FORESEE

Future proofing strategies FOr RESilient transport networks against Extreme Events

Case Study and Tool Fact Sheets

Background document for the Stakeholders' Reference Group (SRG) Final Event in January 2022

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1 DOCUMENT OVERVIEW

DOCUMENT INTERACTIVITY

This document will present the fact sheets for the case studies and associated main results that have been validated as part of the Future proofing strategies For RESilient transport networks against Extreme Events (FORESEE) project. The document can be read in a conventional manner but can also be read with a particular focus on a given case study or result. In order to improve efficiency and accessibility, hyperlinks have been inserted throughout the document which enable the reader to jump from one section/case study/result to another. Links are indicated by blue text and underline. To jump from one section to another simply click on the highlighted text. For example, (click here to jump directly to the first case study).

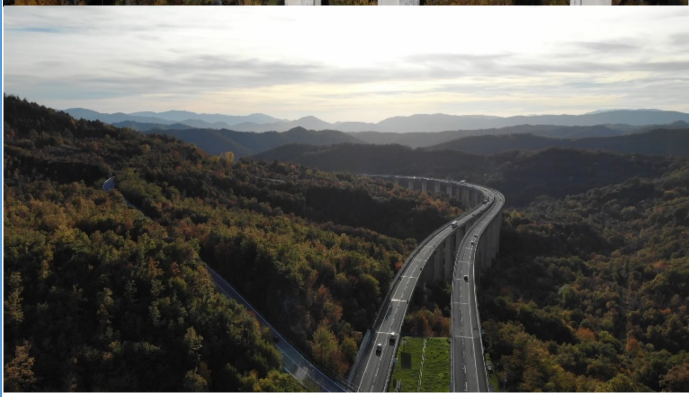
DOCUMENT STRUCTURE

Case Study	Tool Validated	Result
#1 CARSOLI-TORANO (ITALY): A24 HIGHWAY	Traffic Module	It includes a multiscenario software script that makes use of existing traffic simulations, through traditional traffic analysis tools, to estimate the potential loss of service associated with multiple values of resilience indicators from them using stochastic algorithms. The purpose of the Traffic Module is to enable resilience measurements with traffic simulations even when some uncertain input parameters are present.
	Fragility Functions, Vulnerability Functions, Decision Support Interpreter Module	The principal aim of this tool, in collaboration with the traffic module, is to deliver an easy-to-use and efficient instrument to infrastructure managers and owners, allowing them to manage assets and financial resources in an optimal manner, while adhering to the safety levels required.
#2 NAPLES TO BARI (ITALY): A16 HIGHWAY	Virtual Modelling platform and asset failure prediction	This tool leverage satellite InSAR data to constrain predictive slope failure models, adapting existing slope stability model that use rainfall data to predict pore pressures leading to prediction of ground motion.
	SHM BIM based alerting SAS platform	The tool is an API that generates RAG alerts over a BIM and allows 3D visualization. The alerts are raised in correspondence with the datasets of motion observed near on the BIM using landslide failure prediction model, in-situ sensors data and satellite InSAR data.
#3 MONTABLIZ VIADUCT & A-67 (SPAIN)	Governance Module	Tool aimed to integrate the concepts of governance and those of service and resilience to complement assets' governance by making it automatic, simple and transparent, for all stakeholders, providing a rapid response of mitigation actions to disruptive and / or extreme events (even after the event). Applicable to all phases of the infrastructure life cycle.
	Risk Mapping Tool	The main objective of the tool is to identify and assess the risk of natural disasters in different areas of study through the use of an application implemented in GIS. This application analyzes, evaluates, identifies, and consolidates the risks in order to improve decision-making.
#4 RAILWAY TRACK 6185 (OEBISFELDE-BERLIN SPANDAU)	Flooding assessment.	The main investigation topics regarding the considered operating and maintenance phase are flooding impacts on railway operations in combination with maintenance and contingency plans. Additionally, the effects of flooding to different railway track components in dependency of the water level are evaluated model-based.
	Command and Control Center	The C2 will serve to increase the situational awareness of the users of the FORESEE toolkit. Alarms concerning potential hazards to an infrastructure are raised based on efficient anomaly detection techniques using machine learning.
#5 M30 MADRID (SPAIN)	Flooding assessment. Novel methodology	Novel methodology for the study of floods using advanced statistical techniques to improve the calculation of flood extent for different return periods through a better exploration of the space of extremes.
	Hybrid data assessment package	A machine learning tool for data fusion for diagnostics and prognostics of faults in the face of an acting hazard. The module stays general to tackle different structures (bridges or tunnels) and hazards (cyber-attack, flood, earthquake).
	Cybersecurity assessment	Socio economical study considering a cyberattack Affecting the M-30 ring road. Impact on traffic and Alternative routes; scenario caused by a cyber-attack. description of the scenario caused by a cyber-attack on the m-30 ring road.

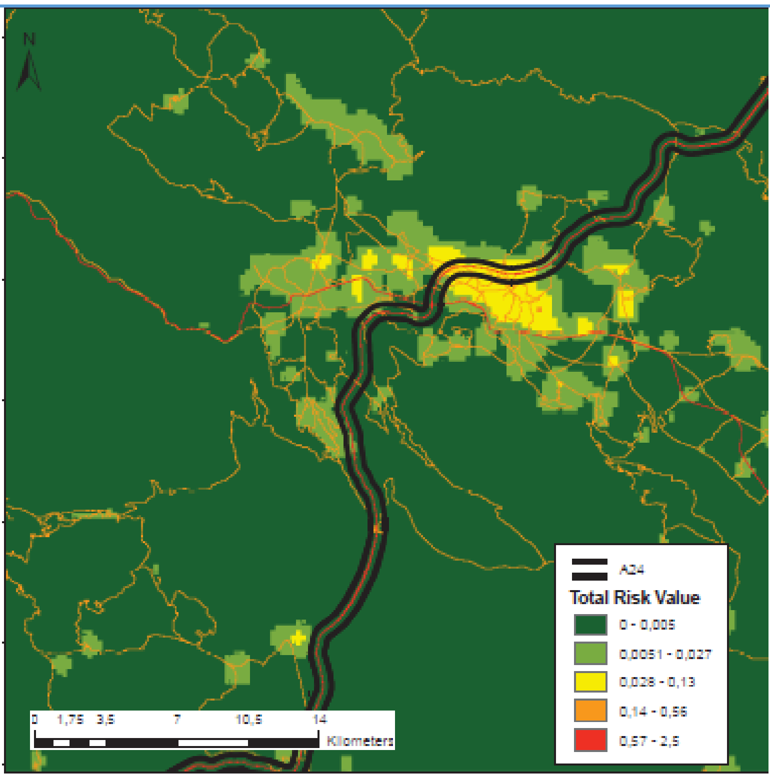
2 CASE STUDY FACT SHEETS

CASE STUDY #1 - CARSOLI-TORANO (ITALY): A24 HIGHWAY	FORESEE PROJECT
Objective & Description	This case study (CS) focusses on heavy snow and earthquake hazards on a section of the A24 Highway (from 52 km to 73 km) to evaluate, through the FORESEE Tools, the enforcement of the contingency plan and the emergency procedures, using the tools for a comparative analysis with a previous disruptive event. The A24 motorway ("Parks motorway") is a strategic and barycentric road system that connects Rome to the Adriatic Sea. The motorway is managed by Strada dei Parchi and plays a vital role in supporting the mobility of production activities, communications, commerce, tourism and social and economic development throughout the country.
Hazard Description	The motorway has been selected as the focus of the first FORESEE case study due to the frequent earthquakes, extreme weather (i.e. heavy snowstorms) and traffic congestion which impact upon the infrastructure. Moreover, this motorway is located within the Abruzzo Region which is well-recognised as a region of considerable seismic activity.
Usefulness for infrastructure owners & operators?	The main benefit of this case study will be in defining the asset's vulnerability/fragility against a specific hazard type: the result of this activity can be used to assess operativity losses for different damage levels. In addition, vulnerability analysis can be conducted to quantify the potential losses in terms of operativity and traffic continuity given a potential disruption.
How does it work?	The A24 path between Carsoli and Torano has been studied in two different scenarios, corresponding to two extreme events, which impact upon the regular service of the highway traffic: • **Earthquake:** risk of moderate or severe events which may result in partial or total closure of the highway, through the FORESEE Tools, to evaluate the enforcement of the contingency plan and the emergency procedures. • **Heavy snow:** improve the emergency/contingency procedures in the face of threats from heavy snow/avalanche.

Case study overview



Key Facts	
Total length:	165 km
Pilot length:	From 52 km to 73 km
Major junctions	
East end:	Teramo
West end:	Rome
Location	
Regions:	Lazio, Abruzzo
Highway system	Italian Highways
Management	
Company name:	Strada dei Parchi
Main threats	
Type:	Earthquake, snow,



Total risk map obtained for CS#1. Carsoli-Torano A24 highway in Italy

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service and Resilience	Guidelines have been adapted by the infrastructure manager, including real data.
Resilience Guidelines to Set Resilience Targets	Guidelines have been adapted by the infrastructure manager, including real data.
Risk Mapping	CS leader reviewed and compared the results coming from the tool with the already available procedures.
Traffic Module	CS leader provided the traffic and asset data and traffic management expertise. Then the CS leader reviewed the outputs and provided their overall considerations on the tool and the result.
Fragility and Vulnerability Analysis & Decision Support Module	CS leader provided the traffic and asset data and traffic management expertise. Then the CS leader reviewed the outputs and provided their overall considerations on the tool and the result.
Definition of framework: use cases, risk scenarios and analysis of impact	The CS leader used the tool, reviewed and compared the results with the already available procedures.
Design, construction and remediation plans	CS leader reviewed and compared the results with the already available procedures.
Operational and maintenance plans	CS leader reviewed and compared the results with the already available procedures.

On the next page, a summary to the main results that have been validated in this case study is presented as an introduction to the explanations to be provided during the next workshop.

Further information and complementary documents will be available before the workshop.

The Conclusion report of all the results that have been validated in this CS will be public and accessible to the audience. The FORESEE SRG members can also have access to specific documents of any result of their interest. These requests can be addressed to:

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Main validation from CS#1

TRAFFIC MODULE

The Traffic Module includes a multi-scenario software script that makes use of existing traffic simulations, through traditional traffic analysis tools, to estimate the potential loss of service associated with multiple values of resilience indicators from them using stochastic algorithms. The purpose of the Traffic Module is to enable resilience measurements with traffic simulations even when some uncertain input parameters are present.

The application on CS#1 was made to test the capability of the Traffic Module, together with the Fragility and Vulnerability analysis tool.
The specific application to the "Carsoli - Torano" case study was done to evaluate the behaviour of traffic in the face of seismic events that produce disruptions in the structures of the concession. The traffic module shows how the events produce a reduction of the road capacity in the structures that generate variations in travel time and traffic volume.

This method allows selection of specific origin/destination (OD) trips, therefore it will provide resilience awareness analysis based on OD characteristics, such as long vs short distance effects or the size of population centres (as a criticality factor). The resulting values are useful to compare scenarios and alternatives. The process does not allow the evaluation of resilience for specific transport infrastructure sections or components (bridge, tunnel, etc.).

Was this type of analysis made before FORESEE? How was it made?	There are currently some tools to manage traffic, but there is no specific software already implemented for planning. It is not required due to the lack of heavy traffic and strong interferences.
How does FORESEE improve the results/analysis previously made?	Such type of analysis was never applied.
How does this result increase the resilience of your infrastructure?	Passing between the current statistical static study of traffic to a multi-scenario software, with the possibility to change some boundary condition about the infrastructure, can improve the overall resilience, easing the management of hazard scenario.
How does this FORESEE result improve your infrastructure's management?	The capability to directly combine and test some potential effects on the network, in terms of traffic disruption, can bring a potential benefit to the infrastructure manager. Moreover, this type of tool can facilitate some trial tests by simulating specific events and the related consequences.
If it was not made, how does this FORESEE result improve your infrastructure's management?	This tool can facilitate specific training. In addition to the specific feature for the infrastructure manager, the results of this tool can be also shared with external stakeholders (eg. Civil protection, firefighters) to

	conduct joint activities related to disaster preparedness and response.
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	At the moment the activity is carried out based on expertise and previous experience: the adoption of this tool can bring to a decrease in the training and learning time and introduce new practice exercises. Potential benefits: • Scenario adherence to reality • Enhanced training for workers, reducing time for training and increase in disaster preparedness and response

FRAGILITY FUNCTIONS, VULNERABILITY FUNCTIONS AND DECISION SUPPORT INTERPRETER MODULE

The principal aim of this tool, in collaboration with the traffic module, is to make a helpful instrument available to the infrastructure managers and owners in addressing the economic resources in the achievement of the safety levels required.
The main objectives of the two main components of the tool are:

- The Fragility and Vulnerability Analyses Tool for the definition of the disruption events caused by different hazard scenario and the asset's fragility characterization against the considered hazards.
- Decision Support System (DSM) Tool with the aim of the Losses and Resilience Assessment of the Transport Infrastructure system.

The infrastructure is represented with two different layers, the one concerning the assets' description form a structural point of view and the other from a transport flows point of view.
The interaction between the two representative models has the principal aim of the final Resilience Assessment of Transport Infrastructures through simulation method. The principal aim is to assist organisations in their decision-making process or in the planning of response to critical situations in terms of **reduction of time and costs of recovery**.

The tool was used and applied to the A24 motorway segment between the interchanges of Carsoli and Torano considering the **earthquake** as a main hazard.
Once the fragility functions are chosen, for the specific infrastructure's assets and hazard typology, vulnerability analysis has been performed. As mentioned above, through vulnerability analysis, it is possible to evaluate an asset's **operativity losses** for different damage levels scenario. While the asset's direct losses, caused by disruptive events, are obtained considering the level of damage into the assets and the correspondent economic loss generated, for the indirect losses the asset's operativity levels should be known. Thus, the reduction of operativity or functionality of infrastructure's assets for different disruptive events causes indirect economic losses to the affected section of society around the system. Then, for each limit state the operativity loss is considered after a different number of days. Thus, combining these quantities it is possible to have the curves that correlate the intensity measures with the probability to have an operational loss for different days after the event, vulnerability curves.

The Decision Support Module is performed through the connection of the structural vulnerability against disruptive events and correspondent transport flows modifications, with the aim of guaranteeing an instrument that helps Infrastructure Managers with disruptive hazards impacting effects on their infrastructures.

To achieve this aim, the connection between the representative model concerning the network and the model concerning the mobility demand (also through the Traffic Module) are requested. The outputs of the Traffic Module are then utilised for the definition of the Losses for the OD (Origin-Destination) matrix routes and Level of Service (LoS) for the infrastructure's elementary components. Starting from the LoS variations within the situation of no hazard and the situations of hazard occurrence, it is possible to conduce the Resilience Assessment of the Transport Infrastructure.

In order to give a correlation between LoS and the speed and volume/capacity ratio, a graphic representation of the different LoS's ranges is reported.

Starting from this assumption, it is possible to give an overview of the LoS distribution over the transport infrastructure, before and after the event.

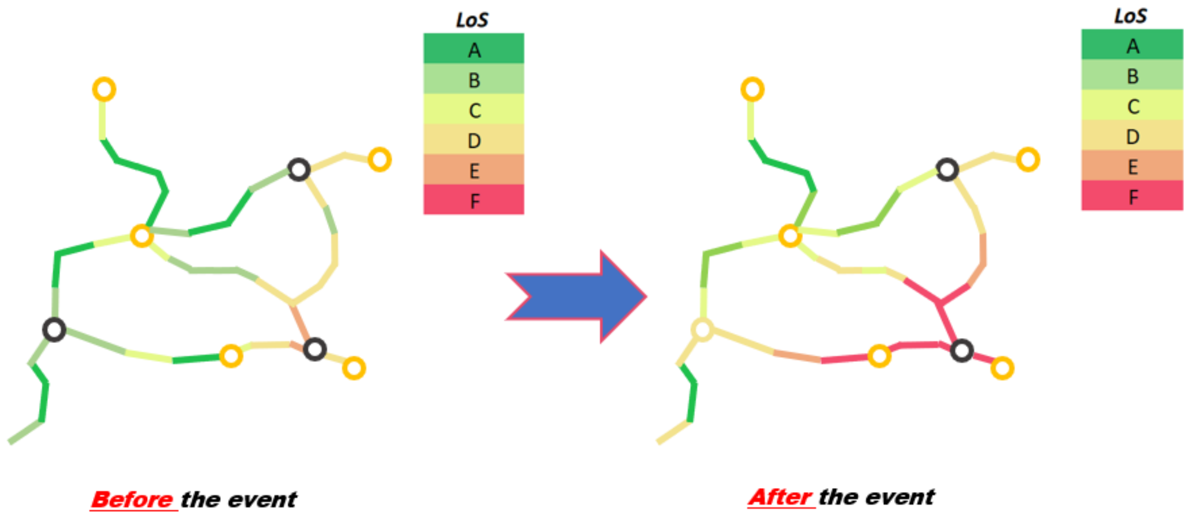
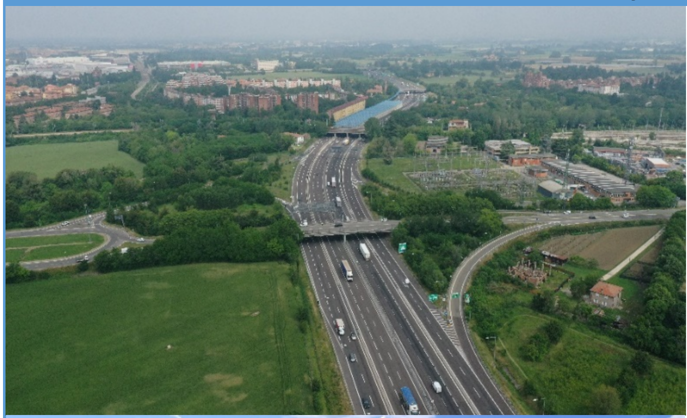


Figure 1: Example of LoS scenario before and after the event (A-B in the level of LoS based on flow density)

Was this type of analysis made before FORESEE? How was it made?	At the moment the analysis is carried out using an asset management tool, which basically catalogues and establishes an historical database of the features of each relevant element (e.g. bridge, tunnel, viaduct). Every single defect is tracked and monitored, but there is no correlation between a hazard and its effect on the structure element. The decisions are taken based on the evidence of the analysis, without a direct link between hazard, risk and status of the infrastructure.
How does FORESEE improve the results/analysis previously made?	The current tools do not provide a complete analysis and overview of all the different factors and elements.
How does this result increase the resilience of your infrastructure?	These tools make it possible to manage and create different hazards scenarios and, thus, foresee the possible impacts that an event may cause in terms of LoS reduction, having different pictures before and after a possible event's impacts, regarding risks, losses, operativity levels, directly converted in Level of Service and resilience indicators.
How does this FORESEE result improve your infrastructure's management?	The main factor is the capability to define asset's vulnerability/fragility against a specific hazard type: the result of this activity can be used for asset's operativity losses for different damage levels scenarios to make a vulnerability analysis to quantify the potential losses in terms of operativity and traffic continuity.
If it was not made, how does this FORESEE result improve your infrastructure's management?	The main impact of this tool is related to the possibility of having an estimation in terms of direct economic loss, taking into account all the different elements (e.g. traffic, infrastructure condition state, level of resilience). Moreover, the possibility of having an estimation related to the operativity loss leads to added value for the infrastructure manager to have a clear idea, in the case of a specific event, about which are the main affected elements, for how many days there will be a decrease in the operativity, the different risk scenarios and the resilience estimation.

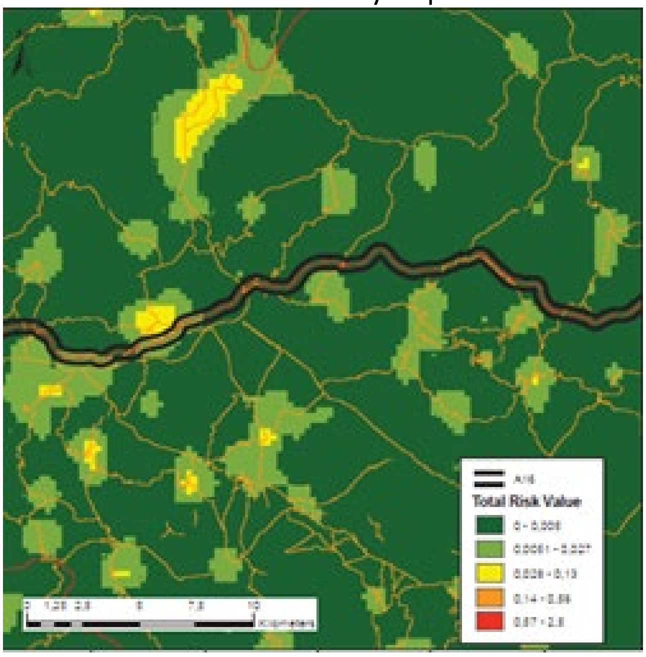
# CASE STUDY #2 - NAPLES TO BARI (ITALY) - A16 HIGHWAY	
Objective & Description	The A16 highway ("Motorway of the Two Seas") runs from Naples to Bari along the TEN-T Corridor 5. Built in the late 1960's, it provides a link between the Tyrrhenian and Adriatic coast and plays a crucial role in the mobility of production and commercial activities across southern Italy, thus contributing to the social and economic development of the country.
Hazard Description	The A16 has been selected for the second FORESEE case study (CS) because of its geographic location (i.e. high seismic hazard zone) and extreme weather conditions (i.e. snow). Moreover, as the highly clayey nature of the soils strongly influences the stability of the slopes, landslides are the specific risk scenario taken into account. The highway is subject to heavy traffic of goods and passengers throughout the year.
Usefulness for infrastructure owners & operators?	This study will improve the current practices adopted by infrastructure managers in relation to risk evaluation of the territory, highway and highway users with a potential positive impact on preventative maintenance interventions and deployment of contingency and/or emergency operations, where the selected hazard is represented by landslides. Moreover, it has the potential to support managers of similar infrastructures in their long-term asset management plans.
How does it work?	In particular, two tools have been validated through CS#2: 1. **The Virtual Modelling platform and asset failure prediction**, integrates both (in situ) terrestrial and satellite data, GIS, and numerical modelling to predict failure of assets, considering rainfall a triggering factor. 2. **The SHM BIM based alerting SAS** is a comprehensive Internet based tool which compares observed motion values against threshold failure values and thereby creates a capability that issues alerts based on the comparison. A test area of approximately 30 km along the A16, including 20 bridges, has been used to develop and validate the results of the project. Hence, the findings will offer valuable insight into how to deal with, in daily operation or in long term planning, the challenge posed by potential landslides over a wider population of structures throughout Italy and further afield.

Case study overview



Key Facts	
Total length:	172.5 km
Construction year:	Late 1960's
Pilot Focus	
Section length:	30 km
Number of bridges	20
Location	
Regions:	Campania, Puglia
Major Junctions	
East end:	Bari
West end:	Naples
Main threats	
Type:	Landslides

The GIS based risk analysis platform generating prioritised ranked site/asset risk map, developed in the project, could be a valuable tool to be used as it is aimed at identifying the strategic areas where implementing measures to mitigate the impacts of extreme natural events and to optimise the use of available resources as efficiently as possible.



Total risk map obtained for CS#2. Naples to Bari A16 highway in Italy.

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service and Resilience	Guidelines have been adapted by the infrastructure manager, including real data. Identification of KPIs and KERs.
Resilience Guidelines to Set Resilience Targets	Guidelines have been adapted by the infrastructure manager, including real data. Identification of KPIs and KERs.
Risk Mapping	Hazard maps and risk maps of the infrastructure's area to identify the risks prior to the more accurate and more local scale quantification, were produced based on CS data. Locations to install permanent monitoring systems were chosen on the basis of the hazard maps.
Virtual Modelling Platform	CS leader reviewed and compared the results coming from the tool with the already available procedures. Permanent monitoring systems have been installed on two bridges to calibrate the Virtual Modelling Platform and the SHM BIM based alerting SAS.
SHM BIM based alerting SAS	Based on data from CS#2 a toolkit has been developed covering different features such as: georeferenced representation of the territory and infrastructure, integration of different sources of data, and alerts thresholds. The CS leader used the tool, reviewed and compared the results with the already available procedures.
Fragility and Vulnerability Analysis & Decision Support Module	Asset's fragility characterization against landslides depending on the criticality levels of the asset's main features and functionality to evaluate asset's operativity losses for different damage levels scenario. CS leader provided the traffic & asset data, reviewed the outputs and provided their overall considerations on the tool and the result.
Definition of framework: use cases, risk scenarios and analysis of impact	Definition of a framework to develop the Resilience Plan for the Use Case: Roadway+Highway+Landslides.
Design, construction and remediation plans	Design, construction and remediation plans in order to adapt and increase the resilience of the infrastructure. CS leader reviewed and compared the results with available procedures.
Operational and maintenance plans	Increasing transport infrastructures' safety, efficiency and productivity factors in relation to extreme events. CS leader reviewed and compared the results with available procedures.

On the next page, a summary to the main results that have been validated in this case study is presented as an introduction to the explanations to be provided during the next workshop.

Further information and complementary documents will be available before the workshop.

The Conclusion report of all the results that have been validated in this case study will be public and accessible to the audience. The FORESEE SRG members can also have access to specific documents of any result of their interest. These requests can be addressed to:

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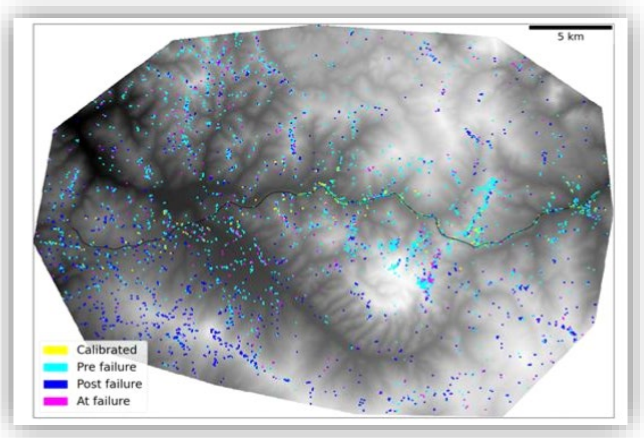
Case Study #2 Leader:	Livia Pardi	lpardi@autostrade.it

Validation Outcomes on CS#2 (1/2)	
Virtual Modelling Platform	
The Virtual Modelling Platform and asset failure prediction present an approach on slope monitoring, covering its implementation and validation over the A16. Rainfall is considered the triggering factor. The application to CS#2 is of particular importance as validation as it includes data, not only from satellite observations, but also complemented by data from instrumental geotechnical regular monitoring (inclinometers and piezometers data) in the timeframe covering the period 2012-2019. The main output of the model validation is represented in the figure (below) where most of the failures predicted to occur before the observed failure are near the road, where more information is available, while failures further away from the road tend to be modelled after the observed event. This may be relevant for managing purposes (for both preventative actions, due to the location of the "expected failure", or for emergency procedures), with the timeframe of 25 days having to be updated from subsequent measures in time.	
	***Map of calibrated points, alongside validation points. Calibration points are concentrated along the road. "At failure" means predicted failure within a window 25 days before observed failure. Post failure points concentrate at higher elevations far from the road.***
For the purposes of validation, permanent monitoring systems have been installed to validate the predictive models for hazard management, based on the results of the analysis. The real time acquisition rate of the permanent monitoring system, fundamental for alerts purposes, complements the rate of acquisition of InSAR data and it contributes to anchoring to the ground the wide satellite images, both for shallow and in depth observed/predicted displacements. The limited reliability of the proposed predictive model correlating landslides to rainfall (from pore pressure measures) might be improved by future acquisition of data. In order to improve the precision of the models, a sensor for the monitoring of water vapour has also been installed on one of the bridges. Water vapour is correlated to rainfall, a triggering factor for the landslide predictive model.	
Was this type of analysis made before FORESEE? How was it made?	It appears important to improve landslide forecasting and hazard management, which includes hazard identification, hazard assessment and hazard information. In particular, monitoring can be an important tool for these purposes,

	because it can be used to identify failure potentials, to understand their mechanisms and to find reliable correlations between movement events and their triggering factors.
How does FORESEE improve the results/analysis previously made?	Thresholds values should be discussed in depth in cooperation with infrastructure owners and operators, matched with their daily operation and mobility management and re-calibrated after a period of observation and collection of data from on-site monitoring and satellite interferometry.
How does this result increase the resilience of your infrastructure?	The Virtual Modelling platform and asset failure prediction of landslides that may impact an infrastructure, based on historical displacement data, data from satellite interferometry and/or on-site monitoring, related to rainfall recorded data and consequent increase in interstitial pressures, to identify warning thresholds, exceeded which, it is expected for a landslide to trigger or to reach an appreciable velocity, is certainly useful for the safe management of the infrastructure.
How does this FORESEE result improve your infrastructure's management?	It could be interesting to re-evaluate the method in the medium term, following further monitoring data detected by the systems in place on the network (continuously) or by the rainfall data that we could detect from instruments to be installed suggested by the studies in progress on the hydrogeological instability on the network
If it was not made, how does this FORESEE result improve your infrastructure's management?	The timely warning of potential events has a positive impact on mobility and safety.
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	Benefits are in terms of: • Optimised use of economic resources • Increased efficacy of maintenance inventions • Reduced impact of traffic flow due to the reduction in the number of subsequent interventions • Reduced impact on mobility for emergency situations

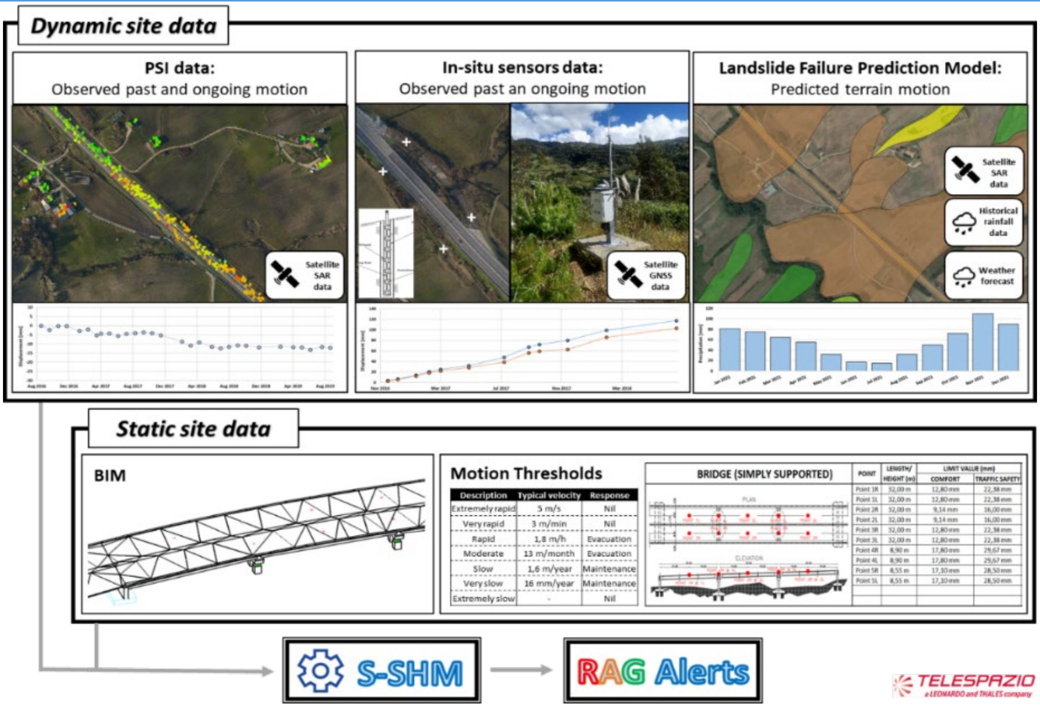
Validation Outcomes on CS#2 (2/2)

SHM BIM based alerting SAS

The final and comprehensive result is the toolkit which compares observed motion values against threshold failure values and thereby creates a capability that issues alerts based on the comparison.

The SHM BIM based alerting SAS is based on dynamic site data (satellite, in situ sensors, landslide failure prediction model), providing the motion observed on the infrastructure and its surroundings and static data, and providing information on the infrastructure (BIM, motion thresholds). These two sets of data are combined and linked, and RAG alerts are raised for each BIM element. A 3D visualisation of the alerts along the critical infrastructure is also provided.

The S-SHM tool is only available for CS#2, as this is the only area with InSAR results. The toolkit allows access to the 3D visualisation and to the alerts table.



Scheme on S-SHM Algorithm.

During the summer of 2021, some GNSS data sensors were installed over two of the bridges in CS#2. These sensors measure displacement and provide the measurement automatically through an API, to allow a smooth validation of the tool; and to provide updated information on the bridge's status.

As for the other type of measurements already integrated in S-SHM, the tool ingests the location of each GNSS sensor and evaluates which BIM elements are near each measurement point. After that, the recorded displacements are compared with the motion thresholds table in order to raise Red, Amber or Green alerts.

	***Example of 3D visualisation of the alerting system over one of the bridges in CS#2. The BIM is coloured by RAG (Red-Amber-Green) alert values.***
Was this type of analysis made before FORESEE? How was it made?	Activities are carried out at both local and central levels in the company along the network for the relevant sites, kept under control both visually and instrumentally, even continuously, with sets of alerts. However, an integrated internet tool is not available to manage all the aspects linked to the hydrogeological risk.
How does FORESEE improve the results/analysis previously made?	The BIM model of the infrastructure as a whole, comprising different structures with totally different behaviours/stiffnesses, is an added value to keep under control the entire infrastructure and its elements. The integrated model allows different parameters and sources of information to be kept under control. Timely alerts allow a smoother management of emergency situations.
How does this result increase the resilience of your infrastructure?	The identification of warning thresholds, based on the displacements that the infrastructure is able to undergo, in the absence of damage or with acceptable damage, will be much more reliable, thus increasing resilience of the infrastructure.
How does this FORESEE result improve your infrastructure's management?	The proposed tools integrate the company's strategy of digitalisation. Internet based tools for management of alerts are gaining importance, however the key factor is the rate of acquisition of data onsite from permanent monitoring systems.

If it was not made, how does this FORESEE result improve your infrastructure's management?	The use of a comprehensive tool, covering, different sources of data and functions, allows an integrated control "in real time" of the infrastructure and its elements both in terms of maintenance and traffic conditions.
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	Benefits are in terms of: • Optimised use of economic resources • Increased efficacy of maintenance inventions • Reduced impact of traffic flow due to the reduction in the number of subsequent interventions • Reduced impact on mobility for emergency situations

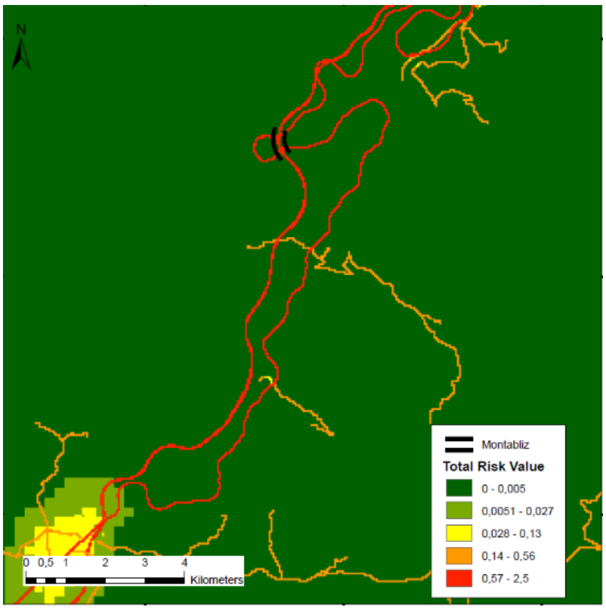
CASE STUDY #3 – MONTABLIZ VIADUCT & A-67 (SPAIN)

Objective & Description	This case study (CS) focuses on the risks of strong winds and snowfall on a section of the A-67 motorway (Reinosa - Los Corrales de Buelna), to evaluate, through the FORESEE Tools, the different phases of the life cycle of the project, comparing its use with current tools. The A-67 motorway ("Autovía de la Meseta") is part of the radial network of motorways in Spain that connect Madrid with the rest of the Spanish territory, playing a vital role in the connection of the capital of the country with the Cantabrian Sea and its maritime connection with Europe.
Hazard Description	Wind: Montabliz viaduct prevailing winds south and west. Snow: several times a year and along the highway. Flooding: on the highway area of the Corrales de Buelna.
Usefulness for infrastructure owners & operators?	The benefit offered to operators is focused on managing the operation of the infrastructure in case of extreme events higher than those used in the project definition.
How does it work?	The Montabliz Viaduct & A-67, has been designed for the three phases of the lifecycle of the project, using different FORESEE tools. **Risk Mapping:** Hazard maps and risk maps of the infrastructure's area to identify the risks prior to the more accurate and local scale quantification, wind and snowfall. To Evaluation & Decision Phase. **Governance Module:** Making design decisions, to mitigate specific infrastructure hazards, wind. To Design & Construction Phase. **Flooding Methodology:** Flood Map different return period. To Operation & Maintenance Phase.

Case study overview

Key Facts

Total length:	47 Km
Pilot length:	24 Km
Major junctions	
Sud end:	Reinosa
West end:	Los Corrales de Buelna
Location	
Regions:	Cantabria
Highway system	Spain Highways
Management	
Company name:	Ministerio de Transportes
Main threats	
Type:	Wind, snow, flooding



Total risk map obtained for [CS#3. Montabliz Viaduct & A-67, Cantabria, Spain.]

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service &Resilience	Guidelines have been adapted by the infrastructure manager, including real data
Resilience Guidelines to Set Resilience Targets	Guidelines have been adapted by the infrastructure manager, including real data
Risk Mapping	CS leader reviewed and compared the results coming from the tool with the already available procedures.
Traffic Module	CS leader provided the traffic & asset data and traffic management expertise. NO RESULTS
Governance Module	Guidelines have been adapted by the infrastructure manager, including real data
Flooding Methodology	Guidelines have been adapted by the infrastructure manager, including real data

On the next page, a summary to the main results that have been validated in this case study is presented as an introduction to the explanations to be provided during the next workshop.

Further information and complementary documents will be available before the workshop.

The Conclusion report of all the results that have been validated in this case study will be public and accessible to the audience. The FORESEE SRG members can also have access to specific documents of any result of their interest. These requests can be addressed to:

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Project Coordinator: Iñaki Beltrán Inaki.beltran@tecnalia.com

Case Study #3 Leader: Irune Indacoachea Vega irune.indacoechea@unican.es

<table>
<tr><th colspan="2">Main validation from CS#3</th></tr>
<tr><td colspan="2">RISK MAPPING
The Risk Mapping tool developed in T2.2 of the FORESEE project is aimed at the early large scale identification of the risks to extreme natural disasters to which road infrastructures are exposed, as well as to approach the vulnerability of these infrastructures. This application is to be employed at early phases of the project design, when the relevance of risks potentially involved can be initially estimated, and prior to a more detailed data collection and analysis for a given impending regional or local extreme natural event. Two main outcomes can be obtained from running the tool: hazard and risk maps at a European scale.

The methodology for risk mapping follows an empirical approach as it is based on a series of past real extreme natural events occuring all over Europe in the last few years. For assessing the risk of occurrence of the three most significant natural disasters - floods, landslides and earthquakes, regression models have been developed that made use of the catalogue of past real events as the response variable and a series of geo-referenced databases as factors or predictor variables. Those factors with the highest level of significance were finally used for the modelling of the hazard maps.

Vulnerability refers to the group of individuals or goods potentially exposed to the action of hazards. For the purpose of this tool, vulnerability of roads concentrated the greatest effort. In this sense, for the vulnerability assessment of the different types of roads (motorways, primary, secondary and tertiary roads) a MCDM analysis was carried out that made use of different criteria: traffic, length, costs and accidents rate. As the vulnerability of transport infrastructures is also related to the people living around them, potential personal damage must have an impact on the vulnerability factors defined.</td></tr>
<tr><td>Was this type of analysis made before FORESEE? How was it made?</td><td>This type of analysis was not done before FORESEE.
It was done through expert judgment.

COMPARISON AGAINST CURRENT TOOLS</td></tr>
<tr><td>How does FORESEE improve the results/analysis previously made?</td><td>FORESEE maps the specific risks of the area to study the infrastructure.

DESCRIPTION OF CURRENTLY USED TOOLS</td></tr>
<tr><td>How does this result increase the resilience of your infrastructure?</td><td>The FORESEE result significantly increases resilience, to the select of infrastructure location.

RESILIENCE TOOL</td></tr>
<tr><td>How does this FORESEE result improve your infrastructure’s management?</td><td>It provides an objective update of the risks affecting the network and helps to prioritise corrective actions to reduce those risks.</td></tr>
<tr><td>If it was not made, how does this FORESEE result improve your infrastructure’s management?</td><td>It standardizes and objectivises the decision making according to decisions agreed in advance.</td></tr>
</table>

What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	This module could help to select the best project alternatives at the decision-making phase and the best processes during the operation phase, reducing the total costs.

GOVERNANCE MODULE

When planning, designing and executing a new project (infrastructure), the owner and contractors based on hazards, KPIs and KRTs, make decisions with the aim of mitigating risks, maintaining stable service level and obtaining maximum profitability. This decision-making is carried out automatically and transparently, through the governance module.

1. Thus, the owner defines the KRI and the KRT, depending on the specific hazards of the infrastructure.
2. Subsequently, and prior to each of the phases, the owner selects, through the governance module and depending on the hazards, both the type of contract and the most appropriate contractor for its execution. The interested contractors apply for the tender and declare their abilities to carry out the work, by completing the KPIs and KRTs defined by the owner.
3. Once the selection is made, both the contractor and the owner use the governance module for the selection of the different governance, technical and financial issues to define the infrastructure, based on the KRIs and KRTs, with the basic objective of mitigating the hazards in the different phases of Evaluation & Decision, Project and Construction and Operation and Maintenance.

Was this type of analysis made before FORESEE? How was it made?	This type of analysis was not done before FORESEE. It was done through expert judgment. **COMPARISON AGAINST CURRENT TOOLS**
How does FORESEE improve the results/analysis previously made?	FORESEE makes decision-making based on technical and transparent results. **DESCRIPTION OF CURRENTLY USED TOOLS**
How does this result increase the resilience of your infrastructure?	The FORESEE result significantly increases resilience, to the maximum possible taking into account form, materials and economic disposition. **RESILIENCE TOOL**
How does this FORESEE result improve your infrastructure's management?	This result achieves a resilient infrastructure against its specific risks, thus improving its management against them. **ADDED VALUE OF THE TOOL**

<table>
<tr>
<td>If it was not made, how does this FORESEE result improve your infrastructure's management?</td>
<td>The FORESEE tool confirmed that the decision-making of infrastructure design, in the face of specific risks, was very adequate.

POTENTIAL TECHNICAL BENEFIT AFTER THE TOOL'S ADOPTION</td>
</tr>
<tr>
<td>What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year;
reduction of maintenance costs (20%-25%),
Return on Investment (ROI) – 10-15%,
increase in productivity 25-30%)</td>
<td>Reduction of maintenance costs (20%-25%),
Return on Investment (ROI) – 10-15%
Increase in productivity 25-30%)

EXPECTED BENEFIT AFTER THE TOOL'S ADOPTION</td>
</tr>
<tr>
<td colspan="2"><u>FLOODING METHODOLOGY</u>
Most often, to obtain the flood risk associated with some return period, the associated floods are obtained from the hyetographs corresponding to each return period and, by means of hydrological modeling, obtain the associated flood hydrograph to determine flood depths. In short, the extreme regime is obtained for precipitation and then, this extreme regime is assigned to every other derived variable, that is, it is normally assumed that the 100-year return period rainfall induces the 100-year return period flood. However, in this study, a new methodology is proposed in which the precipitation series of the existing rain gauges are taken as starting data. This allows, by means of hydrological simulation, the obtaining of flow series from which the events that exceed a certain threshold beyond which flooding occurs are selected. Once the events have been selected, thousands of years of flow events are generated synthetically through a copula model (Ben Alaya et al., 2014). Due to the need to simulate hydrology and subsequently the use of a hydraulic model, it is necessary to select a reduced number of synthetic events using data mining methods (Camus et al., 2011). To calculate the threat produced for a certain return period, the extreme statistics are computing for the flood depth and speed, not for the precipitation as in the traditional methodology. The proposed approach assumes explicit consideration of flood statistics, including some of the uncertainty that other methods overlook.
There is another variant to this methodology, which is to synthetically generate precipitation events from the separation of time series events of this meteorological variable and subsequently follow the same process. But in this case, there is the limitation that long series with an hourly time resolution are needed, which are occasionally not available.</td>
</tr>
<tr>
<td>Was this type of analysis made before FORESEE? How was it made?</td>
<td>This type of analysis was not done before FORESEE.
It was done through expert judgment.

COMPARISON AGAINST CURRENT TOOLS</td>
</tr>
<tr>
<td>How does FORESEE improve the results/analysis previously made?</td>
<td>FORESEE defines a specific infrastructure for this type of risk.

DESCRIPTION OF CURRENTLY USED TOOLS</td>
</tr>
</table>

How does this result increase the resilience of your infrastructure?	The FORESEE result significantly increases resilience, to the maximum for this risk type. **RESILIENCE TOOL**
How does this FORESEE result improve your infrastructure's management?	This result achieves a resilient infrastructure against its specific risks, thus improving its management against them. **ADDED VALUE OF THE TOOL**
If it was not made, how does this FORESEE result improve your infrastructure's management?	The FORESEE methodology confirmed that the infrastructure design, in the face of specific risks, was very adequate. **POTENTIAL TECHNICAL BENEFIT AFTER THE TOOL'S ADOPTION**
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	Reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15% Increase in productivity 25-30%) **EXPECTED BENEFIT AFTER THE TOOL'S ADOPTION**

CASE STUDY #4 – RAILWAY TRACK 6185 (OEBISFELDE-BERLIN SPANDAU)

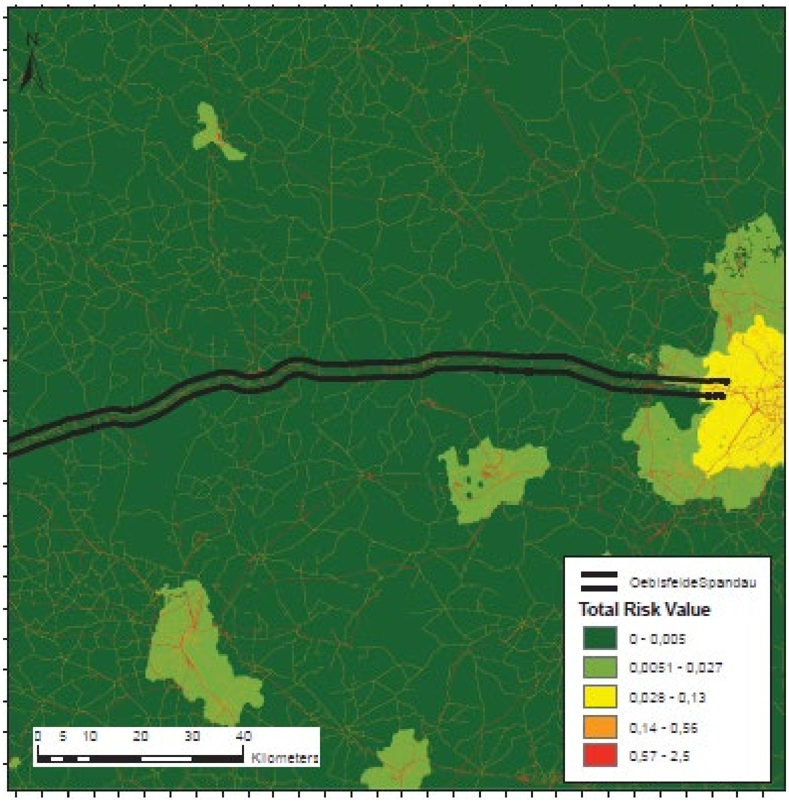
Objective & Description	This case study (CS) focusses on flooding hazards on railway tracks on the German railway track no. 6185 between Oebisfelde and Berlin-Spandau, which is part of the high-speed railway (HSR) Hannover – Berlin (HB). The approximately 150 km long track section between Oebisfelde (267,9 km) and Berlin-Spandau (112,7 km) supports approximately 170 trains and 10,000 passengers per day. The HB-HSR was the first German line constructed with mostly slab (ballastless) and can sustain maximum train speeds of up to 250 km/h. The HB-HSR has been selected as the focus of the fourth FORESEE case study due to the track being composed of several bridges that cross the **river Elbe** and several smaller rivers which have all been the location of severe flooding events in recent years (especially the Elbe Flood in June 2013).
Hazard Description	Due to former flooding events (especially the Elbe Flood in June 2013), there are data available regarding risks and damages caused by flooding. As a result of the Elbe flood in June 2013, the Haemerten bridge and an approximately 5 km long track section near Schoenhausen were closed due to flooding. Due to large-scale deviations, delays of one to two hours occurred. The Deutsche Bahn (DB) introduced an interim timetable, which was later changed several times. Regular service was not resumed until months later in November 2013. Due to the actuality, the available data and the impact as an extreme event, the Elbe flood 2013 is used in CS#4 for validation and as a benchmark for evaluation of the FORESEE tools.
Usefulness for infrastructure owners & operators?	This case study will test and validate several tools from the FORESEE Toolkit. The outcomes of this case study will provide infrastructure owners and operators with superior intelligence to support their decision-making processes for the selection and design of technical solutions. In particular, the outcomes will highlight the best technical solutions before (i.e. preparation and preventative), during (event management and control center) and after a hazard event (predictive maintenance and emergency planning).

How does it work?	The main investigation topics regarding the considered operating and maintenance phase are ***flooding impacts on railway operations*** in combination with ***maintenance and contingency plans***. Additionally, the ***effects of flooding to different railway track components*** in dependency of the water level are evaluated (model-based). For the determination of input variables of the influences on railway operations in case of flooding, the case study utilises a traffic simulation model and an Artificial Intelligence (AI) based risk model, which takes former weather data and flooding events into account. The infrastructure and operations model are based on RailSys® and include all the traffic and infrastructure data of the railway track 6185. This also helps to evaluate the effects of different contingency plans to improve restoration works, and select or design the best technical solutions for preventive maintenance. In addition, current guidelines, recommendations for action, and procedures of the Deutsche Bahn (DB) for major incident management are used here for the tool comparison. In this context, existing maintenance, operational and contingency plans (if any) are also analysed and compared. The input variables from the existing models and comparative data mentioned above will be comparatively validated with the output from the newly developed FORESEE tools in order to improve the resilience of the railway infrastructure in the event of hazards.

Case study overview

Key Facts	
Total length:	150 km
Location	
East end:	Berlin
West end:	Hannover
Train and passenger flow	
Trains per day:	170
Passengers per day:	10,000
Pilot focus	
Area:	Section between Oebisfelde (267,9 km)

	and Berlin-Spandau (112,7 km)
Main threats	
Type:	Flooding, heavy rain, rising river tides



Total risk map obtained for [CS#4. Railway track 6185 Oebisfelde – Berlin Spandau in Germany]

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service and Resilience	Guidelines have been adapted by the infrastructure manager, including real data.
Resilience Guidelines to Set Resilience Targets	
Bridge Flooding Model	Case study leader reviewed and compared the results coming from the tool with the already available procedures.
Risk Mapping	
Command and Control Center	
Definition of framework: use cases, risk scenarios and analysis of impact	
Design, construction and remediation plans	
Operational and maintenance plans	
Management and contingency plans	

On the next page, a summary to the main results that have been validated in this case study is presented as an introduction to the explanations to be provided during the next workshop.

Further information and complementary documents will be available before the workshop.

The Conclusion report of all the results that have been validated in this case study will be public and accessible to the audience. The FORESEE SRG members can also have access to specific documents of any result of their interest. These requests can be addressed to:

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Project Coordinator:	Iñaki Beltrán	Inaki.beltran@tecnalia.com
Case Study #4 Leader:	Sebastian Kantorski	sebastian.kantorski@ivembh.de

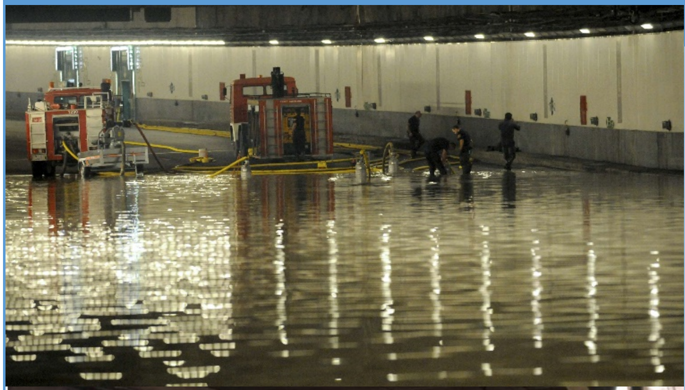
Main validation from CS#4	
BRIDGE FLOODING MODEL To validate the Bridge flooding model, the Elbe bridge at Haemerten is simulated. The situation around the Elbe bridge Haemerten is chosen because of the damage caused by the Elbe flood in 2013. The model consists of the parts earthworks, railway overpass, superstructure and a culvert. In the model, the water level can be increased step by step to find out which damages are associated with which water level. In the model, a design flood level of +7.50 m is assumed for the Haemerten Bridge as a 100-year event. The water level is assumed because the levels of the peak wave of the Elbe flood in 2013 had levels between approx. +7.00 m and +10.00 m. In the model, operation is no longer possible from a water level of +3.30 m, as the level of the track in front of and behind the bridge has been reached. From water level +5.00 m the culverts are flooded and from water level +11.75 m the bridge or railway overpass itself.	
Was this type of analysis made before FORESEE? How was it made?	The requirements for constructions are statically defined in guidelines (Ril). With regard to railway bridges, the guideline catalogue Ril 836 sets requirements for earthworks including culverts. The design flood level is also defined here.
How does FORESEE improve the results/analysis previously made?	Compared to the currently used guidelines, this tool enables a water level dependent assessment of usability by means of an updatable and adaptable simulation model to assess the best technical improvements of railway track components.
How does this result increase the resilience of your infrastructure?	This tool contributes to enhance the presence of a maintenance strategy and the extent of interventions executed prior to the event.
How does this FORESEE result improve your infrastructure's management?	The added value of the tool is to develop measures to optimise track components which can reduce the probability or the intensity of the damage in the event of flooding.
If it was not made, how does this FORESEE result improve your infrastructure's management?	The validation of the tool's adoption indicates in this case as a result that the arrangement of additional culverts and water-resistant installation of electrical control and safety systems (LST) have the most potential technical benefit.
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	The Bridge Flooding Model can help to identify optimal solutions to reduce the probability or intensity of damage and thus directly the maintenance costs. This is not about a realistic and detailed planning of individual measures, but about the development of fundamental strategies to avoid a repetition of the consequences of flooding like the one in summer 2013 at the Elbe with total damage to the infrastructure in the amount of 150 million euros.

Main validation from CS#4	
COMMAND AND CONTROL CENTER The Elbe flood 2013 is also used for validation of the Command and Control Center as a benchmark, since there is plenty of data available for this main event regarding automatised findings of potentially dangerous outliers and anomalies from the normal state in Big Data of hazard events. The input variables are historical water levels provided by the Waterways and Shipping Authority (WSV) from the (near) gauge stations of interest at Wittenberge, Tangermünde and Strombrücke in the period 1997 to 2018. This data is supplemented with precipitation data from the German Weather Service (DWD). The validation of the determined output data shows that the dam break at Fischbeck on 10 June 2013 (in the immediate vicinity of the Haemerten railway bridge) is recognised as an anomaly by the Command and Control itself with the aid of the Big Data analysis and could have generated an automated warning.	
Was this type of analysis made before FORESEE? How was it made?	There are currently no comparable tools available.
How does FORESEE improve the results/analysis previously made?	Since no comparable tools are currently available or can be described, the Command and Control Center offers completely new functions for Big-Data-based automated and early hazard detection and risk prevention.
How does this result increase the resilience of your infrastructure?	This tool contributes to enhancing the operational management and monitoring during a hazard event as well as an ad hoc updating possibility of emergency plans in real time.
How does this FORESEE result improve your infrastructure's management?	The main added value of the tool is the ability to automate decisions from previous events for the present and future. This type of situational awareness (SA) organises large amounts of data and summarises them so that a human operator can process them.
If it was not made, how does this FORESEE result improve your infrastructure's management?	Finding potentially dangerous outliers and anomalies from the normal state in Big Data of hazard events in real time to generate automated alerts indicates the most potential technical benefits after the tool is implemented.
What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	The positive expected effects of the Command and Control Center are essential for this case study as it is the only tool with the possibility of an ad hoc (during the event) update of emergency plans. In addition to this new and important safety feature, the real-time automatic warning can also save working hours in manual operation monitoring and thus increase productivity.

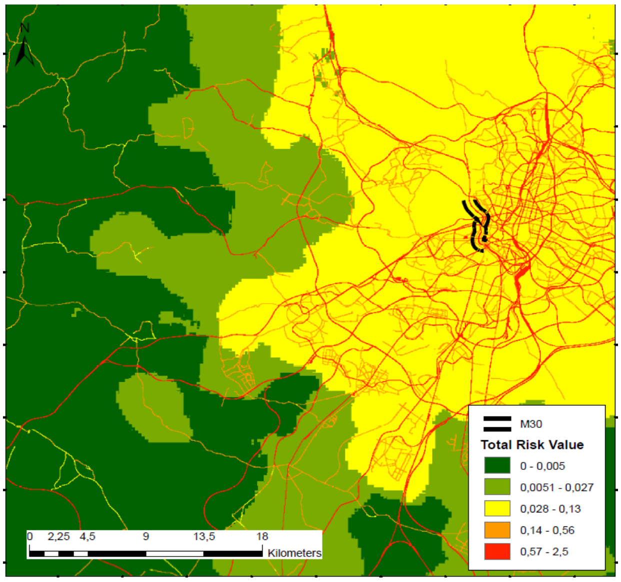
CASE STUDY #5 - M30 MADRID (SPAIN)	
Objective & Description	This case study (CS) will test and validate the FORESEE toolkit (in the Madrid Calle 30 Ring Road, Spain) in order to select and design the best technical solutions for preventive maintenance, future maintenance, continency and emergency interventions and to set up of procedures for events management.
Hazard Description	**Cyber-Attack** CS#5 is the only FORESEE case study that investigates a direct anthropogenic hazard such as cyber-attacks. Although the "hacking hazard" is relatively new within the sphere of transport infrastructure, incidents have been reported resulting in significant disruptions (see Haifa Highway Cyber-attack (2013)). Cyber-attacks have a broad range of potential consequences that can arise from a successful attack. Namely, a malfunction of specific systems, disruption of the network control centre, resulting in loss of partial or complete control and visibility of operating systems, rendering the operation unsafe, and, in the worst case, causing direct or indirect fatalities. **Flooding** As part of the FORESEE programme, the Environmental and Hydraulics Institute "IHCantabria" have produced a novel methodology for improving the estimation of return periods of flooding events. This innovative procedure aims to provide a better understanding of the true magnitude of disruptive flood events. With the aid of Calle 30 and Ferrovial Construction, the methodology has been applied to the M-30 motorway to check its response against low frequency events at two specific locations along the Manzanares River: - Upstream of "Puente de Toledo" - Upstream of DamNº9 **Fire** Another hazard that has been analysed and studied for the M-30 Ring Road case scenario is fire. Some fire dynamic simulations that are explained in the deliverable D7.4 have been performed in this pilot.

Usefulness for infrastructure owners & operators?	The main use of this case study is to provide infrastructure owners and operators with superior intelligence to mitigate the risk posed by cyber-attacks, flooding and fires. Also, this case study is one of the first to consider the impact of a cyber-attack on a critical infrastructure. Thus, it can be used by infrastructure owners and operators to improve resilience levels of their infrastructure in the case of a cyber-attack event.
How does it work?	Real world data will be utilised to highlight the advantages of predictive maintenance strategies. The data gathered includes traffic and speed of vehicles, weather and intelligent transport systems out of service.

Case study overview



Key Facts	
Total length:	220 km
Location	
Regions:	Madrid, Spain
Highway system	M30 (Circles the central districts of Madrid)
Traffic flow	
Vehicles per day:	200,000
Main threats	
Type:	Cyber-attacks, flooding, fire



Total risk map obtained for [CS#5. M-30 ring-road in Madrid – Spain]

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service and Resilience	Guidelines have been adapted by the infrastructure manager, including real data.
Resilience Guidelines to Set Targets	Guidelines have been adapted by the infrastructure manager, including real data.
Traffic Module	CS leader provided the traffic and asset data and traffic management expertise. Then the CS leader reviewed the outputs coming from the traffic module and provided their overall considerations of the tool and the results.
Flooding Methodology	CS leader provided the raw climatic data. Then the Ferrovial Hydrological department did the HEC-HSM hydrological simulation and the HEC-RAS hydraulic modelling. Results coming from the new flood elevation reconstruction and the calculation of the return periods have been checked.
Hybrid Data Fusion Framework	CS leader provided the traffic and asset data and traffic management expertise. Then the CS leader reviewed the outputs coming from the Hybrid Data Fusion Framework and provided their overall considerations of the tool and the results.
Command and Control Center	CS leader provided traffic data and the specific dates when a flooding event happened. Command and Control Center results have also been checked.
Definition of framework: use cases, risk scenarios and analysis of impact	The CS leader used the tool, reviewed and compared the results with the already available procedures.
Design, construction and remediation plans	CS leader reviewed and compared the results with the already available procedures.
Operational and maintenance plans	CS leader reviewed and compared the results with the already available procedures.
Management and contingency plan	CS leader reviewed and compared the results with the already available procedures.

Case Study Outcomes
Case scenarios for cyber-attack, flooding and fire.
Application of a new methodology for improving the estimation of flooding frequencies in the M-30.
Generic actions to be adopted to improve resilience level of the transport system in the case of a cyber-attack event.
Analysis of the infrastructure control systems, and their vulnerability in case of a cyber-attack.
Alternatives for crisis management in the total failure of the Main Control Center.
Recommendations to improve the resilience of the M-30 Ring Road.
Comparison between the existing management plans of the M-30 and the updated ones developed as part of the Foresee Project.
Potential improvements of the Toolkit for real commercialisations.
Socioeconomic analysis for a cyber-attack event
Contingency and emergency updated plans considering a dynamic perspective of fire simulations

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Main validation from CS#5

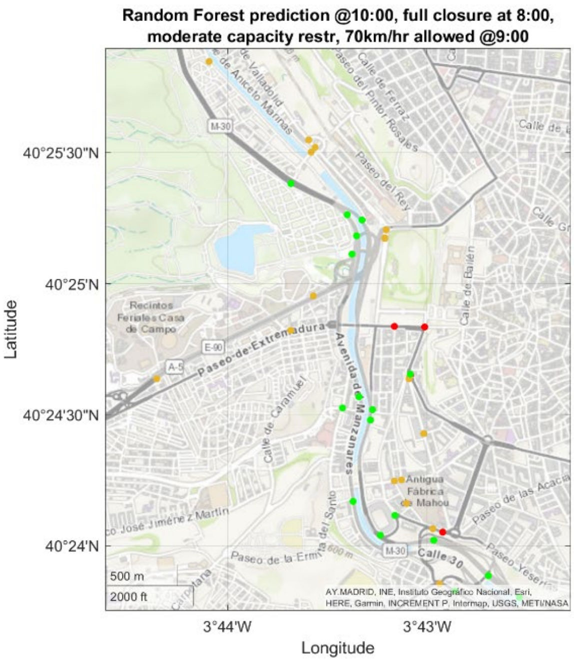
HYBRID DATA FUSION FRAMEWORK

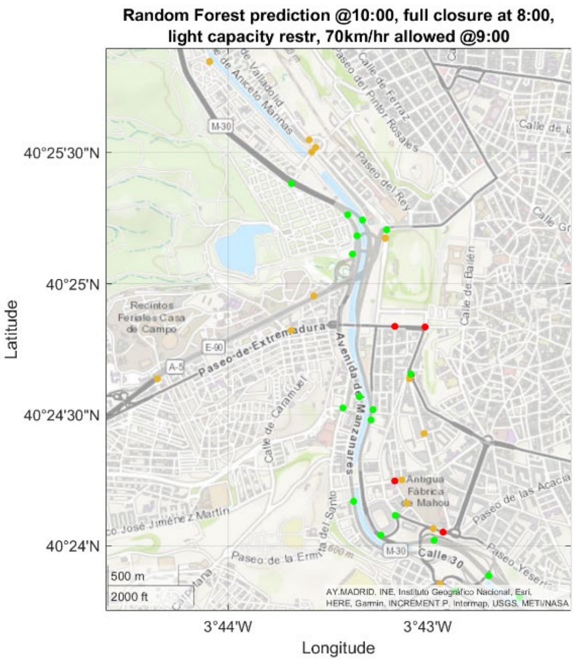
Two classes of tools were presented and further described in Deliverable 4.6, namely Bayesian Networks and Random Forests, which reflect a learning framework trained on heterogeneous (hybrid) data. Such data can be obtained either via monitoring information and telemetry, or from simulations exploiting appropriate models.

Bayesian Networks (BNs) have, within the Tasks 4.4. and Task 5.2.1 FORESEE context, primarily been developed as tools for classification for the purpose of diagnosing faults, or occurrence of events under extremes. BNs come with a probabilistic description, which ideally situates them as aids for decision support.

On the other hand, the Random Forest (RF) framework is within the FORESEE toolkit, primarily set up as a tool for regression, i.e., prediction of the value of a continuous Quantity of Interest (QoI), which is thought critical for driving decisions under occurrence of an extreme event. This is the case in prediction of the evolution of traffic flow and distribution within a network, particularly in the face of extreme events (e.g. flood or cyber-attack). This tool, which comprises a further graph-based machine learning approach, has been demonstrated on an illustrative example that draws from CS#5 – The Madrid Ring Road. This simulation, which was delivered as part of Deliverable 4.6, involved an artificial highway network, serving as an imitating case study, allowing for conceptualization and demonstration of the predictive algorithm. Telemetry information from the nodes (links) of this network is assumed available, with the RF used to **predict the k-hour-ahead traffic intensity level** on a given node, given context information, such as **weather** (precipitation) **or events** (e.g., sporting events, or cyber-attacks).

The outcome of the predictions of the tool aim to support decisions on road closure, based on the predictions of the trained Random Forest algorithm regarding the expected loading (traffic flow & speeds) of the network.

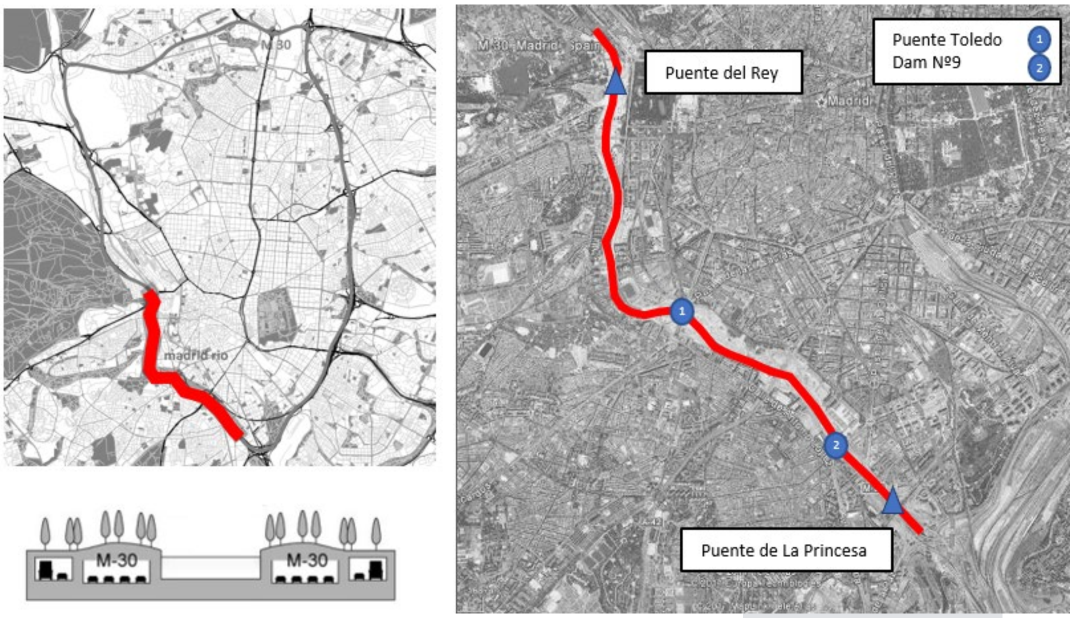




Was this type of analysis made before FORESEE? How was it made?	This is a module that predicts the k-ahead traffic by using two types of algorithms and relying on heterogeneous data. They are able to learn from traffic simulations and give future predictions based on this previous learning. Traffic simulations are done by using commercial software; however, this kind of analysis has never been done before.
How does FORESEE improve the results/analysis previously made?	This kind of study has never been applied before.
How does this result increase the resilience of your infrastructure?	It allows you to predict how the traffic will be after a hazard depending on how you manage it.
How does this FORESEE result improve your infrastructure's management?	It gives you additional information to value the impact of partially or totally closing some lines or the whole section of the tunnels.
What cost/resource efficiencies you expect these tools/results to have on your day-to-day business? (e.g. decrease in working hours over the first year; reduction of maintenance costs, Return on Investment (ROI), increase in productivity.	The application of this tool can reduce travel time, the traffic volume at a future time and the cost of travel time after a hazard event. It is complicated to quantify the impact in terms of cost or ROI, but it will surely have an important impact.

FLOODING METHODOLOGY

The proposed methodology has been applied in a study of the Manzanares River in Madrid (Spain). More precisely, this study focusses on the stretch of the river that runs parallel to the M-30 motorway and is affected by the undergrounding works conducted in 2007. The next figure shows the stretch of the Manzanares River under study, starting at “Puente del Rey” and finishing 700m downstream of “Puente de La Princesa”.



The main methodology is based on the methodology proposed (IH Cantabria, 2020) where the main source of the work is the flow series. In this case, we start from a situation in which we have hourly information on precipitation at the basin's stations. With hourly information at the stations in the basin, it is possible to characterise in detail the hyetograph corresponding to the storm events at each station.

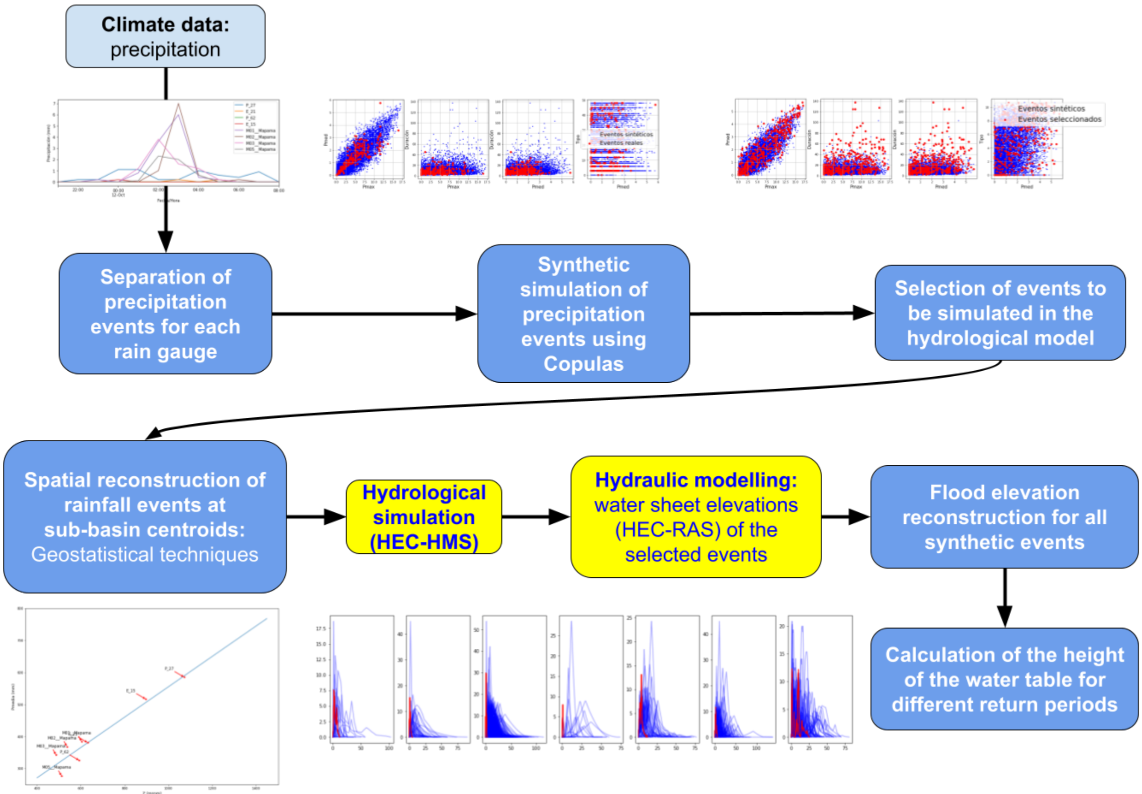
Furthermore, by having simultaneous information at all stations, it is possible to simultaneously characterise the correlations between stations. With this information, the stochastic generator can be calibrated to perform the flood analysis.

The stochastic generator is calibrated to reproduce the most important precipitation statistics at each station (mean rainfall, maximum rainfall, event duration, etc.). The generator automatically reproduces the observed correlations and therefore serves to produce realistic rainfall events at all stations simultaneously.

The generator would be used to produce multiple events (equivalent to several decades or centuries of observations). From this database of events, the most representative events would be selected for dynamic simulation, i.e., for transformation into flood elevation through the hydrological and hydraulic model. Once this dynamic transformation has been carried out, machine learning methods (statistical) are used to calculate the flood level and flow of the remaining cases.

Finally, an extremes analysis is carried out on the flood elevation time series.

The next figure shows an outline of the methodology developed in this study.



Was this type of analysis made before FORESEE? How was it made?	This is a new methodology to calculate the flood elevation reconstruction for all synthetic events, and to calculate the height of the water table for different return periods. This is something that is always done during the design and construction phase, but by using the current methodologies included in the Spanish code.
How does FORESEE improve the results/analysis previously made?	It allows the creation of a better design for the infrastructure considering a new methodology that is more accurate
How does this result increase the resilience of your infrastructure?	Taking into account the hazard of flooding, this methodology is stricter. Therefore, designing the infrastructure using this novel approach will lead to a more resilient infrastructure.
If it was not made, how does this FORESEE result improve your infrastructure's management?	This tool is useful during the design and construction phase. For management purposes, it can give you decision support if some reconstruction or elevation of the water defences is needed.

What cost/resource efficiencies do you expect these tools/results to have on your day-to-day business? (e.g. decrease in working hours over the first year; reduction of maintenance costs, Return on Investment (ROI), increase in productivity	It will highly reduce the maintenance cost if a flooding event bigger than the calculated during the design phase is triggered

SOCIO ECONOMICAL STUDY CONSIDERING A CYBER-ATTACK - IMPACT ON TRAFFIC AND ALTERNATIVE ROUTES

Calle 30 is made up of a system of tunnels, connection galleries with the exterior, connections with other infrastructures and emergency galleries, interrelated with each other, and with a single Main Control Centre, which means that if one section is affected, the safety of the rest will be compromised.

As a preliminary starting point, any intrusion by means of a cyber-attack on the management systems of the Calle 30 Control Centre, provided that one of the systems or subsystems considered critical has been affected, should mean that access to and evacuation of the tunnel system should be cut off, until the possible scope of the attack is known.

It is logical to think that if the cyber-attack is executed by experts through this type of actions, it will be carried out in such a way that it will be difficult to attribute initially the loss of control to an attack of this type, then the time of incidence will be longer.

For this reason, we consider that the first thing should be to generate tools that allow ruling out other circumstances or failures as quickly as possible, in order to be able to quickly take the actions to neutralize and reduce the damage caused.
Therefore, we proceed to describe the scenarios that we consider possible, detailing the severity of the consequences from least to greatest:

- Is a cyber-attack the control system failure reason?
- Does the Control Center maintain total or partial management capacity?
- Is the cyber-attack only limiting the Control Center's ability to operate?
- Does the cyber-attack allow the intruder to maliciously operate management systems?
- Once the questions have been answered, we proceed to describe the possible affected systems.

It should be noted that in the operational response protocol, the actions to be taken immediately by the M-30 Ring Road Control Center will be detailed to guarantee the safety of users and operators, even in these circumstances.

But in the scenario that occupies us, we must pay our attention to the services, systems, and critical facilities affected.

For this reason, and in order of severity, we list those facilities that we consider critical, even if they only manage to simulate the failure in the system, a series of actions or decisions can be triggered that would generate dangerous situations.

- Tunnel closure system
- External and internal power supply
- Ventilation system
- Firefighting control system and equipment, water mist system
- Lighting system
- Variable Signalling system
- Video surveillance system, DAI
- SOS Calling points / PA / VA systems
- Analysis and control systems for environmental factors
- Evacuation management systems
- Communications equipment

Social Impact

In this section we include the effects on the following matters:

- Environmental aspects:
  - Derived from the environmental pollution that will be produced due to the circulation of all the vehicles on the surface, without the corrective factor of the elimination of harmful gases through the filtering elements in the circulation tubes, in the ventilation systems, which means that the air released to the outside is free of polluting elements.
  - Effects derived from the generation of an increase in noise, due to the surface traffic of all the circulation.
- Social aspects:
  - Decrease in average speed on equivalent journeys, due to congestion on surface roads, due to the increase in traffic.
  - Increased travel times on equivalent journeys, due to lower average speed.
  - Increased accident risks as a result of the increase in traffic intensity, possible adverse weather phenomena, and the composition of traffic, in which heavy traffic is present, and even the possibility of the circulation of dangerous goods.
  - Increased access times for emergency vehicles due to traffic congestion and complexity.

Economic Impact

While it is true that direct and, in some cases, indirect costs are derived from all the social and environmental impacts, there are others that are inferred directly from the cyber-attack event itself.

- Damage caused to the management system itself, and the costs of restitution.
- Possible damage caused to the infrastructure, caused directly or indirectly, among which we highlight:

- Possible flooding as a consequence of the stoppage of the leakage control pumps.
- Damage to pipes as a result of uncontrolled start-up of water mist systems.
- Damage due to uncontrolled operation of ventilation systems.
- Damage to evacuation systems and subsystems (external ramps, pressurisation systems and others).

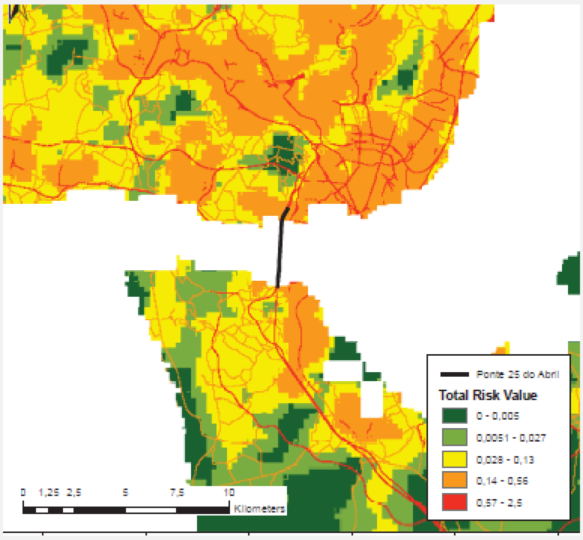
- Increase in the economic cost of travel times, for which the tables in the previous deliverables will be used.
- Possible claims from users of the infrastructure, due to loss of capacity and collateral damage.

# CASE STUDY #6 - 25TH APRIL SUSPENDED BRIDGE - LISBON (PORTUGAL)	FORESEE PROJECT
Objective & Description	The 25th April suspension bridge is a multimodal rail and road megastructure that connects the city of Lisbon to the municipality of Almada. The bridge has been selected as the sixth case study for the FORESEE project due to its location in a region of significant seismic activity. This case study focusses on earthquake hazards on the 25th April suspension bridge to evaluate, test and validate, through the FORESEE Tools, the project outcomes regarding risk assessment. Also, to select and design the best technical solutions for preventive maintenance to plan future maintenance, the enforcement of the contingency plan and the emergency procedures, traffic management analysis and to set up procedures for events management to ensure users' safety, using the tools for a comparative analysis with a previous disruptive event and with the already available procedures.
Hazard Description	The primary hazard considered as a threat to this structure is an earthquake. To a similar extent, man-made hazards such as rail accidents pose a substantial threat to the resilience of the structure. Hence, for resilience improvement, indicators regarding the infrastructure, the environment, and organisation, among others are being considered.
Usefulness for infrastructure owners & operators?	The outcomes of this study will seek to achieve safer and cost-effective maintenance operations while considering current traffic flow, social dimension and psychological aspects of earthquakes and rail accidents, as well to promote the enforcement of the operational, maintenance, contingency plan and the emergency procedures with a special focus on the management of people (communication, contingency, emergency and evacuation) during and after the event.
How does it work?	The 25th April Bridge has been studied in two different scenarios, which impact upon the regular service of the road and railway traffic: • **Earthquake**: risk of moderate to severe events which may bring partial or total closing of the bridge to evaluate, through the FORESEE tools, the enforcement of the operational, maintenance, contingency plan, and the emergency procedures. • Simulation of a train accident with a special focus on the management of people (communication, contingency, emergency, and evacuation)

during and after the event: using the tools for a comparative analysis with actual procedures and a previous disruptive event.

Case study overview

Key Facts	
Total length:	2300 m
Central span:	1012 m
Clearance below:	70 m
First opened:	1966
Location	
Regions:	Lisbon, Portugal
Traffic flow	
Users per year:	100 million
Main threats	
Type:	Earthquake, railway accidents



Total risk map obtained for [CS#6. 25th April suspended bridge. Portugal.]

List of FORESEE tools selected to improve the resilience of this infrastructure are:	Validation process
Resilience Guidelines to measure Level of Service and Resilience	Guidelines have been adapted by the infrastructure manager, including real data.
Resilience Guidelines to Set Resilience Targets	
Risk Mapping	Hazard maps and risk maps of the infrastructure's area to identify the risks prior to the more accurate and more local scale quantification, were produced. Case study leader reviewed and compared the results coming from the tool with the already available procedures.
Traffic Module	Case Study leader provided the traffic and asset data and traffic management expertise. Then the Case Study leader reviewed the deliverable and provided their overall considerations on the tool.
Command and Control Centre	Case Study leader provided the traffic and asset data and traffic management expertise. Then the Case Study leader reviewed the deliverable and provided their overall considerations on the tool.
Definition of framework: use cases, risk scenarios and analysis of impact	Case study leader reviewed and compared the results coming from the tool with the already available procedures
Design, construction and remediation plans	
Operational and maintenance plans	
Management and contingency plan	

Further information and complementary documents will be available before the workshop.

The Conclusion report of all the results that have been validated in this Case study will be public and accessible to the audience. The FORESEE SRG members can also have access to specific documents of any result of their interest. These requests can be addressed to:

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AISCAT:	Federico Di Gennaro	federico.digennaro@aiscatservizi.com
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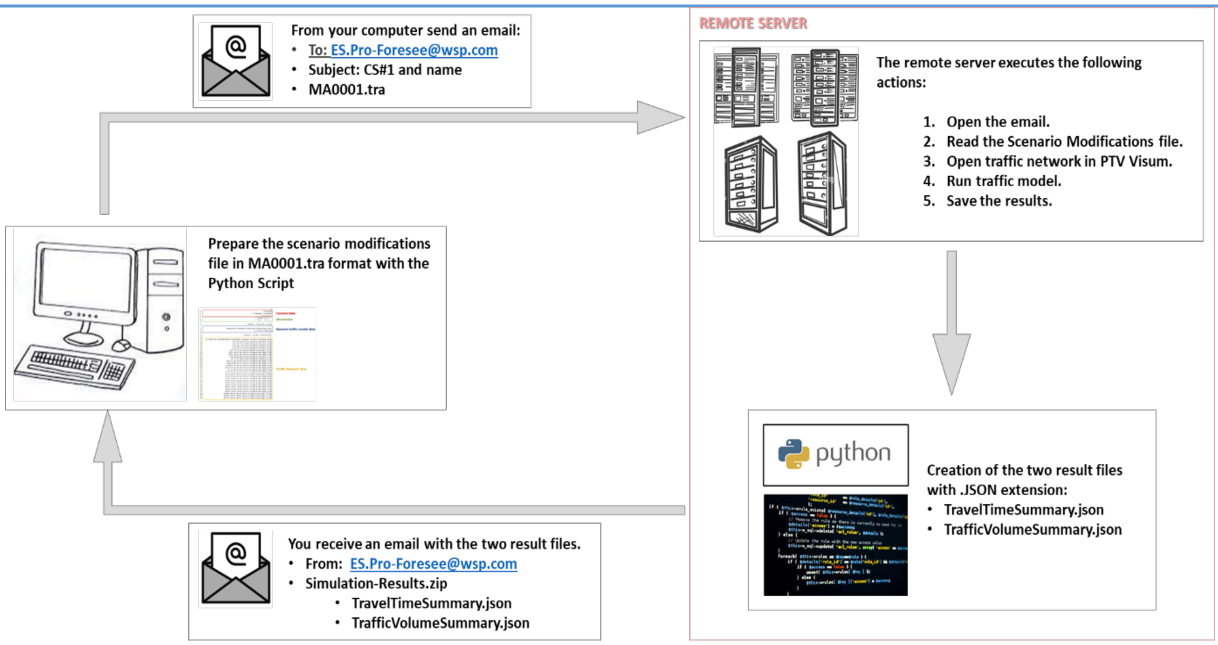
3 RESULTS FACT SHEETS

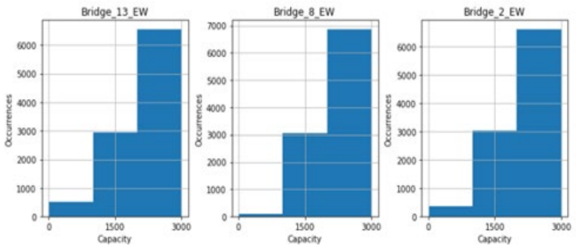
TRAFFIC MODULE TOOL	
Objective & Description	The Traffic Module includes a multiscenario software script that makes use of existing traffic simulations, through traditional traffic analysis tools, to estimate the potential loss of service associated with multiple values of resilience indicators using stochastic algorithms. The purpose of the Traffic Module is to enable resilience measurements with traffic simulations even when some uncertain input parameters are present.
Connection with resilience	Traffic simulations are very powerful tools to measure and compare the service provided with and without events and interventions. This module has enabled Monte-Carlo simulations to be used in conjunction with traffic modelling tools to assess the resilience of traffic to disruptive events on road structures. The integration of Monte-Carlo simulations in a traffic model has made it possible to assess the uncertainty in the resilience analysis.
Usefulness for infrastructure owners & operators?	The traffic module will allow them to assess different probabilities of a disruptive event occurring in the infrastructure and to forecast traffic behaviour in the moment when the event occurs. Therefore, by applying the traffic module they will be able to identify mobility patterns both currently and in case of capacity reduction caused by a disruptive event.
How does it work?	The traffic module combines Monte Carlo simulations of the probability of occurrence of a disruptive event with simulations of traffic behaviour in a traffic model developed ad-hoc for the Case Study. The traffic module runs on a remote server that allows partners to simulate scenarios remotely.
FORESEE linked document	T 3.4., D 3.7. Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	WSP Contact person: Herrera, Antonio antonio.herrera@wsp.com Antolin San, Gonzalo Gonzalo.Antolin@wsp.com

Application example
The traffic module has been fully applied to CS#1 "Carsoli - Torano". In CS#1, a system has been developed to remotely analyse different scenarios of disruptive events in infrastructures. Additionally, we have developed traffic models for CS#3 and CS#5 that have allowed us to contribute to the results of other deliverables of the project (4.8).

Step by step Toolkit's usage example
STEP 1. Writing the MA00001.tra (this file includes the capacity modifications of the infrastructures to be evaluated with the traffic model) file from the Python script.
STEP 2. Send an email to ES.Pro-Foresee@wsp.com with the MA0001.tra file with the subject "CS#1".
STEP 3. Running the traffic module on the Remote Server. The server receives the modification file and applies it to the Visum traffic model to obtain the traffic variable results.
STEP 4. Preparation of the scripts with the two output files of the Visum traffic model results (travel time and traffic volume data).
STEP 5. An email is received with the two scripts elaborated in the Remote Server from the results obtained in the Visum traffic model.



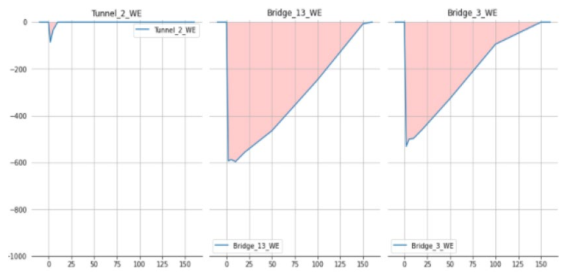
Application of the FORESEE Toolkit to the Case Studies



Histogram results on capacity loss per infrastructure - 2 days after the event

Days after the event	Capacity		
	3000	1500	0
2	0.6036563638119635	0.34660427194155485	0.04973936424648183
5	0.6133342965738275	0.34362739466153824	0.043038308764634145
10	0.6199009662625932	0.3413723331054643	0.03872670063194242
20	0.6324786476895234	0.33650350869908036	0.031017843611396142
50	0.6904273718298933	0.3037580119752145	0.005814616194891972
100	0.8317130065708863	0.1682869934291136	0.0
150	0.9958699035432623	0.004130096456737687	0.0

Example of the normalised probability values for Bridge_1_EW



Mean Value results on capacity loss per infrastructure link and period after the event

Asset	AUC
Bridge_1_WE	-50,589.075
Bridge_1_EW	-50,589.075
Bridge_13_EW	-50,510.850
Bridge_13_WE	-50,510.850
Bridge_5_EW	-50,149.200
Bridge_5_WE	-50,149.200
Bridge_4_EW	-46,312.275
Bridge_4_WE	-46,312.275
Bridge_11_EW	-46,303.650
Bridge_12_EW	-46,108.200
Bridge_10_EW	-45,361.950
Bridge_9_EW	-45,281.925
Bridge_2_WE	-41,707.500
Bridge_2_EW	-41,707.500

Asset	AUC
Bridge_7_EW	-38,814.525
Bridge_7_WE	-38,814.525
Bridge_6_WE	-38,814.525
Bridge_6_EW	-38,814.525
Bridge_3_EW	-33,990.075
Bridge_3_WE	-33,990.075
Bridge_8_EW	-28,128.300
Tunnel_1_WE	-355,575
Tunnel_3_WE	-355,575
Tunnel_2_EW	-355,575
Tunnel_2_WE	-355,575
Tunnel_1_EW	-355,575
Tunnel_3_EW	-355,575

Area under the curve (the area under the capacity loss curve is an indicator of the inverse of the resilience)

Parameter	Days after the event	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
Mean (Travel time)	2	0.000	28.514	66.564	106.311	24.011	26.446	59.343	49.699	47.583	40.423
	5	0.000	28.512	66.562	106.314	24.014	26.311	59.190	49.700	47.430	40.270
	10	0.000	28.506	66.556	106.322	24.022	26.057	58.885	49.702	47.131	39.971
	20	0.000	28.500	66.550	106.331	24.031	25.538	58.315	49.704	46.555	39.395
	50	0.000	28.483	66.533	106.355	24.055	24.390	57.021	49.709	45.262	38.101
	100	0.000	28.480	66.530	106.360	24.060	24.925	57.526	49.710	45.775	38.615
	150	0.000	28.480	66.530	106.360	24.060	23.983	56.584	49.710	44.833	37.673
STD (Travel time)	2	0.000	0.146	0.146	0.210	0.210	9.687	10.957	0.046	10.957	10.957
	5	0.000	0.142	0.142	0.204	0.204	9.415	10.650	0.045	10.650	10.650
	10	0.000	0.129	0.129	0.185	0.185	8.517	9.640	0.041	9.639	9.639
	20	0.000	0.114	0.114	0.164	0.164	7.571	8.562	0.036	8.562	8.562
	50	0.000	0.048	0.048	0.069	0.069	3.235	3.648	0.015	3.648	3.648
	100	0.000	0.000	0.000	0.000	0.000	0.109	0.109	0.000	0.109	0.110
	150	0.000	0.000	0.000	0.000	0.000	0.054	0.054	0.000	0.054	0.054

Travel time and STD per O-D in the scenarios analysed (Days after the event)

To jump back to the table outlining each case study and its respective validated tool, click here

FRAGILITY FUNCTIONS, VULNERABILITY FUNCTIONS AND DECISION SUPPORT INTERPRETER MODULE TOOL	
Objective & Description	The approach proposed in The Fragility Functions, Vulnerability Functions and Decision Support Module Tool starts with a description of the different assets of the infrastructure and the hazard scenarios likely to occur in the specific site. Then, several performance indicators of the transport infrastructure are derived from the approach as risk or damage probability indexes, possible loss indications for different hazard scenarios, Level of Service assessment before and after the event, and resilience estimation both at asset and network level.
Connection with resilience	The connection with resilience is given from the multiple list of parameters obtained through the proposed tool, starting from possible losses in case of event occurrence, and the Level of Service assessment before and after the event in order to have a picture of the event consequences over the infrastructure mobility. Furthermore, the resilience has been defined for different interruption events through Recovery Curves that determine the infrastructure functionality over the days after the event occurrence.
Usefulness for infrastructure owners & operators?	The Fragility Functions, Vulnerability Functions and Decision Support Module is a helpful instrument for the infrastructure managers and owners in addressing the economic resources in the achievement of the safety levels required. Using the present tool, it is possible to obtain a bigger picture of the infrastructure vulnerability and possible restoration cost.
How does it work?	The Fragility Functions, Vulnerability Functions and Decision Support Module uses infrastructure mechanical and geometric characterization, hazard description and traffic parameters for the analysis's performance. The tool runs on the Foresee Toolkit and allows partners to simulate scenarios changing the different inputs needed.
FORESEE linked document	T 3.4., D 3.8. Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	RINA-C Contact person: Marcello Cademartori marcello.cademartori@rina.org Saimir Osmani saimir.osmani@rina.org

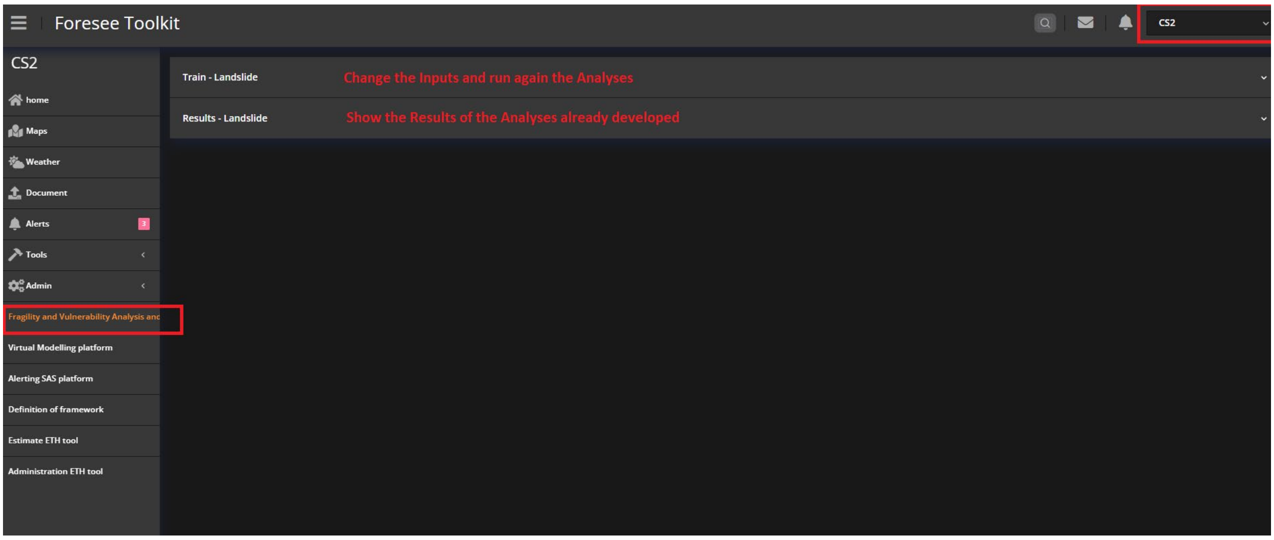
Application example
The Fragility Functions, Vulnerability Functions and Decision Support Module has been fully applied to case study #1 A24 Highway. Additionally, the Fragility Functions, Vulnerability Functions and Decision Support Module has been applied to case study #1, "Carsoli – Torano" Highway. In these

case studies, vulnerability and fragility functions have been developed to analyse different scenarios of disruptive events in infrastructures.

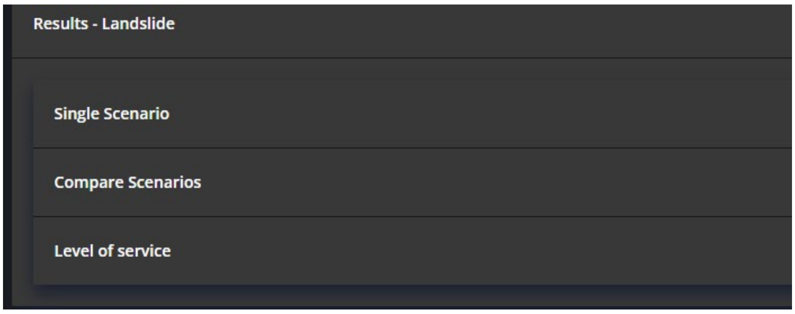
Step by step Toolkit's usage example

STEP 1. Select the Case study and the Fragility Functions, Vulnerability Functions and Decision Support Module Tool.

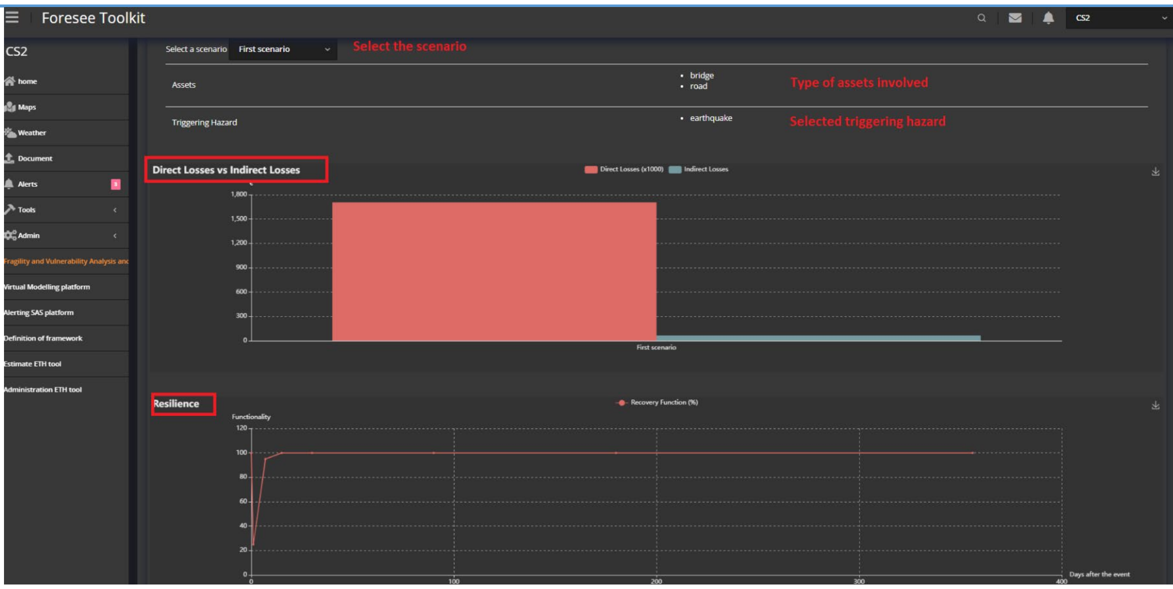
STEP 2. It is possible to show the results of the developed analyses selecting "Results – Hazard" or run again the analyses modifying the inputs selecting "Train – Hazard".



STEP 3. Selecting "Results" will show three possible choices regarding Single scenario, Comparison between scenarios and the Level of Service Assessment.

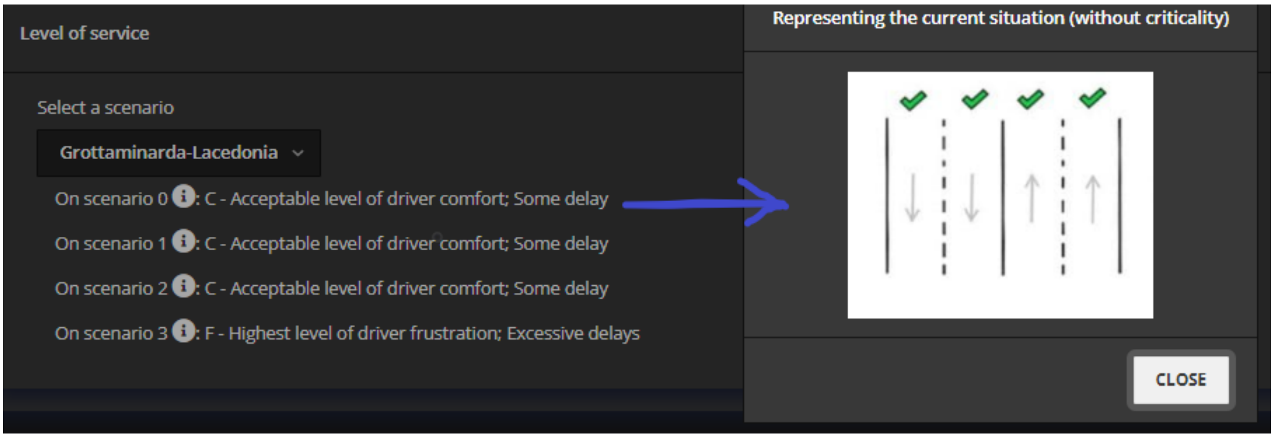


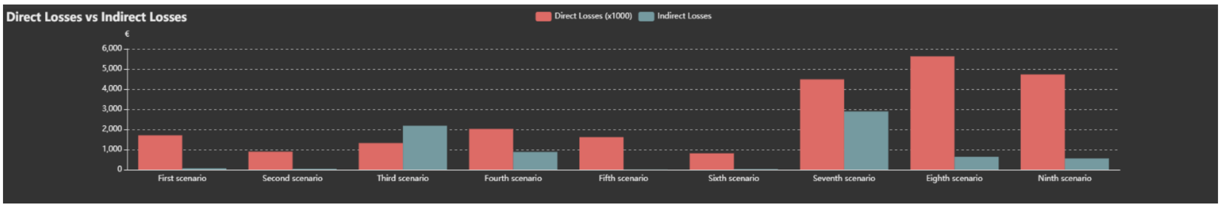
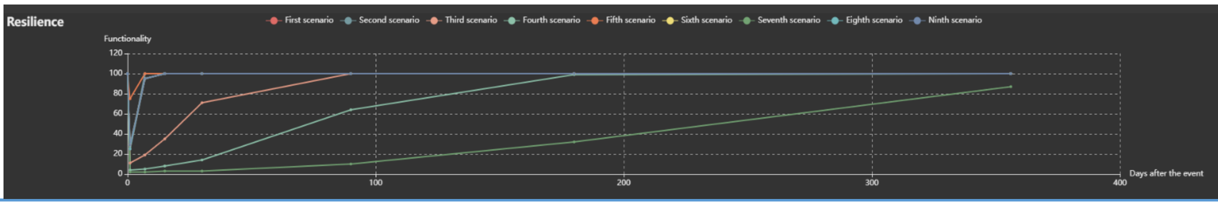
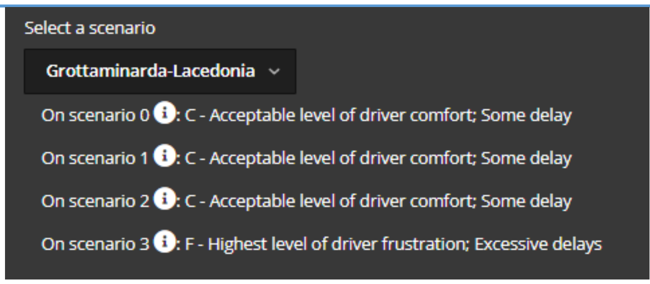
STEP 4. In the first section, the description of the single scenario is illustrated, reporting the hazard considered, the assets involved, direct and indirect losses caused by the scenario and the recovery functions of the Infrastructure section.



STEP 5. In the second section, a comparison between scenarios is illustrated, reporting the direct and indirect losses caused by the scenario and the recovery functions of the Infrastructure section.

STEP 5. In the third section, the Level of Service assessment is shown, comparing the baseline scenario (without hazard occurrence) and the possible disruptive scenarios for the selected Infrastructure section.



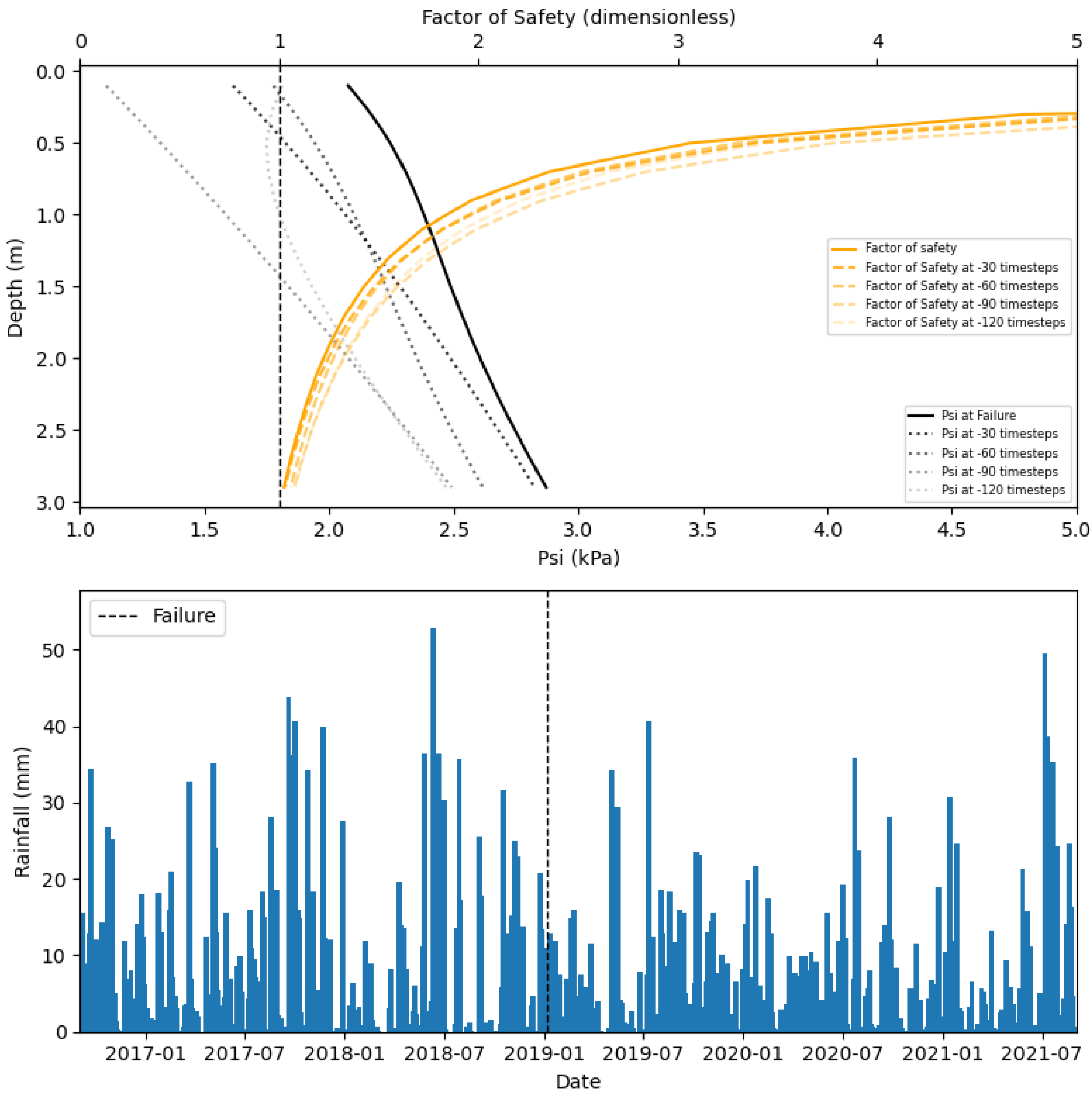
Application of the FORESEE Toolkit to the Case Study 2
 Comparison between scenarios (Direct and Indirect Losses) 
Comparison between scenarios (Recovery Functions)
 Level of Service before the event (Scenario 0) and after the event occurrence (Scenario 1, 2 and 3)

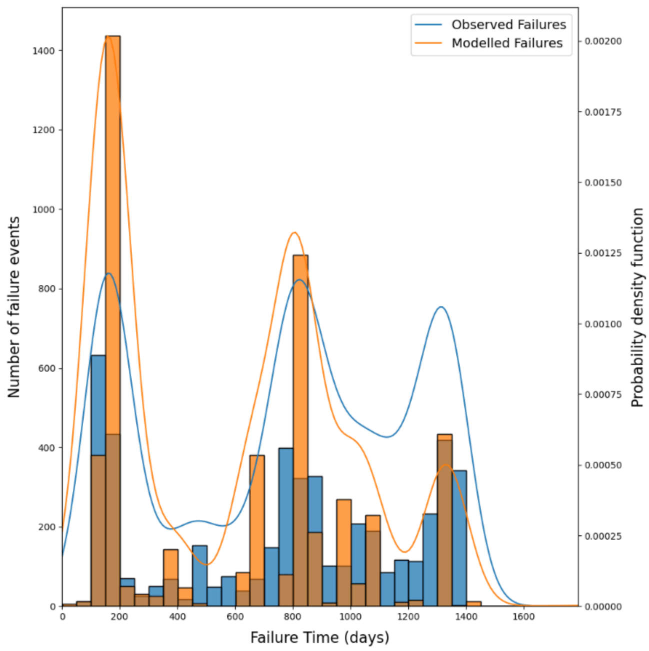
To jump back to the table outlining each case study and its respective validated tool, click here

VIRTUAL MODELLING PLATFORM TOOL	
Objective & Description	The objective of this tool is to calibrate a landslide model using remote sensing data. The calibrated model can then be used for landsliding forecasts.
Connection with resilience	Forecasts from the model can a) help identify predicted rainstorms that might lead to slope failure and b) identify parts of the landscape most sensitive to failure in order to plan mitigation measures.
Usefulness for infrastructure owners & operators?	Infrastructure owners and operators must perform inspections of infrastructure at risk from landsliding and ground motion, and this tool can help in this maintenance schedule. In addition, the tool might provide early warning for landslide failure.
How does it work?	The tool ingests ground motion data derived from radar satellite datasets as an input. It also ingests topographic information (e.g., to calculate slope gradients and water contributing areas) as well as rainfall time series. The tool then performs a calibration step where the ground motion data is used to identify times of “failure” (where ground motion exceeds a threshold), and then a parameter of a slope stability model that best reproduces the observed failure time determined. Once these parameters are determined, the tool can run future rainfall scenarios to determine the probability of slope failure during forecast rainfall events.
FORESEE linked document	T.2.4 Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	UEDIN

Application example

We highlight some outs of the calibrated model. Below is a single point (out of many thousands) that has been calibrated by observed failure. The top figure shows the "Factor of Safety" (if <1 failure is imminent) and the pore pressure in the soil, which controls stability. The bottom panel shows the rainfall record and the time of failure.



Across all samples in the study area (the trunk road connecting Naples to Bari) we find an overprediction of "early" landslides: those that fail in the model before the timing of actual failures detected by satellite.	

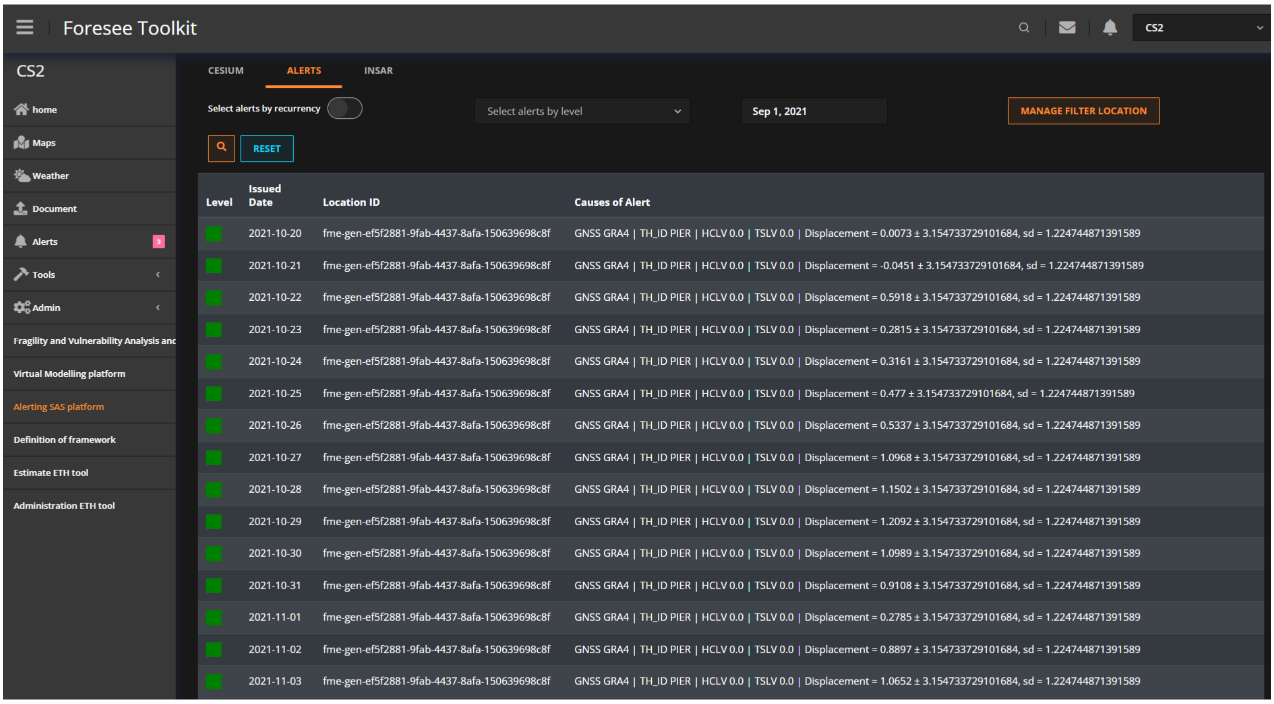
Step by step Toolkit's usage example
We give an example of the web api workflow. This does not run the full calibration. It takes calibrated points and the allows users to see the effect of forecast rainfall.
The user supplies a latitude-longitude pair or list thereof, as well as a rainfall time series as a csv file.
This generates a process on our server. It a) searches the points to see if they are in the calibrated region b) if so, it retrieves the calibrated model parameters c) it runs the numerical model of slope failure using the supplied rainfall time series d) it returns to the user the time series of the factor of safety and the pore pressures at any supplied points e) it also returns a confidence value based on past correlation between predicted ground motion and observed ground motion. These data are returned as a csv file.

To jump back to the table outlining each case study and its respective validated tool, click here

# ALERTING SAS PLATFORM TOOL	
Objective & Description	This tool generates RAG (Red-Amber-Green) alerts over infrastructures by comparing observed motion against threshold failure values. The tool ingests: (i) Motion data from satellites (from PSI technique) (ii) Predicted landslides failure points (from D2.8) (iii) In-situ sensors measurements (iv) Critical threshold asset failure values The output is a table with the raised alerts and a 3D visualisation of the infrastructure BIM RAG-coloured showing the alerts values.
Connection with resilience	The alerting SAS platform provides information on assets elements with unexpected displacement, allowing preventive actions to take place, or planning of maintenance works with a spatially wider knowledge of the event.
Usefulness for infrastructure owners & operators?	The raised alerts allow the infrastructure manager to detect the vulnerable elements of the asset in terms of unexpected displacement. This information can be used to take maintenance actions of the asset focused in the more relevant sections and avoid major issues.
How does it work?	The tool is provided as an API accessible through the FORESEE's toolkit. The results are shown in two ways: as a table of alerts and as a 3D visualization. The toolkit only provides access to the data processed by Telespazio UK. The information is not automatically updated. This tool is only available over CS#2 as it is the only CS with InSAR data available.
FORESEE linked document	D2.9 SHM BIM based alerting SAS platform Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	TELESPAZIO UK Contact person: Erlinda Biescas erlinda.biescas@telespazio.com WSP Contact person: Sergio Saiz sergio.saiz@wsp.com

Application example

3D visualisation of a section of the BIM coloured by RAG alert values in CS#2 area



Level	Issued Date	Location ID	Causes of Alert
	2021-10-20	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.0073 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-21	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = -0.0451 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-22	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.5918 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-23	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.2815 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-24	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.3161 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-25	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.477 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-26	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.5337 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-27	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 1.0968 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-28	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 1.1502 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-29	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 1.2092 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-30	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 1.0989 ± 3.154733729101684, sd = 1.224744871391589
	2021-10-31	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.9108 ± 3.154733729101684, sd = 1.224744871391589
	2021-11-01	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.2785 ± 3.154733729101684, sd = 1.224744871391589
	2021-11-02	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 0.8897 ± 3.154733729101684, sd = 1.224744871391589
	2021-11-03	fme-gen-ef5f2881-9fab-4437-8afa-150639698c8f	GNSS GRA4 | TH_ID PIER | HCLV 0.0 | TSLV 0.0 | Displacement = 1.0652 ± 3.154733729101684, sd = 1.224744871391589

Example of table of alerts, in CS#2.

Step by step Toolkit's usage example
Access FORESEE's toolkit:
1. Activate C#S2 tools.
2. Go to Alerting SAS platform. The tool has 2 tabs: Global View and Alerts.
3. In the tab Global View, a 3D view of the area can be seen. Using the mouse, the area can be navigated. In the bottom side of the screen there is a time bar that can be moved to select the appropriate time to be visualised; the alerts change accordingly. The BIM element colour represents the RAG alerts. When an element is clicked, the list of alerts in these elements are shown on the right side of the screen.
4. In the Alerts tab, the complete table of alerts can be visualised. Several types of filter can be applied.

Application of the FORESEE Toolkit to the Case Studies
This tool has been only applied to CS#2 as this was the only one with an available PSI analysis. Some images on its application have been already included in page 2.

To jump back to the table outlining each case study and its respective validated tool, click here

GOVERNANCE MODULE

Objective & Description	The main objective is to integrate to the infrastructure governance decision-making, service level and resilience considerations, in the case of disruptive and/or extreme events, so that they can be used by the different organizations in their management mechanisms throughout the entire life cycle.
Connection with resilience	This tool solves the objective of the FORESEE Project, in terms of resilience governance and service level, of infrastructures versus extreme events, and is applicable to all types of infrastructures and at all stages of its lifecycle.
Usefulness for infrastructure owners & operators?	This Resilience Decision Making Tool against extreme events, based on Multicriteria Analysis, helps to introduce resilience concepts in the decision making.
How does it work?	Previous: 1. Definition of Infrastructure Indicators, if possible in economic terms D1.2. 2. Hazard Determination, Natural and Artificial, Weight by Impact, D1.1. 3. Selection of Indicators according to Risks. Tool: Decision making through Multicriteria Analysis, which orders select solutions based on risk mitigation.
FORESEE linked document	T. 1.3., D 1.3 - Examples of using Levels of Service and resilience in governance. D 6.4 - SP Case Study #3. Montabliz Viaduct & A-67 Highway
FORESEE contact info	University of Cantabria Grupo de Investigación de Tecnología de la Construcción (GITECO) E.T.S.I.C.C.P., Avda. de los Castros 44, 39005 Santander Contact person: Pérez María Antonia antonia.perez@unican.es Acebes Luis luis.acebes@unican.es Torres Javier javier.torres@unican.es Cuartas Miguel miguel.cuartas@unican.es Ivanova Tania tivanova@transmodalbots.com TECNALIA Contact person: García David david.garciasanchez@tecnalia.com
Application example	
CS#3 Montabliz Viaduct & A-67 Highway	

Figure 1. Montabliz Viaduct, with the Pile more high of Spain.

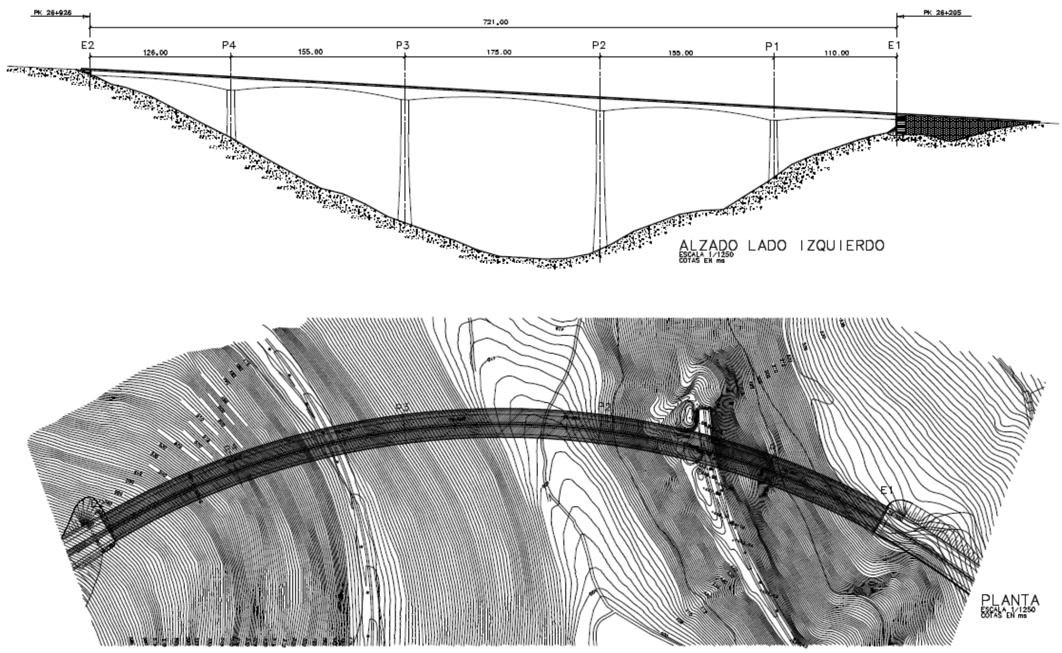


Figure 2. Elevation and Plan CS#3.

Select Resilience Structural Typology based to mitigation principally risks

When planning, designing and executing a new project (infrastructure), the owner and contractors, based on hazards, KPIs and KRTs, make decisions with the aim of mitigating risks, maintaining stable service level and obtaining maximum profitability. This decision-making is carried out automatically and transparently, through the Governance module.

1. Thus, the owner defines the KRI and the KRT, depending on the specific hazards of the infrastructure.
2. Subsequently and prior to each of the phases, the owner selects, through the governance module and depending on the hazards, both the type of contract and the most appropriate

contractor for its execution. The interested contractors apply for the tender and declare their abilities to carry out the work, by completing the KPIs and KRTs defined by the owner.

3. Once the selection is made, both the contractor and the owner use the governance module for the selection of the different governance, technical and financial issues to define the infrastructure, based on the KRIs and KRTs, with the basic objective of mitigating the hazards in the different phases of Evaluation & Decision, Project and Construction and Operation and Maintenance.

Select Indicators D1.1, Risks & Target D1.2

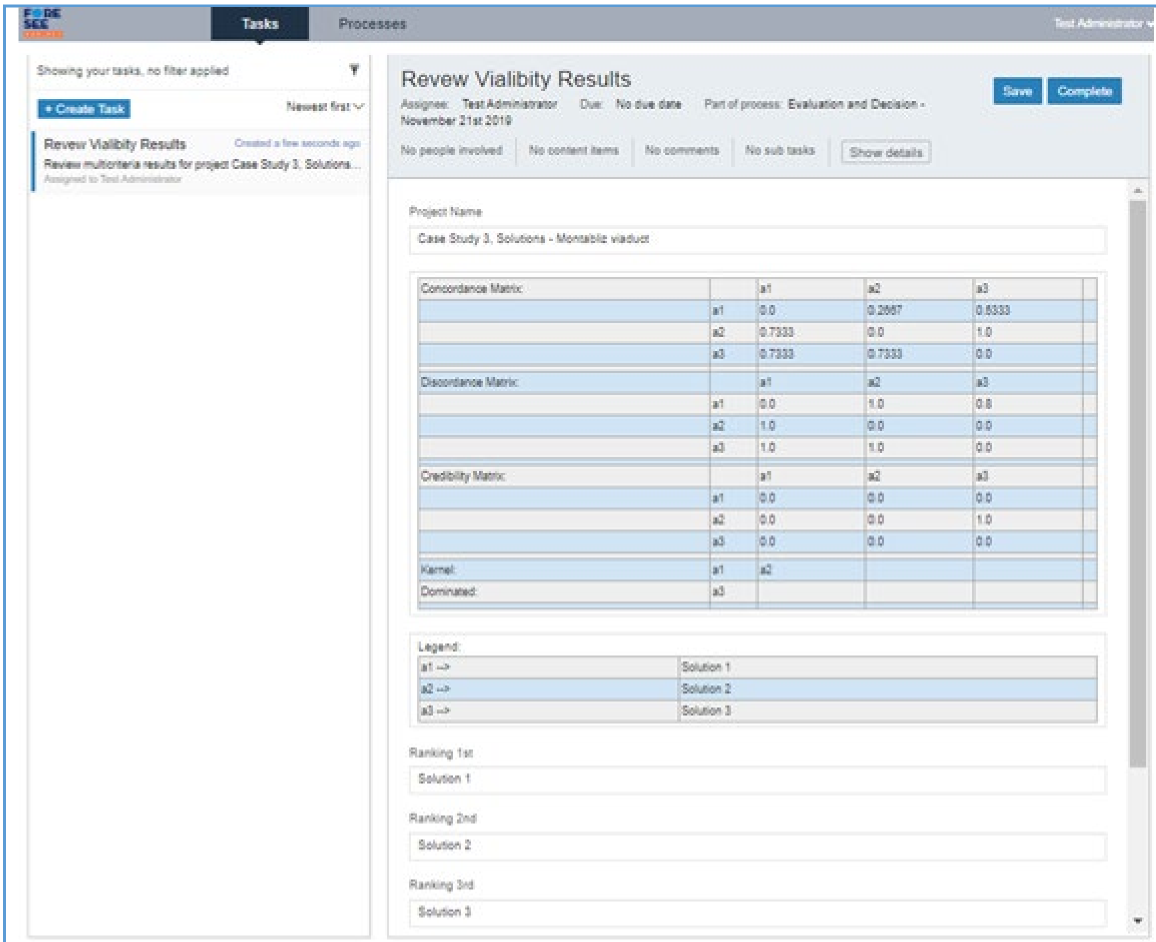
	D&C
DOCUMENT:	DESIGN & CONSTRUCTION
MAIKING DECISION:	SOLUTIONS DESIGN
SATKEHOLDER	DESIGNER & CONSTRUCTOR

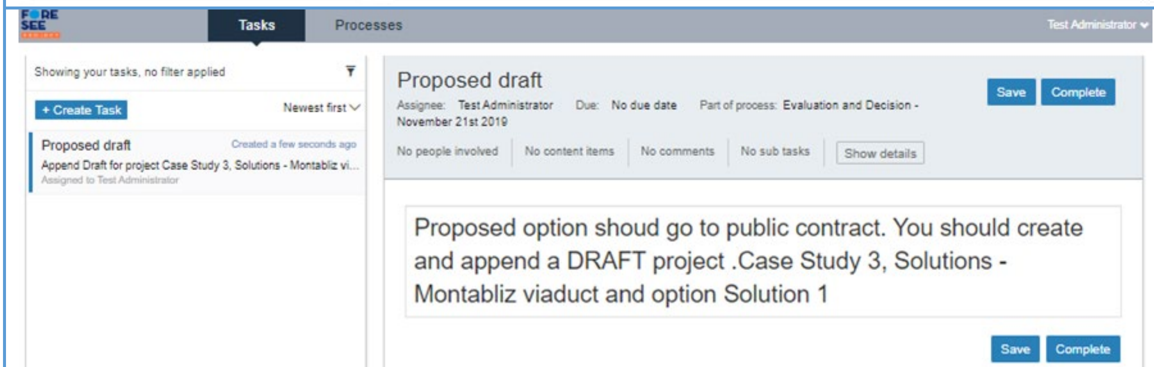
CASE STUDY 3

RISK	ID	Indicator	Number of possible values		Number of possible values Possible values and meaning		Target.indic._BC	%	SOLUTION 1	SOLUTION 2	SOLUTION 3
WIND	W										
	W1.3.1	Adequacy of hazard effect reduction system (barriers to wind)	1		0/1	Not adequate	1	100%	1	2	1
					1/1	Adequate					
	W.2.1.2	Frequency of past hazards	3		0/3	> 10 events per year	0	25%	1	2	1
					1/3	> 7, < 10 events per year					
					2/3	> 3, < 7 events per year					
					3/3	< 3 events per year					
	W.2.1.4	Frequency of future hazards	3		0/3	2 weeks	0	25%	1	1	2
					1/3	1-2 weeks					
					2/3	1 day- 1 week					
					3/3	0 days					
	W.2.1.5	Severity of future hazards	3		0/3	Strong increase	2	75%	2	1	1
					1/3	Soft increase					
					2/3	Soft decrease					
					3/3	Strong decrease					
	W.2.1.8	Traffic*	3		0/3	< 20% of capacity	3	100%	2	1	1
					1/3	> 20%,< 50% of capacity					
					2/3	> 50%,< 80% of capacity					
					3/3	> 80% of capacity					
FOG	H										
	F1.3.1	Adequacy of hazard effect reduction system (pavement lines and visibility sticks)	1		0/1	Not adequate		50%	1	2	2
					1/1	Adequate					
	F.2.1.2	Frequency of past hazards	3		0/3	> 10 events per year	0	33%	3	3	4
					1/3	> 7, < 10 events per year					
					2/3	> 3, < 7 events per year					
					3/3	< 3 events per year					
	F.2.1.4	Frequency of future hazards	3		0/3	2 weeks	0	33%	1	2	2
					1/3	1-2 weeks					
					2/3	1 day- 1 week					
					3/3	0 days					
	F.2.1.5	Severity of future hazards	3		0/3	Strong increase	2	100%	1	2	2
					1/3	Soft increase					
					2/3	Soft decrease					
					3/3	Strong decrease					
	F.2.1.7	Traffic*	3		0/3	< 20% of capacity	1	50%	2	3	3
					1/3	> 20%,< 50% of capacity					
					2/3	> 50%,< 80% of capacity					
					3/3	> 80% of capacity					
SNOWFALL	S										
	S.1.3.1	Adequacy of hazard effect reduction system (barriers to snow)	1	2	0/1	Not adequate	1	100%	1	2	1
					1/1	Adequate					
	S.2.1.2	Frequency of past hazards	3	4	0/3	> 5 events per year	1	50%	2	2	1
					1/3	> 2, < 5 events per year					
					2/3	> 1, < 2 events per year					
					3/3	1 events per year					
	S.2.1.4	Frequency of future hazards	3	4	0/3	2 weeks	0	25%	1	1	2
					1/3	1-2 weeks					
					2/3	1 day- 1 week					
					3/3	0 days					
	S.2.1.5	Severity of future hazards	3	4	0/3	Strong increase	0	25%	1	2	2
					1/3	Soft increase					
					2/3	Soft decrease					
					3/3	Strong decrease					
	S.2.1.7	Traffic*	3	4	0/3	< 20% of capacity	3	100%	1	2	2
					1/3	> 20%,< 50% of capacity					
					2/3	> 50%,< 80% of capacity					
					3/3	> 80% of capacity					

Possible Solutions, expressed based on Indicators & Targets

Governance Tool

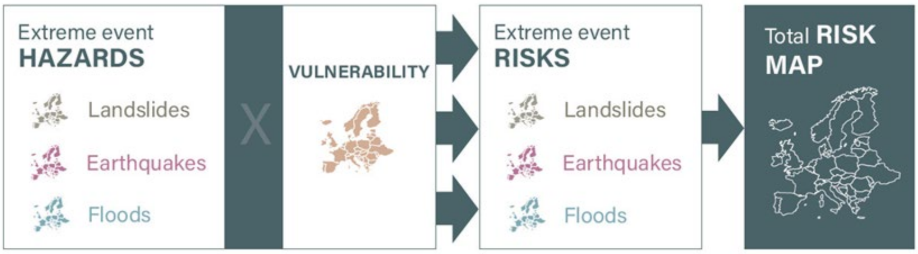




Results: Excellent results to selection, alternatives of solution, typology of viaduct, to the better design in front of the hazards, in the Design & Construction phase and selects the expert contract to developer the Plan of Operation & Maintenance.

To jump back to the table outlining each case study and its respective validated tool, click here

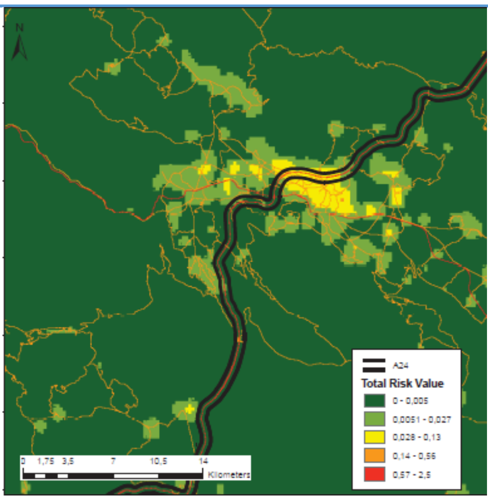
RISK MAPPING TOOL

Objective & Description	The main objective of the *Risk Mapping tool* is the early large scale identification by means of a GIS mapping tool of the risk of extreme natural disasters to which road infrastructures are exposed. Using the ArcGIS software platform, the working process has been automated by creating a tool capable of establishing the risk of different natural disasters such as landslides, floods and earthquakes in a specific area of the European territory, taking into account the impact of these events on the population and infrastructures.
Connection with resilience	This tool is intended to make it easy for final users to make a large-scale evaluation of the risks for infrastructures at early phases of the project design. Thus, by using the application, the identification and posterior analysis in detail of regional or local extreme natural events is more straightforward and precise, as well as the proposal of measures to improve the resilience to the infrastructure.
Usefulness for infrastructure owners & operators?	Initial approach to potential harmful natural events and therefore, improvement of the decision-making at early phases of the infrastructure design.
How does it work?	The GIS-based [Risk Mapping Tool] application is formed by four scripts written in Python in order for the user to interact with the application. Once installed, the geoprocessing and calculations necessary to standardise, connect and unify the necessary databases are carried out and the maps selected are returned. Two main outcomes can be obtained from running the GIS mapping tool: hazard maps and risk maps.  Hazard maps are obtained based on an empirical approach that relates a series of past real extreme natural events occurring all over Europe in the last few years (response variable) and a series of geo-referenced databases (predictor

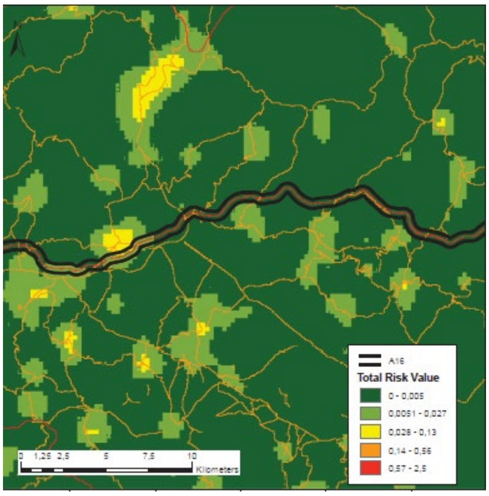
	variables). For the determination of the risk maps, the vulnerability of the road infrastructures is incorporated. Thanks to the Python scripts, the generation of maps is a very smooth operation and some of the parameters involved, whose values are set by default, can be easily adjusted.
FORESEE linked document	Deliverables D2.4 and D2.5 define the theoretical and methodological basis for the development of the GIS mapping tool as well as some of the potential results that can be obtained. Confidential documents. Only for partners and SRG members authorized.
FORESEE contact info	University of Cantabria Grupo de Investigación de Tecnología de la Construcción (GITECO) E.T.S.I.C.C.P., Avda. de los Castros 44, 39005 Santander Contact person: Alejandro Roldán alejandro.roldan@unican.es Pablo Pascual pablo.pascualm@unican.es Daniel Castro daniel.castro@unican.es

Step by step Toolkit's usage example
The first step to set the GIS-based application is to download the folder where the scripts are and access them through the ArcCatalog interface. When running the tool, a new window comes up through which the map to be consulted is requested and the different databases required have to be added. Likewise, different parameters can be adjusted if necessary. Once the databases are incorporated, the corresponding script begins to run. This process may take some minutes or hours depending on the capacity of the computer used. During this process, the calculations necessary for standardising, connecting and unifying the databases added before are carried out, which eventually results in the map previously selected. This map is stored in an ArcGIS folder assigned by default. The symbology for the purpose of this GIS-based tool can be imported from the Simbology.lyr files, which are part of the tool package. For the quick printing of the maps in a proper format and style, a template has been also included within the GIS tool package.

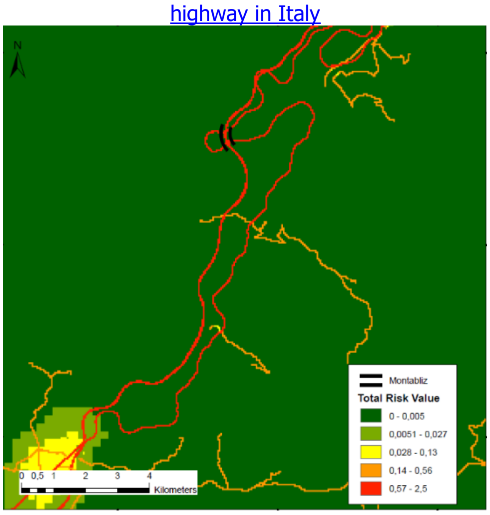
Application example
Application of the FORESEE Toolkit to the Case Studies



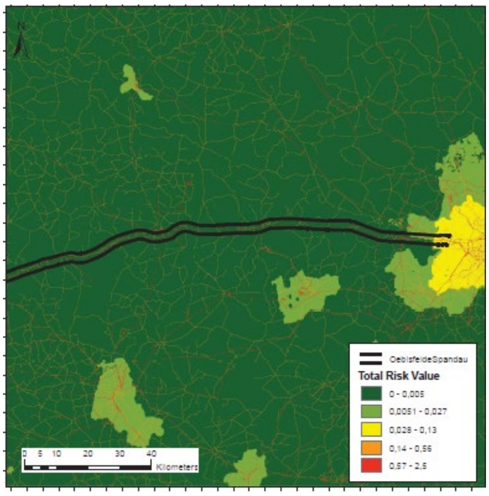
Total risk map obtained for [CS#1. Carsoli-Torano A24 highway in Italy]



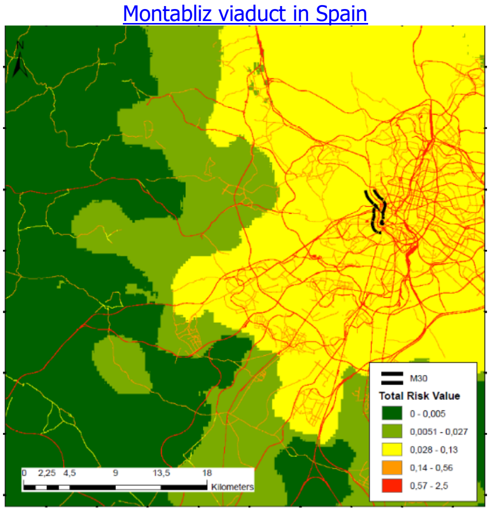
Total risk map obtained for [CS#2. Naples to Bari a16 highway in Italy.]



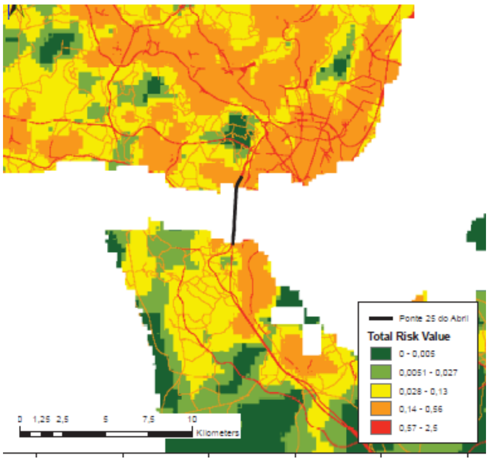
Total risk map obtained for [CS#3. A67 highway – Montabliz viaduct in Spain]



Total risk map obtained for [CS#4. Railway track 6185 Oebisfelde – Berlin Spandau in Germany]



Total risk map obtained for [CS#5. M-30 ring-road in Madrid – Spain]



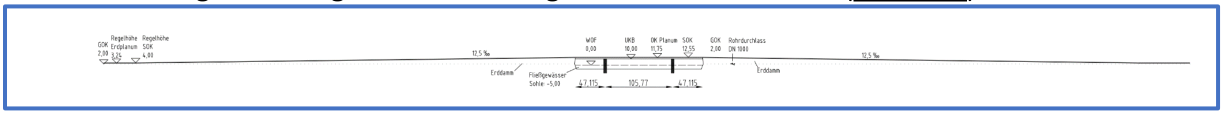
Total risk map obtained for [CS#6. 25th April suspended bridge. Portugal.]

To jump back to the table outlining each case study and its respective validated tool, click here

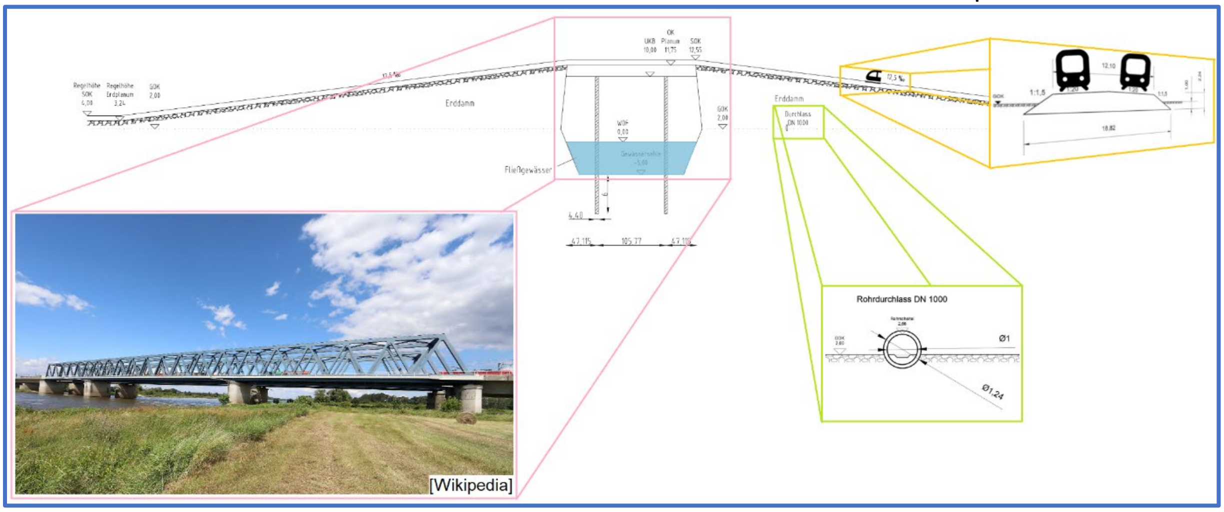
BRIDGE FLOODING MODEL TOOL	FORE SEE PROJECT

Objective & Description	The **Bridge Flooding Model** was developed at the University of Brunswick Institute of Transport, Railway Construction and Operation for the analysis of the condition of a railway track model under the stress of flooding in 2018. The model focuses on the topic of flooding on railway bridges. The target of the tool is to identify which damage is associated to which water level in order to develop measures which can reduce the probability or the intensity of the damage in the event of flooding. Various influences to damage predefined railway track components are used and assessed in this process.
Connection with resilience	This tool contributes to enhancing the presence of a maintenance strategy and the extent of interventions executed prior to the event.
Usefulness for infrastructure owners & operators?	The Bridge Flooding Model will support the infrastructure manager to assess and identify the best technical optimisations of railway track components before (i.e. preparation and preventative) a flooding to ensure the serviceability of the railway track in the case of damage.
How does it work?	Re-modelling a small-scale CAD model of a railway bridge over a river with earth dams in front and behind it and culverts for the water passage. In the model, the water level can be increased step by step to find out which damages are associated with which water level to identify which of the following six defined influences have the potential to damage the assessed railway track components that its serviceability is no longer given and it can no longer be operated without repair work: • Undercutting of foundations • Softening of earthworks • Overflow of electrical installations • Effects of faster flowing water • Positional changes of the superstructure • Input of foreign substances into railway track components
FORESEE linked document	IVE Project / Master thesis: “Analysis of the condition of a rail under the stress of flooding” (IVE, 2018) Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	IVE Contact person: Kantorski, Sebastian sebastian.kantorski@ivembh.de

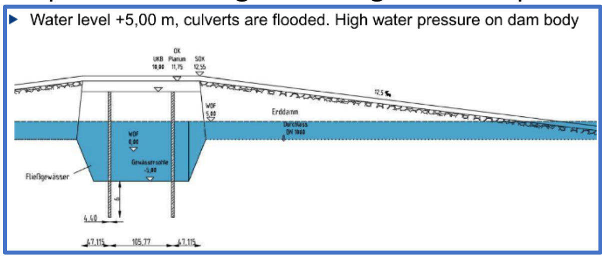
Application example
CAD-based Bridge Flooding Model: → longitudinal section (full scale)

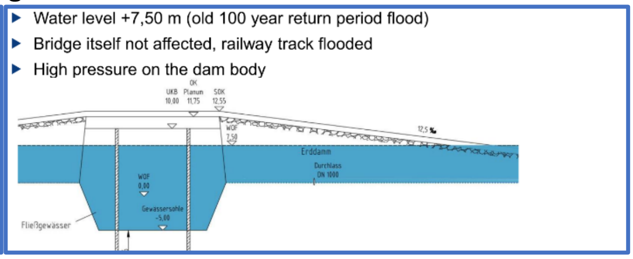


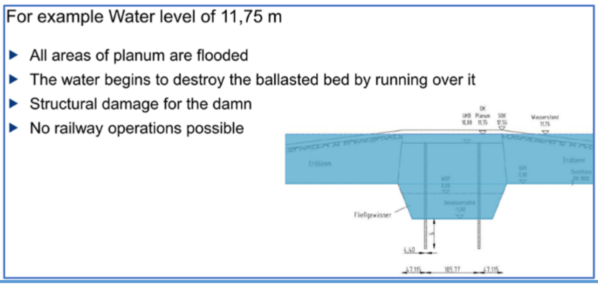
→ longitudinal section (10x height)
→ visualisation of different model components



Outputs from Bridge Flooding Model depending on different water levels:







Step by step Toolkit's usage example
This particular tool was not expected in the Foresee Toolkit.

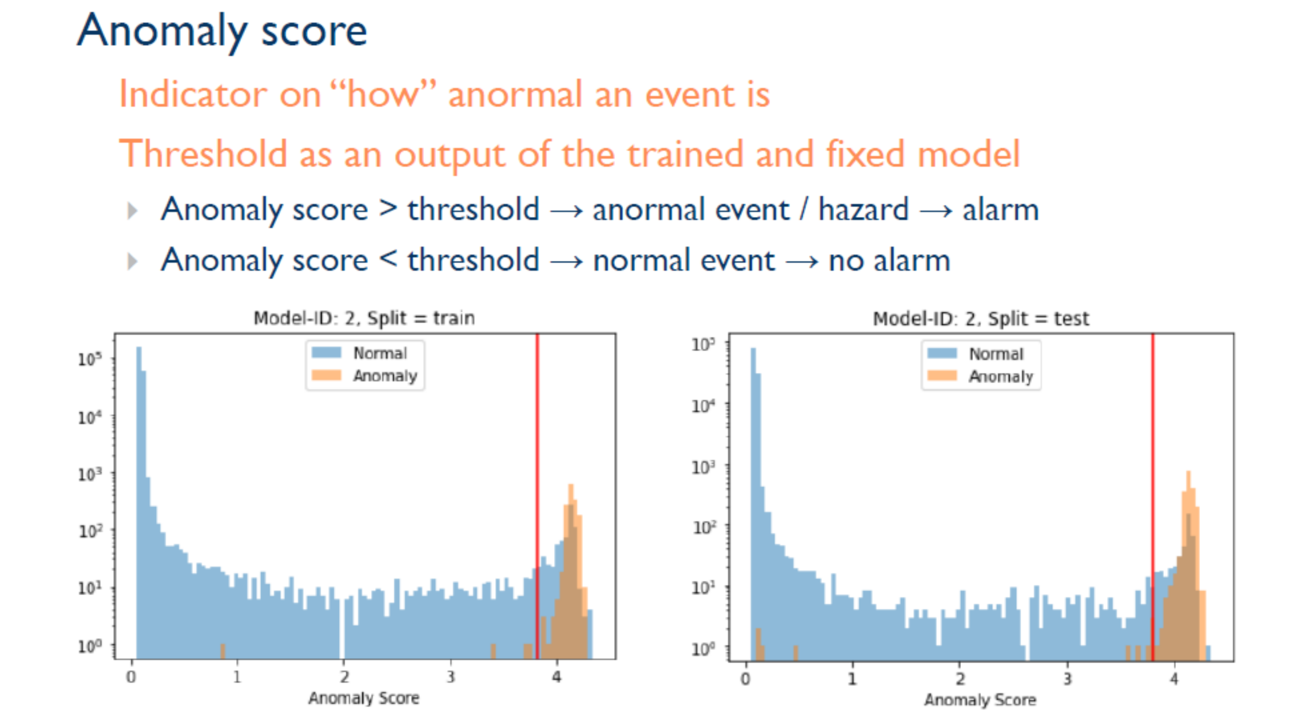
Application of the FORESEE Toolkit to the Case Studies
This particular tool was not expected in the Foresee Toolkit.

To jump back to the table outlining each case study and its respective validated tool, click here

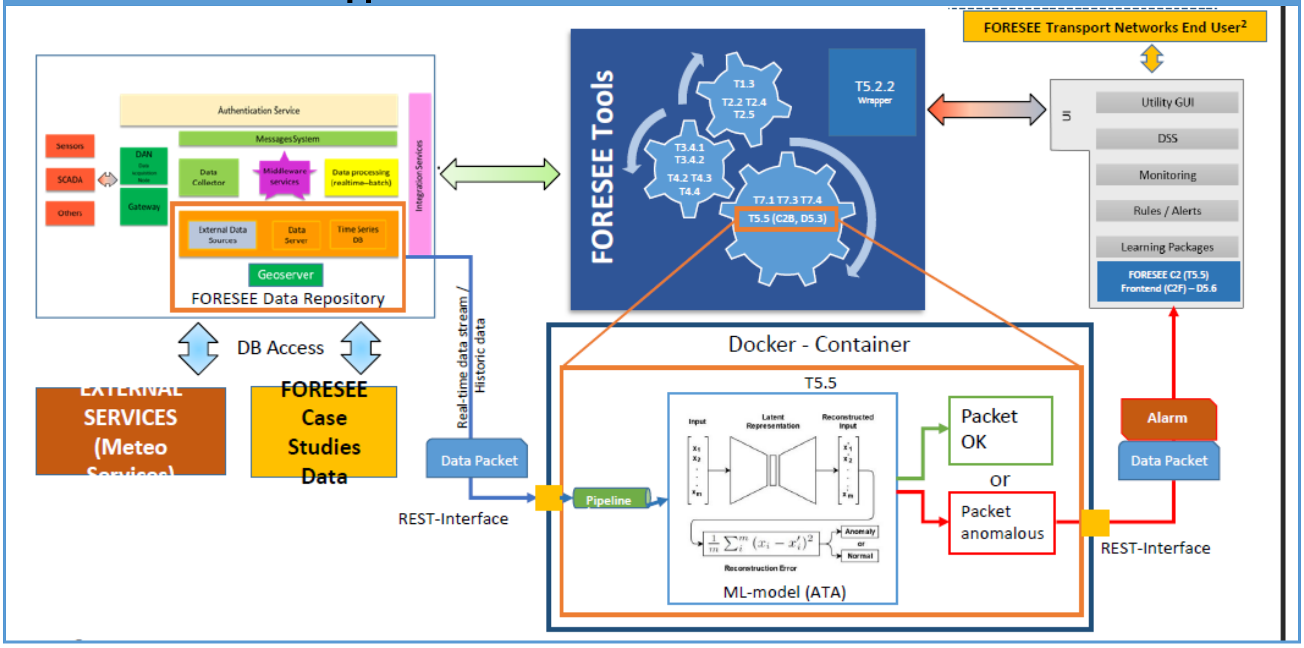
COMMAND AND CONTROL CENTER

Objective & Description	The C2 will serve to increase the situational awareness of the users of the FORESEE toolkit. Alarms concerning potential hazards to an infrastructure are raised based on efficient anomaly detection techniques using machine learning.
Connection with resilience	The C2 acts at the resilience stages of *Preparation* and *Response*. Being a warning system it allows preparation to reduce the consequences of an extreme event (*Preparation*). During the event it continues monitoring and in that way can support the choice of emergency operations (*Response*).
Usefulness for infrastructure owners & operators?	The C2 will increase the situational awareness during normal and extreme hazard events and therefore allow an earlier response time and a shorter duration of down-time in case of an extreme hazard event.
How does it work?	A model was built using historic infrastructure and/or hazard-related data (e.g. weather data) for a specific hazard of a case study. The data was given as input to the C2. The model has learned for each hazard to distinguish between normal and anomalous events based on this input data. In operation mode, real-time infrastructure and/or hazard-related data are applied as input to the fixed model of the C2. The C2 returns a warning in case of an anomalous event. Furthermore, it can continuously display the input-data to allow permanent monitoring by the operators.
FORESEE linked document	T 5.5, D 5.3, D.5.6. Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	Fraunhofer IAIS Contact person: Richter, Marvin marvin.richter@iais.fraunhofer.de

Application example
The C2 is being applied to CS#3 Montabliz Viaduct, CS#4: Oebisfelde Berlin Spandau, Germany and CS#5: M 30 Ring Road & Tunnels, Spain



Application of the C2 in the FORESEE Toolkit



To jump back to the table outlining each case study and its respective validated tool, click here

A FULLY STOCHASTIC FLOODING PREDICTION METHODOLOGY

Objective & Description	Novel methodology for the study of floods using advanced statistical techniques to improve the calculation of flood extent for different return periods through a better exploration of the space of extremes.
Connection with resilience	According to the definitions of resilience and service given by the guideline for measuring levels of service and resilience in infrastructure (deliverable D1.1), the use of novel methodologies for flood studies allows infrastructure and populations with a high probability of flooding to be more resilient through early mitigation of the effects that floods can cause. The use of this type of methodologies allows for more accurate studies to assess the extent of flooding, thus making it possible to anticipate the negative effects of floods before they can occur. Therefore, as a summary, this tool: • Obtains flood spots with the lowest possible uncertainty that allows the determination of the existing risk in flooded areas in the face of a flood for different return periods. • Considers the uncertainty in the risk assessment of floods caused by extreme events using hybrid downscaling and the generation of synthetic events.
Usefulness for infrastructure owners & operators?	It is useful for operators managing warning states in river basins or even for organizations managing urban planning. More accurate studies allow operators or organizations to anticipate risk situations before extreme floods.
How does it work?	The use of tools based on hybrid downscaling methodologies allows a reduction in the uncertainty of flood studies resulting in more accurate flood extensions for different return periods. This allows urban planning and infrastructure design in places where there is little or no flood hazard.
FORESEE linked document	D 4.10.- A fully stochastic flooding prediction methodology Confidential document. Only for partners and SRG members authorised.
FORESEE contact info	Universidad de Cantabria (UC) – Environmental Hydraulics Institute (IHC) C. Isabel Torres, 15, 39011 Santander, Cantabria Contact person: Manuel del Jesus Peñil manuel.deljesus@unican.es Salvador Navas Fernández salvador.navas@unican.es

Application example

The application of methodologies based on hybrid downscaling for the study of floods can be applied to any area of a river basin where channel overflows occur.

Step by step usage example

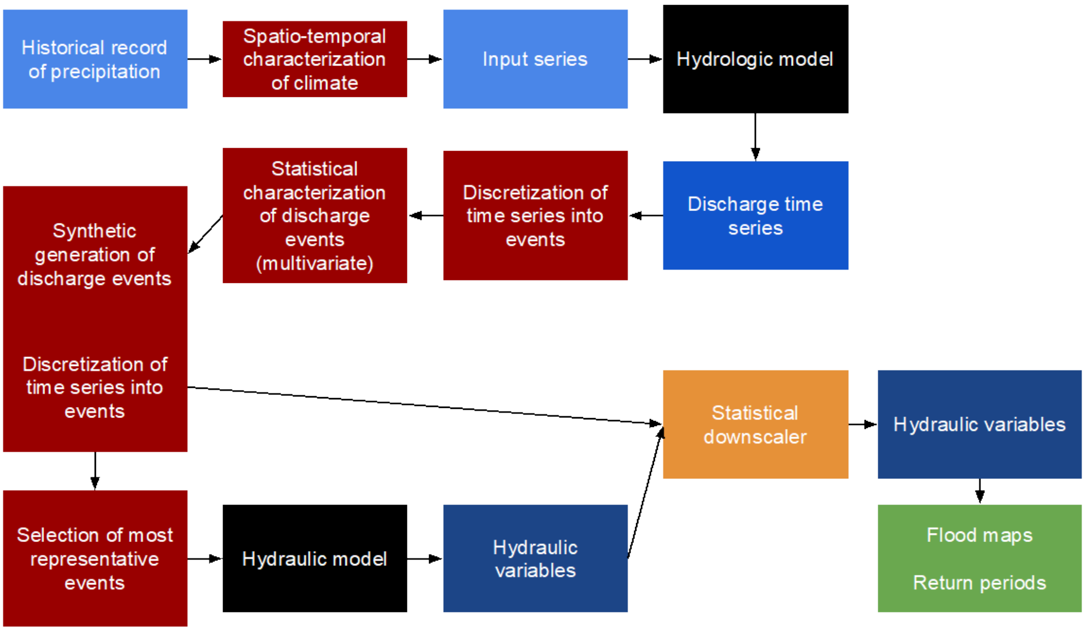


Figure 1: Workflow of the fully stochastic flooding methodology

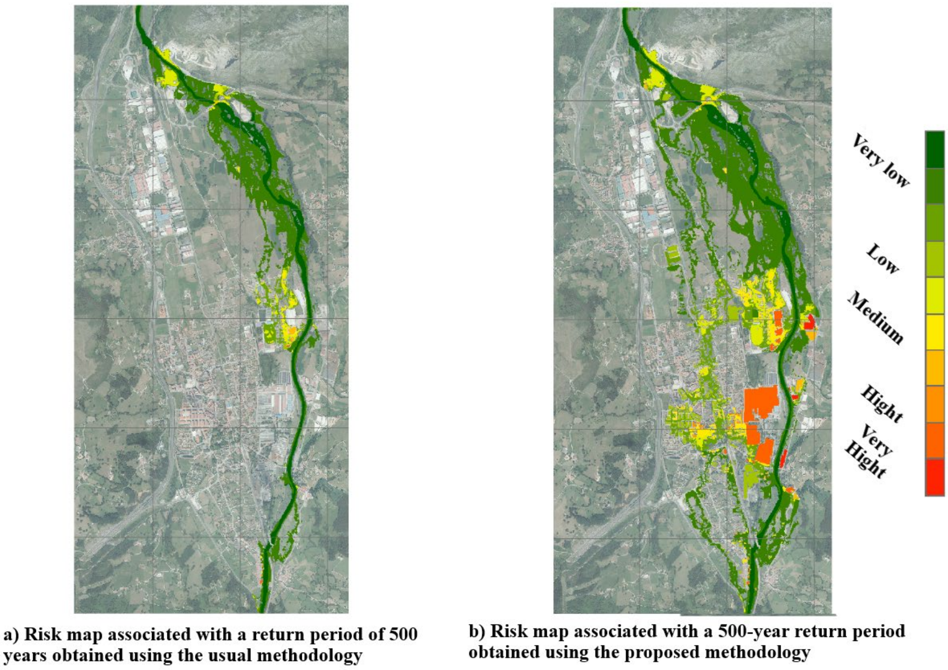


Figure 2. Comparison in the results of the risk maps obtained using the proposed methodology and the usual methodology

To jump back to the table outlining each case study and its respective validated tool, click here

HYBRID DATA ASSESSMENT FOR DIAGNOSIS AND PROGNOSIS TOOL

Objective & Description	The Hybrid Data Assessment (HDA) tool encompasses a machine learning tool for diagnostics and prognostics of faults experienced by critical infrastructure in the face of an acting hazard. The module is general, in the sense that it can be applied in different contexts, to tackle different structures (bridges or tunnels) and hazards (cyber-attack, flood, earthquake).
Connection with resilience	The HDA tool aims to support *resilient* decisions for infrastructure assets, when extreme events occur, provided measurements form diverse sources are available. The tool is termed "hybrid" due to its capacity to incorporate two sources of inputs, namely simulation models and actual monitoring data. Data stem from monitoring measurements, that is collected via use of telemetry and appropriate sensors; simulated data can be generated via use of appropriate models, depending on the case study at hand (e.g. structural analysis module for the case of a bridge, or traffic simulation model for the case of a highway).
Usefulness for infrastructure owners & operators?	The HDA tool allows owners and operators to forecast the behaviour of an asset, e.g. performance/possible damage on a bridge, or traffic behaviour in a critical portion of a road network, when an event (e.g. earthquake, flood, cyber-attack) occurs. When using the tool, owners and operators will be able to identify the probability for an existing or impending occurrence of faults, and accordingly decide on important actions for intervention and repair (e.g. road/bridge closure, repair of bridge deck, etc).
How does it work?	The tool is based on two machine learning algorithms: i) Bayesian Networks (BNs) and ii) Random Forests (RFs), which are trained on heterogeneous monitoring data. BNs are used as classifiers for the purpose of diagnosing faults or occurrence of events under extremes. RFs are primarily set up as a tool for regression, i.e., prediction of the value of a Quantity of Interest (QoI) which is critical for driving decisions. An example is the prediction of the evolution of traffic flow and distribution within a network, particularly in the face of extreme events (e.g. flood or cyber-attack), which we demonstrated on CS#5 – The Madrid Ring Road (D4.8 report).
FORESEE linked document	T 4.4, D 5.2.1, linked to the method in D 4.3, D4.6 & 4.8.
FORESEE contact info	ETHZ Contact person: Chatzi, Eleni chatzi@ibk.baug.ethz.ch

Application examples

The first application example of the HDA tool is CS#1 – A24 Highway, where the BN module was demonstrated for diagnosing faults for the case of a monitored bridge system which experiences an earthquake event (Figure 3).

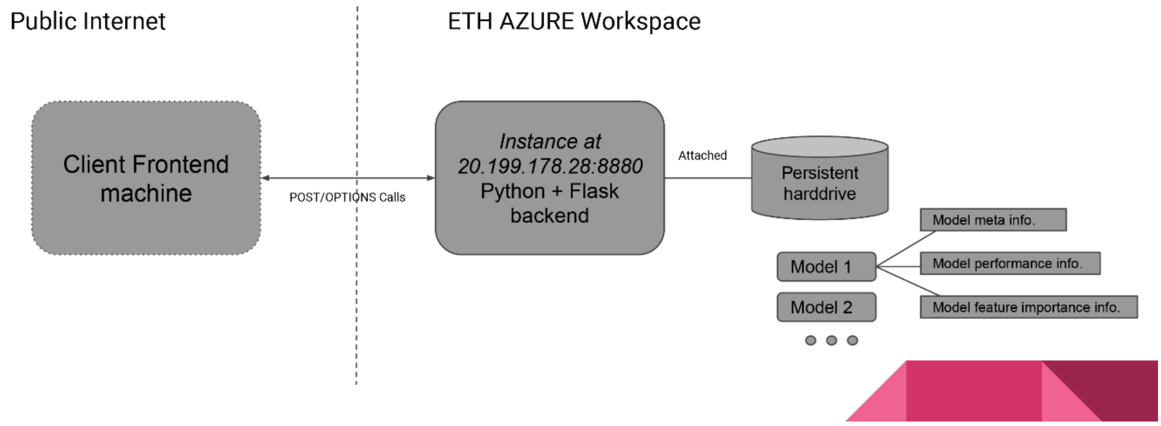
The second application example of the HDA tool is CS#5 – the Madrid Ring Road for the scenario of a cyber-attack affecting the network which included critical elements such as tunnels. This is described next in the usage example.

Step by step Toolkit's usage example

*The final interface to the tool is not yet completed. Thus, we offer here a step-by-step usage example relying on steps that refer to our core computation code for the RF module, which is made freely available here: https://github.com/IAbda/FORESEE_ETHZ.git[1]

STEP 1. TRAIN MODE: For practical purposes the input features are first collected via CSV files. Each column corresponds to a different variable, while each row reflects a time/date stamp. This data can be generated over a time period, either via different simulations (e.g. through the traffic module), or via measurements obtained at different points in time.
*This input will eventually feed the HDA Tool interface (API), which is under development and will interface to the overall FORESEE architecture.

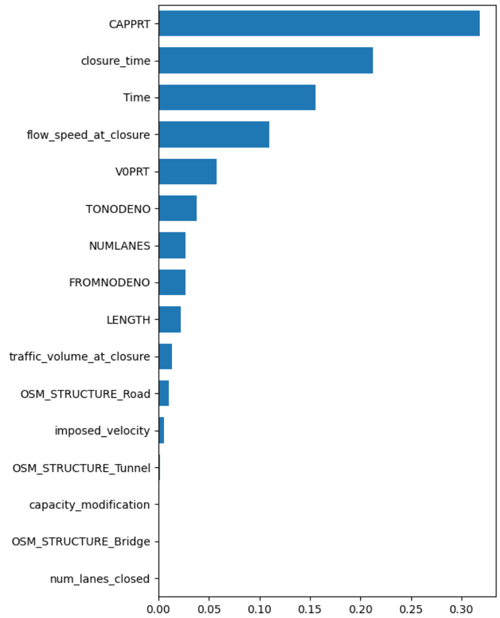
STEP 2. TRAIN MODE: A predictive RF model is then trained for the predefined input/output sets, contained in the CSV files and is then saved to disk using the Pickle framework. This is done via the "TRAIN" of the interface (Figure 2).
The model is run on the ETH Azure Workspace, as illustrated below:



STEP 3. TRAIN MODE: Assess the quality of training by observing the performance metrics offered by the interface, as illustrated below. If performance is acceptable then the model is considered as valid, and one can proceed further.

[1] The BN module is correspondingly made available here: https://gitlab.ethz.ch/tatsisk/foresee

Trained RF model performance: comparing the target to the model predicted one-hour-ahead traffic intensity.



Measure of Importance of Random Forest features

STEP 4. The outputs are typically delivered spatially for this module, since it is configured to handle a network of nodes, as is the example for the Madrid Case study (D4.8 report) using a Red-Amber-Green (RAG) alert system. The thresholds that define the RAG flagging system, are defined by the user in the HAD tool interface, as shown in the Figure below (left).

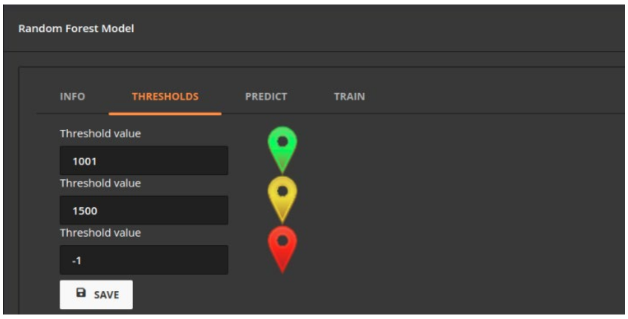
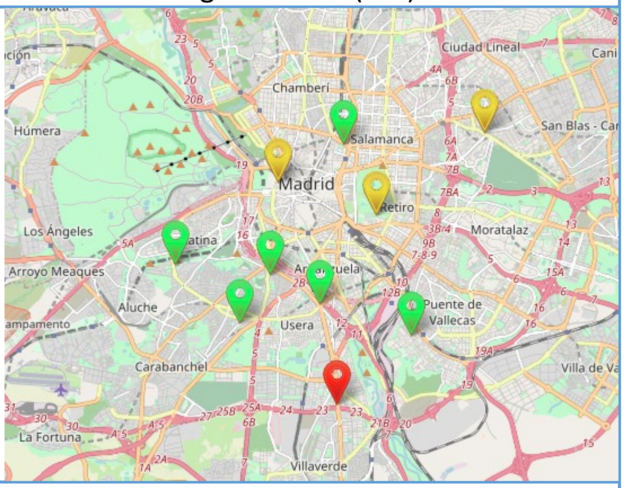


Figure 2. The HAD Tool Interface – specification of the thresholds for RAG flagging



Step 5. PREDICT MODE: The saved and verified model can then be called again, via the "PREDICT" tab of the interface (Figure 2) to predict the value of output variables (e.g. traffic flow) on new input data (e.g. new instance of cyber-attack/flood scenario for a road network). The data is visualized as in the Figure above (right).

Application of the FORESEE Toolkit to the Case Studies

Case Study 1 – A24 Highway / The BN Module of the HDA Toolkit

The BN module is used to diagnose faults occurring on a monitored bridge system which experiences an earthquake event (Figure 3). The bottom layer of the network reflects the so-called *symptom nodes*. This is the layer where available information on input is fed into the network. This can reflect information on:

a. the acting hazard (e.g. temporal, spectral characteristics of the earthquake[2])
b. further loads (e.g. wind/traffic) and operational information (e.g. temperature, humidity)

An intermediate layer exists, which is linked to *observations*. This pertains to further inputs, beyond loads, which can be made available as, for example, measurements from (possible) monitored nodes of the asset (e.g. observations extracted via use of SHM or remote monitoring methods). When no monitoring information is available, then this layer will be omitted.

The final layer links the symptoms and observations (inputs) to *component states* (outputs). As aforementioned, these states can be estimated either using (long-term) monitoring data or via simulation, given availability of a suited model. In the example reported in the D4.6 report, and plotted in Figure 3, this link is offered from simulation via structural analysis software (SAP2000). The simulations are run and given different parametrized earthquakes, for which the structural response in different critical elements of the structure is computed. Such critical elements are, for example, found in support points, as for instance the employed Unbolted Neoprene Pads (UNPs) which form nonlinear elements that are sensitive to damage.

The very last layer is what we term the *outcome layer*. This reflects the prediction of the algorithm, on the basis of feeding of new input (new earthquake event. After it has been trained (on simulated data or previous recordings), existing codes and standards are used to classify the system performance in discrete categories reflecting condition, e.g. No damage, minor damage (Limit State I), moderate damage (Limit State II), or major damage (Limit State III). For the case of bridges, for instance, damage is often linked to the recorded displacement in critical components of the bridge (piers, bearings, deck, support points).

[2]Information on how earthquake time series can be decomposed into characteristic parameters, which describe their temporal and spectral characteristics is offered in the Deliverable D4.6 report of FORESEE.

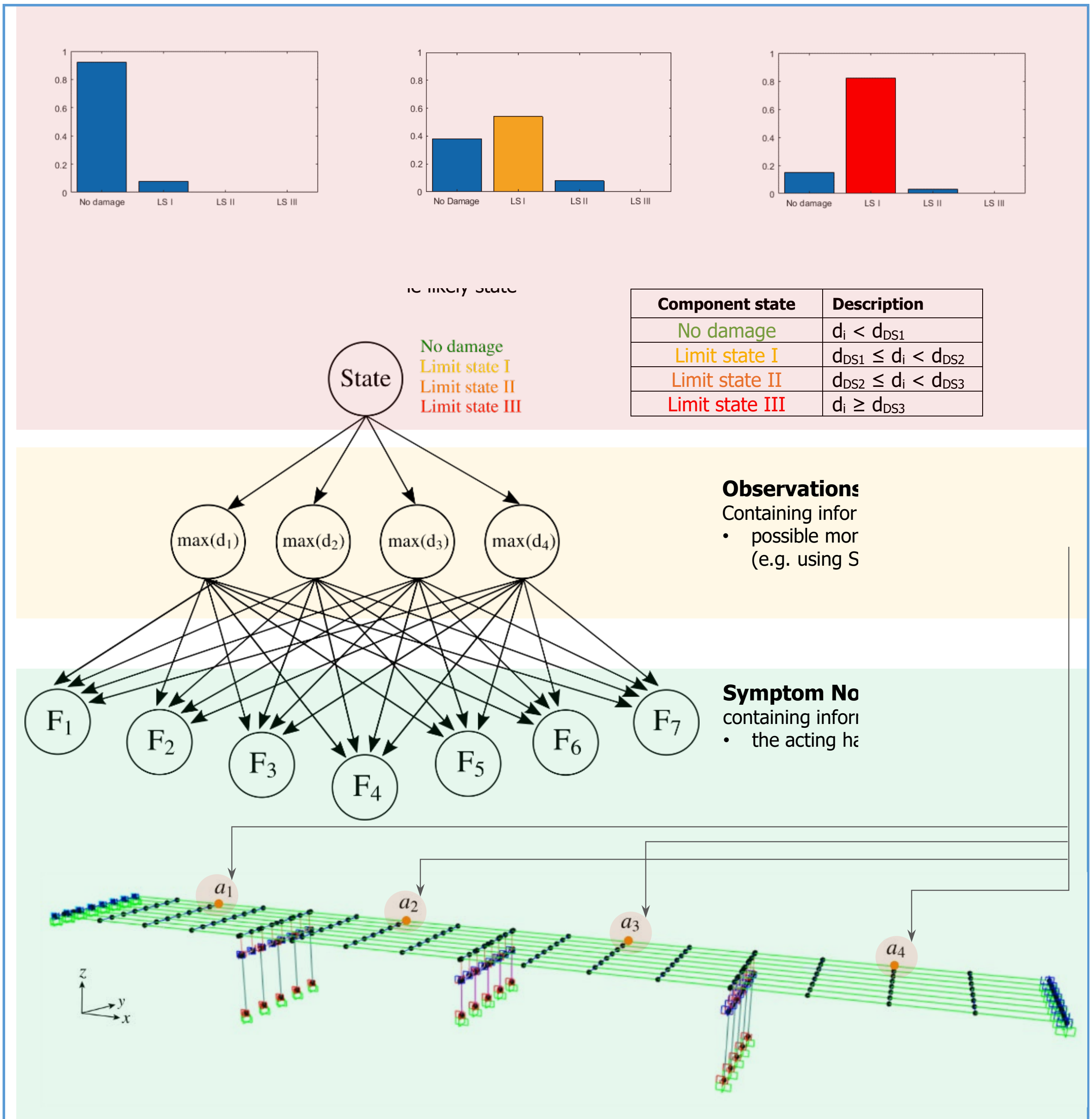


Figure 3. Flowchart of the application of the BN module of the HDA tool for damage diagnosis on a bridge, given occurrence of an earthquake event. The outcome is delivered for different components of the network (e.g. unbolted neoprene pads)

Case Study 5 – The Madrid Ring Road / The RF Module of the HDA Toolkit

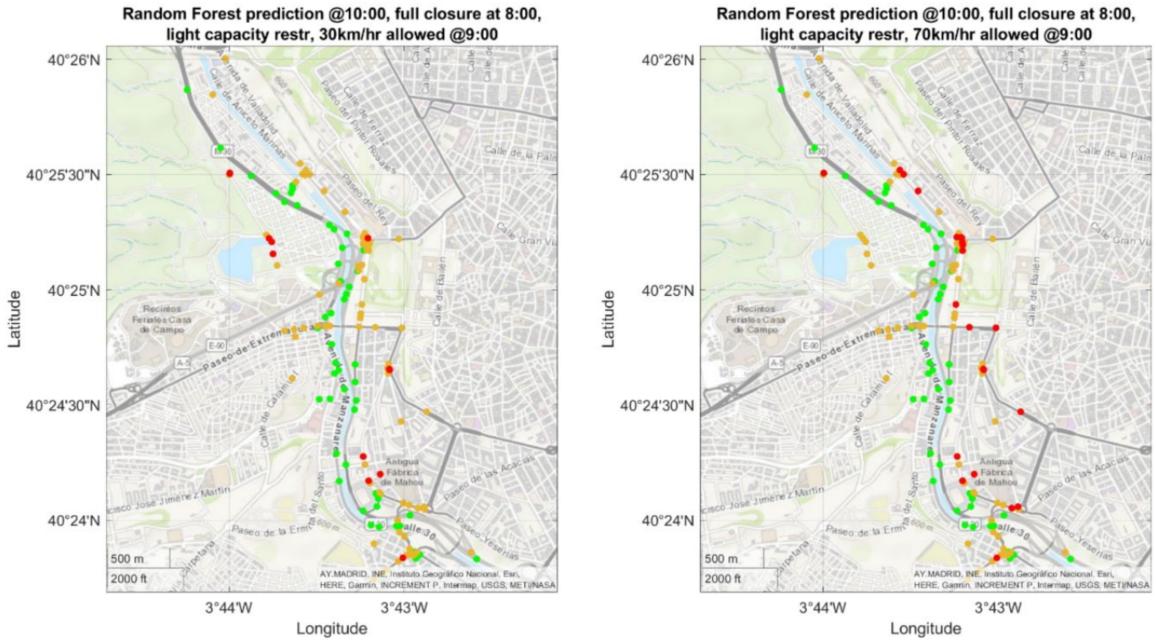


Figure 4. RAG time annotation of traffic flow in terms of the index r_{rec}, which quantifies the recovery of flow as compared against the traffic flow at closure time. In this plot we illustrate the effect of two separate actions scenarios which relate to a change in permissible speed (30 vs. 70 km/hr during re-opening). These maps are offered for a closure scenario due to a cyber-attack occurring at 8:00 with partial reopening at 9:00 and prediction of traffic flow at the time of full reopening at 10:00.

To jump back to the table outlining each case study and its respective validated tool, click here

CYBER-ATTACK ASSESMENT – MADRID CALLE 30

Objective & Description	One of the main hazards that could cause the total or partial collapse of the Madrid Calle 30 infrastructure is a cyber-attack. Therefore, a deep analysis of this hazard has been performed, which has led to the development of three annexes that will help the infrastructure manager with the maintenance and operation activities in the case of cyber-attack affecting the highway. - Scenario caused by a cyber-attack. Description of the scenario caused by a cyber-attack on the M30 ring road Control System and its associated response. - Socioeconomical study considering a cyber-attack affecting the M30 ring road. Impact on traffic and alternative routes. - Recommendations to be adopted.
Connection with resilience	This tool contributes to updating the current maintenance, operation, contingency and emergency plans/strategy considering a cyber-attack event.
Usefulness for infrastructure owners & operators?	These annexes will support the infrastructure manager to assess and identify the best technical operations during the maintenance and contingency phases in case of a man-made event affecting the infrastructure to ensure the serviceability, operability and safety of the tunnel section of this highway.
How does it work?	Calle 30 is made up of a system of tunnels, connection galleries with the exterior, connections with other infrastructures and emergency galleries, all interrelated with each other and with a single Main Control Centre, which means that if one section is affected, the safety of the rest will be compromised. As a preliminary starting point, any intrusion by means of a cyber-attack on the management systems of the Calle 30 Control Centre, provided that one of the systems or subsystems considered critical has been affected, should mean that access to and evacuation of the tunnel system should be cut off until the possible scope of the attack is known. It is logical to think that if the cyber-attack is executed by experts in this type of actions, it will be carried out in such a way that it will be difficult to attribute initially the loss of control to an attack of this type, then the time of incidence will be longer. For this reason, we consider that the first thing should be to generate tools that allow ruling out of other circumstances or failures as quickly as possible, in order to be able to quickly take the actions to neutralize and reduce the damage caused.

	Therefore, we proceed to describe the scenarios that we consider possible, detailing the severity of the consequences from least to greatest: • Is a cyber-attack the control system failure reason? • Does the Control Center maintain total or partial management capacity? • Is the cyber-attack only limiting the Control Center's ability to operate? • Does the cyber-attack allow the intruder to maliciously operate management systems? • Once the questions have been answered, we proceed to describe the possible affected systems. It should be noted that in the operational response protocol, the actions to be taken immediately by the M-30 Ring Road Control Center will be detailed to guarantee the safety of users and operators, even in these circumstances. But in the scenario that occupies us, we must pay our attention to the services, systems and critical facilities affected. For this reason, and in order of severity, we list those facilities that we consider critical. Even if they only manage to simulate the failure in the system, a series of actions or decisions can be triggered that would generate dangerous situations. • Tunnel closure system • External and internal power supply • Ventilation system • Firefighting control system and equipment, water mist system • Lighting system • Variable signalling system • Video surveillance system, DAI • SOS calling points / PA/VA systems • Analysis and control systems for environmental factors • Evacuation management systems • Communications equipment
FORESEE linked document	Confidential document. Only for partners and SRG members authorized.
FORESEE contact info	FER Contact person: Fernández Haro, David d.fernandezharo@ferrovial.com

Application example
Social Impact In this section we include the effects on the following matters:

- Environmental aspects:
    - Derived from the environmental pollution that will be produced due to the circulation of all the vehicles on the surface, without the corrective factor of the elimination of harmful gases through the filtering elements in the circulation tubes and in the ventilation systems, which means that the air released to the outside is free of polluting elements.
    - Effects derived from the generation of an increase in noise due to the surface traffic of all the circulation.

Social aspects:

- Decrease in average speed on equivalent journeys due to congestion on surface roads, due to the increase in traffic.
- Increased travel times on equivalent journeys, due to lower average speed.
- Increased accident risks as a result of the increase in traffic intensity, possible adverse weather phenomena, and the composition of traffic, in which heavy traffic is present, and even the possibility of the movement of dangerous goods.
- Increased access times for emergency vehicles due to traffic congestion and complexity.

Economic Impact

While it is true that direct and, in some cases, indirect costs are derived from all the social and environmental impacts, there are others that are inferred directly from the cyber-attack event itself.

- Damage caused to the management system itself, and the costs of restitution.
- Possible damage caused to the infrastructure, caused directly or indirectly, among which we highlight:
    - Possible flooding as a consequence of the stoppage of the leakage control pumps.
    - Damage to pipes as a result of uncontrolled start-up of water mist systems.
    - Damage due to uncontrolled operation of ventilation systems.
    - Damage to evacuation systems and subsystems (external ramps, pressurisation systems and others).
- Increase in the economic cost of travel times, for which the tables in the previous deliverables will be used.
- Possible claims from users of the infrastructure, due to loss of capacity and collateral damage.

To jump back to the table outlining each case study and its respective validated tool, click here