Pamplona Council (left) and Navarra Government (right)

Likewise, the previous figure also depicts the corporate network of the Navarra Government (in red), which in later years has done a huge effort to bring fiber-optic connections to even small villages that are not served by commercial telecom. This network runs along the main roads of the community and has been installed by the microtrenching procedure, which uses an automatic machine to cut a tiny slot on the side of the road and insert a small conduit where fiber cables are later inserted. The advantage of this installation for our purposes is that the fiber cable is tightly coupled to the road, and hence, vibrations from the vehicles and their interaction with the pavement irregularities are received with great SNR. The entity operating Navarra's network is Nasertic, which has already made clear its desire to collaborate in this project by giving access to dark fiber in their network and is close to signing an agreement for that purpose with the UPNA.

Therefore, in Task T2.4 we will first connect directly from our lab with Pamplona's, and probably Navarra's, network with access to real traffic measurements without the need for an operational field interrogator. However, once the prototype interrogator developed in task T2.3 becomes available it will be directly connected to the mentioned networks at specific equipment rooms to initiate the final campaign to demonstrate the system in its operational environment (TRL7).

Having access to the fiber networks of public institutions has an added benefit; because these institutions are the end-clients of the product that we aim to develop. Both municipalities and governments are interested in having a precise traffic monitoring solution and also to have information regarding the condition of their road networks.

From lab to market: transference plan for the future UPNA´s Technological Base spin-off company

Considering previous knowledge about entrepreneurship obtained during the application and training in the different actions and calls aforementioned, we have an overall idea about the tasks we must achieve to propose a viable entrepreneurship project. Hence, before the establishment of the spin-off, we will need to consider all these aspects:

- Promoter team and roles.
- To create a solid business model.
- To explore and investigate the market and the potential customers.
- To build an attractive “value proposition” from the developments.
- To set the channels of communication with market actors.
- To explore and create a commercial protocol with customers and the commercial and marketing plan.
- To develop a supplier portfolio.
- To define the basic internal activities to drive the business.
- To establish strategic partnerships.
- To create a solid financial plan to make the whole idea viable.

The previous steps are required for a viable spin-off generation. However, not all these aspects will be developed within this project. It should be clarified that some of these steps have been already taken during the SENSA project, specifically related to the business idea ‘Menditech', which will be further developed here. During this previous experience, we established contacts and trained with business consultants, both public and private, that helped us to define and prioritize the future steps for the spin-off creation.

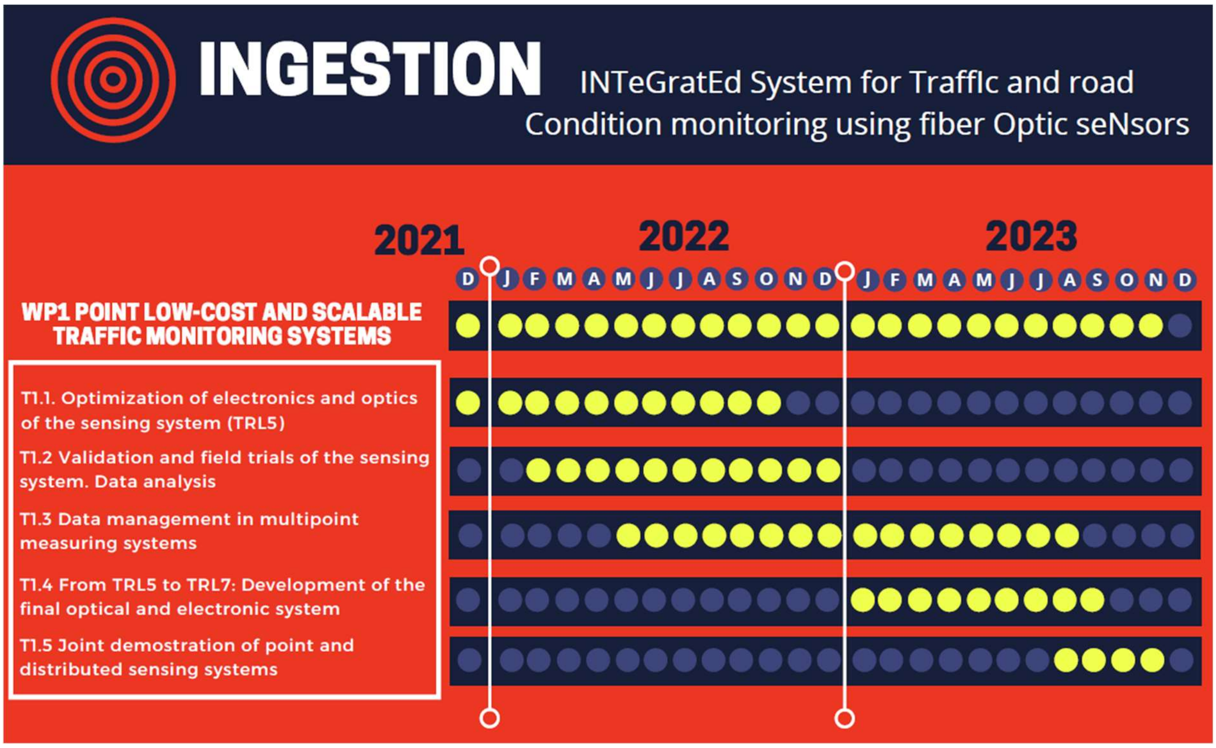
Consequently, we will keep working with CEIN (Centro Europeo de Empresas e Innovación de Navarra) and LUCE (Laboratorio Universitario de Creación de Empresas) to commercialize the products. Also, we consider that some essential tasks for the business creation must be hired externally. We include a separate budget line to explore and correctly determine the market and to create a business model and business plan accordingly. These two deliverables will be essential to create a Technological Base Spin-Off Company (EBT) from Universidad Pública de Navarra.

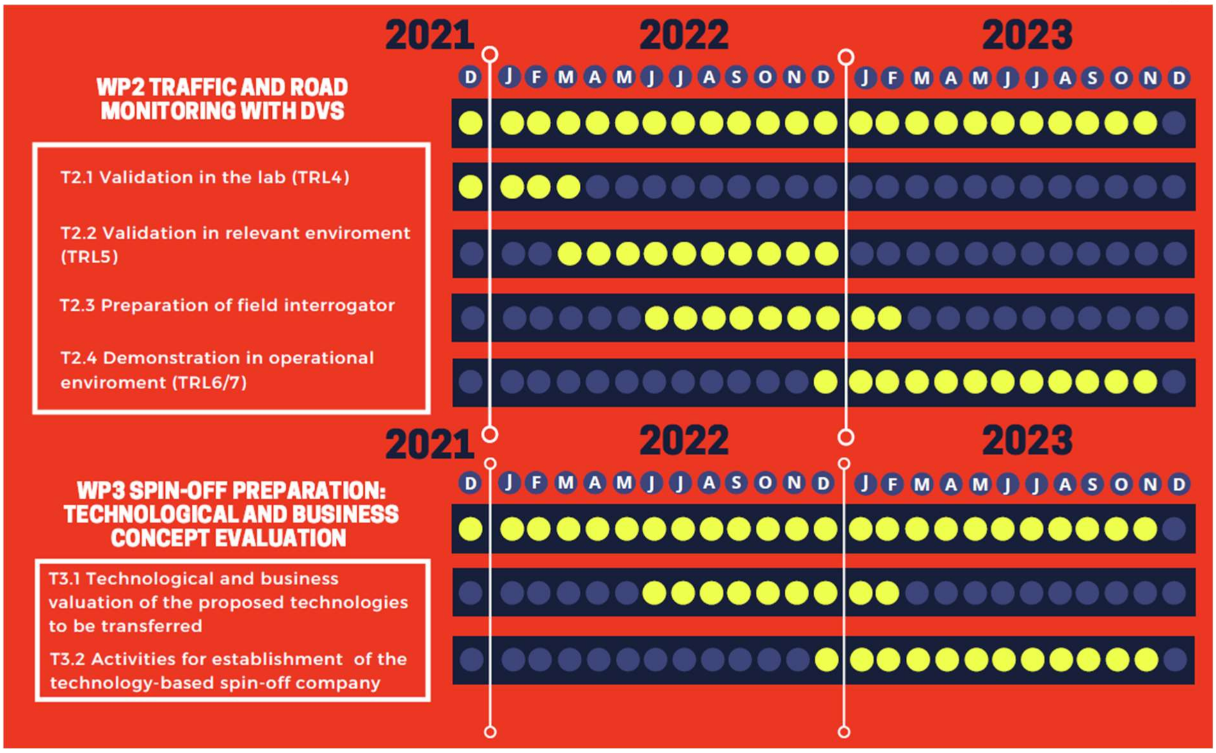
Implementation Plan

A list of the personnel from both groups involved in the project with the acronyms used in task descriptions is shown in the following table:

	No	UPNA		Tit	UC		Tit
Research Team	1	MLA	Manuel López-Amo Sainz (IP)	Dr	JMLH	José Miguel López Higuera (IP)	Dr
	2	ALL	Alayn Loayssa Lara (IP)	Dr	ACG	Adolfo Cobo García (IP)	Dr
	3	MGG	Marko Galarza Galarza	Dr	OCP	Olga Conde Portilla	Dr
	4	MSG	Mikel Sagüés García	Dr	JMS	Jesús Mirapeix Serrano	Dr
	5	RPH	Rosa Ana Pérez Herrera	Dr			
	6	MBA	Mikel Bravo Acha	Dr			
W. Team	1	DLG	Daniel Leandro González	Dr	EG3	Engineer (to be hired)	Eng
	2	ASG	Arturo Sánchez González	Lic			
	3	EG1	Engineer (to be hired)	Eng			
	4	EG2	Engineer (to be hired)	Eng			

The **Gantt chart** of the project is as follows:





A detailed description of the working packages and tasks of the above-shown chart is explained in detail below:

WP1	Development of point low-cost and scalable traffic monitoring system
Objective:	To boost the technology developed during project SENSA. To obtain pre-commercial products that can be transferred to companies, initially to a technology-based start-up. The demonstration of the system will be conducted with a real deployment on the streets of Pamplona City.
WP leader	Manuel López-Amo (UPNA)
Starting point:	State of the art, existing facilities, and prototypes from project TEC2016-76021-C2-1-R. Past experience of the groups and know-how in asphalt monitoring.
Timeline:	Month 1-24

Task T1.1	Optimization of electronics and optics of the sensing system (TRL5)
Objectives:	**General:** *To optimize the current prototypes* **Specific:** i) To design new electronics and improve the signal processing of sensing systems. ii) To design robust interferometric sensors suitable for quick and low-cost installation on roads
Leader:	Manuel López-Amo (UPNA)
Activities:	i) Rework and optimize the electronic system. The performance of the system is tightly linked to the electronic design, so it will a priority to improve the detection and laser driver performance in terms of SNR, besides the implementation of signal processing and communications unit. All the previous will need of the development of a firmware that drives all hardware systems together.

ii) Robust and optimized sensors transducers will be developed using specially designed pieces, in order to have a secure and quick installation of sensors on roads. In this task, also different sensor sensitivities and ranges will be tested to optimize the response of the sensors to each situation. For example, depending on the vehicle type: car, truck, motorbikes, bikes, or even pedestrian detection.

Personnel: **(UPNA) MLA, MBA, DLG, EG1 (UC) OCP**

Materials: The interrogator will be assembled using equipment and components that UPNA's group already owns. Complementary components will be purchased from the budget of the project, as is detailed in its section.

Results: Optimized electronic schematics. Final design of the transducers.

Risks & mitigation plan: i) Installation procedure of sensors in asphalt will be optimized using a robust design. This is a critical part to achieve a successful product. Several alternative designs of the sensors will be checked, using sensor parts specifically designed by us.

ii) Viability of the technological transference depends on the costs of the development. Thus, it will be taken special care on selecting the components. To mitigate this risk, a trade-off between price and performance will be considered.

Timeline: Month 1-12

Task T1.2 Validation and field trials of the sensing system. Data capture and analysis

Objectives: To create the installation protocols, to test the interrogator prototype in-field, and to obtain real data to create the system specifications.

Leader: Manuel López-Amo (UPNA)

Activities: i) To install and check the developed sensing systems in real conditions (several locations in Pamplona City). This subtask includes the protocol preparation, material acquisition, transductor and interrogation prototypes fabrication, and organization with the construction company and the tiers of government.

ii) Once the sensors are installed, to capture and analyze the measured data it is necessary to prepare the connections and protections in the installation place to protect and to drive properly the interrogation unit. This subtask will be used to optimize the sensing system sensitivity and to prepare Task 1.3 of this project as well.

Personnel: (UPNA) MLA, DLG, MBA, RPH, EG1 (UC) ACG, JMS

Materials: The interrogator will be assembled using equipment and materials that we already own. Complementary components and materials for the installation process will be purchased from the budget of the project, as is detailed in the budget

Results: Protocols for sensor and interrogator installations on-site. New locations for the technology demonstration.

Risks & mitigation plan: No special technological risks are foreseen in this task apart from those regularly associated with applied research. There are two concurrent research lines to improve the existing interrogation systems in this task. So that in the event that less significant results were achieved in one of them, the focus will move to the others. Certain risk is however focused on the installation itself. Asphalt is a harsh environment to install optical fiber. Thus, to avoid unnecessary risk, special care on the fiber protection and installation process must be taken into account.

Timeline: Months 3-12

Task T1.3	**Data management in multipoint measuring systems. Software for analysis, processing, storage, and representation of acquired data.**
Objectives:	i) To merge the already installed sensors in a single network. ii) To develop a sensor signal processing system that provides automatic "high-level" information in real-time, that is, that converts raw signals into information, creating and training Deep learning networks. iii) To introduce the processing system of the data of these sensing networks in “Edge computing” devices that work in low-cost embedded systems, so a complementary product could be created.
Leader:	Adolfo Cobo García (UC)
Activities:	i)For subtask 1, to introduce sensors installed in the city of Pamplona in a single network, it is necessary to develop a full communication system, from the physical layer to the session layer in the OSI model. This must be done before giving access to the following activities. i) For subtask 2 (To develop a sensor signal processing system) the following activities will be carried out: a) Definition of relevant information to be extracted b) Generation of a dataset from in-field measurements c) Anomaly detection (unexpected traffic, automatic detection of traffic conditions, asphalt deterioration, structural damaging) d) Vehicle counting and/or classification. i) For subtask 3, to introduce the processing system in low-cost embedded systems, the following activities will be carried out: a) Programming and training of the deep learning networks. b) In-lab test and validation, c) Implementation in a low-cost low-power edge device (such as RPi4, Google Coral or Nvidia Jetson) d) Validation and testing in real conditions.
Personnel:	(UPNA) MLA, MGG, MBA, DLG, ASG, EG1 (UC) JMLH, ACG, OCP, JMS, EG3
Materials:	This task will use mainly computing and programming resources achieved in previous projects.
Results:	Analysis and representation of the acquired data of the point sensing systems
Risks & mitigation plan:	The risks are related to the management of big amounts of data where huge infrastructures are required to provide computing resources able to cope with the measured datasets. The mitigation plan involves petition of processing and storage devices and, if further requirements appear thorough the project, collaborations will be settled with institutions of parallel computing as the Altamira Supercomputing node. Also, the final decision about subtask 2 could be negative, but we think that the trial is compulsory nowadays.
Timeline:	Months 5- 20

Milestone: Internal reports (IRT1.1) including the final design of the software for processing and display the measured data of the sensing system.

Task T1.4 **From TRL5 to TRL7: Development of the final optical and electronic system**

Objectives: Development of an optimized sensor system for traffic monitoring applications.

Leader: Manuel López Amo (UPNA)

Activities: i)To optimize electronics in terms of components, noise, electromagnetic conditioning, power supply, fit specifications of the sampling rate and signal processing unit, and develop a firmware. that can be commercially produced and tested in a real verification test.
ii) To prepare the "product" (interrogator and transducer) to achieve the certificates and marks needed to introduce the product into the real market. A step forward to TRL8 might be considered if the commercial interest in the product matches the expectations.

Personnel: (UPNA) MLA, MGG, RPH, DLG, MBA, ASG, EG1

Materials: The interrogator and point sensors will be assembled using equipment that we already own. Additional components will be charged to the project's budget. Additional professional electronic design from this project will be purchased to achieve a TRL7 Product. The certification process could be carried out also in this task depending on the clients/users feedback.

Results: Final design and specifications of the sensing system for road traffic monitoring

Risks & mitigation plan: The main risk comes from the lack of experience of our group in certification processes. In the case, we validate the commercial interest and move to TRL8, that is, certification, unexpected delays may happen. However, from the experience of other researchers in similar projects, we think that we can manage those delays inside the project time limits.

Timeline: Month 13-24

Milestone: Two internal reports (IRT1.2, IRT1.3) including the gained knowledge and technique in WP1 and final designs

Task T1.5 **Joint demonstration and comparison of point and distributed sensing systems in an operational environment**

Objectives: To check in an in-field demonstration both sensing systems developed in the project in tasks T1.4 and T2.4

Leader: Manuel López-Amo (UPNA)

Activities: Joint measuring campaign of the two developed systems in this project. Analysis of the achieved data. Calibration of the distributed system using point sensors. Besides, other technologies will be compared in parallel. It can be already installed sensors or some installed by us. For example, the installation of commercial magnetometers.

Personnel: (UPNA) ALL, MLA, RPH, MSG, MBA, DLG, ASG, EG1 (UC): JMLH, ACG, OCP, JMS

Materials: The working prototypes achieved in tasks T1.4 and T2.3. Installation material to develop the in-field tests

Results: Calibration, comparison, and development of a new product for the spin-off company planned in this project.

Risks & mitigation plan: If both systems are correctly developed and connected, the risks are related to the management of big amounts of data where huge infrastructures are required to provide computing resources able to cope with the measured datasets. The mitigation plan involves a request for processing and storage devices and, if further requirements appear thorough the project, collaborations will be settled with institutions of parallel computing such as the Altamira Supercomputing node.

Timeline: Month 18-24

Milestone: Internal report (IRT1.4,) including the comparative study of the measuring systems developed in WP1 and WP2. Publications on prestigious international journals or conferences if convenient (if there is no conflict of interest with the protection of the developed technology)

WP2 Demonstration of a system for traffic and road condition monitoring using distributed fiber optic vibration sensors

Objective: To leverage the Distributed Vibration Sensor techniques developed during project TEC2016-76021-C2-1-R "Photonic Sensors for Safety and Security (SENSA)" to demonstrate in an operational environment a system for monitorization of traffic and road condition monitoring. The demonstration of the system will be conducted with real deployment on the streets of Pamplona City and also on the roads of the Comunidad Foral de Navarra.

WP leader Alayn Loayssa (UPNA)

Starting point: State of the art, existing facilities, and prototypes from project TEC2016-76021-C2-1-R. Experience of the groups.

Timeline: Month 1-24

Task T2.1 Validation of distributed vibration sensing technology in the lab (TRL4)

Objectives: Assemble a laboratory setup of an enhanced distributed vibration sensor based on the techniques developed during the SENSA project and optimize its performance for the detection of the vibrations generated by vehicles in their interaction with road pavement irregularities.

Leader: Alayn Loayssa (UPNA)

Activities: We will apply the techniques developed in the SENSA project to assemble a distributed fiber-optic vibration sensor based on optical pulse compression. This setup will be based on coherent optical time-domain reflectometry using a narrow linewidth optical laser and deploy phase demodulation to measure the variations in optical phase for the Rayleigh backscattering from contiguous positions along the fiber. This sensor setup will deploy Perfect Periodic Autocorrelation (PPA) codes to obtain a spatial resolution below 1-m, which is a considerable enhancement to current commercial offerings. The target range for this sensor setup will be at least 25 km, although we expect to obtain more, and the required performance in terms of the gauge length, strain sensitivity, and sampling rate will be determined according to our proprietary assessments based on our analysis of traffic vibration signals. We will fine-tune the setup until this performance is obtained. Notice that this does not require the measurement of actual vibration signals. On the contrary, during this task, we will use fiber optic spools introduced in acoustic and vibration isolation boxes and use the measurement sensitivity as the fundamental yardstick to assess that the required performance has been achieved.

Personnel: (UPNA) ALL, MSG, DLG

Materials: This experimental setup will be assembled with the components and equipment that we already have in our lab.

Results: Distributed vibration interrogator setup with the required performance for traffic vibration detection operative.

Risks & mitigation plan: The risk of this task is considered to be low because we have demonstrated in the past DVS with similar performance to the one required for traffic vibration detection.

Timeline: Month 1-4

Task T2.2 Validation of traffic and road condition monitoring via DVS in a relevant environment (TRL5)

Objectives: Validate the use of DVS to monitor traffic-induced vibrations in a relevant environment, which will be a section of a city street with real traffic.

Determine the most adequate signal processing methods and machine learning algorithms to convert the raw vibration measurements into actionable information.

Leader: Alayn Loayssa (UPNA)

Activities: We will connect the DVS interrogator laboratory setup to the fiber optic cable that departs from the Photonics lab of UPNA and goes to Av. Cataluña where it is installed in the street lighting conduits that run below the sidewalk in parallel to the road.

In the first phase of the task, we will carry on a measurement campaign with controlled conditions, i.e., measuring when in low or no traffic conditions (at night) using our own vehicles equipped with GPS trackers. This will provide a controlled scenario in which we will have precise information of the origins of the vibration associated with the presence of a vehicle at a specific position.

The results of this measurement campaign will be given to the UC Team, which will analyze them and apply their signal processing and machine learning expertise. The optimum signal processing to obtain the cleanest possible signal suitable for later classification stages will be determined. In addition, the UC team with determine the most suitable algorithm to use in the classification of events. The problem of determining which event is associated with a perturbation in the fiber constitutes a time series classification problem for which there are literally hundreds of available machine learning algorithms. In our previous developments, we have started to work on applying machine learning algorithms for vehicle detection. During this project, with the expertise of the UC team on machine learning, we will improve those algorithms and evaluate new developments in the processing of time-series data (such as transformers) to extend them to the application of road condition monitoring. Extensive measurement data will be obtained to properly train the devised algorithms. The collaboration of a hired engineer at UC is requested for these activities.

In a second phase in the development of this task, we will carry on a measurements campaign with real traffic and test the implemented algorithms.
During this task, we will use the information in terms of the performance of the DVS sensor obtained during the measurements to fine-tune the experimental setup, if that is necessary.

Personnel: (UPNA) ALL, MSG, DLG (UC) JLH, ACG, JMS, OCP, EG3

Materials: This task will use components and equipment already available to us.

Results: Validation of the traffic and road condition monitoring system with the DVS in a real street with real traffic.

Risks & mitigation plan: The risks in this task are basically associated with the performance of the machine learning algorithms. However, there are a large number of algorithms that can be tested, and we are confident that we will get the required performance for traffic and road monitoring with several of them

Timeline: 4-13

Task T2.3 Modular interrogator field prototype

Objectives: To have available a transportable, reliable DVS interrogator prototype that can be installed in the field in networks' Points of Presence or equipment rooms.

Leader: Alayn Loayssa (UPNA)

Activities: We will implement a field prototype based on a modular design that we are already designing. This will be modified with the inputs of previous tasks to ensure that it has the performance required for road condition monitoring application. The approach that we will follow is to have an operative prototype that will not be optimized in terms of cost or footprint. That will come at a later stage (after the end of this project) when the steps to take the prototype all the way to TRL8 and TRL9 in order to have a commercial product will be performed.
The current field prototype will use commercial OEM modules for the laser source, EDFA, electrical signal generation, optical receiver, and digitizing card. These modules are typically controlled using RS-232, RS485, or SPI buses that be easily interfaced to a controlling PC. Therefore, no or minimal development of new electronics is expected. We will just need to program the communications of the different modules in a rugged industrial PC that will be integrated with the system and that will implement the measurement algorithms.
As for the mechanical design of the prototype, we will aim at a simple scheme that will largely disregard footprint considerations. The OEM modules and passive and active photonic components required in the DVS prototype will be embedded in a 19'' rack box. The necessary auxiliary mechanical parts for their fitting to the box will be 3D printed.

Personnel: (UPNA) ALL, MSG, DLG

Materials: The interrogator will be assembled using modules and components that we have obtained in previous projects. No additional components will be charged to the project's budget.

Results: Operative DVS field interrogator prototype

Risks & mitigation plan: No significant risks are appreciated for this task as the group has plenty of experience in developing this sort of prototype and even of final pre-commercial products.

Timeline: Month 7-15

Task T2.4	**Demonstration of technology and system prototype in relevant and operational environment (TRL6/7)**

Objectives: Demonstrate the traffic and road condition monitoring system in a real-world operational environment.

Fine-tune the machine learning algorithms used to provide actionable information.

Leader: Alayn Loayssa (UPNA)

Activities: In this task, we will make the transition from validation of the system in a relevant but somewhat limited environment, the single street section used in task T2.2, to a demonstration in a real operational environment.

In the first phase, we will connect directly the setup in our lab with the Pamplona municipal fiber network that has a Point of Presence at less than 100m from the campus. With this connection, we will have access to many of the streets in the city including its main arteries. Probably, it will be also possible to connect with the Navarra government network directly from our lab. This has the advantage of making the availability of the field DVS interrogator unnecessary from the start of this task, hence providing extra margin to cover possible eventualities. However, as the prototype interrogator assembled in T.2.3 becomes available, it will be deployed with the advantage that it will give access to even more measurement locations.

The access to a large number of streets and roads with different fiber cable types, cable installations, types of road (streets, avenues, national roads, highways) conditions of the road pavement (rugosity, cracks, potholes,…), traffic patterns, etc. will open up the possibilities to tune and operate our system in different scenarios.

As in task T2.2, we will start by operating the system with controlled traffic, i.e., different types of GPS-tracked vehicles. Extended-time measurement campaigns will be undertaken. This will serve to fine-tune the machine learning algorithms. We intend also to introduce controlled degradations in the pavement to contemplate their effect on the measurements. Later, we will proceed to measurement with real traffic. In this phase, we expect to have access to images of the CCTV traffic control of the Pamplona municipality and the Navarra Government to assess the location of vehicles. In addition, we will perform collocated measurements with the point traffic sensors deployed in WP1

Notice that this task is quite intense in terms of personnel hours for fieldwork on the part of UPNA. Therefore, we request the hiring of an engineer (Eng2) so as not to overload the academic team members involved. This Eng2 will have a Master's degree and be able to operate and tune the systems working independently after a short training phase.

Personnel: (UPNA) ALL, MSG, DLG, EG2 (UC) JLH, ACG, OCP

Materials:

Results: Successful demonstration of the traffic and road condition monitoring system in a real scenario. From this demonstration, we will proceed to the transfer of the results so that the necessary final steps of its commercialization are covered.

Risks & mitigation plan: To cover the unlikely event that there are delays with the delivery of the interrogator we will extent the measurement phase using a direct connection from the lab to the Pamplona municipality network.

Timeline: Month 12-24

WP3	Spin-off preparation: technological and business concept evaluations

Objective: To pave the way for the creation of a technological base spin-off company from UPNA that would transfer research results from SENSA to market

WP leader Manuel López-Amo (UPNA)

Starting point: Previous experience on transference (UPTech sensing). Previous participation in entrepreneurship acceleration programs such as "Impulso Emprendedor" with the initial results achieved in SENSA. Contacts with business and innovation centers such as CEIN or LUCE.

Timeline: Month 1-24

Task T3.1	Technological and business valuation of the proposed technologies to be transferred

Objectives: To obtain the required information to understand and validate the product's potential. Design a roadmap to create UPNA´s spin-off company.

Leader: Manuel López-Amo (UPNA)

Activities: Market exploration and competitors' technologies research. Business model and business plan development. For this, the personnel implied will determine the potential applications on traffic monitoring such as smart cities, inter-urban traffic monitoring, "shadow tolls", etc. Once the list of applications was ready, they will have to define the "value proposition" for each application before starting to build the business model and business plan. For this objective, expert external consultancy will be needed.

Personnel: (UPNA) MLA, DLG, MBA, RPH

Materials: No materials are needed for this task

Results: A business plan

Risks & mitigation plan: The main risk is related to the validation and adequacy of the value propositions by the market. Mitigation –based on a lean start-up basis- would be based on pivoting and searching other potential "value propositions" for the developments.

Timeline: Month 7-15

Task T3.2	Activities for the establishment of the technology-based spin-off company

Objectives: To establish a new and viable UPNA´s Technology Base Spin-Off company

Leader: Manuel López-Amo (UPNA)

Activities: To create a supplier network; to establish relations with potential partners; to interview key interlocutors from the full value chain; to negotiate the company establishment with UPNA and to prepare the shareholders agreement;

Personnel:	(UPNA) MLA, DLG, MBA, RPH
Materials:	No materials are needed for this task
Results:	The results will be the tools to correctly establish a transference-based company in UPNA's environment. These will include the contacts network and the main activities to launch the spin-off.
Risks & mitigation plan:	Wrong negotiations would lead to the non-viability of the business model. These would be mitigated by using external consultancy to prevent conflicts and prepare negotiations.
Timeline:	15-24

Project's organizational structure

Each task leader will supervise its development and report to a steering committee that will oversight the implementation of the project. This committed consists of the 4 principal investigators (IPs), which are also leaders of different tasks. Regular online meetings will be arranged (at least a short videoconference once every 2 weeks) to assess the project progress. Plenary (all team members) online meetings with a highly structured format (short conference-like presentations) will be organized monthly to report on particular topics related to the project progress or results.

Justification of personnel hiring

This is quite an ambitious project that requires many personnel hours. There is a good number of academic staff involved that is going to contribute part-time with their work. However, this staff has other responsibilities related to their academic work with lecturing, research, and management. There are also 2 postdocs and 1 Ph.D. student in the team that will collaborate, but the main focus of this personnel is on research, and this project is not focused on research but the development, innovation, transfer, and valorization of technology. Therefore, it is highly desirable to have personnel fully devoted to the project precisely with this profile. Hence, to ensure the best possible outcome for this project, we request funds for the hiring of 3 engineers (2 at UPNA and 1 at UC).

Hired Engineered 1 (EG1, UPNA): This Engineer will be hired at the beginning of the project to work on tasks 1.1 and 1.2. Most of EG1 working time will be used in the optimization of electronics and optics of the sensing system, 3D design of specific parts of the transducer, he/she will be in charge of logistics and materials purchase for the in-filed demonstration of task 1.2. Also, he/she will program the software employed to communicate, retrieve data and perform basic processing and will also have responsibility for conducting the measurement campaigns needed to prepare task 1.3 including the data transfer to Universidad de Cantabria.

Hired Engineered 2 (EG2, UPNA): This Engineer will be hired for the final year of the project to work on the demonstration of the use of distributed vibration sensing for the implementation of traffic and road condition monitoring systems in a real-world operational environment in task 2.4 of the workplan. For this task, we require an engineer at the master's level with experience in the development of technology. More than an engineer highly specialized in one topic, we need someone that can play different technical roles. EG2 will be in charge of tweaking the hardware and software of the system to make it work in a real streets and roads scenario. EG2 will have responsibility for conducting the measurement campaigns needed to feed the deep learning algorithms and he will coordinate all the logistics needed for the system demonstration.

Hired Engineered 3 (EG3, UC): This engineer will be hired to deal with the implementation, training, and testing of the deep learning algorithms. We expect to hire an engineer with a master's level and experience in data science. EG3 will participate in the following tasks: T1.3 and T2.2, starting in month 6 once enough and relevant data are available.

6. Research team

In the following, we describe the experience of the research team members on the objectives and activities planned in this project. In addition, their experience in the transfer and exploitation of research results is highlighted.

Universidad Pública de Navarra

The Optical Communications group of the Public University of Navarra (UPNA) has a total of 51 researchers, 29 of them doctors, which have complementary expertise and a trajectory of more than 20 years working together. This research group uses well-equipped facilities that are built around four laboratories. The equipment in these labs includes high tech measurement and fabrication systems for optical fibers sensors. Our group is internationally recognized in the field of optical fibers sensors, being the research group with more communications accepted in the top international conference on this topic (International optical fiber sensors conference, OFS) in the last 10 years. (More information in: http://www.unavarra.es/optical-communications-group)

From this group, 8 researchers (7 of them doctors) compose the research team of UPNA in this project. This team is formed by 1 Full professor, 1 Associate professor, 3 Readers (*profesores contratados doctores*), 1 Post-doc researcher (1 Beatriz Galindo fellowship) and 1 post doc (ISC-UPNA) and 1 Pre-doc researcher.

Manuel López-Amo Sainz (IP)

Professor (Catedrático de Universidad) with a research experience of more than 30 years in fiber-optic sensors. In the last 10 years, he has co-authored 91 JCR papers, 71 contributions to international scientific conferences and 2 book chapters on this topic. He has also supervised 6 doctoral theses in this period on fiber-optic sensors and networks and participated in 19 technical committees of international conferences such as Optical Fiber Sensors conference or I3 Sensors. He has been associated editor of several journals and Guest Editor of several Special Issues on Optical Fiber Sensors published in Journals such of J. of Lightwave Technology or in Sensors MDPI.

In addition, Manuel López-Amo has been involved in the following research transfer and valorization activities related to the objectives of the project:

He is the inventor of one international patent related to the utilization of optical fiber in wind generators, with the company Gamesa Eólica. He is one of the promoters of the future spin-off company Menditech, together with Drs. Mikel Bravo, Daniel Leandro and Rosa Ana Perez Herrera (also members of the Research Team of this project) and a former PhD student. In the promotion phase of this entrepreneurial effort, we received the following awards:

- “Impulso Emprendedor Award” (2020) from the Centro Europeo de Empresas e Innovación de Navarra (CEIN) and the Navarra Government. This gave us access to some initial funds for the development of the idea and, above all, access to the mentoring for the development of the business plan. Also “Iniciate 2nd Award” for new business ideas (2020)
- Best Business Idea awarded from Campus Iberus and CLH company (2020).
- Selected business idea to collaborate with Pamplona city hall SMART PAMPLONA LAB 2020, inside European project “Stardust”.

In the last 10 years MLA had led or participated in 6 European projects, 3 competitive national one and 2 competitive regional ones related with optical fiber sensors. He has also participated and lead industrial R&D projects and transference projects with public backing for optical fiber sensor applications to industrial companies such as Azkoyen, AH&A, or AIN.

In the project, Manuel Lopez-Amo is going to lead all the activities related to the demonstration of the system for traffic monitoring using point interferometric optical fiber sensors in WP1. Also, the activities for launching the projected spin-off company in WP3.

Alayn Loayssa Lara (IP)

Associate Professor (Profesor Titular de Universidad) with a broad research experience in one of the fundamental technologies underpinning this project: distributed fiber-optic sensors. In the last 10 years, he has authored 37 JCR papers, 33 contributions to international scientific conferences and 4 book chapters on this topic. He has also supervised 5 doctoral theses in this period on Brillouin and Rayleigh distributed fiber-optic sensors and participated in National and Regional public-funded research projects in activities related to development of this technology.

In addition, Alayn Loayssa has been involved in the following research transfer and valorization activities related to the objectives of the project:

- He is the inventor of two international patents related to distributed fiber-optic Brillouin sensors that has been licensed and are exploited by a company, Uptech Sensing S.L. (uptech-sensing.com).
- He was promoter and later founder of the spin-off company Uptech sensing together with Prof. Mikel Sagues (also member of the Research Team of this project) and a PhD student. In the promotion phase of this entrepreneurial effort, we received the following awards:
    - "Impulso Emprendedor Award" (2015) from the Centro Europeo de Empresas e Innovación de Navarra (CEIN) and the Navarra Government. This gave us access to some initial funds for the development of the idea and, above all, access to the mentoring of Grupo Mondragón Coorporación Cooperativa for the development of the business plan.
    - Best Business Idea awarded from Campus Iberus and CLH company (2016).

He has also participated and lead industrial R&D projects and transference projects with public backing for the transferred of distributed fiber-optic sensor applications to industrial companies such as Siemens Gamesa Renewal Energy (blade structural monitoring), Acciona Energía (SHM of hydraulic engineering structures), Confederación hidrográfica del Ebro (SHM of hydraulic engineering structures), LKS Ingeniería, STI Norland (SHM of PV solar tracker) and Aragon Photonics (Distributed fiber optic sensor manufacturer). The total budget for these projects in the 2016 to 2021 period has been over half a million euros.

In the project, Alayn Loayssa is going to lead all the activities related to the demonstration of the system for road condition monitoring using distributed vibration sensors in WP2.

Mikel Sagües García (Research team)

Assistant Professor (Profesor Contratado Doctor) with a broad research experience in one of the fundamental technologies underpinning this project: distributed fiber-optic sensors. He has authored 23 JCR papers 16 contributions to international scientific conferences and 1 book chapters on this topic. He has also supervised 1 doctoral theses in this period on Brillouin distributed fiber-optic sensors and participated in National and Regional public-funded research projects in activities related to development of this technology. He is co-inventor with Prof. Alayn Loayssa of two international patents related to distributed fiber-optic Brillouin sensors that has been licensed and are exploited by a company, Uptech Sensing S.L. (uptech-sensing.com). He was also promoter of this spin-off company. He has also participated and lead industrial R&D projects and transference projects with public backing for the transferred of distributed fiber-optic sensor applications to industrial companies such as Siemens Gamesa Renewal Energy (blade structural monitoring) and Aragon Photonics (Distributed fiber optic sensor manufacturer). In August 2015 he was appointed General Manager of Digitalization, Telecommunications and Public Innovation of the Government of Navarra, a position he held for four years until August 2019.

In the project, Mikel Sagues is going to participate in all the activities related to the demonstration of the system for road condition monitoring using distributed vibration sensors in WP2.

Marko Galarza Galarza (Research team)

Assistant Professor (Profesor Contratado Doctor) with a broad research experience in optoelectronics and in optical fiber-optic sensors. He is a Dr. Since 2003 and he has participated in five research projects of plan Nacional in the last 10 years, among others. His experience in optical interferometers will be very well suited for tasks corresponding to WP1 optimizing optical transducers of the sensing system.

Rosa Ana Pérez Herrera (Research team)

Assistant Professor (Profesora Contratada Doctora) with a broad research experience in one of the fundamental technologies needed in this project: point fiber-optic sensors multiplexing. She is the author of more than 100 scientific publications in national and international journals and congresses, all of them related with optical fibers sensors, lasers and networks. Her experience in optical fiber sensors and networks perfectly fits in tasks 1.1, 1.2, 1.4 and 1.5 of this project. She also will participate in WP3. She is also one of the promoters of the future spin-off company.

Mikel Bravo Acha (Research team) and Daniel Leandro (Working team)

Both Drs. hold a Beatriz Galindo grant (BEAGAL18/0016) and Institute of Smart Cities grant for senior researchers (UPNA), respectively. They have a broad experience on fiber optic sensors, in particular optical structures optimization for low-cost applications. They were promotors of the asphalt monitoring research line due to his close relation with companies in the industry. Thus, they have participated in various projects funded by public organizations and coauthored 37 journal papers and 33 communications at international conferences. They have focused part of their efforts in technological transference by promoting the future creation of a UPNA´s EBT spin-off company having obtained various prizes in different calls such as “Impulso Emprendedor Award” (2020) from the Centro Europeo de Empresas e Innovación de Navarra (CEIN) and Navarra´s Government. This gave him access to some initial funds (13000€) for the development of the idea and, above all, access to the mentoring for the development of the business plan. Also “Premios Iniciate” 2nd award (4000€) for new business ideas (2020). Best Business Idea awarded (5000€) from Campus Iberus and CLH company (2020). And the business idea was selected to participate in the “Smart Pamplona Lab” 2020, part of the European project “Stardust”. Most part of their working effort in this project will be shared in WP1 and WP3.

Arturo Sánchez González (Working team)

ASG is a Ph.D student with previous experience in machine learning acquired in AIN (Asociación de la Industria Navarra)

Universidad de Cantabria

The Photonics Engineering Group (PEG) of the University of Cantabria (UC) generates knowledge and technique in Photonics with a special focus on solving real problems. PEG-UC has more than 30 researchers following a dynamic model, where part of the members are dedicated more intensively to the generation of knowledge and training, and others, to the application of knowledge and technique (I+D+I for the optimization and transference of results to the productive sector). This, in turn, provides a feedback of real problems to be solved and resources need to carry out their mission.

Since its foundation (1992), the PEG-UC has been focused on Photonic/Optical/Fiber optic sensors; fiber light sources; optoelectronics instrumentation; techniques of detection, measurement and monitoring of events and processes using imaging, for any sector of application.

The UC team for INGESTION is integrated by 4 senior researchers (2 full professors and 2 associate professors/profesores titulares), and an engineer to be hired for the project. The UC-GESTION team contributes to the project with expertise in the processing of optical fiber sensor signals, using in particular machine learning techniques. Several PhD thesis, competitive research projects and projects funded by companies are being or has been carried out in this topic. The two main researchers (Investigadores Principales -IP) are both full professors and have a long experience both as investigators and as research managers specially on the sensing using light technologies area, and in technology transfer. More information on:

http://www.teisa.unican.es/gif/index.php?option=com_contact&catid=17&Itemid=35

José Miguel López Higuera (IP)

R&D LEADER AND ORGANIZER: Founder and head of the Photonics Engineering Group, PEG, UC (1992). Member of +27 international Committees of Conferences (including Steering ones), R&D Institutions and Companies; 15 Spanish Committees in the field of Sensing and Instrumentation. General Chairman of the international conferences EWOFS, 2004 and OFS23, 2014.

EDUCATOR: Director of 20 PhD theses (7 with extraordinary PhD award) framed inside the Photonics/fiber sensing field.

RESEARCHER AND R&D MANAGER. His work focusses on Optical Fiber Sensor Systems and Instrumentations for Civil Engineering, Construction, Electrical Power Generation, Aero-space, Siderurgy, Automotive, Environmental, Medical and Biomedical, Smart Structure applications. 120 R&D&i projects (+80 on open competitive public and/or private funding calls acting on +90 as manager, coordinator or main researcher. More than 810 research publications. 539 international including four books, 15 chapters of books, 481 peer reviewed papers (164 in regular journals); 80 invited talks (39international). Editor and co-author of four R&D international books. Co-Editor of several conference proceedings and magazines. Guest Editor of several Special Issues on Optical Fiber Sensors published on IEEE Sensor Journal, on Optical Fiber Technology, on Journal of Light wave Technology and on Sensors MDPI.

TECHONOLGY TRANSFER & PATENTS: +40 projects as Principal Investigator funded by companies of many sectors to create or transfer technology. 24 patents closely related to optical and fiber techniques for sensors and instrumentations; two in preparation to be filled. Has helped to create three spin-off companies to commercialize technology developed at the Photonics Engineering Group: Empiric Technologies, Sadiq Engineering, eDrónica, Tecnología para Vehículos no Tripulados.

His role in this project will be the technical management of the UC contribution and technology transfer and knowledge protection actions.

Adolfo Cobo García (IP)

Adolfo (B.Eng. in Industrial Electronics, 1991, M. Eng. degree in Telecommunications, 1994, Ph.D. in 1999) currently holds a position as Full Professor at the TEISA department of the UC. His research interests are related to optical sensors, laser induced breakdown spectroscopy (LIBS) for diverse application, and the data processing of sensor signals, based on deep learning approaches. He is co-author of more than 70 papers in scientific journals and more than 150 presentations in national or international conferences. He has collaborated in 32 competitive research projects funded by public bodies and has supervised 5 PhD theses (4 more currently been supervised).

Regarding his technology transfer efforts, he has participated in 45 research contracts funded by companies in the aeronautical, nuclear, and automotive industry, to create or transfer technology. He is the co-inventor in 11 patent applications (one of them a PCT/EP application) and has also contributed to the creation of three spin-off companies (Sadiq Engineering, Empiric Technologies, and eDrónica). All of them have received several innovation and entrepreneurship awards.

His participation in this proposal will be focused on intelligent data processing of the sensor signals using techniques of deep learning. He has several papers published in this topic and is currently leading as Principal Investigator two research projects applying deep learning techniques for the analysis of underwater ecosystems.

Olga Mª Conde Portilla (Research team)

M.Eng, Ph.D in Telecom.Eng at the UC in 1994 and 1999. Associate Professor at UC since 2003, IDIVAL and CIBER-BBN member in 2015 and 2016. At PEG-UC since 1999 developing industrial/biomedical instrumentation and statistical/artificial intelligence for automated diagnosis. Co-author of 50 scientific papers (46-JCR, 49-SJR), 4 book chapters and 180 contributions in PR conferences. Supervision of 3 doctoral theses (another 4 in progress) and 75 BsEng/MsEng theses. She is co-inventor of 14 patents (1 USA, 1 PCT/EP) and founder of the spin-off company “Empiric Technologies SL”. Researcher and PI in 48 competitive projects and in 52 contracts with public/private companies. She has accomplished 5 complete six-year terms (4-research, 1-transfer of technology).

She will participate in this proposal on the intelligent data processing of the sensor signals using techniques of machine and deep learning. She has several papers published and is currently supervising several PhD theses in these topics. Also, she is leading as Principal Investigator several research projects related to this proposal.

Jesús Mirapeix Serrano (Research team)

Jesús Mirapeix Serrano obtained his Master Degree in Telecommunications in 2000 and his PhD in 2007 with a thesis focused on the use of plasma optical spectroscopy in the quality monitoring of welding processes. Since 2012 he has been working as Associate Professor in the Photonics Engineering Group of the University of Cantabria. He has collaborated in research projects funded by the European Union (2), and by national entities (20). He has also participated in 9 research contracts with public and private companies. He is author/co-author of more than 30 papers in international journals (h index=11 (Scopus)), and has collaborated in 5 patents. Nowadays his research interests are focused on distributed sensor systems based on Brillouin scattering, and he is co-founder of Sadiq Engineering, a spin-off devoted to the development of industrial monitoring systems based on photonic technology.

He will help in this proposal with the pre-processing of sensor data and the design of the data processing algorithms. He has several papers and has supervised one PhD thesis focused on data processing in this kind of sensors.

7. Scientific and technical impact

The INGESTION project, with its development of novel technologies to improve transport systems, is conceived to have an impact at different levels:

Technology development. A new low-cost scalable traffic monitoring system based on a simple fiber optic sensor transducer and interrogators will be created. This is a clear enhancement compared to most current applications of fiber optic sensors that tend to be niche applications with a high cost. In addition, new systems based on distributed vibration sensors will be available to assess the condition of the roads opening a new paradigm for the maintenance of these vital assets.

Technological transfer. The nature of the project ensures a high impact from the transfer perspective. The tools that we will leverage will be <u>industrial property protection</u> and the <u>creation of a spin-off company</u>. We are currently exploring the preparation of a patent application for the point sensor system, which we expect to submit during the INGESTION project lifetime. Also in a high stage of development is the promotion of a new spin-off company to commercialize the technology. We have been already involved in a 6-month business acceleration program (IMPULSO EMPRENDEDOR AWARD) to validate the business potential of our idea and confirm its driving hypotheses.

Nevertheless, it is expected that other opportunities arise during the prototype/product development. For example, it is expected that little variations of the product could open the door for new applications, such as weigh-in-motion or access control. In this manner, we will be constantly monitoring exploitation opportunities for the technology. The market interest of possible additional products will be determined following steps to define the target application, investigate the market and identify the possible clients, set the hypotheses required for successful business-model creation, perform a series of interviews and meetings to validate the hypotheses and, depending on the results, reevaluate, discard, or initiate the process for a business model definition. This process will be supported by UPNA's Laboratory for the Creation of Innovative Companies (LUCE) and the European Center for Business and Innovation of Navarra (CEIN).

A wide range of external agents could be interested in solutions for road monitoring. The type of agents will vary depending on the specific application but also depending on the transfer approach followed. For example, in urban traffic monitoring, the end-users will be the public entities such as city councils, but the clients will be mainly global solution integrators as Kapsch, Indra, etc. On the other hand, the clients for road-condition monitoring solutions will be mostly highway/speedway managers and national/provincial public entities. In any case, a careful, objective, and fair analysis of the applicability and opportunities will be done to select the most appropriate approach, counting always with the advice of specialized entities.

8. Social and economic impact

This project is heavily focused on developing and transferring innovative solutions that can contribute to solving transport and mobility problems. Thus, it works towards the consecution of a more efficient, safe, and sustainable transport network, directly **improving some crucial aspects for society** such as:

Safety: Optimizing the maintenance and monitoring the condition and use of road networks directly works towards improving the safety of structures and vehicles, and consequently, passengers and load.

Sustainability: More efficient maintenance and transportation systems directly impact the reduction of the carbon footprint.

This project aims to promote and accelerate the creation of technological products based on previous research, and to transfer it to society using different mechanisms. In particular, it is planned the **creation of a spin-off from UPNA** that will generate a direct economic impact apart from the indirect positive impacts of the new technologies that will become available.

The business idea of the spin-off would be based on the fabrication and commercialization of fiber optic sensor systems that alleviate problems related to the need for reliable traffic information. These systems will provide information about the flow, speed, acceleration, lane direction, classification, axle information, and weight estimation. The spin-off activities would include the design, development, fabrication, and commercialization of traffic fiber optic sensors, combined with communication hardware and data processing software. The high performance and excellent ratio of cost-information, compared to other technologies, will promote the creation of massive multi-sensor networks. These networks will pave the way for the development of new applications in dynamic mobility and signaling, a concept closely linked with Smart City approaches. Moreover, the possibility of weight-in-motion will be a distinctive feature of the technology, opening new opportunities in road maintenance & design management, considering the crucial impact of overweight on the performance and wear of roads.

Sensing technologies for traffic is a growing market that has experienced a huge increase in the last years. It is expected that this market doubles in 5 years, from 2000 M$ in 2019 to more than 4400 M$ in 2023 [https://www.juniperresearch.com/researchstore/key-vertical-markets/smart-cities-research-report]. The needs regarding road monitoring solutions follow a steeply rising trend due to the constant increase in urban population, but also due to the evolution towards smart cities, where mobility plays a key role. Moreover, mobility is one of the major concerns at the regional, national, and European levels. In fact, the investigation towards efficient, inclusive, and sustainable mobility is one of the main challenges covered by the European innovation strategy Horizon Europe [https://ec.europa.eu/research/pdf/horizon-europe/annex-5.pdf].

The end-users of the traffic monitoring system developed in INGESTION will be public entities in charge of the urban management in areas of mobility, conservation, citizen security, and signaling; as well as managers of interurban roads, such as the road management entities linked to Regional or State governments, or the Directorate-General for Traffic (Dirección General de Tráfico, DGT). On the other hand, within the private sector, companies that require traffic data are identified as potential end-users, such as motorway administrators or signaling managers. The first commercial contact with possible clients will be based on the material obtained in previous technology demonstrations. At this point, it is crucial to obtain an outstanding set of results that evidence the performance of the system, also backed by prescribers such as the Ayuntamiento de Pamplona, UPNA, Smart Cities Institute (ISC), or CEIN.

Finally, we would like to point out that the results of the project will be disseminated via social networks, press releases, attendance of industrial exhibitions, and also collaborating with University activities such as the annual Science Week, the program of Science and technology talks for secondary education students (https://www.charlascientificas.com/) and others. In addition, a more formal scientific dissemination of results will be done via participation in technical conferences and possibly applied science journal publications.

9. Analysis according to the «DNSH principle»

Description of the measure: This project supports the industrialization of a system for road traffic and condition monitoring using fiber optic sensors that either have a small footprint and can be installed with minimal work on the streets and roads pavement, or directly take advantage of an already existing infrastructure: fiber optic communication cables installed along the road.

As described below the measure either has a negligible negative impact on environmental objectives or directly or indirectly support them substantially according to the Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020.

Part 1 of the checklist

Please indicate which of the environmental objectives below require a substantive DNSH assessment of the measure	Yes	No	Justification if 'No' has been selected
Climate change mitigation		X	The activity that is supported by the measure has an insignificant foreseeable negative impact on this environmental objective, taking into account both the direct and primary indirect effects across the life cycle. Furthermore, the activity that is supported by the measure is expected to contribute substantially to support this environmental objective, according to articles 10 and 16 of the Regulation (EU) 2020/852 of 18 June 2020, by enabling (Art. 10 (i)) the improvement of energy efficiency (Art. 10 (b)) via the enablement of a system for the monitorization of road traffic, which combined with the proper actuation measurements, leads to reduced travel times and energy consumptions for road transportation.
Climate change adaptation		X	The activity that is supported by the measure has an insignificant foreseeable impact on this environmental objective, taking into account both the direct and primary indirect effects across the life cycle.
The sustainable use and protection of water and marine resources		X	The activity that is supported by the measure has an insignificant foreseeable impact on this environmental objective, taking into account both the direct and primary indirect effects across the life cycle. No environmental degradation risks related to preserving water quality and water stress are identified, as no water fittings or water-using appliances are being installed. Besides, the small works on the road are required for the installation of the sensors do not affect in any significant way the water table in the ground as they of very limited extend and only superficial.
The circular economy, including waste prevention and recycling		X	The activity that is supported by the measure has an insignificant foreseeable impact on this environmental objective, taking into account both the direct and primary indirect effects across the life cycle. The measure will not lead to significant inefficiencies in the use of resources nor to increase the generation of waste
Pollution prevention and control to air, water, or land		X	The activity that is supported by the measure has an insignificant foreseeable negative impact on this environmental objective, taking into account both the

			direct and primary indirect effects across the life cycle. Furthermore, the activity that is supported by the measure is expected to contribute substantially to support this environmental objective, according to articles 14 and 16 of the Regulation (EU) 2020/852 of 18 June 2020, by enabling (Art. 14 (e)) the reduction of pollutant emissions into the air (Art. 14 (a)) via the enablement of a system for the monitorization of road traffic, which combined with the proper actuation measurements, leads to reduced travel times and reduced emissions for road transportation.
The protection and restoration of biodiversity and ecosystems		X	The activity that is supported by the measure has an insignificant foreseeable impact on this environmental objective, taking into account both the direct and primary indirect effects across the life cycle. Only very small-scale works on the roads are required and always within the already-built perimeter of the infrastructure, hence, it will not impact in any way biodiversity-sensitive areas.

10. Specific conditions for the execution of certain projects

No specific or special conditions are needed for the execution of this project.