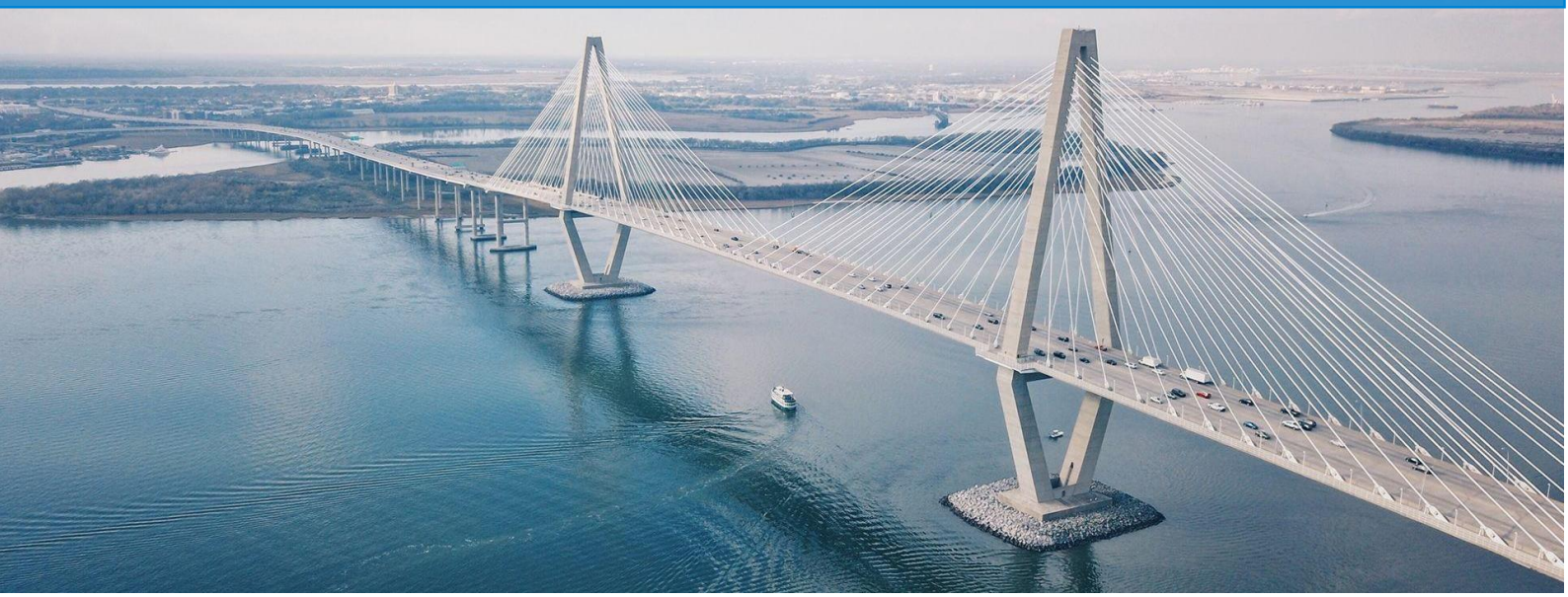
Territorial risks

SIRMA

STRENGTHENING INFRASTRUCTURE RISK MANAGEMENT IN THE ATLANTIC AREA



Benchmarking Report

September 2020 (V1.0)

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SIRMA

STRENGTHENING THE TERRITORY'S RESILIENCE TO RISKS OF NATURAL, CLIMATE AND HUMAN ORIGIN

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Benchmarking Report

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SIRMA Project Synopsis

SIRMA aims to develop, validate and implement a robust framework for the efficient management and mitigation of natural hazards in terrestrial transportation modes at the Atlantic Area, which consider both road and railway infrastructure networks (multi-modal). SIRMA leads to significantly improved resilience of transportation infrastructures by developing a holistic toolset with transversal application to anticipate and mitigate the effects of extreme natural events and strong corrosion processes, including climate change-related impacts. These tools will be deployed for critical hazards that are affecting the main Atlantic corridors that is largely covered by SIRMA consortium presence and knowledge. SIRMA's objectives will address and strengthen the resilience of transportation infrastructures by:

- Developing a systematic methodology for risk-based prevention and management (procedures for inspection, diagnosis and assessment);
- Implementing a decision-making algorithm for a better risk management;
- Creating a hierarchical database (inventory data, performance predictive models, condition state indicators and decision-making tools), where information can be exchangeable between entities and across regions/countries;
- Developing a real-time process for monitoring the condition state of transportation infrastructure;
- Enhancing the interoperability of information systems in the Atlantic Area, by taking account of data normalization and specificity of each country.

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Executive Summary

This Deliverable report (3.1) describes the analysis and evaluation of good practices of previous projects developed at international level, in particular of initiatives implemented in the programme Member States. In this way, a complete reference situation will be established in the theme addressed by the project, namely, transportation infrastructure resilience to risks).

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1. Introduction

In the context of SIRMA project, a robust framework for the efficient management and mitigation of natural hazards in terrestrial transportation modes in the Atlantic Area will be developed, validated and implemented. Before this, it is important to understand and revisit similar efforts that have been conducted in the past by both researchers and practitioners.

The present document is further divided into two main sections. The first one is devoted to analysing the research and development projects conducted in the past. The second one includes some practical projects conducted by transportation management companies. The latter focuses on the particular experience of the SIRMA's partners that are transportation owners in Spain (AZVI), Portugal (Infraestruturas de Portugal) and Ireland (Irish Rails).

2. Research and Development Projects

2.1 Summary

A survey was carried out to find research and development projects of relevance in the context of transportation infrastructure resilience to risks. In the following sections, several projects are introduced, being the most relevant aspects highlighted. It should be noted that the list is not exhaustive, thus there might be some other relevant projects not included herein.

The first step of the work consisted of identifying the possible sources of funding since those should take to the existing projects. The major sources found were:

Horizon 2020 Framework Programme, in the PRIORITY 'Societal challenges', included the topic SOCIETAL CHALLENGES - Smart, Green And Integrated Transport.

To ease the interpretation of the current status in terms of research in the scope of transportation infrastructure resilience to risks, at the end of the present chapter, some metrics are used to compare the existing projects. Those include the type of variables accounts for in the analysed projects, namely:

- Transportation mode.
- Transportation asset.
- Hazard.
- Countries Involved

2.2 Closed Projects

2.2.1 REFINET

Project Full Title

REFINET- REthinking Future Infrastructure NETworks (H2020-EU.3.4 N.653789)

Date

01/05/2015 – 30/04/2017

Website

https://cordis.europa.eu/project/id/653789

Summary

Launching a European long-term ambition and initiative to increase the overall performance of multimodal transport infrastructures, the REFINET CSA intends to 1) create a sustainable network of European and international stakeholders' representatives of all transport modes and transport infrastructure sectors, 2) deliver a shared European vision of how to specify, design, build or renovate, and maintain the multimodal European transport infrastructure

network of the future along with innovative processes so as to enhance the effectiveness of the sector, and 3) elaborate a Strategic Implementation Plan with a comprehensive set of prioritised actions to made the REFINET vision a reality – as well as providing private and public decision makers with a set of up-to-date recommendations and guidelines (including good practices and lessons learnt) for strategic actions and required levels of cooperation between all stakeholders. REFINET will consider two complementary scenarios, namely maintenance and upgrading of existing transport infrastructures, and development of new transport infrastructures. REFINET will contribute to create a European-wide consensus on where to focus in terms of research and innovation to improve the productivity of the assets (reducing maintenance costs, extending the life span…) and reduce drastically traffic disruptions of transport flows from inspection, construction and maintenance activities, and to accommodate increasing/changing traffic demand. Thus, REFINET will pave the way to enhanced technology integration and transfer and mass-market development for innovative materials, components, systems and processes supporting the pan-European generalisation of advanced multimodal infrastructures, handling the demand within various industrial sectors and help match the EU-2020 Strategy, and achieve goals of main stakeholders. The REFINET consortium is made of 8 partners from 5 European countries (Spain, France, Italy, Belgium, United Kingdom).

Overview

The ultimate REFINET objective was to provide a strategic research agenda to integrate and prioritize short-, medium- and long-term research and innovation targets, with a focus on the entrepreneurial consideration of infrastructures targeting the architectural, engineering and contracting eco-system, including socio-economic aspects of the development and the management of infrastructures.

The REFINET project introduced a Multi-Modal Transport Infrastructure (RMMTI) model and framework aimed to create a shared European vision and strategic implementation plan about how the multimodal European transport infrastructure network of the future should be specified, designed, built or renovated, upgraded and maintained. REFINET relied on a sustainable innovation network integrating all transport modes (road, railway, maritime, fluvial...) and transport infrastructure.

The RMTTI model focused on key aspects as: integration of the different transport modes (cost-saving, reduction of energy intensity and subsequent CO2, pollutants and noise emissions); adoption of Green Infrastructures; increasing the infrastructure's capacity and optimising their maintenance costs; enhancing the sustainability, performance and reliability of the infrastructures; extending the life span of ageing transport infrastructure; minimising traffic disruption mainly at upgrading works… The model includes associated KPI (Key Performance Indicators), which allows benchmarking the current transport infrastructures against the model.

RMMTI is a multilevel approach primarily dedicated to the transport infrastructure needs and defined based in a 3 level structure:

- Level 1 – Performance: where to allocate target service level specifications.

- Level 2 – Systemic Approach: to enable the integration of a systemic perspective for cross cutting specifications.
- Level 3 – Technological gaps: to place the technological improvements required.

A cross modal approach of drivers of level of service (performance) for all modes was adopted:

- Availability: lack of disruption during maintenance, extended life time, …;
- Safety and Security;
- Accessibility;
- Harmonization of services in coordination between countries and regions;
- Comfort;
- Standardisation.

A systemic approach along the whole life cycle of new generation of intermodal networks, driven by cost-benefit considerations was carried out. The systems of systems nature of the transport networks was addressed through a coordinated approach to High Level Service Infrastructure (HLSI) performance aspects such as safety, security, sustainability, efficiency, reliability and challenges regarding the demand of knowledge in building more resilient networks to natural and man-made hazards. This systemic approach in the design, construction, operation and maintenance stages of new generation of intermodal networks and infrastructure tried to ensure:

- smooth and efficient mobility services for people and goods;
- overall better service and performance, including multimodal integration and intermodal continuity for the end-user;
- a higher degree of convergence and enforcement of social, health, safety, security and environmental rules for infrastructure;
- interconnected solutions for the next generation of multimodal transport management.

The analysis and decomposition of the architecture of the system of systems enabled the identification and quantification of interdependencies, facilitating the establishment of criticalities.

In order to overcome the gap between “common practices” in design, construction and maintenance of transport infrastructures and the “most sustainable practices” that could be deployed, different technologies offered by the main engineering companies, contractors and maintenance services providers were considered.

The technological demands in the field of infrastructure mainly focus on the following fields:

- Safety;
- Environmental impact, energy efficiency and decarbonisation;
- Road mobility and modal integration;
- Urban mobility;
- Asset management;
- Financial and multi-modal transport infrastructure Business Model;
- Standards, communication and dissemination channels;
- ITS;

- Construction vs. maintenance.

The REFINET project, through the definition of its model RMMTI, aimed to establish an open, active and reference framework that encouraged the following strategic attributes for European transport infrastructure:

- GREEN
- COST-EFFICIENT
- SOCIAL / INCLUSIVE
- RESILIENT
- SAFE / SECURE

It was understood that the European multimodal transport infrastructure should cope with the different challenges that could be included under these five areas or attributes. Thus, it was intended to establish a potential benchmark index (REFINET INDEX) that would serve to value, assess and compare the aforementioned characteristics, based on the specific strategic and operational objectives particular to each case and through the specific indicators defined for it. A definition and areas of study that would result from each of the five factors that define the performance of the multimodal transport infrastructure of the future was presented. The definition of specific values was beyond the scope of the REFINET project.

In Figure 2 is shown the potential REFINET index applied to different infrastructure types which can be established by each infrastructure owner/manager to their individual targets.

The project REFINET delivered in the framework of the project a set of indicators that are the basis for establishing a method to monitor and evaluate the impact of research and innovation actions in the field of transport infrastructure. The SIP was organised according the RMMTI model and the KPIs structure, presenting a coherent manner to identify the areas of investment and evaluate the impacts.

2.2.2 USE-iT

Project Full Title

USE-iT - users, safety, security and energy in transport infrastructure (H2020-EU.3.4 N. 653670)

Date

01/05/2015 – 30/04/2017

Website

https://cordis.europa.eu/project/id/653670

Summary

The transport network across Europe faces challenges relating to carbon reduction targets, energy security, and depletion of natural resources, without sacrificing its efficiency and compromising mobility. In addition, the road and rail infrastructure in particular are ageing

and require renewal. Simultaneously, advances in sensors, mobile communications, smart ticketing and 'big data' offer the potential for customers to become an active part of the transport operations system and have the information to make decisions – for transport to enable 'mode agnostic' personal and business travel and – for freight operators to have more resilience and better reliability in their systems.

The European transport system faces also an unavoidable societal challenge, which is achieving new levels of resource-efficiency, environmental-friendliness, safe and seamless transport for the benefit of citizens, the economy and society.

In order to tackle the challenges and reap the benefits outlined above, infrastructure owners and transport operators will be required to work together, along with other crucial stakeholders, to share knowledge and cooperate in a way that will be beneficial to all parties, and this proposal seeks to facilitate this.

The objective of this project is to better understand the common challenges experienced across transport modes, bring representatives of transport modes together to share experience and skills and to develop a set of common research objectives. The project will draw upon the experience gained from the Joint European Transport platform with the focus on infrastructure operations, and will also focus on research objectives presented in the Forever Open Road programme and the work of the FORx4 - Forever Open Road, Railway, Runway and River – A Cross-modal transport initiative for research for which FEHRL produced a 'Point of View' document.

Overview

The USE-iT project aimed at the identification of common challenges and the development of common research objectives for cross-modal transport (road, rail, water and air) covering three main topics:

(i) User Information

Aimed to empower user-centric transport to offer consistent flow of data for coordinated journeys over all transport modes as indicated by singular client preferences with full straightforwardness of its cost, performance and risk.

(ii) Safety and Security;

Aimed to gather knowledge and understand how to enhance and reinforce safety and security operations and procedures across transport modes.

(iii) Energy Efficiency and Carbon Intensity.

Aimed to identify existing and potential innovations to be used so as to lessen carbon emissions and energy consumption in more than one mode.

For each of this areas, a preliminary investigation across modes and domains was performed to identify best practice approaches, technologies and methodologies with potential to cross over from one transport mode to another. Following this first stage, information and viewpoints from stakeholders, consultants and researchers was gathered, upon which, and to consolidate the topics with the most potential in a reliable and straightforward manner, a method for scoring the technologies under different criteria was used. The used criteria were:

A. Potential of use
B. Transferability and potential for widespread use
C. Efficiency
D. Ease of implementation
E. Co-benefits or dis-benefits

The results of this classification were subsequently analyzed and discussed taking into account the following questions:

1. What needs to happen for the identified technologies/approaches to be implemented?
2. What are the gaps in knowledge?
3. How can different transport modes work together?
4. What are the common research topics for more than 2 transport modes?

This study enabled the identification of a number of common research challenges and opportunities for each of three identified topics. Each challenge was described through a short description, potential technologies with representative examples, opportunities for cross modal implementation, barriers and enablers, maturity level and steps required for implementation. The challenges are identified below by topic.

- User Information
  - Challenge 1 – Predictable Performance for Moving People and Goods
  - Challenge 2 – User Requirements for multimodal user information services
  - Challenge 3 – Cooperation and coordination between transport mode Operators
  - Challenge 4 – Standards for user data exchange format
  - Challenge 5 – Security of data: cyber security, data ownership, privacy
  - Challenge 6 – Interactions between automated/smart vehicles in the multimodal context
  - Challenge 7 – Human acceptance of User Information
- Safety and Security
  - Challenge 1 – Availability and sharing of high-quality data across transport modes
  - Challenge 2 – Improving safety performance at national levels
  - Challenge 3 – Safety education and human factors
  - Challenge 4 – Driver state monitoring
  - Challenge 5 – Cross-modal interaction in a safe and efficient manner: Cross-modal V2V communication
  - Challenge 6 – Automation in the context of multimodal transport
- Energy & Carbon
  - Challenge 1 – Phasing out the use of fossil fuels to power vehicles
  - Challenge 2 – Generating renewable energy/harvesting energy from transport infrastructure
  - Challenge 3 – Improving vehicle fuel efficiency
  - Challenge 4 – Reducing the embodied carbon in transport infrastructure

- Challenge 5 – Improving the energy efficiency of operating transport systems
- Challenge 6 – More efficient asset management
- Challenge 7 – Embedding consideration of carbon and energy in governance and transport planning
- Challenge 8 – Influencing customer behavior

The identification and prioritization of these common challenges and potential solutions were used to develop a roadmap for cross-modal research to foster technologies or approaches to increase the use of user information technologies, to increase safety and security and to reduce carbon emissions and energy consumption. This roadmap, in addition to presenting challenges, offers potential solutions, implementation overviews and potential cross-modal collaborations, representing investment strategies to be used in specific developments to outline business priorities and risk.

2.2.3 FOX

Project Full Title

FOX - Forever Open infrastructure across all transport modes (H2020-EU.3.4 N. 653631)

Date

01/05/2015 – 31/10/2017

Website

https://cordis.europa.eu/project/id/653631

Summary

An efficient and high-quality transport infrastructure is a fundamental requirement for the connectivity of people and goods in Europe and basis for economic growth, competitiveness and territorial cohesion. In general, the transport network in Europe is of a high standard but is still fragmented regarding the geographical distribution and the transport modes.

In recent years, first networking activities and exchange of strategic programmes among the stakeholders of the four transport modes – road, rail, water and air – can be noticed but still a mono-modal, mono-disciplinary culture exists. In the light of the future challenges, e.g. increasing transport demand, ageing infrastructure, scarcity of natural resources, changing climatic conditions, it is inevitable to strengthen the collaboration of the single transport modes in order to create an improved future integrated and functioning transport system for Europe, despite of limited financial resources of the owners of the transport network.

The FOX project aims to develop a highly efficient and effective cross-modal R&D environment and culture which meets the demanding requirements of the transport and connectivity. Based on already existing programmes and agendas related to the aspects of co-modal transport research, the FOX project will identify common needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling & reuse of transport infrastructure. This will be reached by the involvement of all stakeholders (owners, researchers, and industry) of the four transport modes in a phased approach: Starting with

the determination of the state-of-the-art in research and practice, in the next step the most promising practices and ideas will be identified. By mapping the common needs, the final aim is to establish a cross-modal Working Group to develop a roadmap for the whole transport sector and set the agenda for further improvement of cross-modal research development innovation.

Overview

The FOX project aimed at the identification of common research needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling & reuse, through the creation of a research roadmap and the development of a business plan to engage experts beyond the project lifetime.

Due to the fact that many partners and third parties of this project were also involved in the USE-iT project, and also because the leader of both project was the same, USE-iT and FOX operated as one single project, sharing synergies.

Jointly, with the prerequisite that each challenge should cover at least two transport mode, both project identified 42 challenges across the four topic areas in FOX and the three topic areas in USE-iT. All these challenges have been mapped against four domains: infrastructure, technology, governance and customers, and against four levels of applications: urban mobility, long distance corridors, multi-modal hubs and system level.

The project developed a roadmap detailing research implementation strategies to increase co-modal cooperation in order to be used as an investment plan to both research funders and as an investment or strategy document for infrastructure owners, and operators and contractors.

2.2.4 RAGTIME

Project Full Title

RAGTIME - Risk based approaches for asset integrity multimodal transport infrastructure management (H2020-EU.3.4 N.690660)

Date

01/09/2016 – 31/08/2019

Website

https://cordis.europa.eu/project/id/690660

Summary

An efficient asset management process is needed to ensure cost-effectiveness, in planning, delivery, operation and maintenance of large infrastructures or infrastructures network. Infrastructure asset management generally focuses on the later stages of a facility's life cycle, specifically maintenance, rehabilitation, and replacement. However, a process of efficient asset management must define methods and tools for asset tracking, management of

maintenance activity, determine the life cycle and replacement costs of the assets, assistance in determining funding strategies, optimizing capital investments in operation and maintenance, and help with the replacement of assets.

Currently, the procurement, design, construction, exploitation and public communication to the final users and society regarding to the land transport infrastructures are:

- not multimodal, not cross-assets, but focused on individual assets.
- not correctly linked, not being able to exchange information by different stakeholders.
- lack of a common risk based approach and the implementation of resilient concepts throughout the whole life cycle

The aim of the proposal is to establish a common framework for governance, management and finance of transport infrastructure projects in order to ensure the best possible return from limited investment funds in transport infrastructures

The main objective of RAGTIME is to develop, demonstrate and validate an innovative management approach and to lay out a whole system planning software platform, based on standard multiscale data models, able to facilitate a holistic management throughout the entire lifecycle of the infrastructure, providing an integrated view of risk based approach, implementing risk based models, resilient concepts and mitigation actions, with specific reference to climate change related threats perspective, and monitored with smart systems, in order to optimize ROI, management, guarantee LOS and improve resilience through maintaining the service.

Overview

This project is very similar to SIRMA, both in terms of its main objectives and in terms of the adopted approach. The necessity for introducing risk in the asset management process was identified. Also, the necessity for standardize asset management processes worldwide, but particularly in Europe, was identified.

2.2.5 MOWE-IT

Project Full Title

MOWE-IT – Management of weather events in transport system

Date

01/10/2012 – 30/09/2014

Website

https://cordis.europa.eu/project/id/314506

Summary

The MOWE-IT project shall assess factors that prerequisite cross-modal transferability between the air and surface-based European transport systems in order to protect the passengers, shippers, European institutions and citizens against travel delays, cancellations and/or stoppages in freight transfer caused by extreme weather and/or other natural

disasters. The on-going WEATHER and EWENT- projects have established how the different extreme weather events harm the safety and security of passengers and drivers, reduce the inter-urban and regional accessibility, disrupt logistics chains, delay cargo delivery, inflate supply costs for operators and consignees, and immobilise public infrastructure. However, there is still a need to find out how the air and surface transport systems may improve operational resilience by substituting each other's services when suffering from traffic curtailment, infrastructure shutdowns, and/or capacity shortages caused by emergencies. Therefore, the MOWE-IT project shall assess how the companies in passenger and freight transport comply with the European users rights protection legislation shielding theses parties against travel delays, cancellations and/or disruptions, and in case of gaps in conformity, propose new guidelines for cross-modal alignment of decision-making, capacity planning and reserve-building models at transport service and infrastructure providers in addition to incentive structures and policy instruments for more effective legislation enforcement. Such an assessment will also draw from the possibilities to use weather and other information technologies to aid the transport system and operators. The project will have 9 work packages, which focus on management and dissemination, transport-mode specific issues and cross-modal considerations and finally to short-term and long-term solutions and policy options for reducing the negative impacts of extreme weather and natural disasters.

Overview

MOWE-IT project selected a network of major airports in Europe for analysis. Based on passenger flows data, travel cost and time data on alternative transport modes, a comprehensive mapping of travel alternatives in Europe in case of occurrence of disruptive events was completed.

As an outcome, an interactive visualisation tool was developed. This tool provides information on past and future frequency of selected weather phenomena in 134 European locations, and the impact of selected extreme weather events on passenger flows for surface and air transport modes in 14 designated European hubs. The tool helps to understand the effect of climate change on transport systems and provides information on impending closures and how to best alter travel plans.

A collection of guidebooks was produced to improve the resilience of rail, road, aviation, inland waterways and maritime transport. Short-term strategies and long-term policy recommendations were also delivered.

2.2.6 WEATHER

Project Full Title

WEATHER – Weather Extremes: Impacts on Transport Systems and Hazards for European Regions

Date

01/11/2009 – 30/04/2012

Website

https://cordis.europa.eu/project/id/233783

Summary

The WEATHER project aims at adding to the current state of knowledge on the impacts of extreme weather events on economy and society in total and on European transport systems in particular. The project starts from the broad picture of climate scenarios and breaks them down to specific regions. Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors. The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues. Best practices in emergency management are identified by studying the numerous damage cases worldwide and options for adapting to more frequent and / or more extreme weather events are assessed. A particular focal point of the project is to quantify expected damage, emergency and adaptation costs and the benefits of improved emergency management and adaptation. Moreover, the project will identify policy options to implement the recommended measures and demonstrate the competitive potential and the innovation power of a European lead market for adaptation and emergency management technologies and policies. The toolbox of the project consists of literature review, targeted interviews, workshops, cost accounting models and case studies. The project will last for 27 months. The team consists of 8 leading transportation research institutes all having well founded experience in the core research fields of the WEATHER project.

Overview

The project studied climate scenarios per region, examining the effects of serious weather events on transport modes and infrastructures. It also studied cases of damage in the past to identify best practices in managing emergencies and estimating damage costs to the sector.

The European territory was divided in 8 climate zones in order to estimate future trends in extreme weather. Scenarios were used to: (i) forecast direct damage costs to the transport sector having year 2010 as baseline; (ii) to estimate future changes in temperature and precipitation up to year 2050; (iii) to capture economy-wide impacts of the transport sector vulnerability to climate changes.

Over 300 adaptation strategies have been identified by sectors – infrastructures, vehicles, operations and planning, and by transportation modes – road, rail and urban public transport, aviation, maritime and inland navigation, and intermodal transport. These strategies took into account singular extreme weather related events categorized in: temperature, precipitation, wind; atmosphere, consequences.

2.2.7 EWENT

Project Full Title

EWENT – Extreme weather impacts on European networks of transport

Date

01/12/2009 – 31/05/2012

Website

https://cordis.europa.eu/project/id/233919

Summary

The project addresses the EU policies and strategies on climate change with particular focus on extreme weather impacts on EU transportation system. The goal of EWENT is to estimate and monetise the disruptive effects of extreme weather events on the operation and performance of the EU transportation system. The methodological approach is based on generic risk management framework that follows a standardised process starting from the identification of hazardous extreme weather phenomena, followed by impact assessment and concluded by mitigation and risk control measures. In detail, the project will: - Identify and define the hazards on EU transportation systems caused by extreme weather phenomena and develop relevant scenarios. - Estimate the probabilities of harmful scenarios caused by extreme weather - Estimate the consequences of extreme weather events based on developed scenarios - first on EU transport infrastructure, then on operations and finally on supply chains and mobility. - Monetise the harmful consequences per transport mode both on infrastructure and operations (including mobility and supply chain impacts). - Evaluate measures and options for negative impact reduction, control and monitoring in short and long-term. The short-term viewpoint is focused on monitoring processes and forecasting and warning/alarm services on weather phenomena. The long-term view provides the starting point for planning and standard setting. - Analysis of different management and policy options and strategies. EWENT will cover most transport modes (including passenger & freight): road, rail, aviation, waterways and light (pedestrians, cycling). The transport system is viewed from three angles: infrastructure, operations, and indirect impacts to third parties. EWENT will evaluate the efficiency, applicability and finance needs for adaptation and mitigation measures which will minimise the costs of extreme weather impacts.

Overview

The project analysed relevant adverse and extreme weather events from a list of critical disruptive weather events for transport systems, with parameters thresholds, and selected impact mechanisms. The list of events includes: strong winds, heavy snowfall, blizzards, heavy precipitation, cold spells and heat waves. In addition, visibility conditions determined by fog and dust events, small-scale phenomena affecting transport systems such as thunderstorms, lightning, large hail and tornadoes were also considered.

Six high-resolution Regional climate model (RCM) simulations were used to estimate future changes in adverse weather conditions for transport. The analyses compared current climate conditions (1971-2000) with short-term (2011 to 2040) and long-term (2041 to 2070) time horizons. With these scenarios the added risks for delay and accidents where analysed for different regions. The effect of changes in different traffic modes was described in percentage terms in relation to the base scenario.

A risk assessment was performed based on the definition of transport systems vulnerability to extreme weather events in different countries and on calculations of the most probable

event chains, starting from adverse weather phenomena and ending with events that are harmful to the transport network in different climate regions. The probabilistic section is the hazard analysis. The vulnerability of a particular mode in a particular country is a function of exposure (indicated by transport or freight volumes and population density), susceptibility (infrastructure quality index, indicating overall resilience) and coping capacity (measured by GDP per capita, purchasing power adjusted). The extreme weather risk was defined as a product of probability of negative consequences and vulnerability assessment:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

$$= P(\text{negative consequences}) \times f(\text{exposure, susceptibility, coping capacity}).$$

Based on this analytical approach information, the risk indicators for each mode and country have been derived.

2.3 Ongoing/Upcoming Projects

2.3.1 RESIST

Project Full Title

RESIST - RESilient transport InfraSTructure to extreme events (H2020-EU.3.4 N. 769066)

Date

01/09/2018 – 31/08/2021

Website

https://cordis.europa.eu/project/id/769066

Summary

The overall goal of RESIST is to increase the resilience of seamless transport operation to natural and man-made extreme events, protect the users of the European transport infrastructure and provide optimal information to the operators and users of the transport infrastructure.

The project will address extreme events on critical structures, implemented in the case of bridges and tunnels attacked by all types of extreme physical, natural and man-made incidents, and cyber-attacks. The RESIST technology will be deployed and validated at 2 pilots in real conditions and infrastructures.

RESIST will use risk analyses and leverage and further develop recent exploitable research results in robotics, driving under panic, sensing and communications, to dramatically improve the speed and effectiveness, while reducing the cost, of structural vulnerability assessment, situation awareness, response operations and increased users' protection under extreme events towards a high level of resilience of the transport infrastructure at 3 levels: a) increased physical resilience of bridges/tunnels by robotic inspection and predictive analytics; b) restoration of services/routes back to normal quickly and permission of a continuous flow of passengers and freight across different modes of transport soon after an extreme event,

which will be achieved by rapid and accurate robotic damage assessment after extreme physical events, cyber security solutions, alternative secure and continuous communication under emergency operations (including integration of terrestrial and satellite systems) and increased cross-modal flexibility; c) clear and effective communication of transport operators and users, emergency responders and the public in the vicinity, to minimise the impact of the disruption on people and businesses, by exploiting real-time data, available networks, social media and mobile technologies to allow for real-time emergency information dissemination.

2.3.2 FORESEE

Project Full Title

FORESEE - Future proofing strategies FOr RESilient transport networks against Extreme Events (H2020-EU.3.4 N. 769373)

Date

01/09/2018 – 28/02/2022

Website

https://cordis.europa.eu/project/id/769373

Summary

Transportation systemic risks are not well understood across modes, regions, and critical interdependent sectors, creating uncertainty about risks resulting from a major system disruption. There is a lack of resilience schemes, especially for the long term, integrated into transport infrastructure due to the inability to monetize resilience for investment decisions, and there are also strong barriers to its implementation to operating practice. The overall objective of FORESEE is to develop and demonstrate a reliable and easily implementable toolkit for providing short and long term resilience schemes against traffic disruption due to flooding, landslide and structural damage for rail and road corridors and multimodal terminals. It will help move towards a performance based risk assessment framework, relying on: a) an update on best available methodologies, practices and solutions with data-enhanced: models, solutions and cost benefit assessments, b) the development of new solutions regarding drainages, pavements and landslides, and c) a detailed strategy for its successful implementation, integrated into the infrastructure life-cycle usual procedures. Pre-standardization activities will be carried out throughout the life of the project.

The FORESEE toolkit will include: a) A reliable Data Acquisition System, satellite and terrestrial, b) A Situation Awareness System for the prediction and alert of extreme events c) New materials and systems regarding permeable pavements; drainage and culvert systems, and slope stabilization systems d) A Decision Support System to provide better informed resilience schemes e) Guidelines on Standards, Design and Technological recommendations. The setting up of a Stakeholders Reference Group at early stages of the project, will guarantee the accounting for the demands and the acceptance of all end-users. FORESEE will enhance international Cooperation by twinning with world leading institutes.

2.3.3 IN2SMART2

Project Full Title

IN2SMART2 - Intelligent Innovative Smart Maintenance of Assets by integRated Technologies 2 (H2020-EU.3.4.8.3. N. 881574)

Date

01/12/2019 – 30/11/2022

Website

https://cordis.europa.eu/project/id/881574

Summary

Asset management in the railway sector needs to improve significantly. This can be done through innovative technologies, new economic possibilities and enhanced legislative standards. With this in mind, the EU-funded IN2SMART2 project has formed a multi-action plan called the Intelligent Asset Maintenance Pillar to deliver innovative asset management. It aims to achieve this by creating new and optimised strategies, processes, tools, products and systems to implement enhanced risk-based, prescriptive and holistic asset management. Focusing mainly on tactical and operational levels, the project's plan will help to achieve a more efficient railway sector.

This project represents the continuation of the work initially carried out through the In2Rail "lighthouse project" and mainly through the work of the IN2SMART project. These projects form together part of the framework of research and innovation that will deliver the vision and strategy of Innovation Programme 3.

There is a demand for a step change in asset management to be delivered through innovative technologies, new economic possibilities, and enhanced legislative standards in the rail sector. As set-out in the S2R Multi-Annual Action Plan, the Intelligent Asset Maintenance Pillar is a driver to deliver innovative asset management, meeting the best practice set out in ISO55000 in the railway sector. The Intelligent Asset Management Pillar is an accelerator creating new and optimised strategies, frameworks, processes and methodologies, tools, products and systems for the implementation of a step change in risk based, prescriptive and holistic asset management in the rail sector.

A series of vertical TRL 6/7 demonstrators, covering all Asset Maintenance Pillar aspects, such as data collection (TD3.7), data analytics and interfaces (TD3.6), decision support and lean working methods (TD3.8), will be defined and demonstrated in relevant environment, spreading the innovation results throughout European main railway and metro/tram lines. The demonstrator's scope of work in the majority of cases will be on asset management optimization at tactical and operational levels, with a few examples of strategical ones. Innovation potential of aspects such as the utilization of a digital twin and robotic automated platforms will also be investigated in some demonstrators.

Coherence and uniformity will be guaranteed through a common system architecture and Conceptual Data Model usage, common validation approach and final integrated demonstrator, enabling a common monitoring solution collecting heterogeneous inputs from various vertical demonstrators.

2.3.4 RAPID

Project Full Title

RAPID - Risk-aware Automated Port Inspection Drone(s) (H2020-EU.3.4 N. 861211)

Date

01/06/2020 – 31/05/2023

Website

https://cordis.europa.eu/project/id/861211

Summary

Early warning systems are essential for disaster prevention. To minimise disruption and delays to critical supply chains, it is important to detect any deterioration in transport system infrastructure. The EU-funded RAPID project will combine and extend drone technology to deliver a fully automated and safety-assured maintenance inspection service for bridges, ship hull surveys and more. Specifically, the service will combine self-sailing unmanned surface vehicles with autonomous unmanned aerial systems. The aim is to reduce the time and cost of structural condition monitoring of maritime transport infrastructure such as material-handling equipment, cargo and passenger ships, and bridges. RAPID's new system will also facilitate the prioritisation of safer transport infrastructure.

RAPID will save lives by delivering an early warning system that will detect critical deterioration in transport system infrastructure, while also minimising system disruption and delays to critical supply chains. It will achieve this goal by combining and extending state-of-the-art drone technology to deliver a fully automated and safety assured maintenance-inspection (MI) service for bridge inspection, ship hull surveys and more. By combining self-sailing unmanned surface vehicles (USV) with swarms of autonomous unmanned aerial systems (UAS), RAPID will dramatically cut the time and cost of structural condition monitoring. RAPID-enabled MI services will increase efficiency and competitiveness for maritime transport stakeholders – such as ports, shipping companies, and landside transport authorities – and will deliver the safe and seamless operation of supply chain and mobility infrastructures – such as material handling equipment, cargo and passenger ships, and bridges. It encourages prioritisation of safer transport infrastructure where the technology seeks to improve environmental impact. The attractive return on investment will enable RAPID to gain market traction and incentivise commercial proliferation, bringing RAPID into widespread use for the overall benefit of society. By 2028, a newly formed company will generate €124 million and save in the order of 100 lives per year (reaching c. 20% share of the serviceable addressable maritime transport market through strategic partnership with 50

ports). RAPID brings together interdisciplinary partners with the expertise and capacity required to develop and validate this unique service model. The project will develop the consolidated maritime and aviation regulation standard for safe USV / UAS operations and the business model to scale the pilot service. RAPID will validate the high level of digitalisation, automation, and regulation required to support safe, beneficial, and scalable access to U-Space.

2.3.5 Copernicus

Project Full Title

Copernicus – Europe's eyes on Earth

Date

2014 – Ongoing

Website

https://www.copernicus.eu/en

Summary

Copernicus is the European Union's Earth Observation Programme, looking at our planet and its environment for the ultimate benefit of all European citizens. Copernicus builds on a constellation of satellites that makes a huge number of daily observations - taking advantage of a global network of thousands of land, air, and marine-based sensors to create the most detailed pictures of Earth. The technological prowess of Copernicus, especially in terms of availability and accessibility, has made Copernicus the largest space data provider in the world, currently delivering 12 terabytes per day.

Vast amounts of global data from satellites and ground-based, airborne, and seaborne measurement systems provide information to help service providers, public authorities, and other international organisations improve European citizens' quality of life and beyond. The information services provided are free and openly accessible to users.

The climate change service of Copernicus provides authoritative information about the past, present and future climate, as well as tools to enable climate change mitigation and adaptation strategies by policy makers and businesses.

2.3.6 Climate-ADAPT

Project Full Title

The European Climate Adaptation Platform Climate-ADAPT

Date

2014 – Ongoing

Website

https://climate-adapt.eea.europa.eu/

Summary

The European Climate Adaptation Platform Climate-ADAPT is a partnership between the European Commission and the European Environment Agency (EEA). Climate-ADAPT is maintained by the EEA with the support of the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA).

Climate-ADAPT aims to support Europe in adapting to climate change helping users to access and share data and information on:

- Expected climate change in Europe
- Current and future vulnerability of regions and sectors
- EU, national and transnational adaptation strategies and actions
- Adaptation case studies and potential adaptation options
- Tools that support adaptation planning

Climate-ADAPT organizes information under the following main entry points:

- EU Policy: EU Adaptation Policy, Adaptation in EU Policy Sectors (Agriculture, Biodiversity, Coastal areas, Forestry, Water management, Marine and fisheries, Ecosystem-based Approaches, Disaster Risk Reduction, Buildings, Energy, Transport, Health, Urban), EU Regional Policy
- Countries, Transnational regions, Cities
- Knowledge: Topics, Data and indicators, Research and innovation projects, Tools, Practice,
- European Climate and Health Observatory (accessible through "Knowledge")
- Networks

The platform includes a database that contains quality checked information that can be easily searched

2.3.7 UNECE

Project Full Title

The United Nations Economic Commission for Europe (UNECE)

Date

1947– Ongoing

Website

https://unece.org/

Summary

The United Nations Economic Commission for Europe (UNECE) was set up in 1947 by ECOSOC. It is one of five regional commissions of the United Nations.

UNECE's major aim is to promote pan-European economic integration. UNECE includes 56 member States in Europe, North America and Asia. However, all interested United Nations member States may participate in the work of UNECE. Over 70 international professional organizations and other non-governmental organizations take part in UNECE activities. As a multilateral platform, UNECE facilitates greater economic integration and cooperation among its member countries and promotes sustainable development and economic prosperity through:

- policy dialogue,
- negotiation of international legal instruments,
- development of regulations and norms,
- exchange and application of best practices as well as economic and technical expertise,
- technical cooperation for countries with economies in transition.

UNECE contributes to enhancing the effectiveness of the United Nations through the regional implementation of outcomes of global United Nations Conferences and Summits. It gives focus to the United Nations global mandates in the economic field, in cooperation with other global players and key stakeholders, notably the business community. UNECE also sets out norms, standards and conventions to facilitate international cooperation within and outside the region.

3. Practical Projects

3.1 Summary

While in the previous chapter the focus was on existing research projects, the present one addresses practical ones. In fact, it is important to assess what is being done in practice in order to understand whether the results from research projects are being transferred to practitioners.

3.2 Closed Projects

3.2.1 Advanced construction process for simultaneous stabilisation and control of slopes

Summary

This project was done by Azvi in the year 2016 as an innovative technical solution for slope stabilization and monitoring due to a slope failure that occurred on the N-634 road, section Salas - La Espina, close to Porciles (Asturias, Spain).

After days of heavy rains, the partial breakage of the right-hand side slope began affecting first the intermediate berm and the service road. With the successive rains, the volume and the displacements of slipped terrain continued to increase, until its tension crack approached about 30 meters to the nearest buildings. In addition, it invaded the road, with the debris of the concrete pavement of the intermediate berm.

The landslide was classified as “serious” by the authorities, given the special casuistry of the location of inhabited homes adjacent to the landslide. Azvi was engaged to carry out the urgent repair works.

Figure 1. Landslide at Porciles

Repair works phases

PHASE 1. Analysis of the problem, study of slope stability and geotechnical characterization.

The first activity of the project has been destined to establish a theoretical base, as well as a preliminary investigation in order to establish the technical specifications on which the stabilization works, designed in the following activity, will be based.

First, a preliminary study has been carried out on the geological framework of the affected area in order to establish the characteristics of the different layers of land. Second, a geophysical investigation with electrical tomography was carried out to analyse the different layers and to find the origin of the landslide that occurred. Finally, mechanical soundings measuring and laboratory tests have been carried out to determine the contents and the plasticity of quaternary soils.

The causes of the slope failure were analysed, combining the application of Electrical Tomography profiles with the geological-geotechnical information of the explored area.

The field campaign included seven profiles along the slope level lines, seeking to delimit and cross the area moved by the terrain. Special attention has been given to the position and morphology of the sliding mass, as well as the contacts between the quaternary coating and the rocky substrate, in conjunction with the edges of the fault breccia that seems to be associated with the rupture.

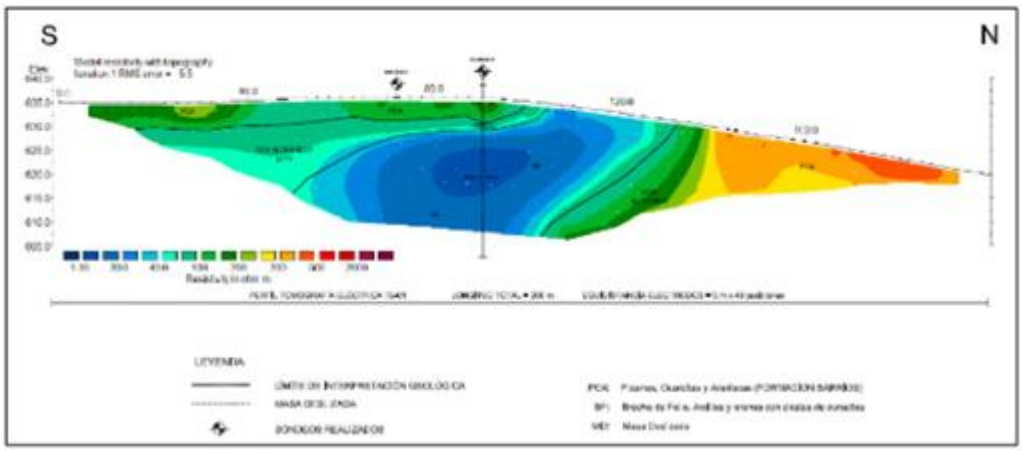

Figure 2. Electrical Tomography profile

A campaign of mechanical soundings and laboratory tests has also been done, whose drills have also been used for the installation of an inclinometer casing in each of them.

PHASE 2. Design, establishment of technical requirements and structural calculation.

The activity includes the design of the construction methodology, which unifies in a single process several solutions that perfectly complement each other, increasing efficiency and effectiveness: micropile barrier, water control through drains, monitoring of slope stability, embankment and vegetation control.

All this process is established as a new base for application in projects with similar characteristics, opening a new modular field applicable to a typology of interventions in a framework of very specific conditions but very difficult to face.

The solution was based on three main actions:

a) First of all it's necessary to remove most of the soil to flatter the slope, and lower as much as possible the gradient of the reconstructed service road, to reduce the destabilizing weight at the head.

   This will be made with the construction of a 90 meters long anchored retaining wall made with micropiles, with two micropiles per linear metre, each one with 200 mm diameter and 20 metres long, reinforced with metallic tube of diameter 139 mm and 8 mm in thickness, and 3 levels of 30 tons anchorages. for which it is necessary to excavate in front of the micropile barrier, using this as a containment element (aided by anchors).

b) It is essential to have a drainage system in the area of the sliding surface, so that it eliminates, by gravity (in the lower part of the slope) the rainwater that will reach there. This drainage area will be constructed by a thick layer of rock (with drainage under it, from the top of the slope to its foot).

c) The lower part of the slope will be reinforced with an embankment which will collect the water provided by the mantle and draining slopes.

<u>PHASE 3. implementation of the designed solution</u>

In this activity, the solution designed by AZVI's technicians has been executed, validating the construction procedure that allows the simultaneous stabilization and control of the buildings and the slope in order to avoid risks derived from the collapse of some of the instabilities as well as their subsequent validation and analysis.

a) Construction of an anchored retaining wall and soil removal

Figure 3. Construction of retaining wall and soil removed

b) Construction of drains

Figure 4. Embankment and three-dimensional geogrid

Figure 5. Project finished

PHASE 4. Validation

In order to validate the solution, a system has been implemented to monitor slope stability, consisting of an inclinometer control and a topography control.

a) Slope inclinometers

To control landslide movement, five inclinometer casing were installed in vertical boreholes (I-1, I-2, I-2 bis, I-3, I-4) in the area affected by the landslide, to monitor the slope stability during and after construction.

In a seven-month period eleven tests were done until results on each borehole were stabilized. Monitoring tests were done according to the ASTM standard (D 6230-98), "Standard Test Method for Monitoring Ground Movement Using Probe-Type Inclinometers".

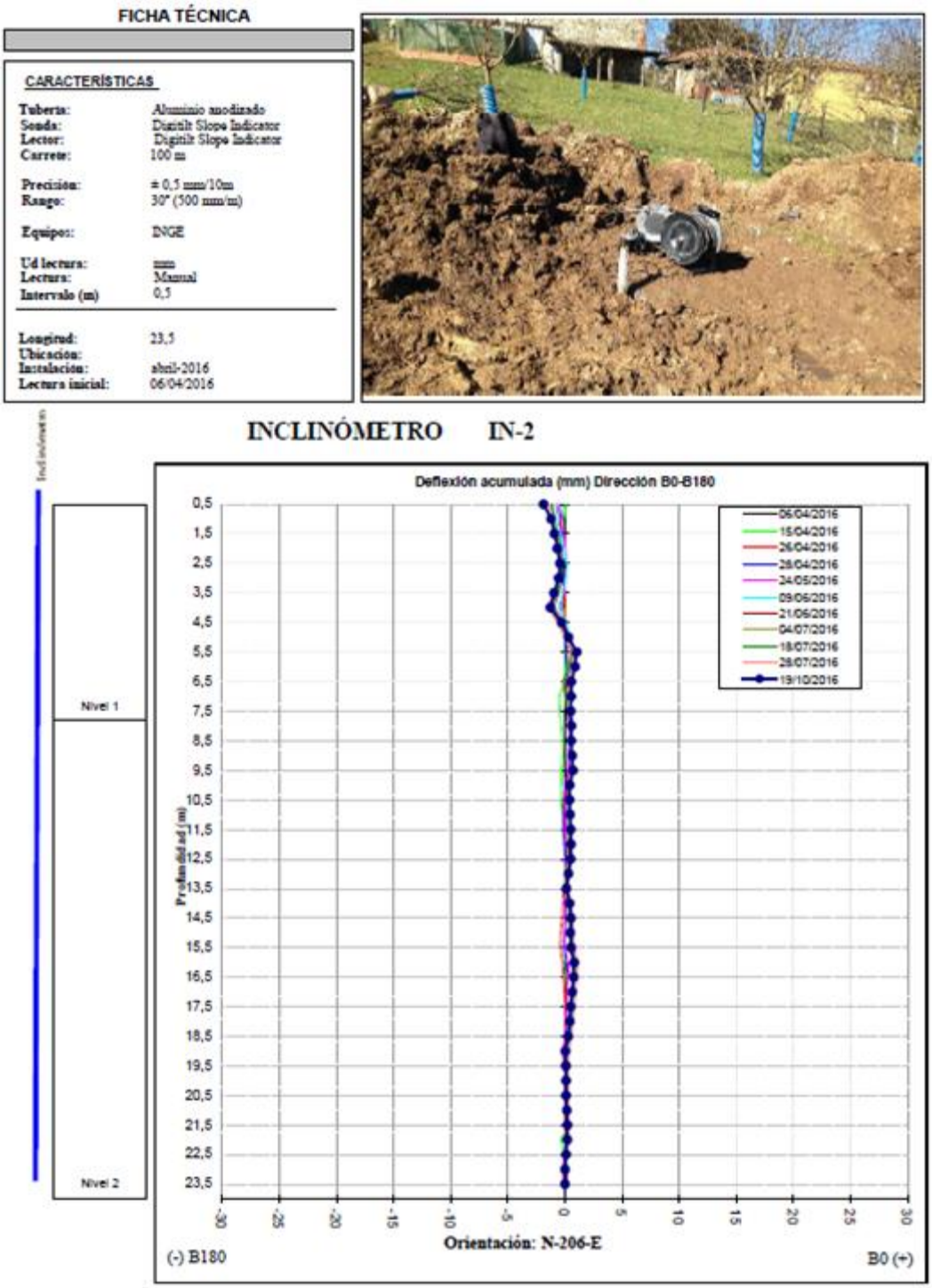

Figure 6. Cumulative deflection on inclinometer I-2

b) Topographic control

There were seven topographic controls of eleven control points arranged on the anchors installed on the retaining wall. All these topographical control points are controlled from a total station to guarantee good precision in data collection.

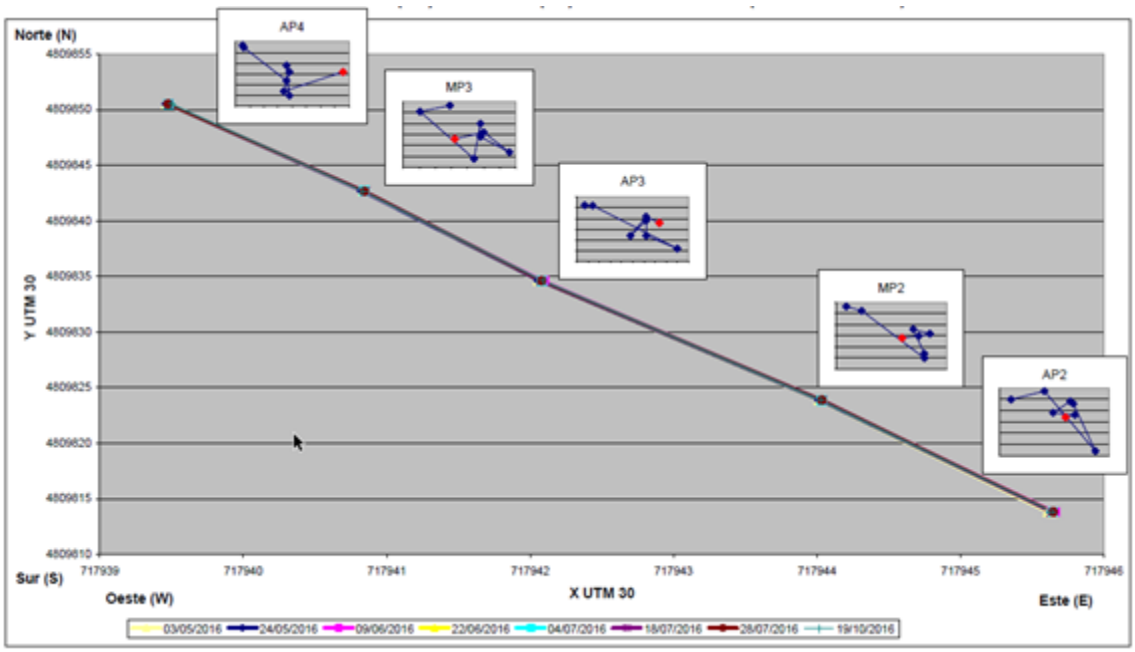

Figure 7. Results of the measurements of the monitoring system (control points in the central part of retaining wall)

The outcome of the topographic controls, shows a tendency to stabilize the results measured at the control points.

c) Validation conclusions

From both validation tests carried out, the practically total absence of movements is evident, validating the novel construction procedure developed by AZVI, allowing the company to acquire new technological knowledge that allows it to specialise in flattening and slope stabilisation works.

Conclusion

The objective that has been achieved with this project is the development of a new and complete technologically advanced construction procedure, which allows to stabilize the slope and monitor it by simultaneous and continuous control of nearby buildings and infrastructures in order to avoid derived risks of the collapse of some of the instabilities.

Innovation and Success Factors

The success factors gained in the project, are the following:

1. Greater efficiency and effectiveness in the execution of construction processes for slope stabilisation.
2. Reduction in execution times, due to a more agile and safe construction process.
3. Monitoring of the movements of the slope during the execution of the works and subsequently in operation.
4. Maximum safety in the mixed stabilization process.

5. Minimal impact on road traffic cut-off.

Figure 8. Initial situation, construction procedure completed

The technological challenge of this project was the design of a novel construction process of stabilization and simultaneous control of adjacent buildings and slopes which allows for the control of risks that may occur both on the road and in the homes, which is substantially different from the usual solutions of the sector.

3.2.2 Rock fall detection system (trip-by-wire)

Summary

This project was implemented by Infraestruturas de Portugal (formerly REFER), since 2005, as a passive protection for Rockall detection, increasing railway security and resilience.

In mountainous areas, usually associated with periods of intense rainfall, geologic phenomenon, slides and rock falls, can occur, producing serious accidents in transport infrastructures, with fatalities and damages in the infrastructure and vehicles.

Especially in some railway lines, due to the geometry, length and development and geologic nature of adjacent slopes, the cost of its treatment/correction is extremely high, it's not possible to implement active stabilization solutions (avoiding rock falls into the rail line).

In these cases, is necessary a correct ponderation of the type of solution, to prevent future accidents. One type of passive protection is the electric detection of rock falls, using trip-by-wire technology that is compliant with transport exploration regulation and signalling, reducing or eliminating the consequences of geologic events to the railway lines.

Figure 9. Railway platform destroyed by rock fall

System and implementation

The rock fall detection system is composed of several consecutive vertical support poles, with horizontal sets of isolated conductive wires, parallel to each other, forming a mesh, that detects rock falls, when occurs a wire rupture, originating an alarm information to the Central Command Post (CCO) and respective signalling.

Starting from 2005, several locations in the Portuguese railways, in mountainous areas (including tunnel entrances), considered with a high risk of geologic events, were chosen to implement this system.

Year	Line	Location	Length (m)
2005	Beira Baixa	Between Belver and Vila Velha de Rodão stations	1130
2010	Douro	Loureiro / Má Passada tunnels	70
2014	Douro	Rapa tunnel	134

Figure 10. Distribution of the rock fall detection system

Attached to the rock fall detection system itself, there is an adjacent technical closet (for connections) and specific signalling posts, placed at a distance of around 1000 meters, informing directly the trains, in case of an event (rupture of the wires), reducing or stopping the march.

After a detected event, it's required inspection and maintenance works, to identify the cause and its consequences. As the places are usually remote, it takes a while for maintenance teams to verify and analyze the incident.

(a) (b)

Figure 11. Detection system: (a) Beira Baixa line; (b) Tunnel entrance

Since its implementation, this system has detected numerous events, most of all referring to real rock falls, generally coinciding with periods of larger precipitation. The system has also detected several false alarms, due to biological activity (wild animals, severing and breaking cables) and wearing of the systems' elements.

Afterwards, to improve the system reliability (by diminishing the number of false alarms and delays in the railway exploration) security cameras were installed. In case of an event, they turn-on and allow the Central Command Post operator to see real-time images of the railway line, identifying (or not) an abnormal occupation of the infrastrututcture.

Figure 12. Technical closet and signalling post

Conclusion

The implementation of this project has improved railway security and resilience, using technology compliant with transport exploration regulation and signalling.

The system allows the following applications:

- Real-time monitoring of sections of geotechnical high-risk rail lines, where active protections are not economically viable;
- Prevention of railway accidents;
- Minimize delay impacts on railway exploration, from false alarms.

Figure 13. Rock fall Detection console (as seen in the Central Command Post)

3.3 Ongoing Projects

3.3.1 Adaptation of civil works infrastructures to climate change

Summary

This project is currently underway and will end in 2023, and it's financed by the Centre for the Development of Industrial Technology (CDTI), with aid co-financed by the European Regional Development Fund, 2007–2013. CDTI is a Spanish public business entity, answering to the Ministry of Economy, Industry and Competitiveness, which fosters the technological development and innovation of Spanish companies. CDTI is a Public Business Entity, answering to the Ministry of Economy, Industry and Competitiveness, which fosters the technological development and innovation of Spanish companies.

Azvi is working with the Electronic Engineering Group (GIE) based on the Department of Electronic Engineering (School of Engineering, University of Seville, Spain).

The main objective is to achieve a structural health monitoring system to measure the effects on critical infrastructure elements caused by the effects of climate change on road, railway and dam infrastructures.

Project main actions

<u>Architectural design</u>

The architecture of the system developed in the project is based on the disposition of N nodes (Core) communicating each one of them, via NB-IoT, to a server.

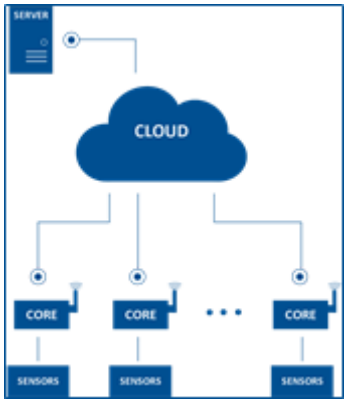

Figure 14. System architecture

The architecture of the Core is composed by a microprocessor, which is in charge to carry out the task of data acquisition corresponding to the diverse sensors installed in the structure and later to send those data to the server. For such purpose, the processor communicates with memory, accelerometer I2C and the transceiver NB-IoT. In addition, to communicate with the sensors installed, the Core has both I2C communication port and serial port.

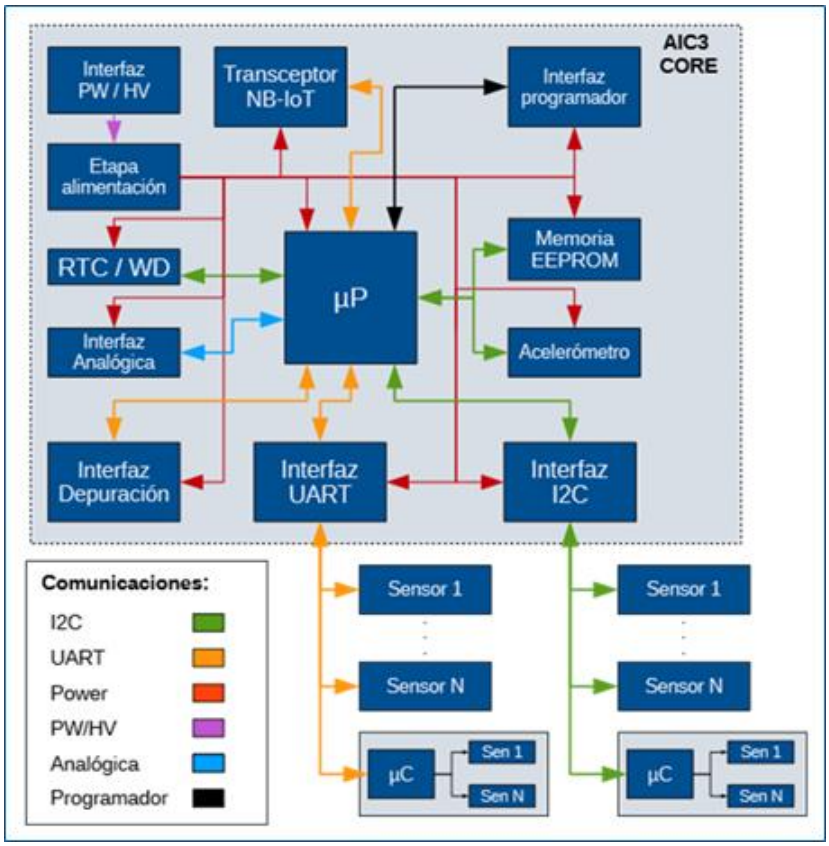

Figure 15. Core architecture

- **Hardware design**

Several iterations of the printed board have been made, the current board has an interface to calculate the power consumption of the microprocessor and the rest of the devices. A socket for the NB-IoT module has also been included. In addition, a board dedicated to evaluate the power consumption of useful sensors for structural monitoring has been developed.

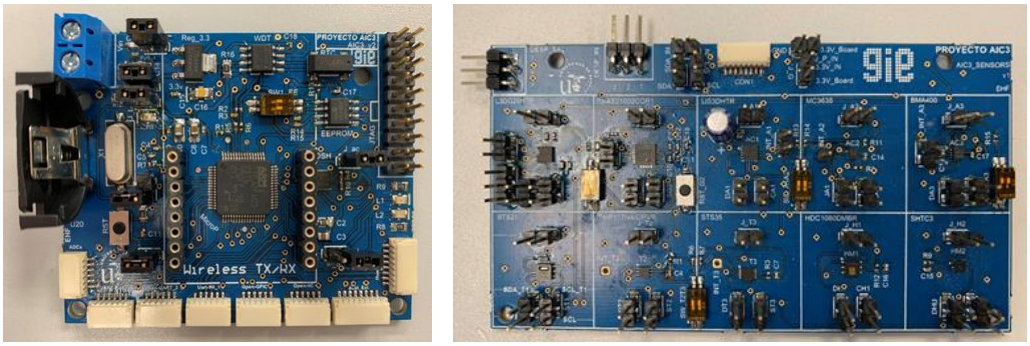

Figure 16. Printed circuit boards

- **Software design**

An operating system has been installed in the microcontroller that provides multitasking capability. In this way, tasks have been created that manage: interruption, timer, acquisition of accelerations, acquisition of temperature and humidity, reading and writing of memory, sending of NB-IoT data packets (currently being implemented), debugging messages useful for programmers, management of the electric consumption of the microprocessor and the other electronic devices.

The electrical consumption when the system is asleep is about 20 microamps, being about 8 milliamps when it is active. The power consumption due to the packets sent by NB-IoT has yet to be calculated, which is expected to cause the highest CORE consumption (according to the module specification sheet, around 200 mA).

- **Sensors**

A selection of accelerometers, gyroscopes, strain gauges, displacement transducers, weather station, humidity and temperature sensors have been made. A printed circuit board has been developed on which several sensors have been evaluated taking into account those that offer better performance and those that have less power consumption.

<u>Communication network</u>

Currently, the NB-IoT module is being integrated into the Core. The consumption of the transceiver has been optimized so that it consumes on the order of 6 micro amps when it's not transmitting.

- **SHM algorithms**

After an analysis of the state of the art, the conclusion reached is that it is necessary to focus on two major sets of algorithms. These are differentiated according to their domain:

- Frequency domain, such as: Frequency-domain decomposition (FDD), Least Square Complex Frequency (LSCF):
    - Advantage: Estimation of natural frequencies and mode shapes.
    - o Disadvantages: It can erroneously identify natural frequencies.
- Time domain, such as: Auto Regressive Moving Average (ARMA), Near End Crosstalk (NeXT), Stochastic. Subspace Identification (SSI), eigensystem realization algorithm (ERA):
    - o Advantage: No conversion needed. It does not manifest vibration modes.
    - o Disadvantage: Stricter data analysis and needs more computing power.

Currently, it is proposed for the project the use of data pre-processing using RDT (Random Decrement Technique) with the aim of using the FDD algorithm in cascade. Evaluating whether to perform the RDT process in the Core or in the server, being sure that the FDD algorithm would be performed in the server.

Work to do

In the upcoming years of the project, the structural health monitoring system will be completed, as well as the laboratory and real structure test beds.

Acknowledgements

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References

Errami M, Garner H. A tale of two citations. Nature. 2008;451(7177): 397–399.

Watkins PJ. ABC of Diabetes. 5th ed. London: Blackwell Publishing; 2003.

Simons NE, Menzies B, Matthews M. A Short Course in Soil and Rock Slope Engineering. London: Thomas Telford Publishing; 2001.

Goldacre B. Dore – the media's miracle cure for dyslexia. Bad Science. Weblog. Available from: http://www.badscience.net/2008/05/dore-the-medias-miracle-cure-fordyslexia/#more-705 [Accessed 19th June 2015].

Goldacre B. Trivial Disputes. Bad Science. Weblog. Available from: http://www.badscience.net/2008/02/trivial-disputes-2/ [Accessed 19th June 2015].

Department of Health. Living well with dementia: a national dementia strategy. Available from: https://www.gov.uk/government/publications/living-well-withdementia -strategy [Accessed 4th June 2015].

Smith A. Making mathematics count: the report of Professor Adrian Smith's inquiry into post-14 mathematics education. London: The Stationery Office; 2004.

Pears R, Shields G. Cite them right: the essential referencing guide. Palgrave study skills. 10th ed. Basingstoke: Palgrave; 2016.

Ramalho R, Helffrich G, Schmidt DN, Vance D. Tracers of uplift and subsidence in the Cape Verde archipelago. Journal of the Geological Society. 2010;167(3): 519–538. Available from: doi:10.1144/0016-76492009-056.