# FORESEE

## Future proofing strategies FOr RESilient transport networks against Extreme Events

## SRG Final Workshop, January 27th, 2022

## Presentations

## Document Overview

This document presents the slides from the final Stakeholder Reference Group Workshop that took place on January 27th, 2022 and which highlighted 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 individual presentation. In order to improve efficiency and accessibility, hyperlinks have been inserted throughout the document which enable the reader to jump from one presentation to the other. Links are indicated by blue text and underline. To jump from one section to another simply click on the highlighted text.

## Agenda

**9:30** Opening and scope of the workshop
Jesús Rodríguez, SRG chairman

**9:45** Main results of the FORESEE project
Iñaki Beltrán, Tecnalia

**First Session**

**Introduction to the validation of FORESEE results**
*Chair: Erlinda Biescas. Telespazio UK Ltd*

**10:15** Scope of the work, short description of the infrastructure assets, hazards that have been considered and how FORESEE results tools are linked to improved resilience. Federico Di Gennaro, AISCAT and David García- Sánchez, Tecnalia

**10:45** Guidelines to measure level of service and resilience and to set target values. Bryan Adey, ETH Zürich

**11:00** Transport Infrastructure Resilience (Design, Operation and Contingency plans). Concepción Toribio, Cemosa

**Second Session**

**Improvements on the resilience of transport infrastructures by means of the application of FORESEE results**. *Chair: Federico di Gennaro. AISCAT*

**11:30.** A24 highway in Italy. Fabrizio Federici, AISCAT

- Traffic Module
- Fragility Functions, Vulnerability Functions, Decision Support Interpreter Module

**11:50.** **A16 highway in Italy**. Livia Pardi, Autostrade per l'Italia S.p.A.

- Virtual Modelling platform and asset failure prediction
- SHM BIM based alerting SAS platform

**12:10.** **Montabliz viaduct in Spain**, Mª Antonia Pérez, University of Cantabria and David García-Sanchez, Tecnalia

- Governance module
- Risk mapping tool

**12:30.** **Railway track 6185 in Germany**, Sebastian Kantorski, IVE

- Flooding assessment. The effects of flooding to different railway track components in dependency of the water level
- Command and Control Center

**12:50.** **Tunnels at M-30 ring-road Madrid** (Spain), Tobías Hanel, Ferrovial

- Flooding assessment. Novel methodology
- Hybrid data assessment package
- Cybersecurity assessment

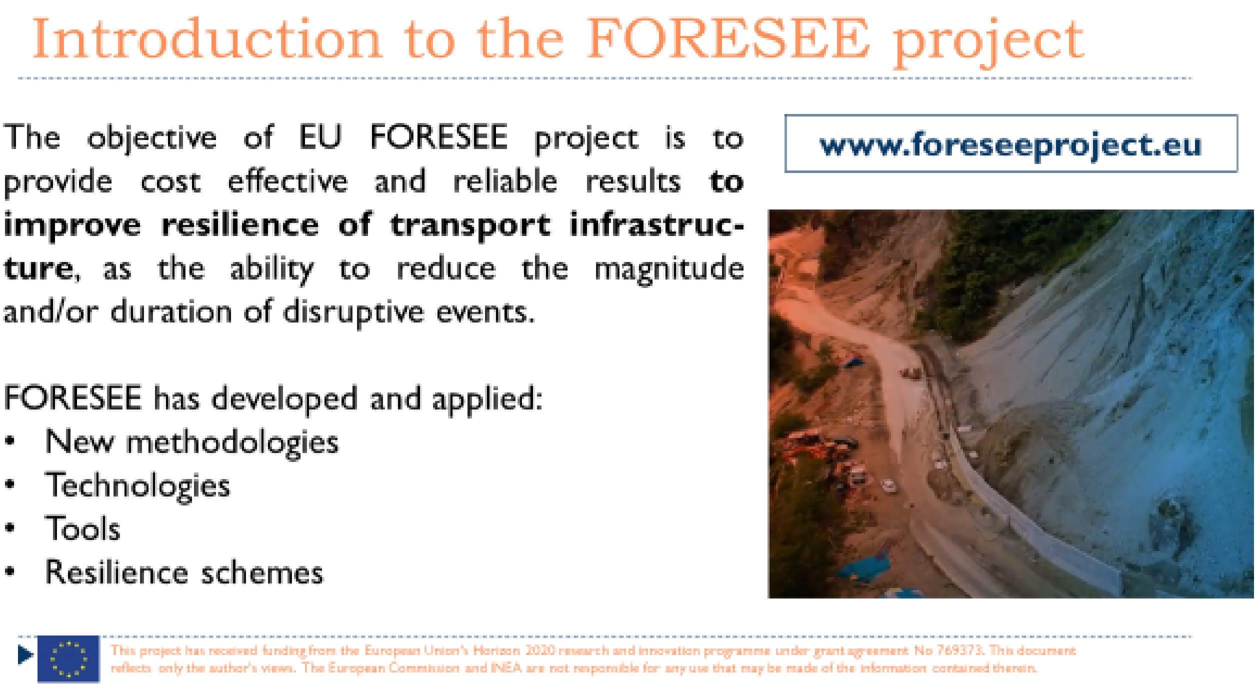
**13:15 Open discussion**

Exchange with transport infrastructure stakeholders (roads, highways, and railways) on the advantages/disadvantages when applying FORESEE results in their infrastructure networks

*Chair: Jesús Rodríguez, SRG chairman*

**14:00 Closing**

9:30 - Opening and scope of the workshop - Jesús Rodríguez, SRG chairman


Introduction to the FORESEE project
Disruptive events covered in FORESEE
Earthquakes
Landslides
Flooding
Accidents
Fires
Cyberattack
Fog
Wind
Others
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CASE STUDIES
Case study #1. A24 Highway. Italy
Case study #2. A16 Highway. Italy
Case study #3. Montabliz Viaduct. Spain
Case study #4. Oebisfede-Berlin Spandau. Germany
Case study #5. M-30 tunnels. Spain
Case study #6. 25th April suspended Bridge.
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## FORESEE consortium

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## Online FORESEE conference

**Towards a more resilient transport infrastructure**

**The FORESEE EU project**

(February 22nd, 2022; 9:30 – 13:15 CET)

- Session on Policy and Regulatory Framework
- Sessions on FORESEE results
- Roundtable with railways and road operators

Contact: José Díez, ERF (j.diez@erf.be; info@erf.be)

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## Stakeholders Reference Group SRG

- Group of external experts to interact with FORESEE project on the **applicability and impact of the main results**, through their participation in 4 workshops and 4 webinars along the project
- Up to now, **SRG** has **240** contact persons from **90** entities and **22** countries (**4** continents)
- Today, about **90 SRG contact persons** are registered from 60 entities plus 30 FORESEE partners and 2 invited attendees from DG Move (Rafal Stanecki) and CINEA (Sergio Escriba).

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## Some SRG events

- **3rd webinar** (**June 2020**) on Algorithms to determine optimal restoration and risk reduction intervention programs for transportation networks
- **2nd workshop (October 2020)** on Adaptation measures for resilient transport infrastructures. Materials and systems.
- **4th webinar (January 2021)** Measuring the resilience of, and prioritizing interventions for, road transport systems in practice
- **3rd workshop (March 18th, 2021)** on Monitoring-based Decision Support for Resilient Transport Infrastructures
- **4th workshop (January 27th, 2022)** on Evaluation of the FORESEE results through their application on case studies

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## Some FORESEE & SRG collaborations

- **PIARC**
  - Collaboration with SRG events
  - A Foresight session in **PIARC 16th World Winter Service and Road Resilience Congress** on 7-11th February 2022, on Resilience Frameworks and Metrics for Road Stakeholders with FORESEE participation (ETHZ, Cemosa)
- **CEN** (through the Spanish CEN member UNE)
  - Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events. CEN WORKSHOP AGREEMENT CWA 17819

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## Final FORESEE SRG workshop (January 27th, 2022)

- Presentation of the main FORESEE results and their application on some cases studies (roads and railways)
- **During the workshop and after**, some feedback on the advantages/disadvantages when applying FORESEE results will be kindly requested to the SRG attendees:
  - Poll questions will be addressed one by one to all attendees
  - All presentations will be uploaded at www.foreseeproject.eu,
  - A "questionnaire" on the applicability and interest of the FORESEE results will be available and answers are expected **before February 11th**

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## Final FORESEE SRG workshop (January 27th, 2022)

**09:30 Scope of the workshop.** Jesús Rodríguez, SRG chairman

**09:45 Main FORESEE results.** Iñaki Beltran, Tecnalia

**10:15 Session 1 Introduction to the validation of FORESEE results**

Chair: Erlinda Biescas, Telespacio UK

**11:15 Break**

**11:30 Session 2 Improvements on the resilience of transport infrastructures by means of the application of FORESEE results**

Chair: Federico di Gennaro, AISCAT

**13:15 Final session. Open discussion with SRG attendees**

Chair: Jesús Rodríguez, SRG chairman

**14:00 Closing.** Rafal Stanecki, DG Move, Sergio Escriba, CINEA

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Back to Agenda

**9:45 -** Main results of the FORESEE project

Iñaki Beltrán, Tecnalia

# Results of the FORESEE project

1. Guidelines to select resilience and service indicators set target objectives.
2. Governance module
3. Risk mapping tool
4. Virtual Modelling platform and asset failure prediction
5. SHM BIM based alerting SAS platform
6. Assessment of traditional solutions in drainage and sustainable drainage systems in linear infrastructures
7. Traffic module
8. Fragility Functions + Decission Support module.
9. New family of pavements
10. Smart and integral slope stabilization protection systems
11. Flooding Methodology
12. Algorithm to determine optimal restoration and risk reduction intervention programs
13. Hybrid data assessment
14. Methodology for the generation of shakemaps from semiempirical appracoh
15. SHM algortihms
16. FORESEE toolkit
17. C2. Command and control
18. Design, construction and remediation plans
19. Operational and maintenance plans
20. Management and contigency plans
21. Flooding assesment
22. Cybertacck Asessment

22 results

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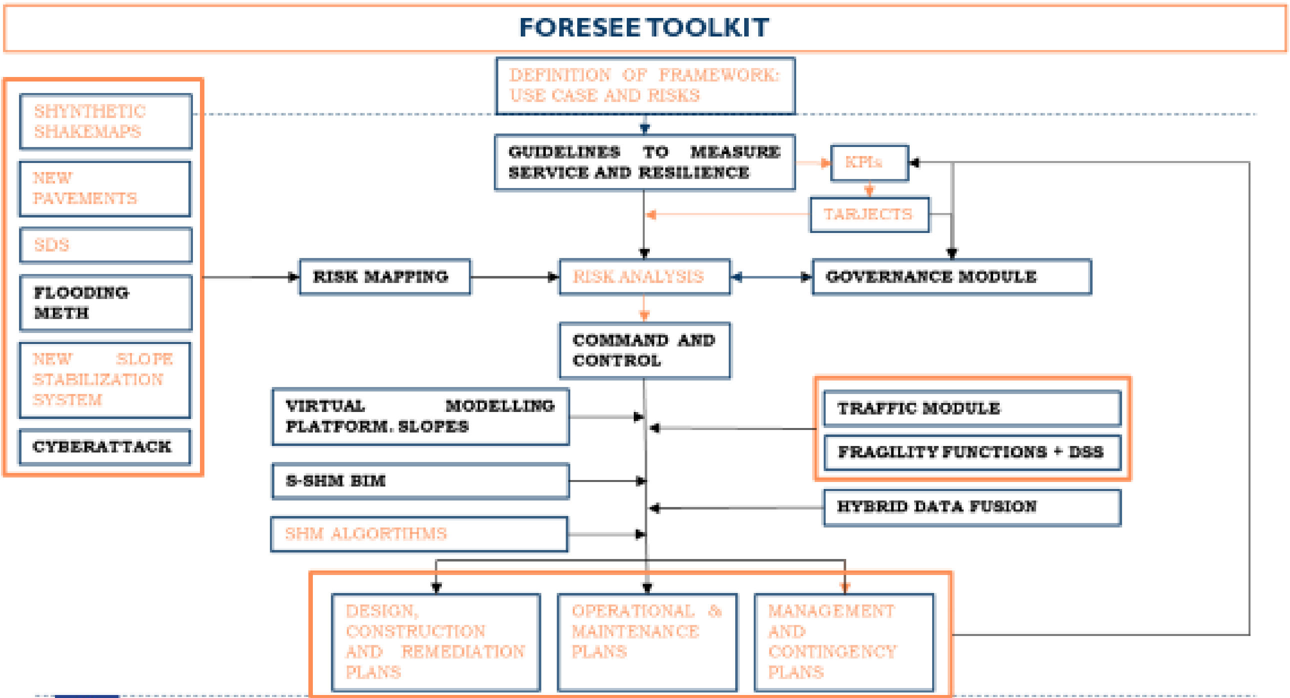


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# Main results of the FORESEE project

- The results presented today are the ones that have used real data coming from the Case Studies and/or adapted specifically for them.
- Some results have been aplied to more than one CSs, today we are presenting the most representatives and/or the results developed by the speakers.
- The other results have used external databases, laboratory and test data, others

1. Traffic Module
2. Fragility Functions, Vulnerability Functions and Decision Support Interpreter Module:
3. Virtual Modelling platform and asset failure prediction:
4. SHM BIM based alerting SAS platform
5. Governance module
6. Risk mapping tool
7. Flooding assessmet (Fully stochastic Flooding Methodology, flooding impacts on railway operations)
8. Command and Control Center
9. Hybrid data assessment package
10. Cybersecurity assessment:

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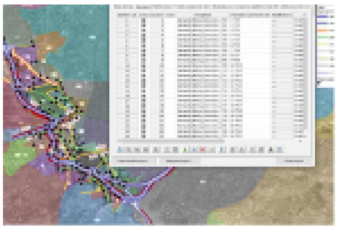
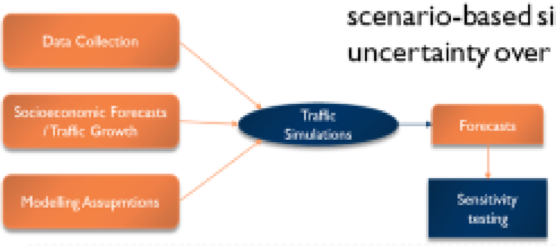
# Main results of the FORESEE project

## TRAFFIC MODULE



Objective: to develop 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 aim of the Traffic Module is to allow running several uncertainty scenario-based simulations, to evaluate the effects of the disruptive event's uncertainty over the traffic characteristics.

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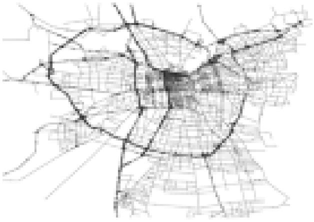
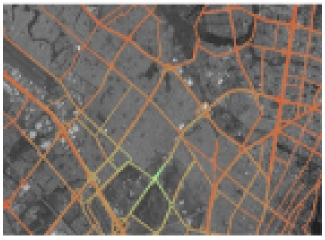
# Main results of the FORESEE project

## TRAFFIC MODULE





- The script makes use of a traffic analysis tool called PTV VISUM, with the purpose of enabling traffic KPI analysis from traffic simulations that can foresee multiple possible disruptive events with associated uncertainty in their capacities.
- The module integrates into the existing traffic tool offering the possibility to perform Monte Carlo simulations on specific variables.

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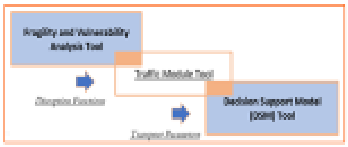
# Main results of the FORESEE project

## FRAGILITY FUNCTIONS, VULNERABILITY FUNCTIONS AND DECISSION SUPPORT INTERPETER MODULE




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

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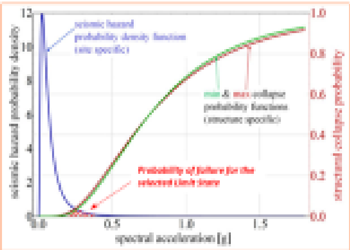
# Main results of the FORESEE project

FRAGILITY FUNCTIONS, VULNERABILITY FUNCTIONS AND DECISSION SUPPORT INTERPETER MODULE




- The first part of the tool defines the disruption curves of the different assets of the Transport System, having considered a scenario in which the hazard intensity and the Transport System are described.

- The Traffic Module outputs are interpreted to define expected losses caused by natural events, Level of service and Resilience assessment after and before the event occurrence

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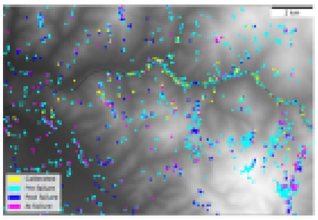
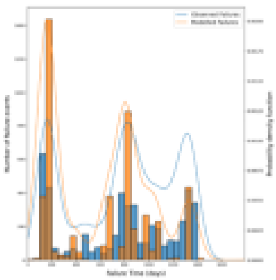
# Main results of the FORESEE project

**Virtual Modelling platform and asset failure prediction**





- Objective: to predict potential landslide failures along infrastructure corridors

Developments are driven by rainfall data and are calibrated based on ground motion detected by satellites (INSAR)

1. Pore Pressure Model.

   Infiltrating rainwater leads to increases in pore pressure within soils. This pore pressure reduces friction in these materials, and thus is a primary driver of slope failure.

2. Data driven approach.

   Data driven machine learning method to predict ground motion

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# Main results of the FORESEE project

## SHM BIM based alerting SAS platform

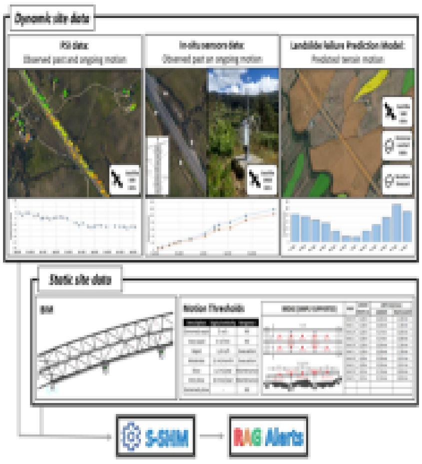


Figure 6. Schema on S-SHM algorithm.

- Objective: to generate RAG alerts over the different elements of a BIM corresponding to a critical infrastructure and to allow a 3D visualization of those alerts.
- Different level of alerts are raised in correspondence with the datasets of motion observed near or on each BIM element

1. Dynamic site data, which provides the motion observed on the infrastructure and its surroundings

   PSI data (INSAR), In –situ sensors, Landslide Failure Prediction Model data

2. Static site data.

   BIM (geometric + structural information) + structural motion thresholds stated at the design phase

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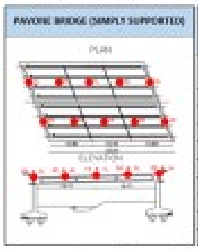
# Main results of the FORESEE project

## SHM BIM based alerting SAS platform

- All bridges are subject to various internal and external factors which may cause wear or malfunction..

| VERTICAL DISPLACEMENT IN CENTER OF SPAN | | | | | |
|---|---|---|---|---|---|
| Simply supported (one span) | | Simply supported (several spans) | | | |
| | | Side span | | Center span | |
| Comfort | Traffic safety | Comfort | Traffic safety | Comfort | Traffic safety |
| L/1750 | L/1000 | L/2500 | L/1430 | L/3500 | L/2000 |




| POINT | LENGTH/HEIGHT (m) | LIMIT VALUE (mm) COMFORT | TRAFFIC SAFETY |
|---|---|---|---|
| Point 1R | 33.00 m | 18.86 mm | 33.00 mm |
| Point 1L | 33.00 m | 18.86 mm | 33.00 mm |
| Point 2R | - | 0.00 mm | 0.00 mm |
| Point 2L | - | 0.00 mm | 0.00 mm |
| Point 3R | - | 0.00 mm | 0.00 mm |
| Point 3L | - | 0.00 mm | 0.00 mm |
| Point 4R | - | 9.43 mm | 16.50 mm |
| Point 4L | - | 9.43 mm | 16.50 mm |
| Point 5R | - | 9.43 mm | 16.50 mm |
| Point 5L | - | 9.43 mm | 16.50 mm |

Figure 11. Theoretical values and control points for Pavone Bridge

| Issued Date | RAG |
|---|---|
| 2018-02-11 | GREEN |
| 2018-02-27 | GREEN |
| 2018-04-16 | AMBER |
| 2018-06-19 | AMBER |
| 2018-07-05 | AMBER |
| 2018-07-21 | GREEN |
| 2018-08-06 | GREEN |
| 2018-08-22 | GREEN |
| 2018-09-07 | GREEN |
| 2018-10-09 | GREEN |
| 2019-01-29 | GREEN |
| 2019-03-02 | GREEN |
| 2019-04-03 | GREEN |
| 2019-06-06 | GREEN |
| 2019-07-03 | GREEN |

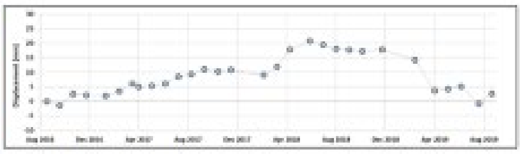
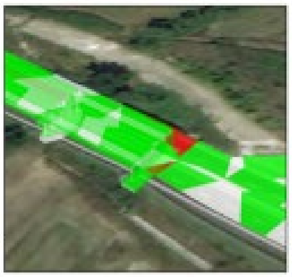


Figure 12. Time series of the PSI measurement point over on the BIM element fme-gen-348b8f33-cc22-4a83-bef1-3ef117479c59, which is located in Loune bridge, near the control parameter 3L.



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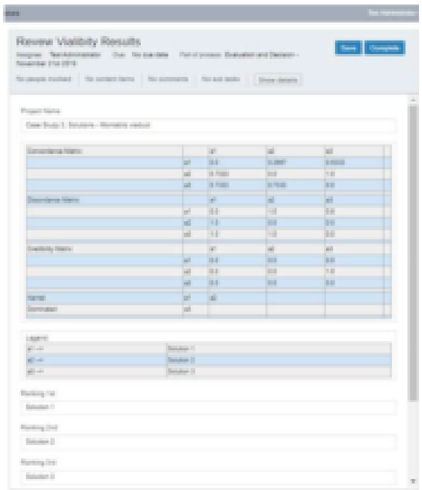
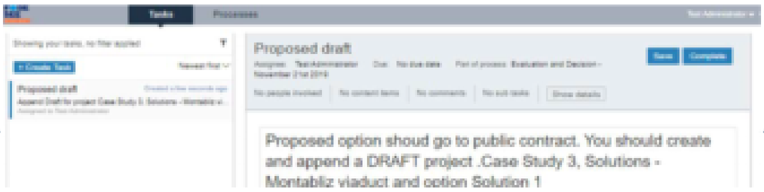
# Main results of the FORESEE project

## GOBERNANCE MODULE



- Objective: to provide effective, transparent and automatic decision-making support for infrastructure resilience managers to extreme events and even in post-event cases.

- Applied in the Decision Making, based on required service and resilience levels
  - To select the most appropriate design and technical solutions
  - to select the experts, who can carry out the different contracts needed for the infrastructure.

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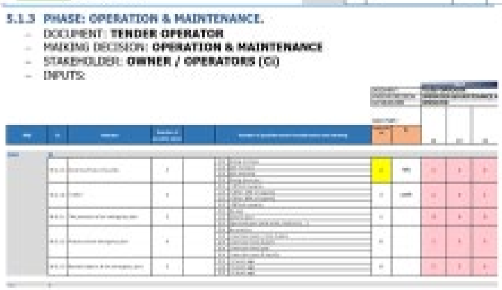
# Main results of the FORESEE project

## GOBERNANCE MODULE



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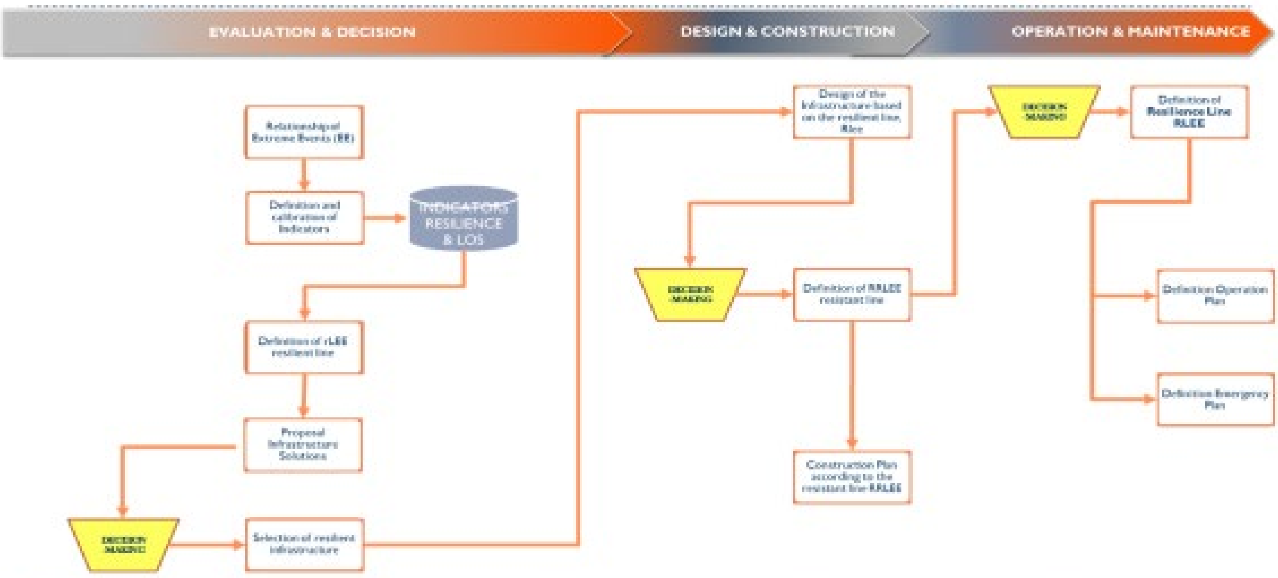
## Main results of the FORESEE project

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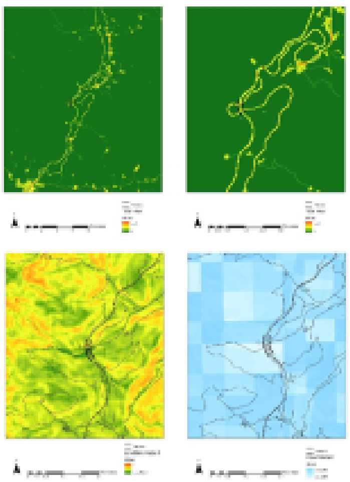
## Main results of the FORESEE project

### RISK MAPPING TOOL



- Objective: Enable large-scale early identification GIS tool of risks to extreme natural disasters affecting regions with road and railway infrastructures
- Estimation of potential risks to be used in the early phases of project design.
- Definition of hazard and risk maps at European level.

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# Main results of the FORESEE project

## RISK MAPPING TOOL


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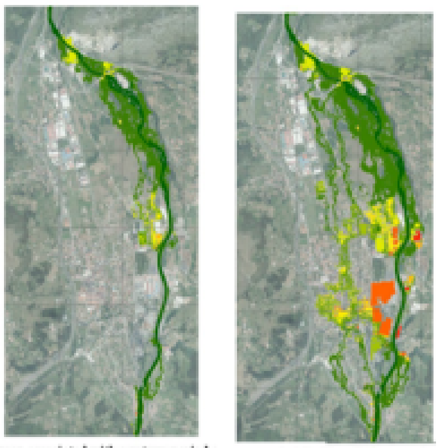
# Main results of the FORESEE project

## FULLY STOCHASTIC FLOODING METHODOLOGY



map associated with a return period o
btained using the usual methodology

ap associated with a 500-year retur
using the proposed methodology

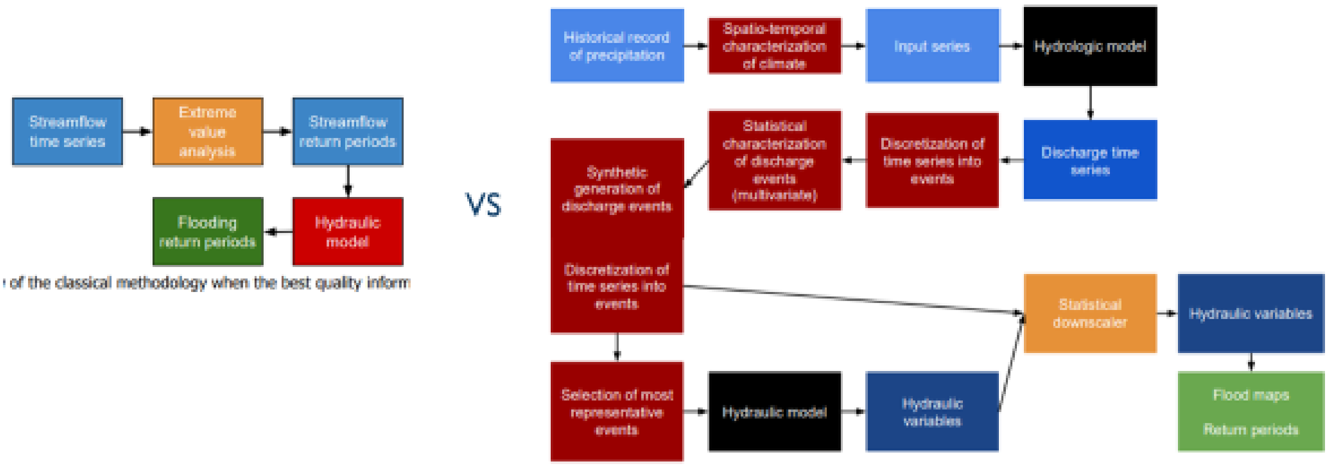

1

- **Objective:** to develop a new methodology to quantify the flooding hazard, based on a complete and robust statistical characterization of the climate variables.

- **Stochastic generation:** Observed time series tend not to be long enough for a complete description of the variability of natural processes, and specially, to properly account for the extreme behavior of the variable of interest.

# Main results of the FORESEE project

## FULLY STOCHASTIC FLOODING METHODOLOGY

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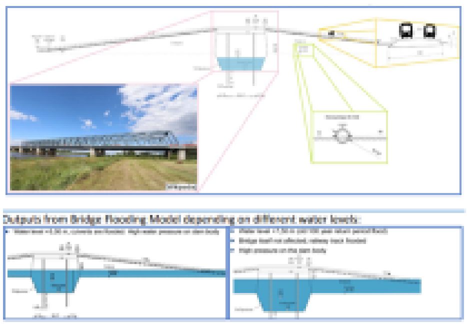
# Main results of the FORESEE project

## BRIDGE FLOODING MODEL TOOL




- Objective: to provide information of the possible serviceability or damage of individual railway track components depending on different water levels in the form of a small-scale simulation
- Identify measures to improve bridges' design or to modify the existing ones
- Simulate water levels affecting railway's operation
- Design water-resistant systems (electric)

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# Main results of the FORESEE project

## COMMAND AND CONTROL

- Objective: to detect when new data points lay outside of its normal behaviour and issue meaningful alerts
- To provide interactive real time visualization and interaction with the data
- To serve for training purposes of infrastructure managers

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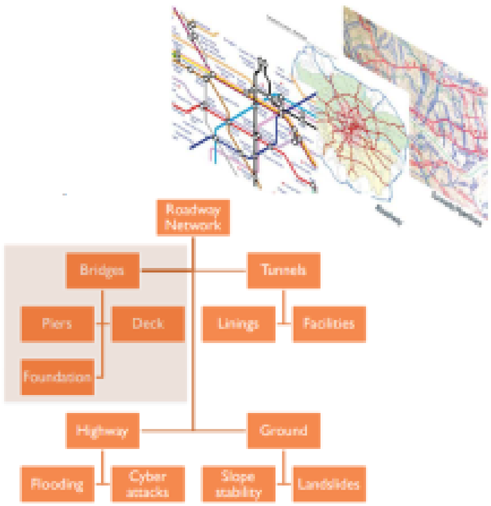
# Main results of the FORESEE project

## HYBRID DATA ASSESSMENT PACKAGE




- Objective: to detect and prognose faults for infrastructure systems in the face of extreme events, representing hazards using an interpretable framework
- relies on information from the system (e.g. bridge, tunnel) response under such extreme loads

- define an object oriented framework
- transport infrastructure networks as a „system of systems"
- goal: diagnose & prognose damaging events/faults

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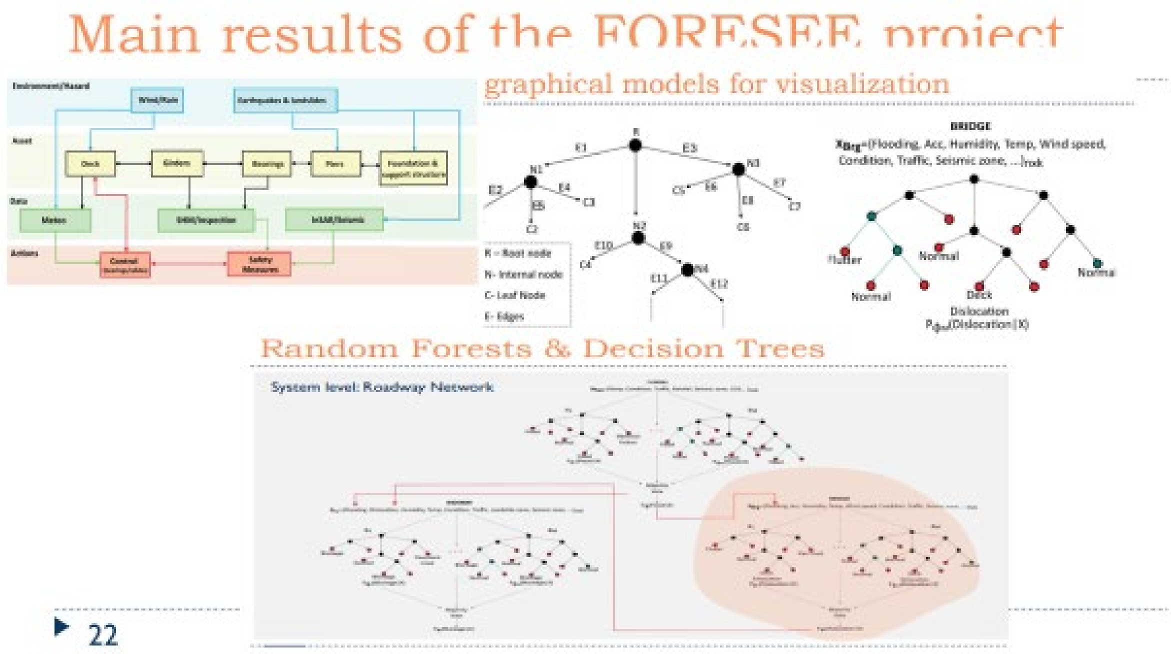
Main results of the FORESEE project
graphical models for visualization
R - Root node
N- Internal node
C- Leaf Node
E- Edges
BRIDGE
Random Forests & Decision Trees
System level: Roadway Network
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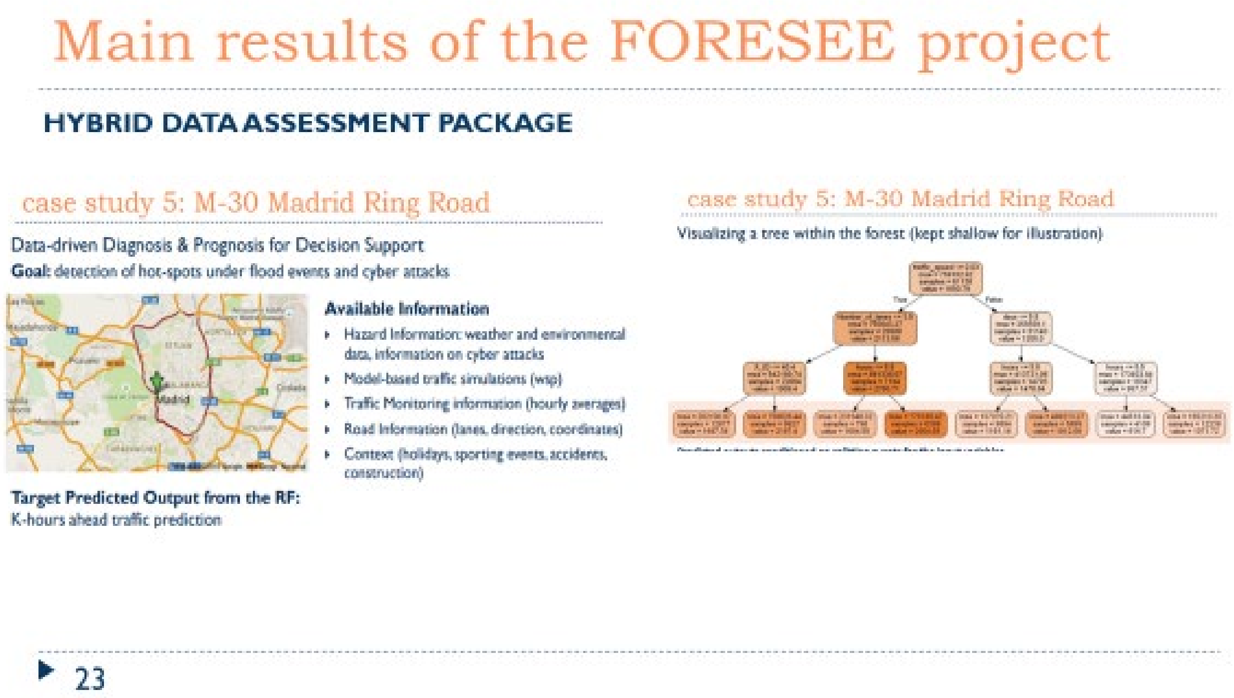
Main results of the FORESEE project
HYBRID DATA ASSESSMENT PACKAGE
case study 5: M-30 Madrid Ring Road
Data-driven Diagnosis & Prognosis for Decision Support
Goal: detection of hot-spots under flood events and cyber attacks
Available Information
Hazard Information: weather and environmental data, information on cyber attacks
Model-based traffic simulations (wsp)
Traffic Monitoring information (hourly averages)
Road Information (lanes, direction, coordinates)
Context (holidays, sporting events, accidents, construction)
Target Predicted Output from the RF:
K-hours ahead traffic prediction
case study 5: M-30 Madrid Ring Road
Visualizing a tree within the forest (kept shallow for illustration)
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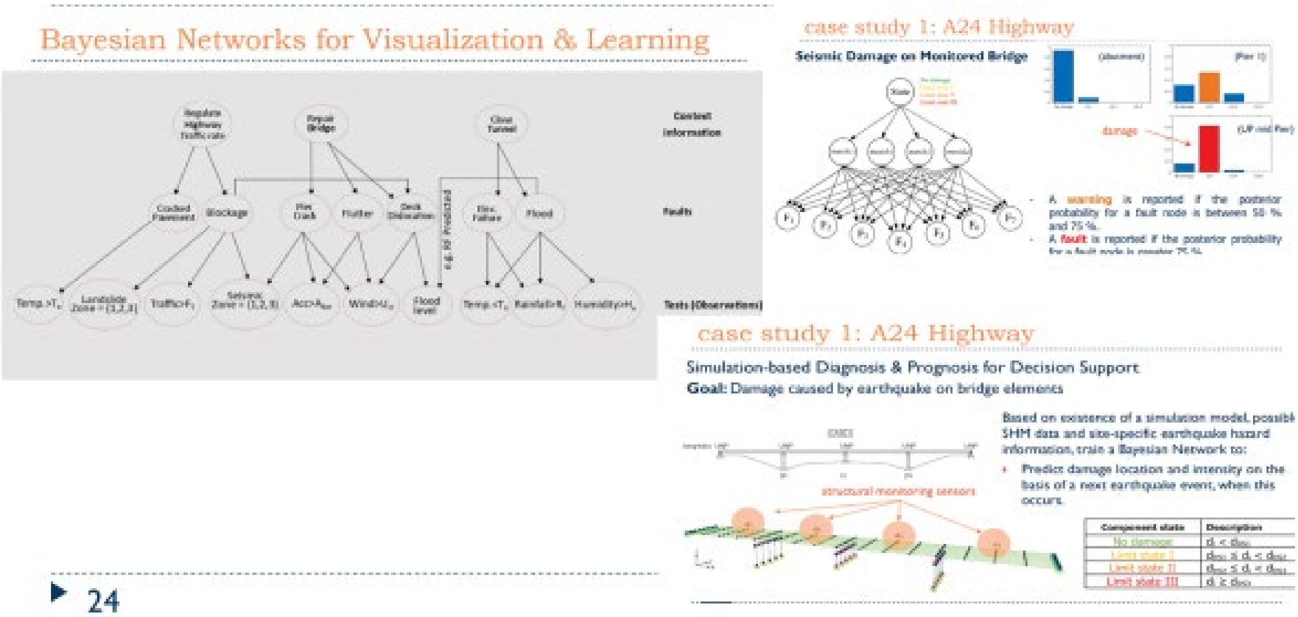
# Main results of the FORESEE project

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# Main results of the FORESEE project

**HYBRID DATA ASSESSMENT PACKAGE**

- Data-driven diagnosis & prognosis for decision support
- Benefits of an Interpretable Approach:

•Visual Interpretability and possibility of connecting multiple objects (bridge, tunnel, etc.)

•Speedy predictions, i.e., no need to re-run traffic models for every eventuality and use case

•Seamless data fusion: environmental data, traffic data, topography data, context and incidents data types can all be combined as input features to make predictions on traffic condition.

•Data augmentation: new use cases may be simulated, and their output can be used to augment the initial model input data in order to retrain, tune and tweak the existing model..

•Tracing of root cause of faults for Diagnostics

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# Main results of the FORESEE project

## CYBERSECURITY ASSESSMENT

- Objective: To describe the impact on traffic and alternative routes to the Madrid Calle 30 tunnel system, analysing the socio-economic impact

- The operational response system, the actions to be taken immediately by the Calle 30 Control Centre have been detailed to guarantee the safety of users and operators, even in these circumstances.

- Preventive measures aimed at preventing a cyber-attack.
- Analysis of the resilience capacity of the facilities and equipment managed by the Main Control Centre.
- Description of possible scenarios.
- Definition of applicable systematics to lessen the effects of a cyber-attack.
- Approval and inclusion of the system in accordance with current regulations.

- -Is a cyber-attack the proven reason of the total failure of the Main Control Center?
- -Does the Control Center maintain total or partial management capacity?
- -Is the cyber attack only limited to nullifying the Control Center's ability to operate?
- -Does the cyberattack allow the intruder to operate the management systems maliciously?

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# Main results of the FORESEE project

## CYBERSECURITY ASSESSMENT

- Some Systems considered critical that are managed from the M-30 Ring Road.

- External and internal power supply system.
- Ventilation and air pollution control system
- Fire fighting system.
- Lighting system.
- Emergency signage system.
- CCTV system.
- SOS posts.
- Evacuation management systems.
- Automatic incident detection (AID)
- Signalling using lights and traffic signals
- Communications network

It would be desirable to create tools that allow rapid discrimination of the existence of a cyberattack.

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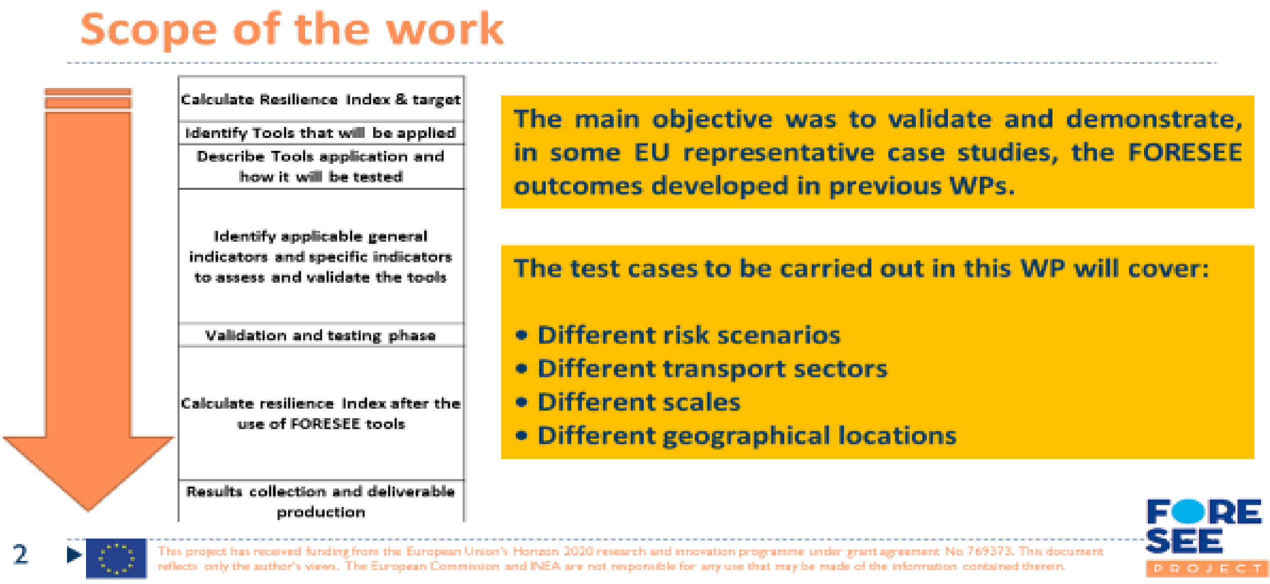
**First Session (10:00 – 11:15)**

**Introduction to the validation of FORESEE results**

10:15 - Scope of the work, short description of the infrastructure assets, hazards that have been considered and how FORESEE results tools are linked to improved resilience.

Federico Di Gennaro, AISCAT and David García- Sánchez, Tecnalia


Scope of the work
Calculate Resilience Index & target
Identify Tools that will be applied
Describe Tools application and how it will be tested
Identify applicable general indicators and specific indicators to assess and validate the tools
Validation and testing phase
Calculate resilience index after the use of FORESEE tools
Results collection and deliverable production
The main objective was to validate and demonstrate, in some EU representative case studies, the FORESEE outcomes developed in previous WPs.
The test cases to be carried out in this WP will cover:
• Different risk scenarios
• Different transport sectors
• Different scales
• Different geographical locations
FORESEE PROJECT
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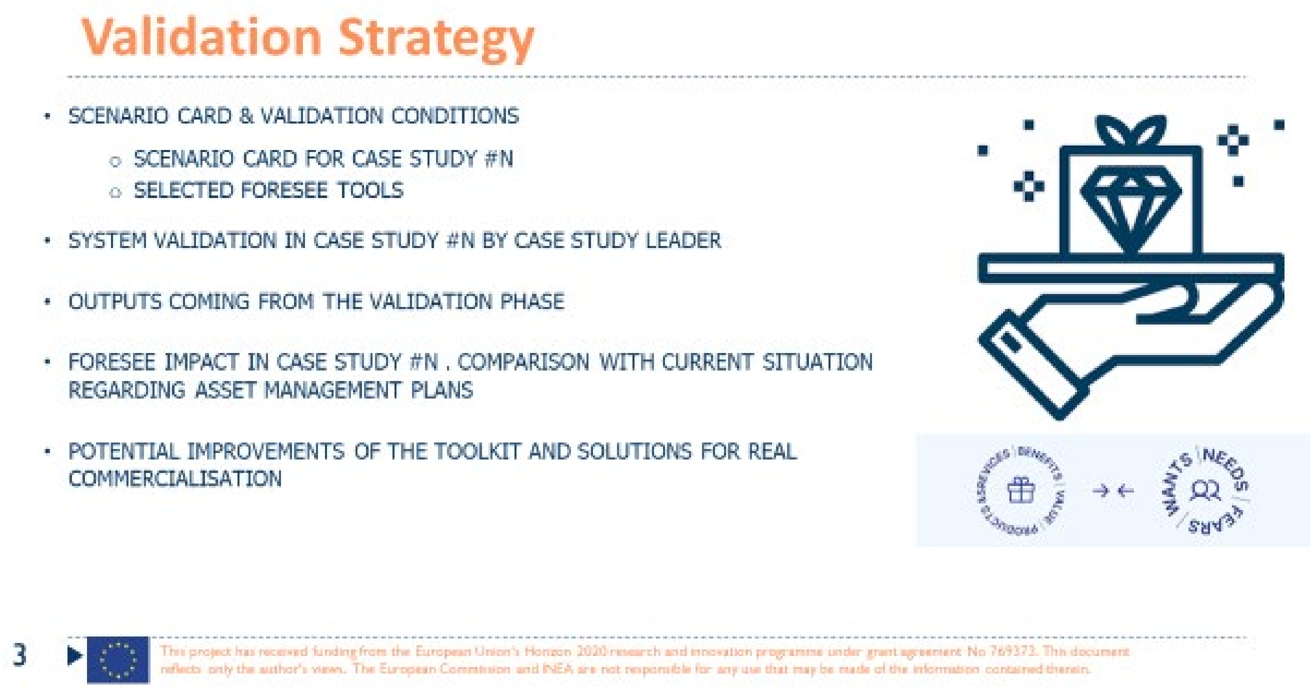
Validation Strategy
• SCENARIO CARD & VALIDATION CONDITIONS
○ SCENARIO CARD FOR CASE STUDY #N
○ SELECTED FORESEE TOOLS
• SYSTEM VALIDATION IN CASE STUDY #N BY CASE STUDY LEADER
• OUTPUTS COMING FROM THE VALIDATION PHASE
• FORESEE IMPACT IN CASE STUDY #N . COMPARISON WITH CURRENT SITUATION REGARDING ASSET MANAGEMENT PLANS
• POTENTIAL IMPROVEMENTS OF THE TOOLKIT AND SOLUTIONS FOR REAL COMMERCIALISATION
WANTS NEEDS FEARS
3
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## Validation Strategy

- SCENARIO CARD & VALIDATION CONDITIONS
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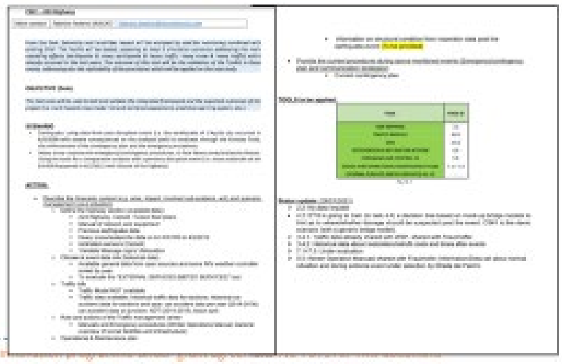
- POTENTIAL IMPROVEMENTS OF THE TOOLKIT AND SOLUTIONS FOR REAL COMMERCIALISATION

*Scenario card provided a detailed overview on*
- *Objective of the Case Study*
- *Main Hazard Scenarios to be considered*
- *Action in terms of data availability*
- *Selected Tools to be validated*



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## Validation Strategy

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*Deliverable for each case Study contain the main outcomes related to the «Validation» activities:*
- *Testing the tools*
- *Reviewing the results*
- *Comparison with current procedure/tools*
- *Assessing the changes in the "level of resilience"*

*Each Case Study responsible provided also a detailed feedback for the future implementation of the tools, by addressing the main potential improvements that can be done for the market deployement*

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## Case Study Overview - Assets

**6 Case Study**

**5 Countries**

**Roads & Railways**

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FORESEE PROJECT

## Case Study Overview - Assets

#1 - Carsoli-Torano A24 Highway.

Pilot Responsible: AIS

#2 - Naples to Bari A16 Highway (TEN-T corridor #5)

Pilot Responsible: ASPI

#3 - Montabliz Viaduct

Pilot Responsible: UC

#4 - Railway Track 6185 (Oebisfelde-Berlin Spandau) –

Pilot Responsible: IVE

#5 – M30 Ring Road Madrid

Pilot Responsible: FERR

#6 - 25th April Suspended Bridge - Lisbon

Pilot Responsible: IP

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FORESEE PROJECT

## Case Study Overview - Assets

A24 Highway (from 52 km to 73 km) is a strategic and barycentric road system that connects Rome to the Adriatic Sea. The motorway plays a vital role in supporting the mobility of production activities, communications, commerce, tourism and social and economic development throughout the country.

**#1 - Carsoli-Torano A24 Highway.**

**Pilot Responsible: AIS**



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## Case Study Overview - Assets

The A24, especially its montaneous section in winter, is particularly prone to bad weather with sudden snowstorms, strong winds, fog and ice.

**#1 - Carsoli-Torano A24 Highway.**

**Pilot Responsible: AIS**

| | |
|---|---|
| HAZARD | The motorway has been selected as the focus of the first FORESEE case study due to the **frequent earthquakes, extreme weather condition** |
| TOOLS | • TRAFFIC MODULE<br>• FRAGILITY FUNCTIONS, VULNERABILITY FUNCTIONS AND DECISION SUPPORT INTERPRETER MODULE |

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## Case Study Overview - Assets

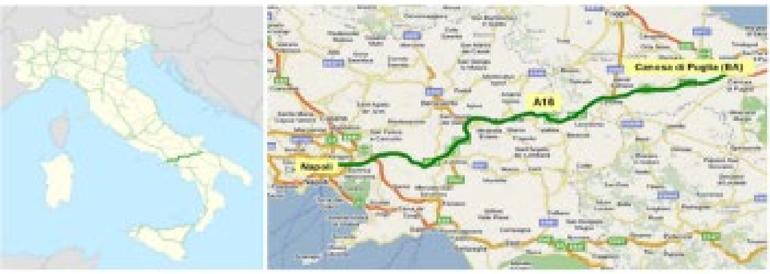
**#2 - Naples to Bari**

**A16 Highway (TEN-T corridor #5)**

**Pilot Responsible: ASPI**

The A16 highway ("Motorway of the Two Seas") runs from Naples to Bari along the TEN-T Corridor 5.

It 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.

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## Case Study Overview - Assets

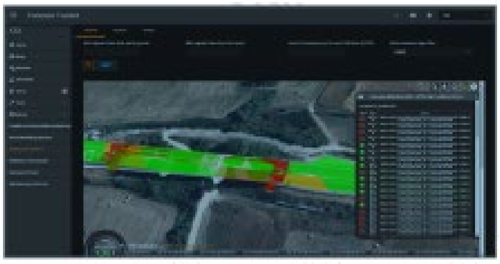
**#2 - Naples to Bari**

**A16 Highway (TEN-T corridor #5)**

**Pilot Responsible: ASPI**

Focus on the section between km. 97-99, where 3 bridges were considered.

| | |
|---|---|
| HAZARD | Specific hazard (i.e. high seismic hazard zone) and extreme weather conditions (i.e. snow). |
| TOOLS | **Virtual Modelling platform and asset failure prediction SHM BIM based alerting SAS** |





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## Case Study Overview - Assets

**#3 - MONTABLIZ VIADUCT**

**PILOT RESPONSIBLE: UC**

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) including the Montabliz Viaduct, to evaluate, through the FORESEE Tools

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## Case Study Overview - Assets

**#3 - MONTABLIZ VIADUCT**

**PILOT RESPONSIBLE: UC**

The case study of Montabliz Viaduct has been studied in two different scenarios, corresponding to two phases of the life cycle.

- **Design & Construction**, **D phase**, definition of the design resilient to the specific hazards, wind and snowfall.
- **Operation & Maintenance**, **M phase**, definition of flood zones on the A-67 motorway, for avenues with different return periods.

| | |
|---|---|
| HAZARD | Strong winds and snowfall on a section of the A-67 motorway |
| TOOLS | • **Risk Mapping**<br>• **Governance Module**<br>• **Flooding Methodology** |

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## Case Study Overview - Assets

**#4 - RAILWAY TRACK 6185 (OEBISFELDE-BERLIN SPANDAU) – PILOT RESPONSIBLE: IVE**

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 approx. 150 kilometres long track section between Oebisfelde (km 267,9) and Berlin-Spandau (km 112,7) is built as ballastless track with a maximum speed up to 250 km/h.

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## Case Study Overview - Assets

**#4 - RAILWAY TRACK 6185 (OEBISFELDE-BERLIN SPANDAU) – PILOT RESPONSIBLE: IVE**

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.

| | |
|---|---|
| HAZARD | Severe flooding events in that zone |
| TOOLS | • Bridge Flooding Model<br>• Command and Control Center |

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## Case Study Overview - Assets

**#5 – M30 Ring Road Madrid**

**Pilot Responsible: FERR**

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.

Madrid Calle 30 Ring Road is the most important and the busiest road infrastructure in Spain. 1.5 million vehicles per day use (part of) the Calle 30, of which 200,000 vehicles per day make a "full" journey that covers the use of all tunnels (48 km in total).

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## Case Study Overview - Assets

**#5 – M30 Ring Road Madrid**

**Pilot Responsible: FERR**

Three different scenarios for three different hazards have been studied specifically in the section of the tunnels that are located in the southwest part of the M30 ring road.

1. Man-made events including cyberattack
2. Flooding and other extreme events derived from raining in the valley
3. Fire inside the tunnels

| | |
|---|---|
| HAZARD | Flooding, fire and cyberattack |
| TOOLS | • Cyberattack assessment<br>• Flooding methodology<br>• Traffic module |

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## Case Study Overview – Assets

**#6 - 25TH APRIL SUSPENDED BRIDGE - LISBON**

**PILOT RESPONSIBLE: IP**

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.


The upper deck carries six car lanes while the lower deck carries an electrified double track railway.

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FORESEE PROJECT

## Case Study Overview – Assets

**#6 - 25TH APRIL SUSPENDED BRIDGE - LISBON**

**PILOT RESPONSIBLE: IP**

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.

| | |
|---|---|
| HAZARD | The primary hazard considered as a threat to this structure is an earthquake. Also man-made hazards such as rail accidents |
| TOOLS | • Virtual Modelling platform and asset failure prediction<br>• SHM BIM based alerting SAS |

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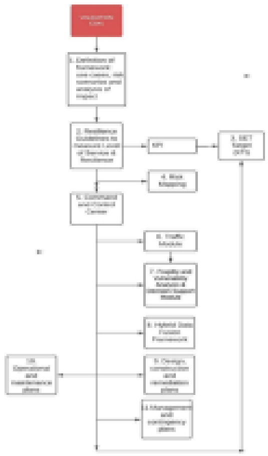
FORESEE PROJECT

# Case Study Overview – FORESEE Tools

| UPDATED | | | ORDER | | | | | |
|---|---|---|---|---|---|---|---|---|
| TOOL | Name | Developer | CS#1 | CS#2 | CS#3 | CS#4 | CS#5 | CS#6 |
| D1.1 | Resilience Guidelines to measure Level of Service & Resilience | ETHZ | 2 | 2 | 10 | 2 | 2 | 2 |
| D1.2 | Set Targets | ETHZ | 2 | 2 | 10 | 2 | 2 | 2 |
| T1.3 | Governance Module | UC | | | 50 | | | |
| T2.2 | Risk Mapping | UC | 3 | 3 | 40 | 3 | | 3 |
| T2.4 | Virtual modelling Platform | UEDIN | | 5 | | | | |
| T2.5 | Alerting SAS platform | TVUK | | 5 | | | | |
| T3.4.1 | Traffic Module | WSP | 5 | 6 | 10 | 5 | 6 | 5 |
| T3.4.2 | Fragility and Vulnerability Analysis & Decision Support Module | RINA-C | 5 | 6 | | 5 | 6 | |
| T4.1 | Flooding Methodology | IH | | | 40 | | 5 | |
| T4.4 | Hybrid Data Fusion Framework | ETH | 6 | | | | 7 | |
| T5.5 | Command and Control Center | FRA | 4 | 4 | 20/20 | 4 | 4 | 4 |
| T7.1 | Definition of framework: use cases, risk scenarios and analysis of impact | CEM | 1 | 1 | 30/30 | 1 | 1 | 1 |
| T7.2 | Design, construction and remediation plans | CEM | 7 | 7 | | 6 | 8 | 6 |
| T7.3 | Operational and maintenance plans | TEC | 8 | 8 | | 7 | 9 | 7 |
| T7.4 | Management and contingency plans | ICC | 9 | 9 | | 8 | 10 | 8 |
| Solutions catalogue | | | | | | | | |
| T4.2 | Earthquake Platform | CEM | 10 | 10 | 60/40 | 9 | 11 | 9 |
| T3.3 | Sustainable Drainage System | CEM | 10 | 10 | 60/40 | 9 | 11 | 9 |
| T4.3 | Development of algorithms for the selection and definition of efficient and optimal actions | ETH/CEM | 10 | 10 | 60/40 | 9 | 11 | 9 |
| D3.5 | New Family of PA-pavements | UC | 10 | 10 | 60/40 | 9 | 11 | 9 |
| D3.6 | Smart & Integral slope stabilization system | UC | 10 | 10 | 60/40 | 9 | 11 | 9 |
| D4.4 | SHM Algorithms | TEC | 10 | 10 | 60/40 | 9 | 11 | 9 |



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# Case Study Overview – FORESEE Tools

| UPDATED | | |
|---|---|---|
| TOOL | Name | Developer |
| D1.1 | Resilience Guidelines to measure Level of Service & Resilience | ETHZ |
| D1.2 | Set Targets | ETHZ |
| T1.3 | Governance Module | UC |
| T2.2 | Risk Mapping | UC |
| T2.4 | Virtual modelling Platform | UEDIN |
| T2.5 | Alerting SAS platform | TVUK |
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| T3.4.2 | Fragility and Vulnerability Analysis & Decision Support Module | RINA-C |
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| T4.4 | Hybrid Data Fusion Framework | ETH |
| T5.5 | Command and Control Center | FRA |
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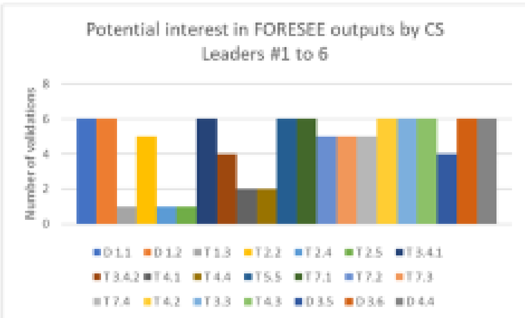


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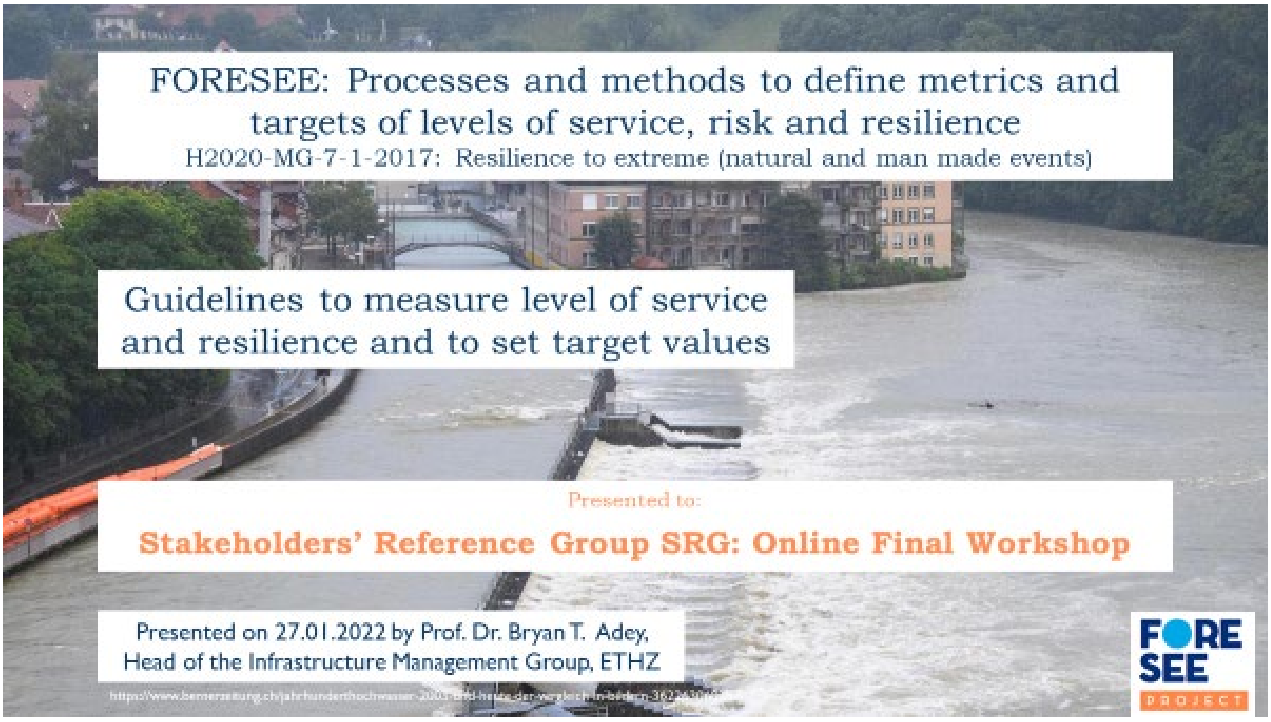
10:45 - Guidelines to measure level of service and resilience and to set target values.

Bryan Adey, ETH Zürich




# Main points

- With a changing climate, decision makers need to have a systematic way to evaluate the resilience of transport systems, whether they are roads, rails, inland water ways or combinations of these

- This requires systematic assessments for the system(s) being assessed that have
  - clear definitions of the system(s) being considered,
  - clear definitions of the service being provided, and
  - consistent assessment of the intervention costs and reductions in service expected if potentially disruptive events occur

- With these systematic assessments, decision makers can devise «stress tests» that should be used in the assessments so they obtain clarity on
  - the resilience of the system(s),
  - the parts of the system(s) that are leading to a lower than desired resilience,
  - the parts of the system(s) that could be improved to improve resilience, and
  - the resilience targets to be set.

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FORESEE PROJECT

# Reports

- Report 1.1 Guideline to measure levels of service provided by, and resilience of, transport infrastructure

- Report 1.2 Guideline to set the target levels of service provided, by and resilience of, transport infrastructure

- CEN/CLC/WS 018 "Assessment of the resilience of transport infrastructure to potentially disruptive events"


An image from Spain's DGT traffic authority of the M-40 cut off near La Fortuna in Leganés

https://english.elpais.com/elpais/2019/08/27/inenglish/1566892886_491442.html

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# Definitions

- **Service** is defined as
  - **the ability to perform an activity in a certain way.**
- Service, with this definition, can be operationalised, for example, as the ability to transport from A to B,
  - goods and persons within a specific amount of time, and
  - goods without being damaged and persons without being hurt or losing their lives.

- **Resilience** is defined as
  - **the ability to continue to provide service if a hazard event occurs.**
- Resilience, with this definition, is operationalised, using
  - each measure of service deemed relevant, in order to assess how service is being affected, and
  - the cost of the interventions required to ensure that the infrastructure once again provides and adequate service.


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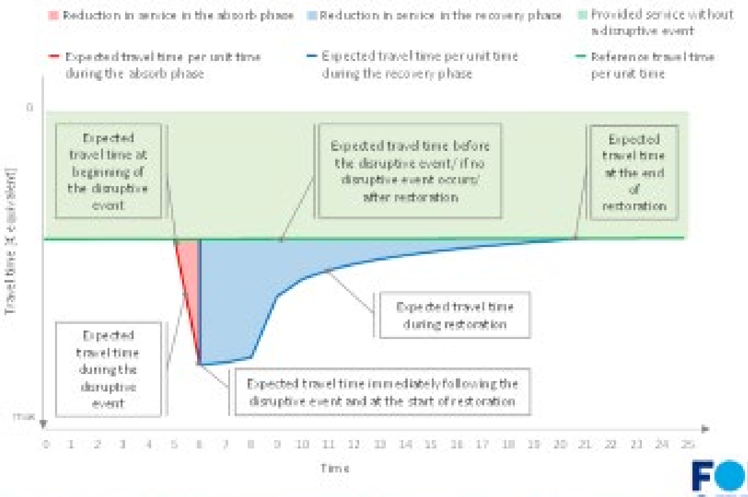
# Illustration of resilience

Using the measure of service <u>expected yearly cumulative travel time</u>, of infrastructure enabling the transport of goods and persons from A to B for a scenario, where a single hazard event occurs and the infrastructure is restored so that it provides that same level of service as it did before the hazard event





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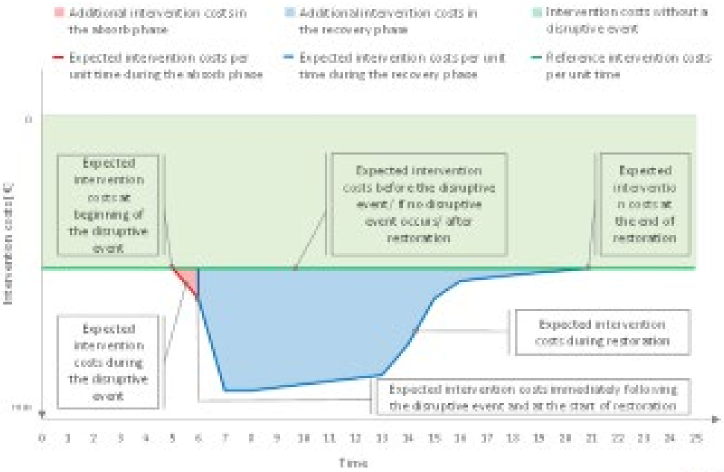
# Illustration of resilience

Using intervention costs, of infrastructure enabling the transport of goods and persons from A to B for a scenario, where a single hazard event occurs and the infrastructure is restored so that it provides that same level of service as it did before the event

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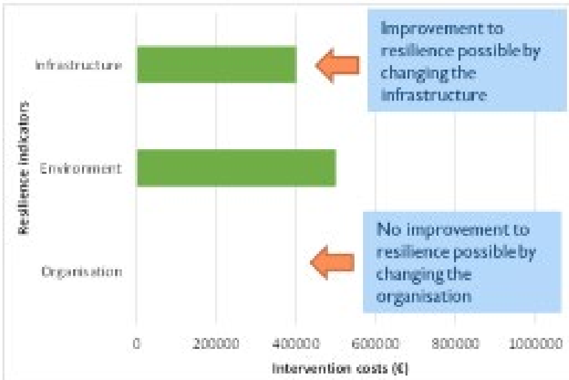
# Steps to measure resilience

1. Define transport system
2. Measure service
   - Define service
   - Determine how to measure service
   - Measure service
3. Measure resilience
   - Identify relevant parts of transport system
   - Determine how to measure resilience
   - Measure resilience directly using lost service and intervention costs
   - Measure resilience using indicators
   - Estimate percentage of fulfilment of resilience indicators




Results of resilience measured using transport systems parts, differentiated weights and intervention costs.

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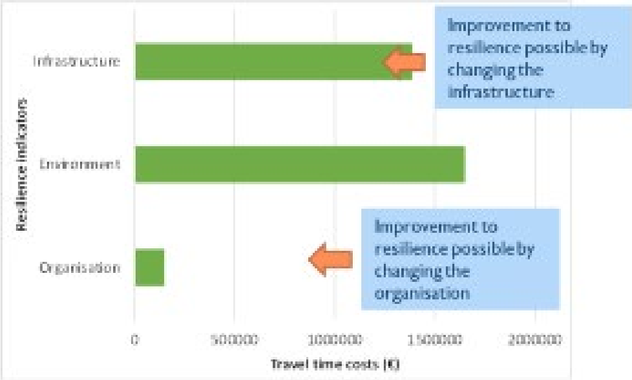


Results of resilience measured using transport systems parts, differentiated weights and travel time costs.

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# Definition

**Target** is defined as

**A level of service or resilience that stakeholders consider acceptable and for which they are willing to take due actions.**

The choice of target, and target setting method, depends on, among other things
- the specific problem to be addressed
- the time frame at disposition
- the expertise available
- the availability of data, and
- how the level of service and resilience are measured.

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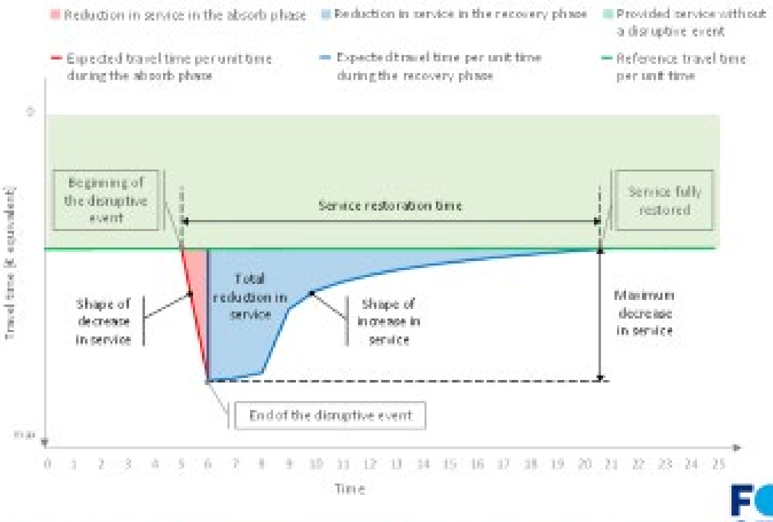
# Illustration of possible targets

Using the measure of service travel time showing the various types of targets, i.e. maximum decrease in service, shape of decrease in service, shape of service curve during restoration, service restoration time and total reduction in service.



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# Targets can be set for…

1. Either intervention costs or a measure of service
2. Combinations of intervention costs and measures of service
3. Multiple hazards

For example, one can concentrate only on the travel time measure of service and set a target for the maximum decrease following the beginning of the hazard event and the time until vehicles can once again travel as they could prior to the event.

For example, one can consider intervention costs and the travel time measure of service and set a target for the total intervention and travel time costs following the beginning of the hazard event.

For example, one can set the maximum additional travel time per week following the beginning of either a 500-year earthquake hazard event or a 500-year flood event.



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# Steps to set targets

Steps:

1. Gather all relevant stakeholders
2. Determine legal requirements
3. Determine stakeholder requirements
4. Set targets

The specific method to be used to set targets, i.e. task 4, depends on:

- how resilience is measured, i.e. using simulations or indicators, and
- whether or not cost-benefit analysis is used.

https://www.gadelius.com/products/disaster_relief03_e.html

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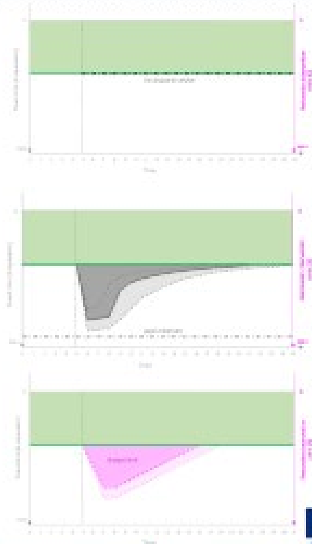
FORESEE PROJECT

# Example targets for service and resilience

| Target set | Label | Des-cription | Targets per type of target | | |
|---|---|---|---|---|---|
| | | | travel time reduction | restor-ation time | restoration intervention costs |
| 1 | No changes in service | No change in travel time given a 100-year flood | None | Not specified | Not specified |
| 2 | Legal minimum | All legal requirements are fulfilled | Largest legally allowed | Largest legally allowed | Not specified |
| 3 | Restoration budget | Available budget will be used fully, in order to maximise the service | Not specified | Not specified | Under the specified restoration budget |



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FORESEE PROJECT

# Example targets for indicators

1. select the resilience indicators for which targets are to be set
2. set each target to the lowest value possible
3. estimate the additional costs and benefits of each unit increase in the value of each indicator from the lowest legally allowed value
4. estimate the benefit/cost ratio for each unit increase for each indicator
5. set targets for all indicators based on the estimated benefit/cost ratios

| Indicator | Legal req. | Possible values | Incre-ment costs | Increment benefit | Benefit / cost ratio | Net benefit |
|---|---|---|---|---|---|---|
| Condition state of asset | - | 1 - worst | - | - | - | - |
| | | 2 | € 8'000 | € 12'913 | 1.61 | € 4'913 |
| | | 3 | € 10'000 | € 10'505 | 1.05 | € 5'418 |
| | | 4 | € 11'000 | € 11'121 | 1.01 | € 5'539 ⇦ |
| | | 5 - best | € 12'000 | € 9'900 | 0.83 | € 3'439 |
| Frequency of monitoring | 2 | 1 - worst | - | - | - | - |
| | | 2 | € 10'000 | € 8'800 | 0.88 | € -1'200 |
| | | 3 | € 12'000 | € 12'200 | 1.02 | € -1'000 ⇦ |
| | | 4 - best | € 15'000 | € 10'244 | 0.68 | € -5'756 |

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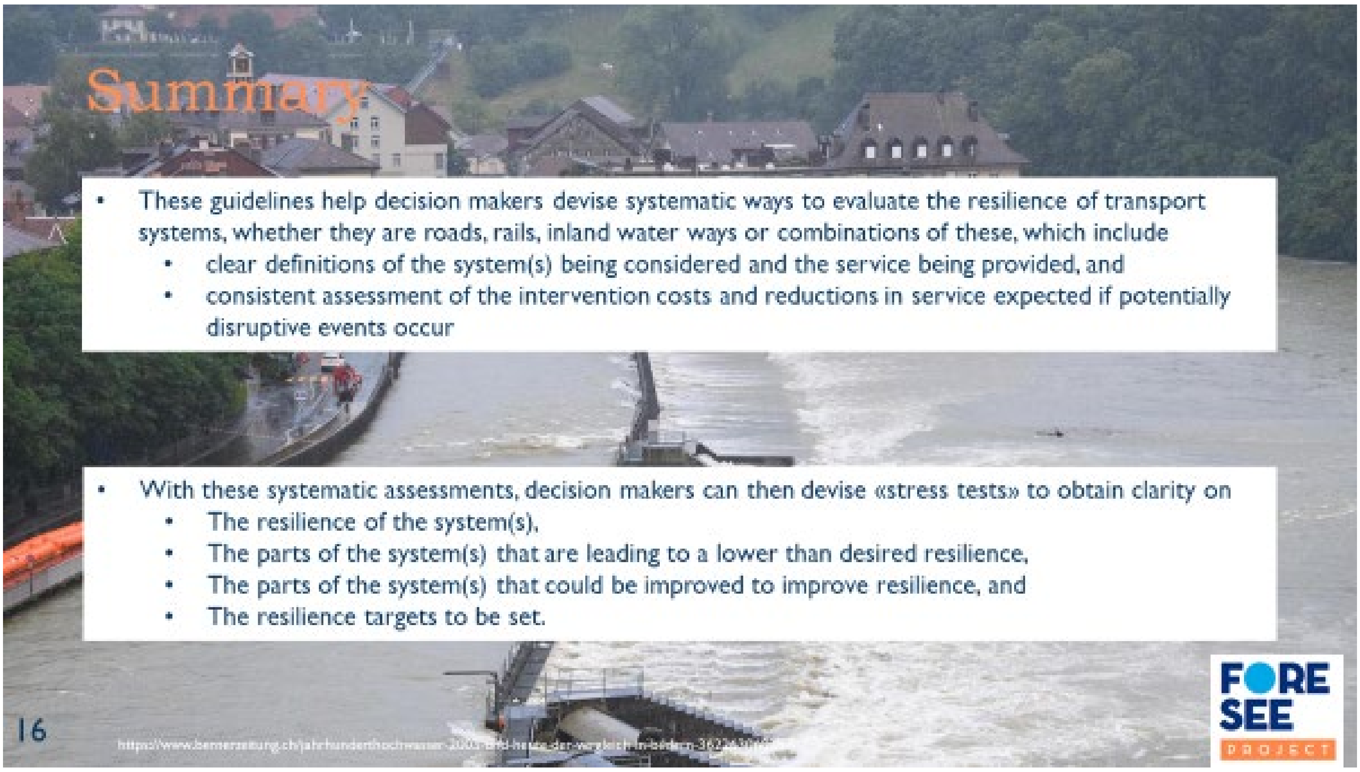
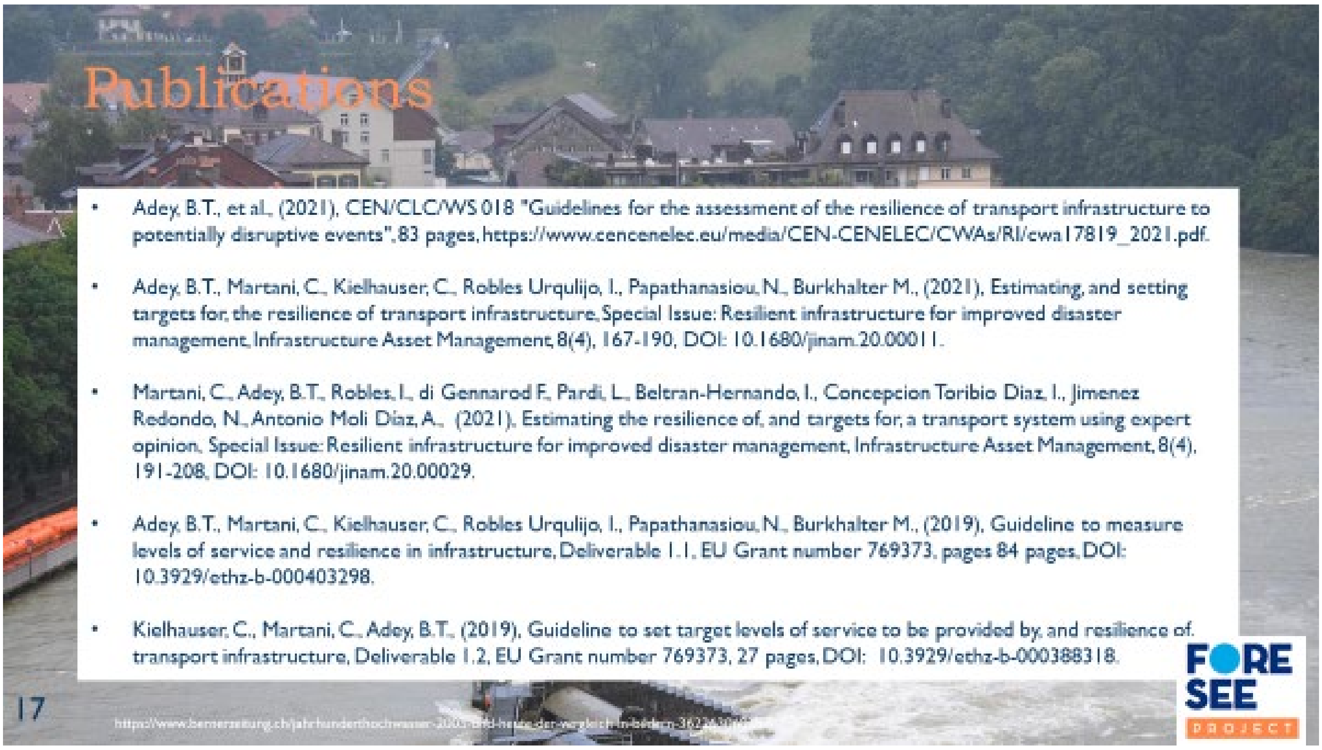
FORESEE PROJECT



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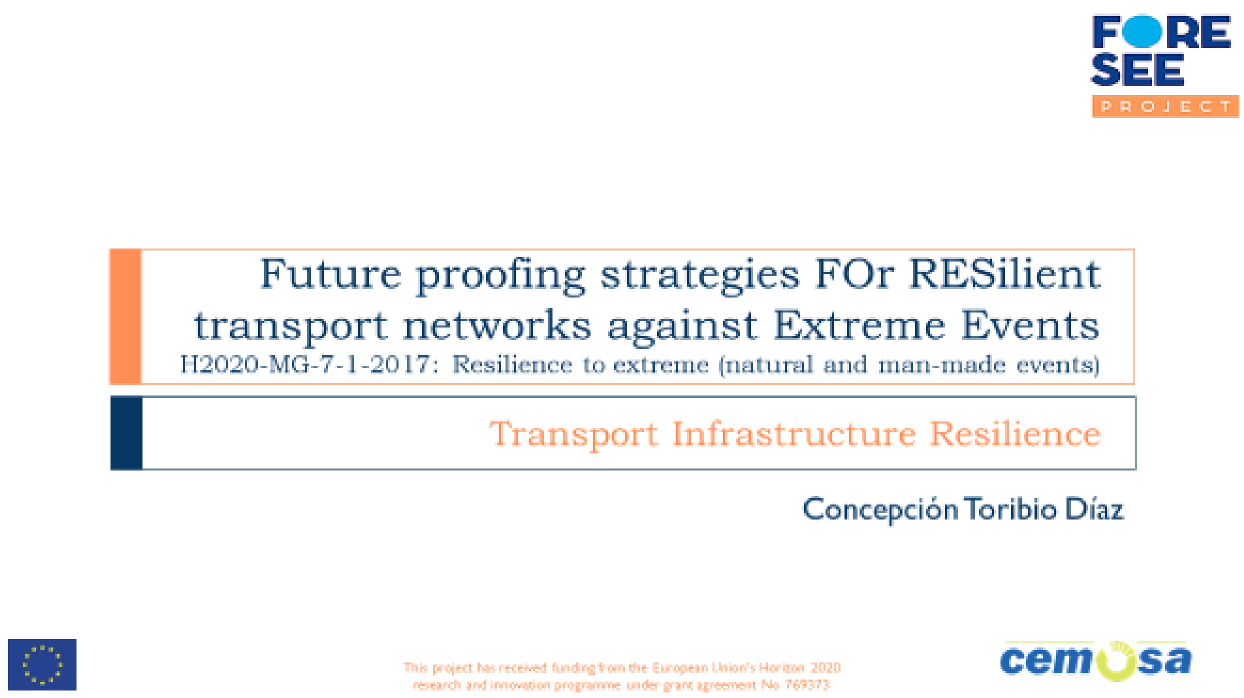
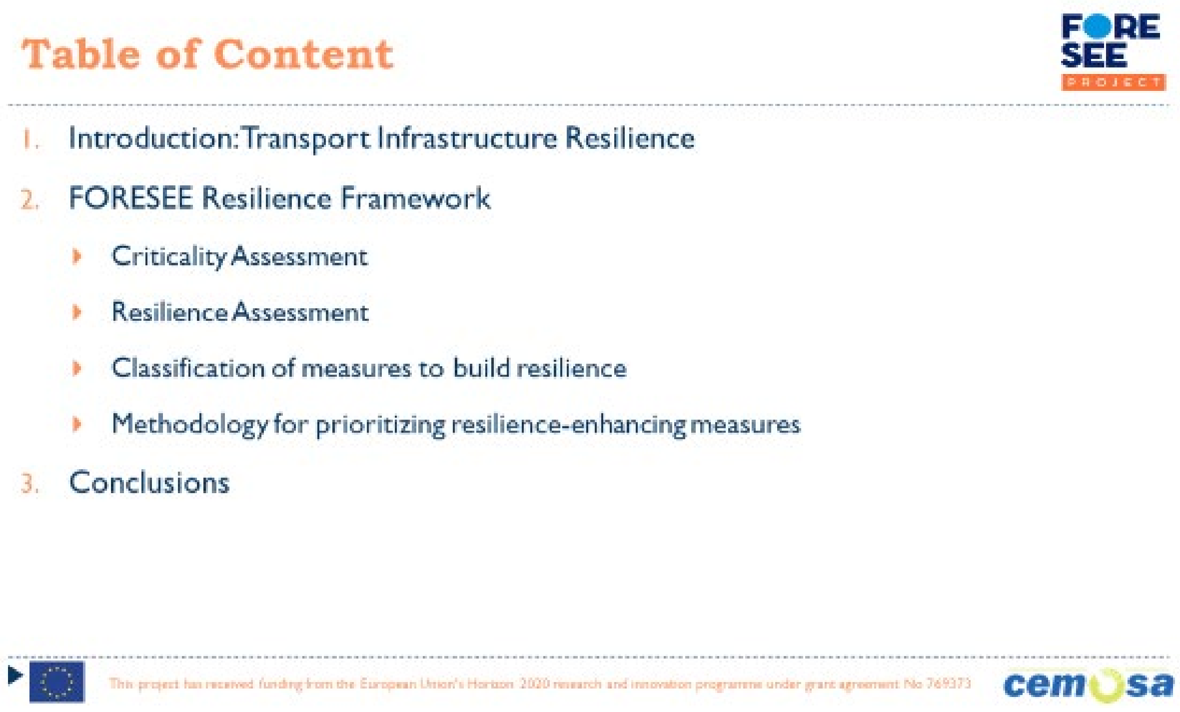
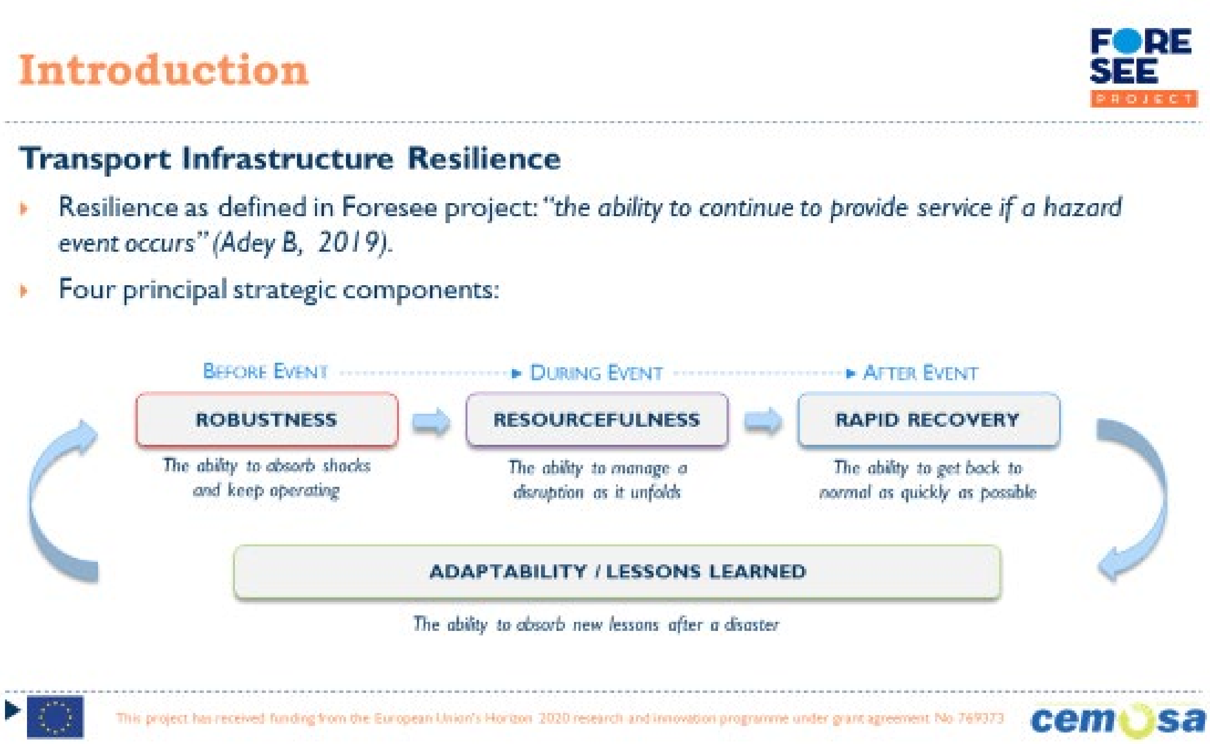
11:00 - Transport Infrastructure Resilience (Design, Operation and Contingency plans).

Concepción Toribio, Cemosa




Introduction
FORE SEE PROJECT
Transport Infrastructure Resilience
Resilience as defined in Foresee project: "the ability to continue to provide service if a hazard event occurs" (Adey B, 2019).
Four principal strategic components:
BEFORE EVENT
DURING EVENT
AFTER EVENT
ROBUSTNESS
The ability to absorb shocks and keep operating
RESOURCEFULNESS
The ability to manage a disruption as it unfolds
RAPID RECOVERY
The ability to get back to normal as quickly as possible
ADAPTABILITY / LESSONS LEARNED
The ability to absorb new lessons after a disaster
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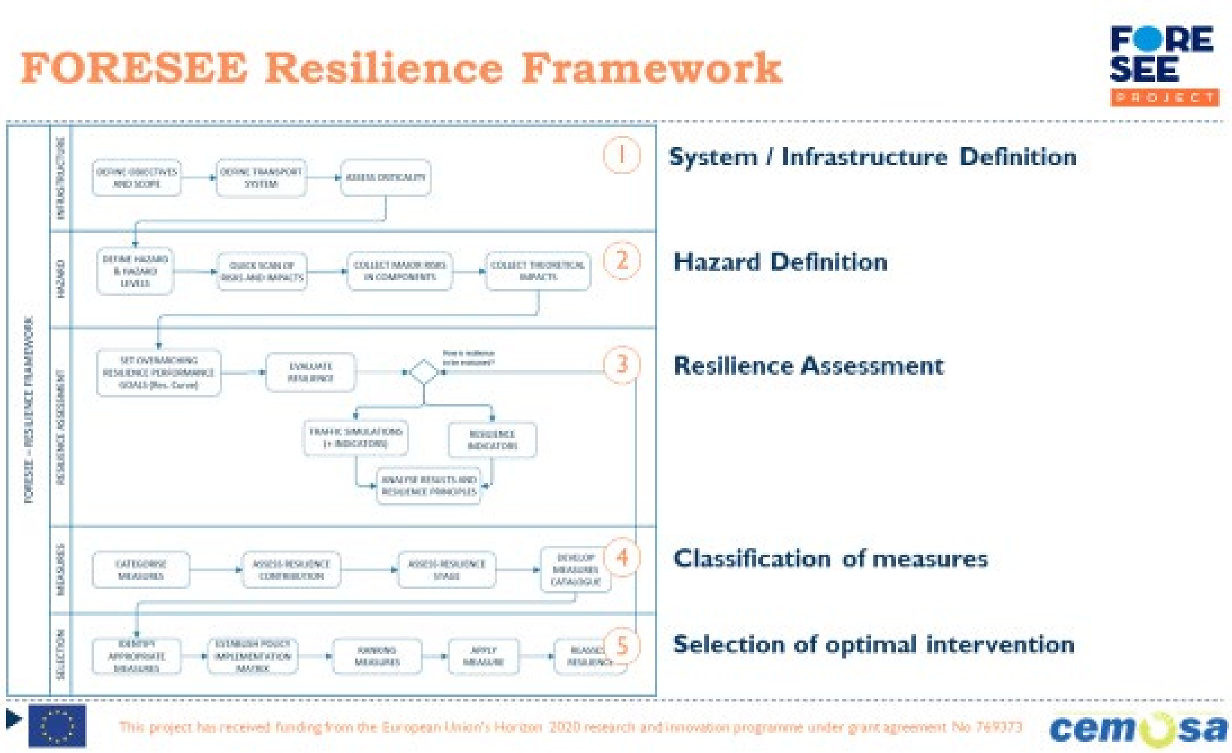
FORESEE Resilience Framework
FORE SEE PROJECT
1 System / Infrastructure Definition
2 Hazard Definition
3 Resilience Assessment
4 Classification of measures
5 Selection of optimal intervention
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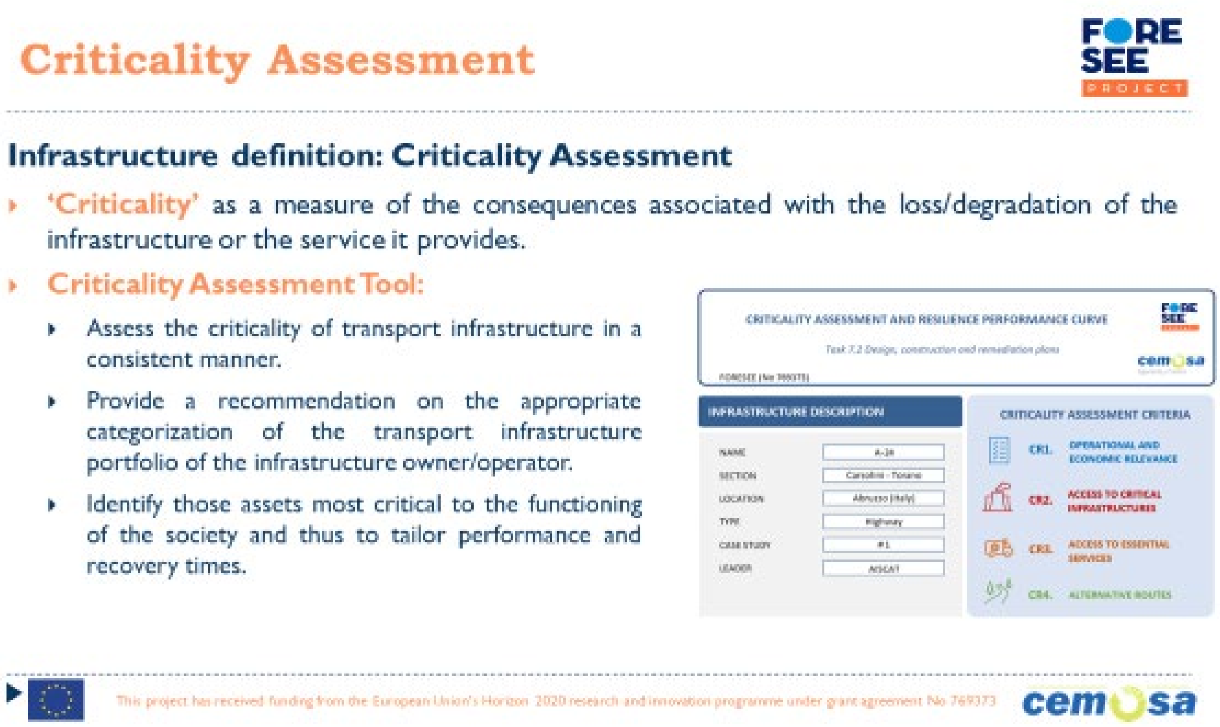
Criticality Assessment
FORE SEE PROJECT
Infrastructure definition: Criticality Assessment
'Criticality' as a measure of the consequences associated with the loss/degradation of the infrastructure or the service it provides.
Criticality Assessment Tool:
Assess the criticality of transport infrastructure in a consistent manner.
Provide a recommendation on the appropriate categorization of the transport infrastructure portfolio of the infrastructure owner/operator.
Identify those assets most critical to the functioning of the society and thus to tailor performance and recovery times.
CRITICALITY ASSESSMENT AND RESILIENCE PERFORMANCE CURVE
INFRASTRUCTURE DESCRIPTION
NAME
SECTION
LOCATION
TYPE
CASE STUDY
LEADER
Highway
CRITICALITY ASSESSMENT CRITERIA
CR1. OPERATIONAL AND ECONOMIC RELEVANCE
CR2. ACCESS TO CRITICAL INFRASTRUCTURES
CR3. ACCESS TO ESSENTIAL SERVICES
CR4. ALTERNATIVE ROUTES
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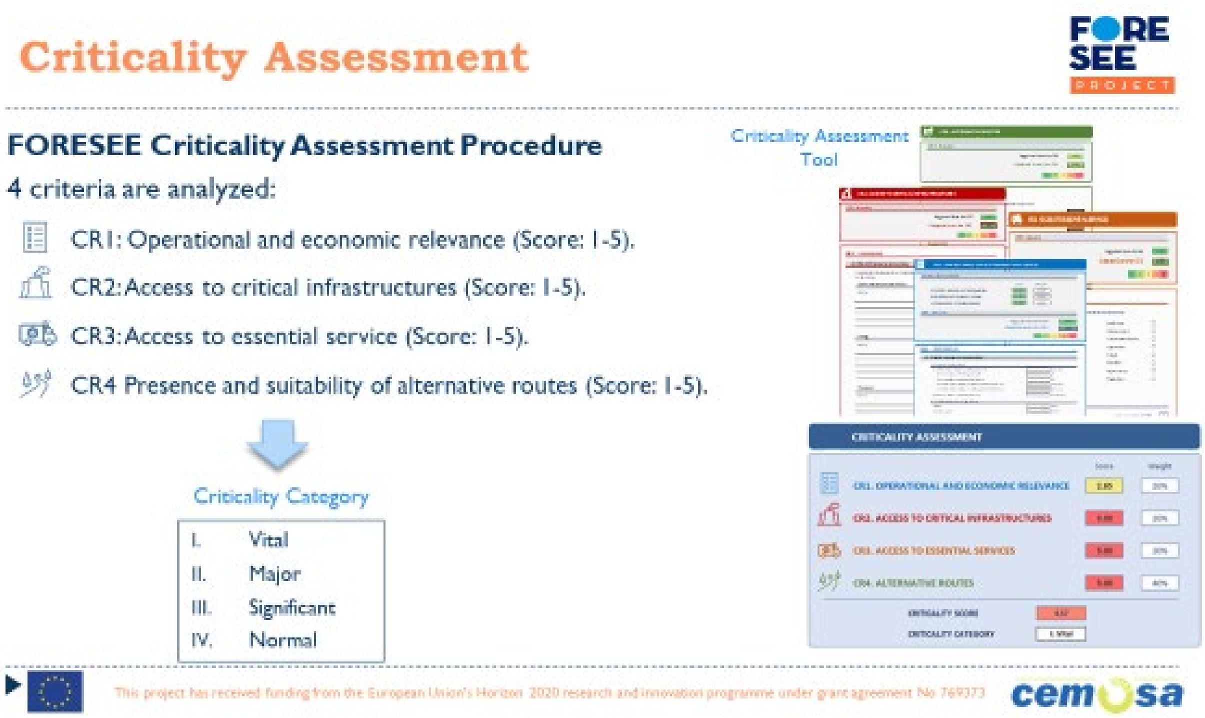
Criticality Assessment
FORE SEE PROJECT
FORESEE Criticality Assessment Procedure
4 criteria are analyzed:
CR1: Operational and economic relevance (Score: 1-5).
CR2: Access to critical infrastructures (Score: 1-5).
CR3: Access to essential service (Score: 1-5).
CR4 Presence and suitability of alternative routes (Score: 1-5).
Criticality Category
I. Vital
II. Major
III. Significant
IV. Normal
Criticality Assessment Tool
CRITICALITY ASSESSMENT
CR1. OPERATIONAL AND ECONOMIC RELEVANCE
CR2. ACCESS TO CRITICAL INFRASTRUCTURES
CR3. ACCESS TO ESSENTIAL SERVICES
CR4. ALTERNATIVE ROUTES
CRITICALITY SCORE
CRITICALITY CATEGORY
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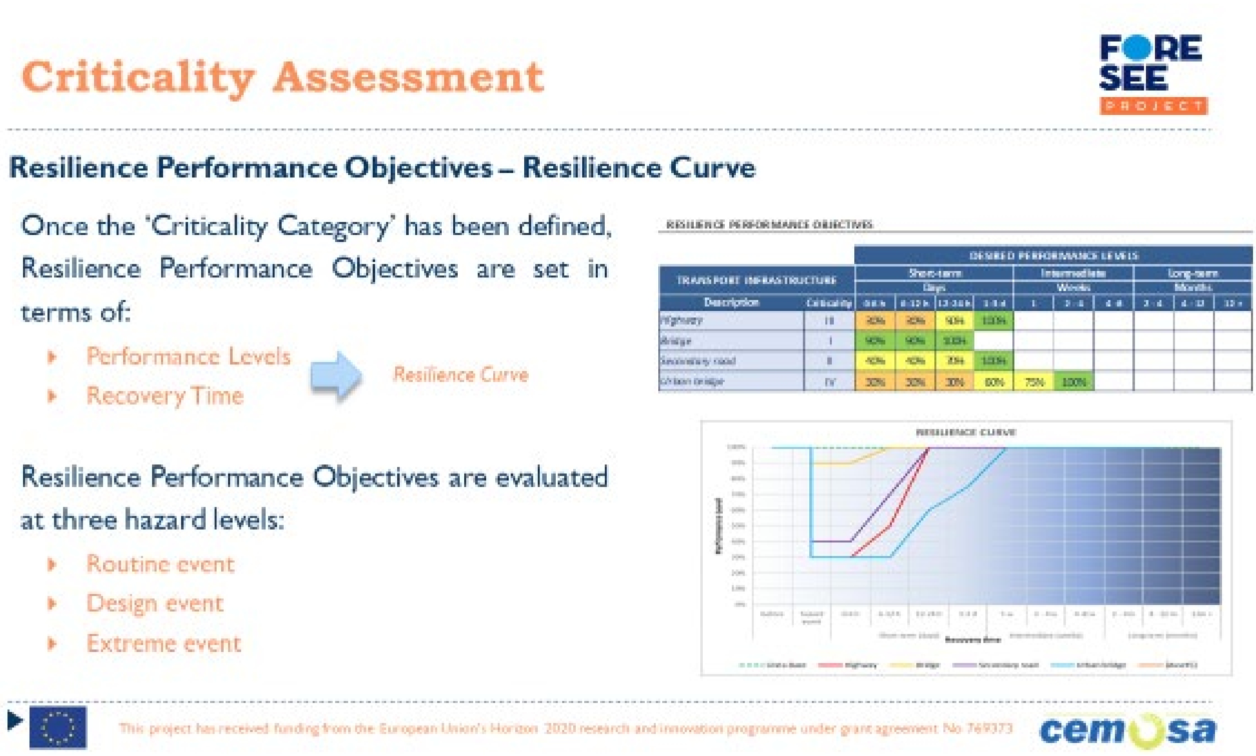
Criticality Assessment
FORE SEE PROJECT
Resilience Performance Objectives – Resilience Curve
Once the 'Criticality Category' has been defined, Resilience Performance Objectives are set in terms of:
Performance Levels
Recovery Time
Resilience Curve
Resilience Performance Objectives are evaluated at three hazard levels:
Routine event
Design event
Extreme event
RESILIENCE PERFORMANCE OBJECTIVES

| TRANSPORT INFRASTRUCTURE | | DESIRED PERFORMANCE LEVELS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Short-term | | | | Intermediate | | | Long-term | | |
| | | Days | | | | Weeks | | | Months | | |
| Description | Criticality | 0-6 h | 6-12 h | 12-24 h | 1-3 d | 1 | 2-4 | 4-8 | 2-4 | 4-12 | 12+ |
| Highway | II | 30% | 30% | 50% | 100% | | | | | | |
| Bridge | I | 90% | 90% | 100% | | | | | | | |
| Secondary road | II | 40% | 40% | 70% | 100% | | | | | | |
| Urban bridge | IV | 30% | 30% | 30% | 60% | 75% | 100% | | | | |

RESILIENCE CURVE
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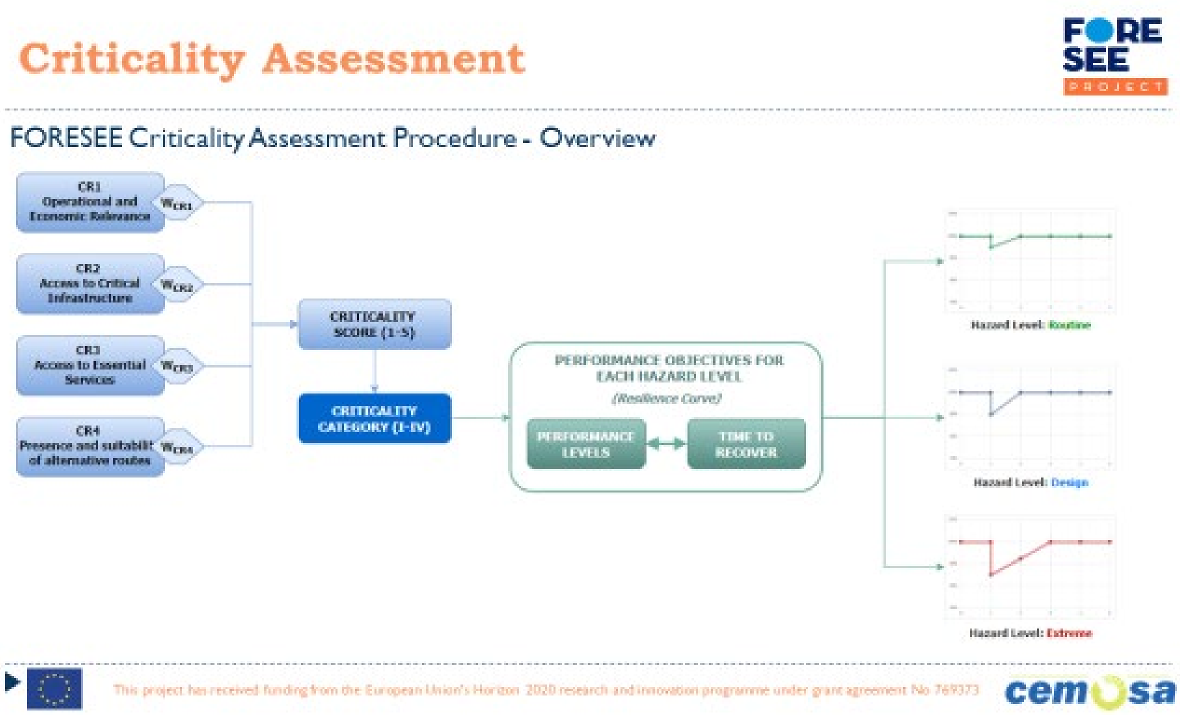
Criticality Assessment
FORE SEE PROJECT
FORESEE Criticality Assessment Procedure - Overview
CR1 Operational and Economic Relevance
CR2 Access to Critical Infrastructure
CR3 Access to Essential Services
CR4 Presence and suitability of alternative routes
CRITICALITY SCORE (1-5)
CRITICALITY CATEGORY (I-IV)
PERFORMANCE OBJECTIVES FOR EACH HAZARD LEVEL
(Resilience Curve)
PERFORMANCE LEVELS
TIME TO RECOVER
Hazard Level: Routine
Hazard Level: Design
Hazard Level: Extreme
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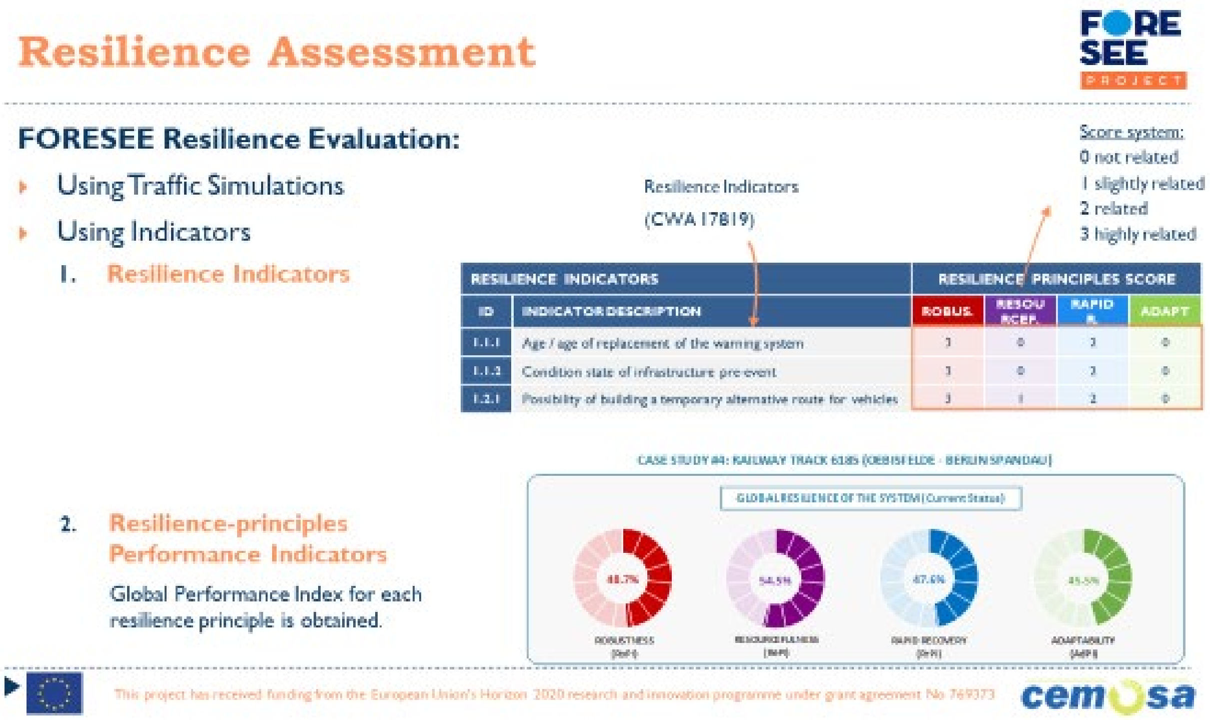
Resilience Assessment
FORE SEE PROJECT
FORESEE Resilience Evaluation:
Using Traffic Simulations
Using Indicators
1. Resilience Indicators
Resilience Indicators
(CWA 17819)
Score system:
0 not related
1 slightly related
2 related
3 highly related
RESILIENCE INDICATORS
RESILIENCE PRINCIPLES SCORE
ID
INDICATOR DESCRIPTION
ROBUS.
RESOU RCEF.
RAPID R.
ADAPT
Age / age of replacement of the warning system
Condition state of infrastructure pre-event
Possibility of building a temporary alternative route for vehicles
CASE STUDY #4: RAILWAY TRACK 6185 (OEBISFELDE - BERLIN SPANDAU)
2. Resilience-principles Performance Indicators
Global Performance Index for each resilience principle is obtained.
ROBUSTNESS
RESOURCEFULNESS
RAPID RECOVERY
ADAPTABILITY
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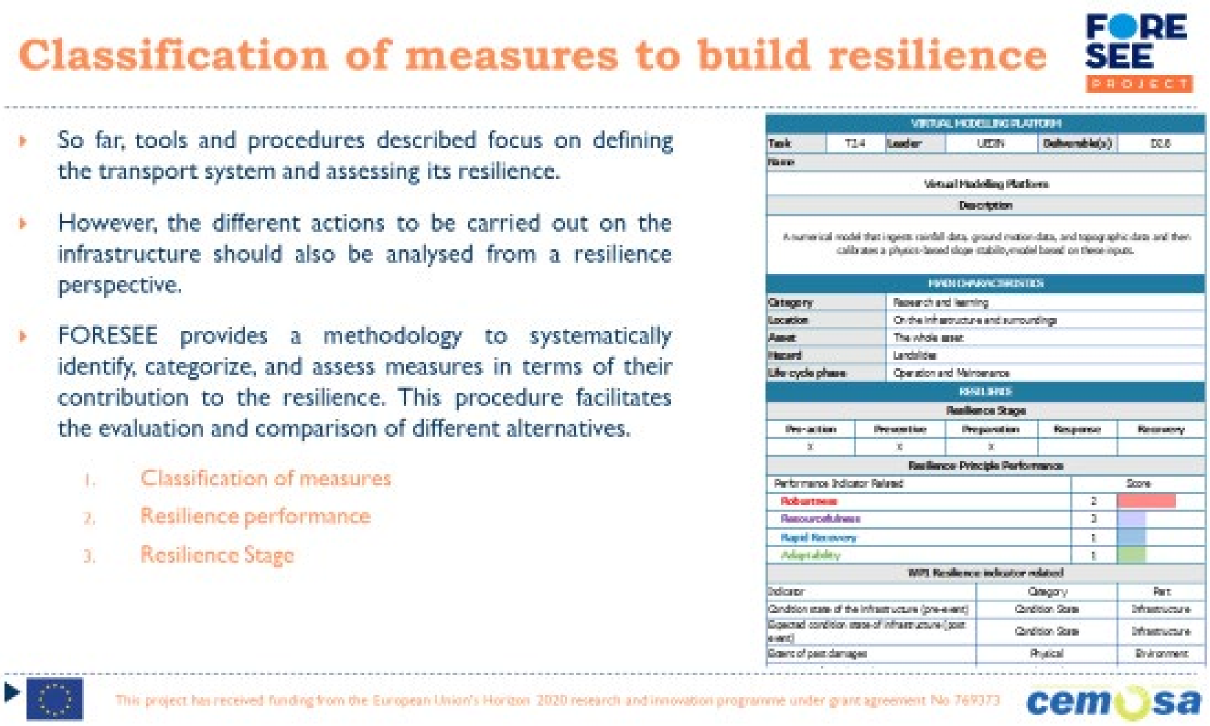
Classification of measures to build resilience
FORE SEE PROJECT
So far, tools and procedures described focus on defining the transport system and assessing its resilience.
However, the different actions to be carried out on the infrastructure should also be analysed from a resilience perspective.
FORESEE provides a methodology to systematically identify, categorize, and assess measures in terms of their contribution to the resilience. This procedure facilitates the evaluation and comparison of different alternatives.
1. Classification of measures
2. Resilience performance
3. Resilience Stage
Task
T2.4
Leader
UEDIN
Deliverable(s)
D2.6
Name
Virtual Modelling Platform
Description
A numerical model that ingests rainfall data, ground motion data, and topographic data and then calibrates a physics-based slope stability model based on these inputs.
Category
Research and learning
Location
On the infrastructure and surroundings
Asset
The whole asset
Hazard
Landslides
Life cycle phase
Operation and Maintenance
Resilience Stage
Pre-action
Prevention
Preparation
Response
Recovery
Resilience Principle Performance
Performance Indicator Related
Score
Robustness
Resourcefulness
Rapid Recovery
Adaptability
Indicator
Category
Part
Condition state of the infrastructure (pre-event)
Condition State
Infrastructure
Expected condition state of infrastructure (post-event)
Condition State
Infrastructure
Extent of past damages
Physical
Environment
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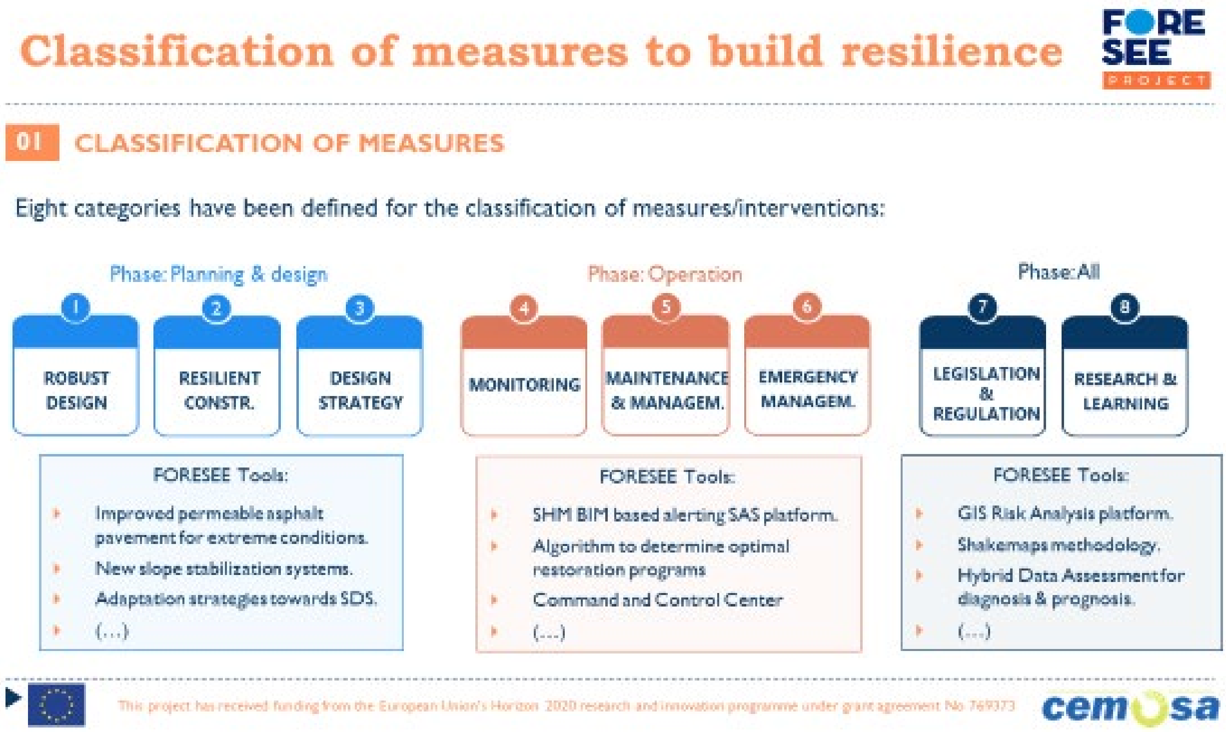


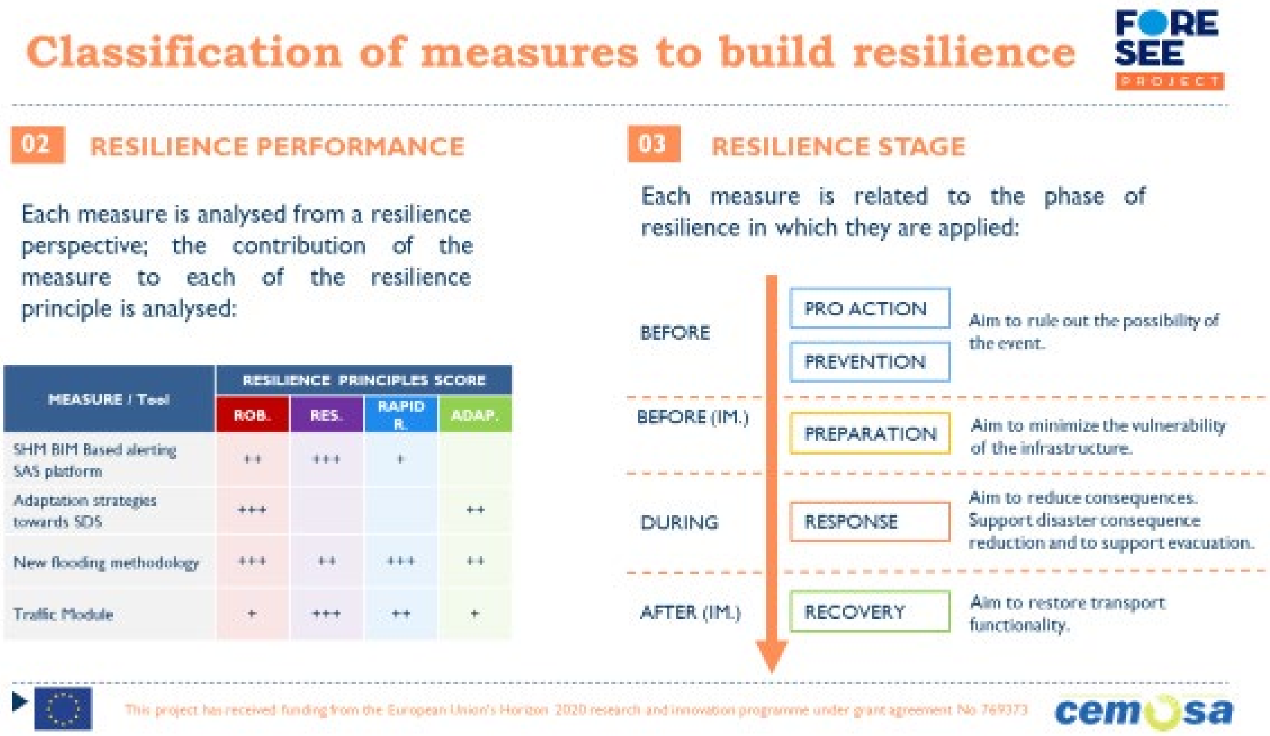


| MEASURE / Tool | RESILIENCE PRINCIPLES SCORE | | | |
|---|---|---|---|---|
| | ROB. | RES. | RAPID R. | ADAP. |
| SHM BIM Based alerting SAS platform | ++ | +++ | + | |
| Adaptation strategies towards SDS | +++ | | | ++ |
| New flooding methodology | +++ | ++ | +++ | ++ |
| Traffic Module | + | +++ | ++ | + |

## Classification of measures to build resilience

| Foresee Task ID | MEASURE / TOOL | MAIN CHARACTERISTICS | | | | LIFE CYCLE | | | | RESILIENCE STAGE | | | | | RESILIENCE PRINCIPLE | | | | SUMMARY SHEET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HAZARD | CATEGORY | LOCATION | ASSET | PLANNING | DESIGN | CONSTRUCTION | O&M | PRO-ACTION | PREVENTION | PREPARATION | RESPONSE | RECOVERY | ROBUSTNESS | RESOURCEF. | RAPID RECOV. | ADAPTABILITY | |
| T1.3 | Governance Module | Any | Design Strategy | General | Infrastructure | | ✓ | ✓ | | | ✓ | | | | 🟢 | 🔴 | 🔴 | 🔴 | |
| T2.1 | GIS Risk analysis platform | Flooding, Landslide, Earthquake | Research & Learning | On the infrastructure and surroundings | Infrastructure | ✓ | | | | ✓ | | | | | 🔴 | 🔴 | 🔴 | 🟢 | |
| T2.4 | Virtual Modelling platform | Landslide | Research & Learning | On the infrastructure and surroundings | Infrastructure | | | | ✓ | ✓ | ✓ | ✓ | | | 🟢 | 🟠 | 🟠 | 🟠 | |
| T2.5 | SHM BIM Based alerting SAS platform | Landslide | Monitoring | On the infrastructure | Infrastructure | | | | ✓ | ✓ | ✓ | ✓ | | | 🟢 | 🟢 | 🟠 | 🔴 | |
| T3.1 | Improved permeable asphalt pavement for extreme conditions | Flooding | Robust design | On the infrastructure | Pavement | | ✓ | | | ✓ | ✓ | | | | 🟢 | 🔴 | 🟠 | 🔴 | |
| T3.2 | New slope stabilization-protection systems | Landslide | Robust design | On the infrastructure | Slopes | | ✓ | | | ✓ | ✓ | | | | 🟢 | 🟠 | 🟠 | 🔴 | |
| T3.3 | Adaptation strategies toward sustainable drainage systems | Flooding | Design Strategy | Outside the infrastructure | Culverts and surroundings | ✓ | ✓ | | | ✓ | ✓ | | | | 🟢 | 🔴 | 🔴 | 🟢 | |
| T3.4 | Traffic Module | Any | Design Strategy | General | Infrastructure | ✓ | ✓ | | | | | | | | 🟠 | 🟢 | 🟢 | 🟠 | |
| T3.4 | Fragility and Vulnerability Functions and Decision Support Module | Earthquake | Design Strategy | General | All assets | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 🟠 | 🟢 | 🟢 | 🟢 | |
| T4.1 | New flooding methodology | Flooding | Design Strategy | General | Infrastructure | ✓ | ✓ | | | ✓ | | | | | 🟢 | 🟢 | 🟢 | 🟢 | |
| T4.2 | Shakemaps methodology | Earthquake | Research & Learning | Outside the infrastructure | Infrastructure | ✓ | ✓ | | | ✓ | ✓ | | | | 🟠 | 🟠 | 🔴 | 🟢 | |
| T4.3.1 | Algorithm to determine optimal restoration programs | Any | Maintenance & Management | General | Infrastructure | | ✓ | | ✓ | | | | ✓ | ✓ | 🔴 | 🟠 | 🟢 | 🔴 | |

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## Methodology for prioritizing resilience-enhancing measures

Once the resilience of the system has been measured and different types of interventions have been identified, the next step is to select the optimal intervention to improve the resilience.

### Methodology for prioritizing resilience-enhancing interventions

- **Aim of the methodology:** To support, at the strategic level, infrastructure managers and operators in decision-making processes for ranking resilience enhancing interventions taking into account initial and target values of resilience indicators.
- **Overview**
  - Based on Analytic Hierarchical Process (AHP) theory: systematic engineering method transforming qualitative analysis into quantitative analysis.
  - Based on the construction of a hierarchical model: decision problem becomes hierarchical, and the complexity is decomposed.
- **Result:** vector that shows the weight of each intervention considered in relation to the resilience of the system.

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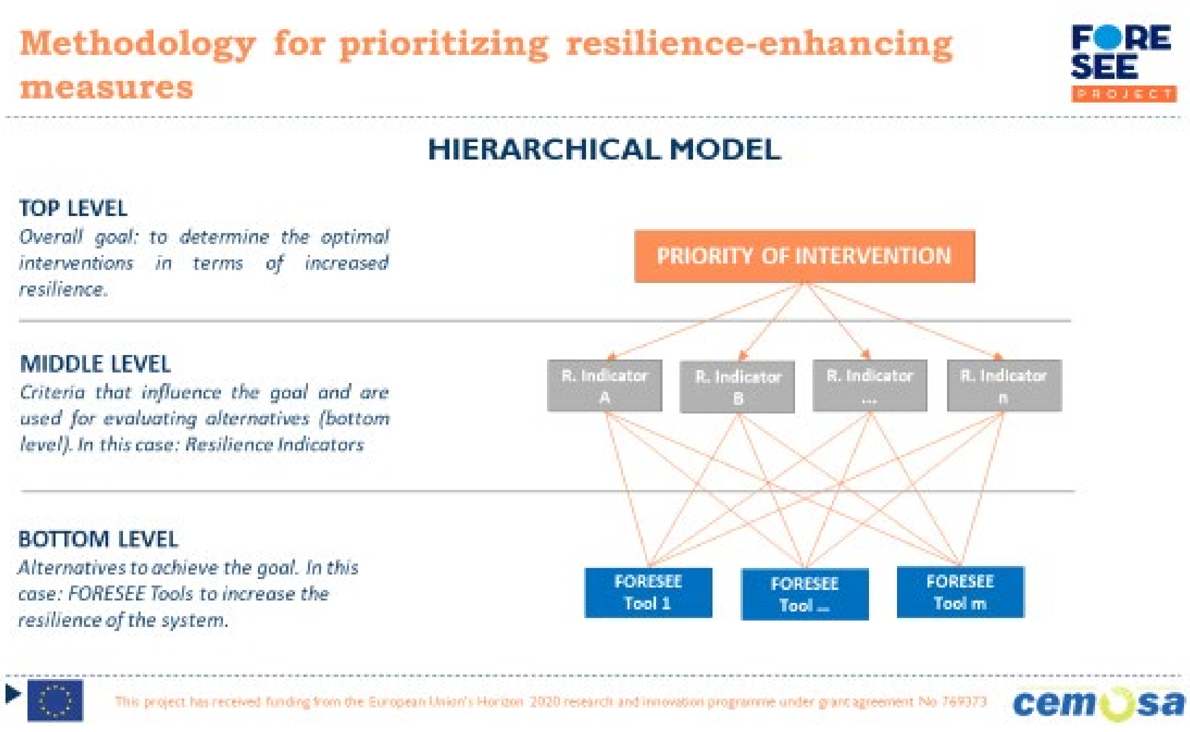
Methodology for prioritizing resilience-enhancing measures
FORESEE PROJECT
HIERARCHICAL MODEL
TOP LEVEL
Overall goal: to determine the optimal interventions in terms of increased resilience.
MIDDLE LEVEL
Criteria that influence the goal and are used for evaluating alternatives (bottom level). In this case: Resilience Indicators
BOTTOM LEVEL
Alternatives to achieve the goal. In this case: FORESEE Tools to increase the resilience of the system.
PRIORITY OF INTERVENTION
R. Indicator A
R. Indicator B
R. Indicator ...
R. Indicator n
FORESEE Tool 1
FORESEE Tool ...
FORESEE Tool m
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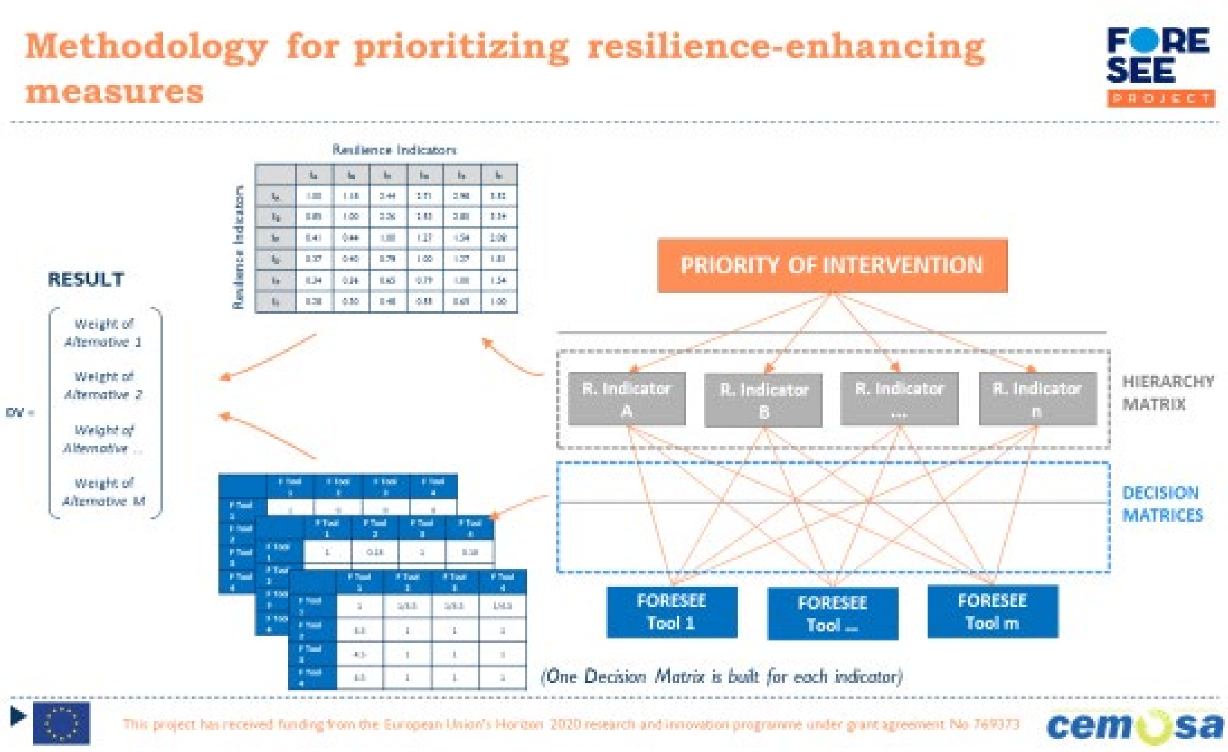
Methodology for prioritizing resilience-enhancing measures
FORESEE PROJECT
Resilience Indicators
RESULT
Weight of Alternative 1
Weight of Alternative 2
Weight of Alternative ...
Weight of Alternative M
PRIORITY OF INTERVENTION
R. Indicator A
R. Indicator B
R. Indicator ...
R. Indicator n
HIERARCHY MATRIX
DECISION MATRICES
FORESEE Tool 1
FORESEE Tool ...
FORESEE Tool m
(One Decision Matrix is built for each indicator)
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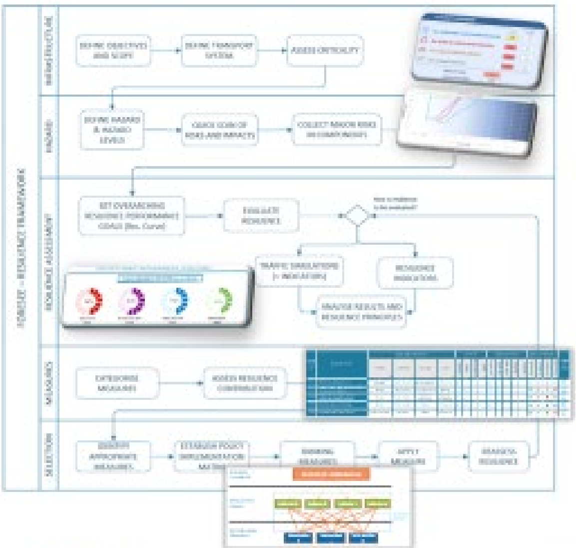
## Conclusions



- **FORESEE RESILIENCE FRAMEWORK provides procedures to:**
  - Assess the criticality of the transport system and set resilience goals accordingly.
  - Assess the resilience of the system using a wide variety of indicators.
  - Analyse, define and classify potential interventions from a resilience perspective.
  - Rank interventions in terms of increased resilience.

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H2020 FORESEE Project
(www.foreseeproject.eu)

CEMOSA
Málaga (SPAIN) 2009
https://www.cemosa.es/?lang=en

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**Second Session (11:30-1:00)**

**Improvements on the resilience of transport infrastructures by means of the application of FORESEE results**

11:30. A24 highway in Italy: Fabrizio Federici, AISCAT

FORESEE PROJECT

Future proofing strategies FOr RESilient transport networks against Extreme Events - CASE STUDY #1 – A24 HIGHWAY (Carsoli-Torano) - ITALY

FORESEE SRG workshop - January 27th 2022

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## A24 Highway (Carsoli-Torano) - Overview

| Asset | Length [m] |
|---|---|
| Bridge_1 | 248 |
| Bridge_2 | 60 |
| Bridge_3 | 272 |
| Bridge_4 | 389 |
| Bridge_5 | 1860 |
| Bridge_6 | 90 |
| Bridge_7 | 90 |
| Bridge_8 | 382 |
| Bridge_9 | 40 |
| Bridge_10 | 100 |
| Bridge_11 | 222 |
| Bridge_12 | 180 |
| Bridge_13 | 539 |
| Tunnel_1 | 1115 |
| Tunnel_2 | 1041 |
| Tunnel_3 | 1559 |

- Most important road linking Rome to Adriatic Sea
- Essential infrastructure for the transport of goods
- Starting from complex urban environment, passing through Appennini
- Carsoli-Torano: N. 13 bridges, n.3 tunnels, AADT 10.705 vehicles.

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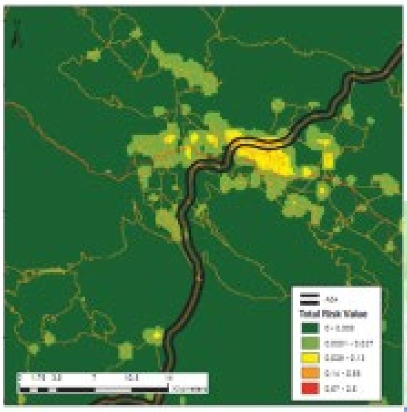
## A24 Highway (Carsoli-Torano) – Network and Hazards



- **Earthquake**: Seismic zone with several events in the last decades
- **Heavy snow**: is particularly prone to bad weather with sudden storms, strong winds, fog and ice. Snow chains on board or snow tyres from 15 November to 15 April are mandatory.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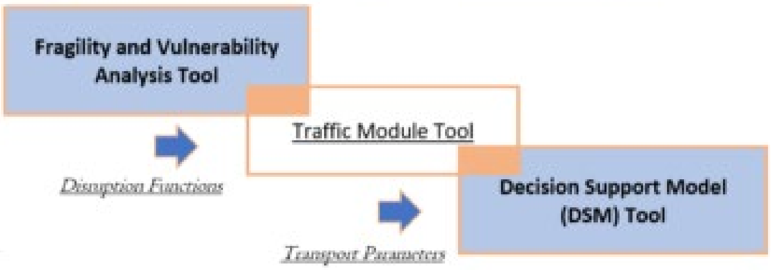
## Foresee: A24 Highway (Carsoli-Torano) – The Tools applied

| MEASURE / TOOL | MAIN CHARACTERISTICS | | | | LIFE CYCLE | | | | RESILIENCE STAGE | | | | | RESILIENCE PRINCIPLE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HAZARD | CATEGORY | LOCATION | ASSET | PLANNING | DESIGN | CONSTRUCTION | O&M | PRO-ACTION | PREVENTION | PREPARATION | RESPONSE | RECOVERY | ROBUSTNESS | RESOURCEF. | RAPID RECOV. | ADAPTABILITY |
| Traffic Module | Any | Design Strategy | General | Infrastructure | ✓ | ✓ | | | | | | | | ● | ● | ● | ● |
| Fragility and Vulnerability Functions and Decision Support Module | Earthquake | Design Strategy | General | All assets | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ● | ● | ● | ● |

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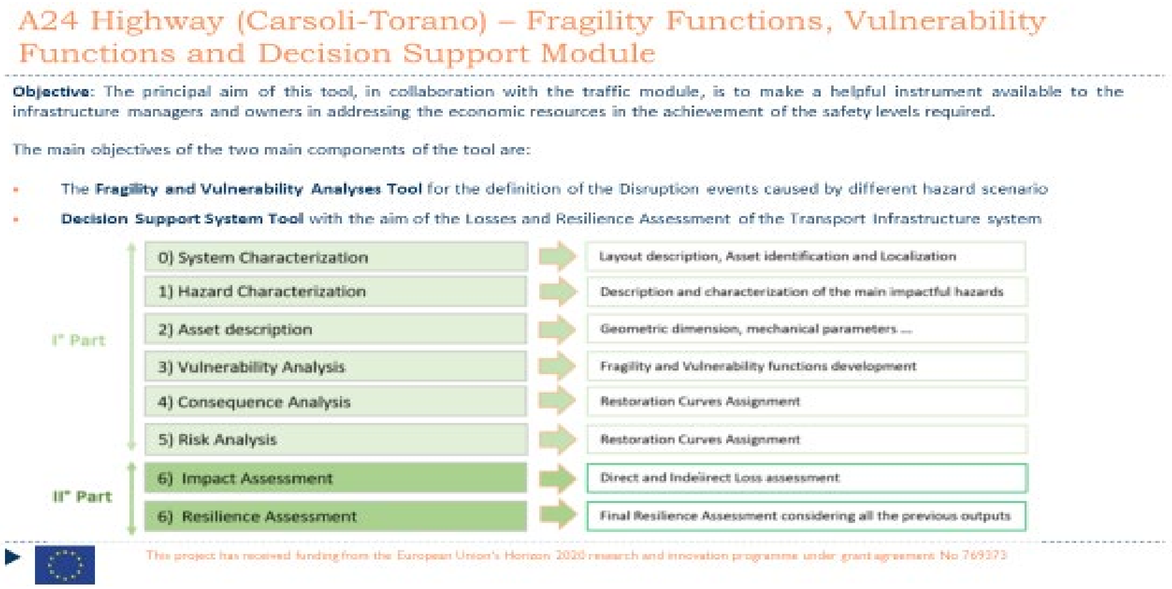
A24 Highway (Carsoli-Torano) – Fragility Functions, Vulnerability Functions and Decision Support Module
Objective: The principal aim of this tool, in collaboration with the traffic module, is to make a helpful instrument available to the infrastructure managers and owners in addressing the economic resources 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
Decision Support System Tool with the aim of the Losses and Resilience Assessment of the Transport Infrastructure system
I° Part
II° Part
0) System Characterization
Layout description, Asset identification and Localization
1) Hazard Characterization
Description and characterization of the main impactful hazards
2) Asset description
Geometric dimension, mechanical parameters ...
3) Vulnerability Analysis
Fragility and Vulnerability functions development
4) Consequence Analysis
Restoration Curves Assignment
5) Risk Analysis
Restoration Curves Assignment
6) Impact Assessment
Direct and Indeiirect Loss assessment
6) Resilience Assessment
Final Resilience Assessment considering all the previous outputs
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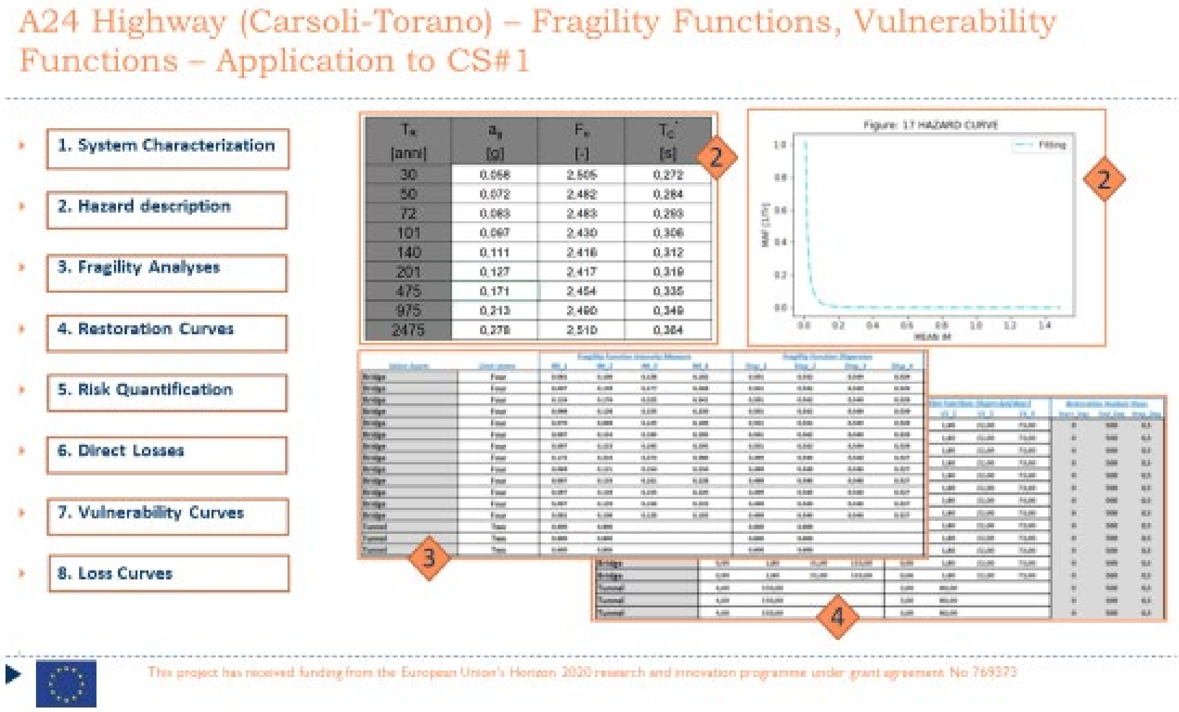
A24 Highway (Carsoli-Torano) – Fragility Functions, Vulnerability Functions – Application to CS#1
1. System Characterization
2. Hazard description
3. Fragility Analyses
4. Restoration Curves
5. Risk Quantification
6. Direct Losses
7. Vulnerability Curves
8. Loss Curves
T_R [anni] | a_g [g] | F_o [-] | T_C* [s]
30 | 0,058 | 2,505 | 0,272
50 | 0,072 | 2,482 | 0,284
72 | 0,083 | 2,483 | 0,293
101 | 0,097 | 2,430 | 0,306
140 | 0,111 | 2,416 | 0,312
201 | 0,127 | 2,417 | 0,319
475 | 0,171 | 2,454 | 0,335
975 | 0,213 | 2,480 | 0,349
2475 | 0,278 | 2,510 | 0,364
Figure: 17 HAZARD CURVE
Fitting
2
3
4
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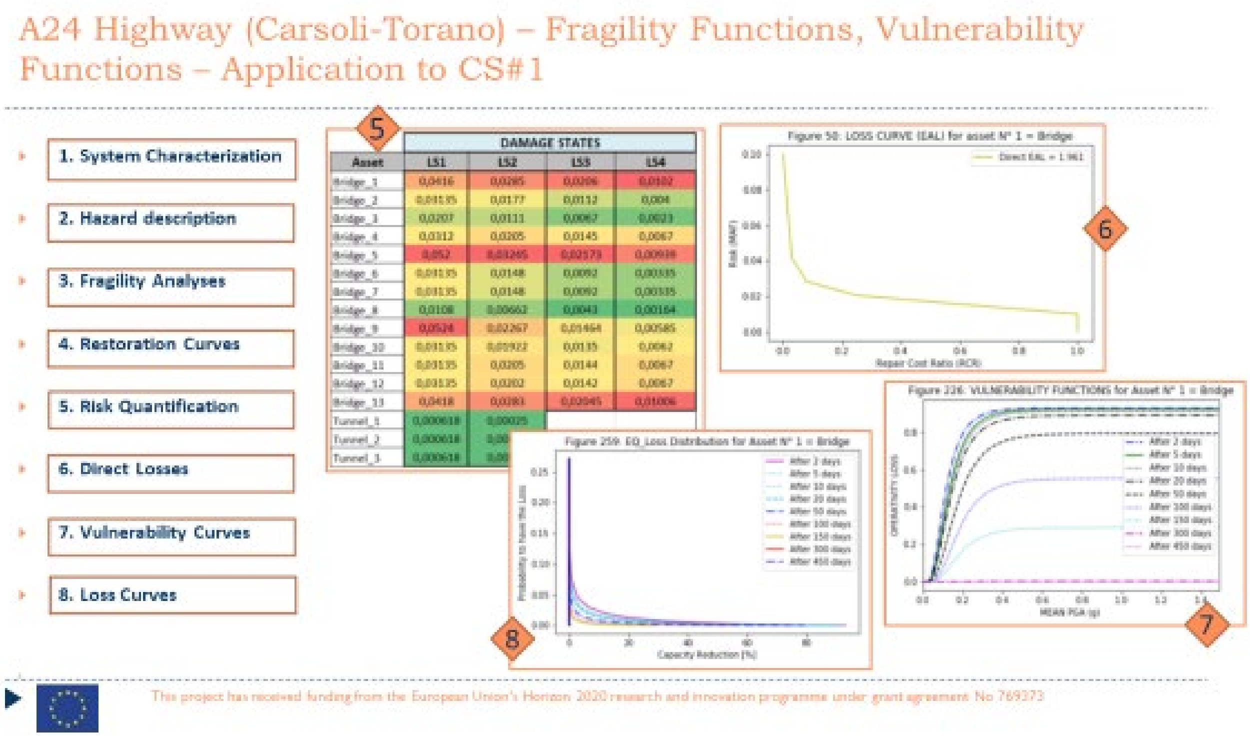
A24 Highway (Carsoli-Torano) – Fragility Functions, Vulnerability Functions – Application to CS#1
1. System Characterization
2. Hazard description
3. Fragility Analyses
4. Restoration Curves
5. Risk Quantification
6. Direct Losses
7. Vulnerability Curves
8. Loss Curves
DAMAGE STATES
Asset
Figure 50: LOSS CURVE (EAL) for asset N° 1 = Bridge
Figure 226: VULNERABILITY FUNCTIONS for Asset N° 1 = Bridge
Figure 259: EQ_Loss Distribution for Asset N° 1 = Bridge
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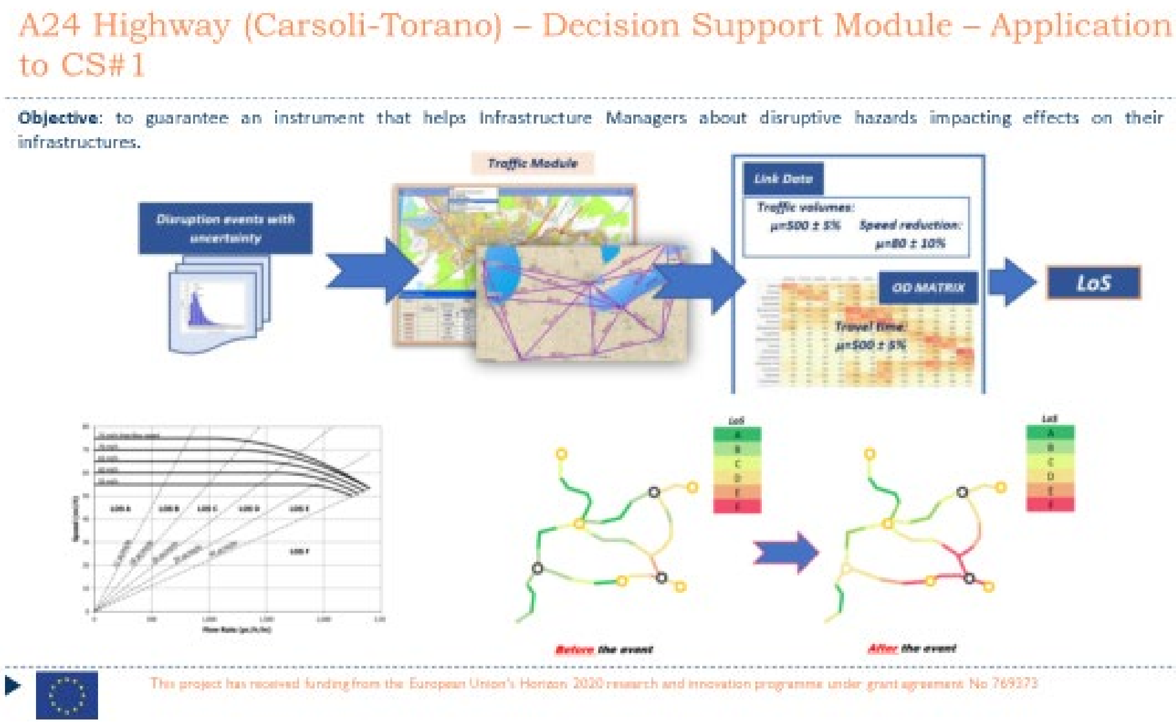
A24 Highway (Carsoli-Torano) – Decision Support Module – Application to CS#1
Objective: to guarantee an instrument that helps Infrastructure Managers about disruptive hazards impacting effects on their infrastructures.
Traffic Module
Disruption events with uncertainty
Link Data
Traffic volumes:
Speed reduction:
OD MATRIX
Travel time:
LoS
Before the event
After the event
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## A24 Highway (Carsoli-Torano) – TRAFFIC MODULE: CS#1 Application

- The module uses as input data the Combined Annual Probability (CAP) for the Capacity Loss

$$CAP_{CL} = \int_{min.Loss}^{max.Loss} (a \cdot ln(Loss_x) + k)dx$$

- Based on this value, the loss of road capacity (veh/h) has been estimated considering the number of lanes in the road.
- From the capacity loss occurrence data, the average values of capacity loss in each infrastructure and period after the event have been obtained.
- It possible to use the area under the capacity loss curve as an indicator of the inverse of the resilience.
- The bigger the area, the less resilient the infrastructure is.
- The smaller the area the more resilient it is.
- This approach will allow us to provide prioritization indicators.

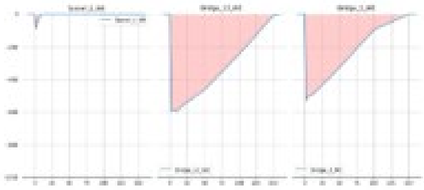

Table 18. Area under the curve (AUC)

| Asset | AUC | Asset | AUC |
|---|---|---|---|
| Bridge_1_WE | -50,589.075 | Bridge_7_EW | -38,814.525 |
| Bridge_1_EW | -50,589.075 | Bridge_7_WE | -38,814.525 |
| Bridge_13_EW | -50,500.850 | Bridge_6_WE | -38,814.525 |
| Bridge_13_WE | -50,500.850 | Bridge_6_EW | -38,814.525 |
| Bridge_5_EW | -50,149.200 | Bridge_8_EW | -38,990.075 |
| Bridge_5_WE | -50,149.200 | Bridge_8_WE | -38,990.075 |
| Bridge_4_EW | -46,312.275 | Bridge_8_EW | -28,128.300 |
| Bridge_4_WE | -46,312.275 | Tunnel_1_WE | -355,575 |
| Bridge_11_EW | -46,303.650 | Tunnel_3_WE | -355,575 |
| Bridge_12_EW | -46,108.200 | Tunnel_2_EW | -355,575 |
| Bridge_10_EW | -45,363.950 | Tunnel_2_WE | -355,575 |
| Bridge_9_EW | -45,281.925 | Tunnel_1_EW | -355,575 |
| Bridge_2_WE | -45,707.500 | Tunnel_3_EW | -355,575 |
| Bridge_2_EW | -45,707.500 | | |

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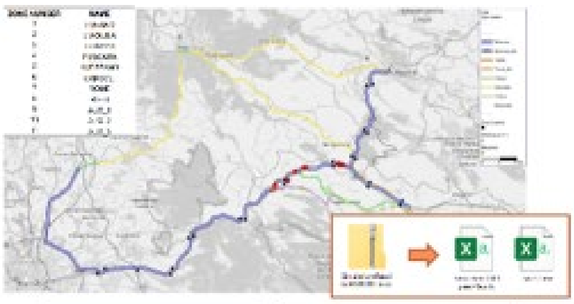
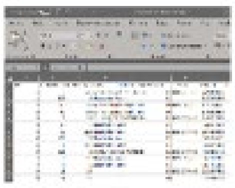
## A24 Highway (Carsoli-Torano) – TRAFFIC MODULE: CS#1 Application

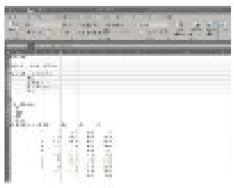
- Tool Outputs: The traffic volume (traffic Volume and Speed per network link) and travel time results between the model zones.
- The table show an example of the results of travel times between OD pairs.

Table 19. Travel time and STD per O-D pairs

| 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 | 66.184 | 105.311 | 24.611 | 26.448 | 59.345 | 49.690 | 47.583 | 40.421 |
| | 5 | 0.000 | 28.012 | 66.082 | 105.314 | 24.614 | 26.311 | 59.180 | 49.700 | 47.430 | 40.270 |
| | 10 | 0.000 | 28.508 | 66.056 | 105.322 | 24.622 | 26.057 | 58.885 | 49.702 | 47.131 | 39.971 |
| | 20 | 0.000 | 28.503 | 66.050 | 105.331 | 24.631 | 25.538 | 58.315 | 49.704 | 46.505 | 39.380 |
| | 50 | 0.000 | 28.443 | 66.033 | 105.355 | 24.655 | 24.300 | 57.021 | 49.700 | 45.202 | 39.191 |
| | 100 | 0.000 | 28.403 | 66.030 | 105.380 | 24.680 | 24.825 | 57.528 | 49.710 | 45.775 | 38.615 |
| | 150 | 0.000 | 28.403 | 66.030 | 105.380 | 24.680 | 23.983 | 56.584 | 49.710 | 44.803 | 37.473 |
| STD (Travel time) | 2 | 0.000 | 0.146 | 0.146 | 0.210 | 0.213 | 9.687 | 10.057 | 0.046 | 10.907 | 10.057 |
| | 5 | 0.000 | 0.142 | 0.142 | 0.204 | 0.204 | 9.415 | 10.650 | 0.045 | 10.658 | 10.650 |
| | 10 | 0.000 | 0.129 | 0.129 | 0.185 | 0.185 | 8.517 | 9.640 | 0.041 | 9.639 | 9.620 |
| | 20 | 0.000 | 0.114 | 0.114 | 0.164 | 0.164 | 7.571 | 8.562 | 0.036 | 8.562 | 8.582 |
| | 50 | 0.000 | 0.049 | 0.048 | 0.069 | 0.069 | 3.235 | 3.648 | 0.015 | 3.648 | 3.648 |
| | 100 | 0.000 | 0.003 | 0.006 | 0.003 | 0.030 | 0.109 | 0.159 | 0.000 | 0.109 | 0.161 |
| | 150 | 0.000 | 0.003 | 0.006 | 0.003 | 0.030 | 0.054 | 0.054 | 0.000 | 0.054 | 0.058 |







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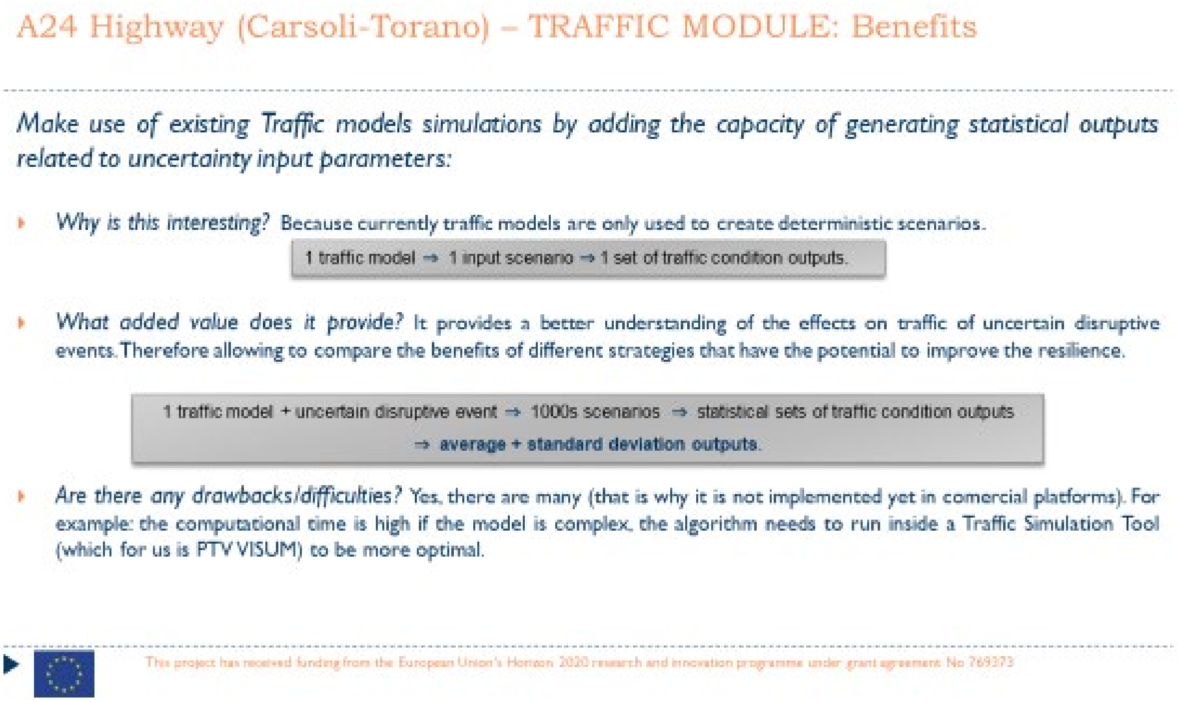
A24 Highway (Carsoli-Torano) – TRAFFIC MODULE: Benefits
Make use of existing Traffic models simulations by adding the capacity of generating statistical outputs related to uncertainty input parameters:
Why is this interesting? Because currently traffic models are only used to create deterministic scenarios.
1 traffic model → 1 input scenario → 1 set of traffic condition outputs.
What added value does it provide? It provides a better understanding of the effects on traffic of uncertain disruptive events. Therefore allowing to compare the benefits of different strategies that have the potential to improve the resilience.
1 traffic model + uncertain disruptive event → 1000s scenarios → statistical sets of traffic condition outputs
→ average + standard deviation outputs.
Are there any drawbacks/difficulties? Yes, there are many (that is why it is not implemented yet in comercial platforms). For example: the computational time is high if the model is complex, the algorithm needs to run inside a Traffic Simulation Tool (which for us is PTV VISUM) to be more optimal.
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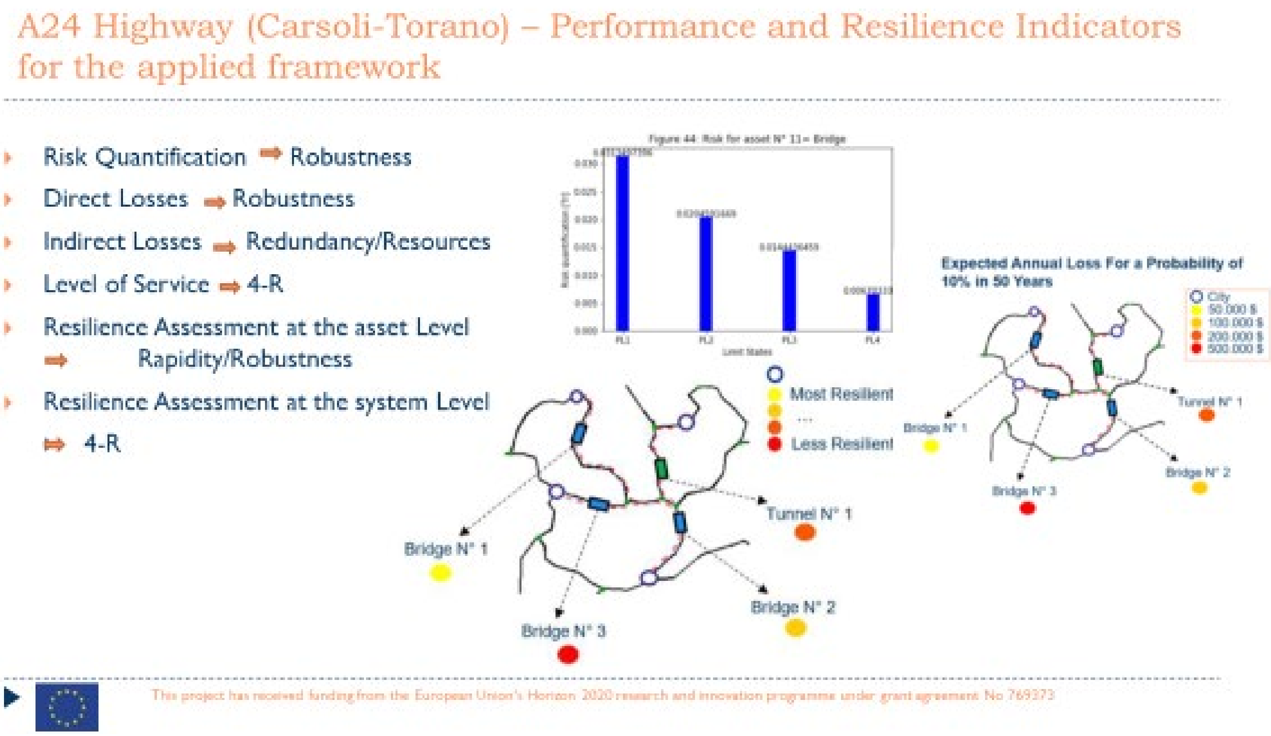
A24 Highway (Carsoli-Torano) – Performance and Resilience Indicators for the applied framework
Risk Quantification ➡ Robustness
Direct Losses ➡ Robustness
Indirect Losses ➡ Redundancy/Resources
Level of Service ➡ 4-R
Resilience Assessment at the asset Level ➡ Rapidity/Robustness
Resilience Assessment at the system Level ➡ 4-R
Figure 44: Risk for asset N° 11= Bridge
Limit States
Most Resilient
Less Resilient
Bridge N° 1
Bridge N° 2
Bridge N° 3
Tunnel N° 1
Expected Annual Loss For a Probability of 10% in 50 Years
City
50.000 $
100.000 $
200.000 $
500.000 $
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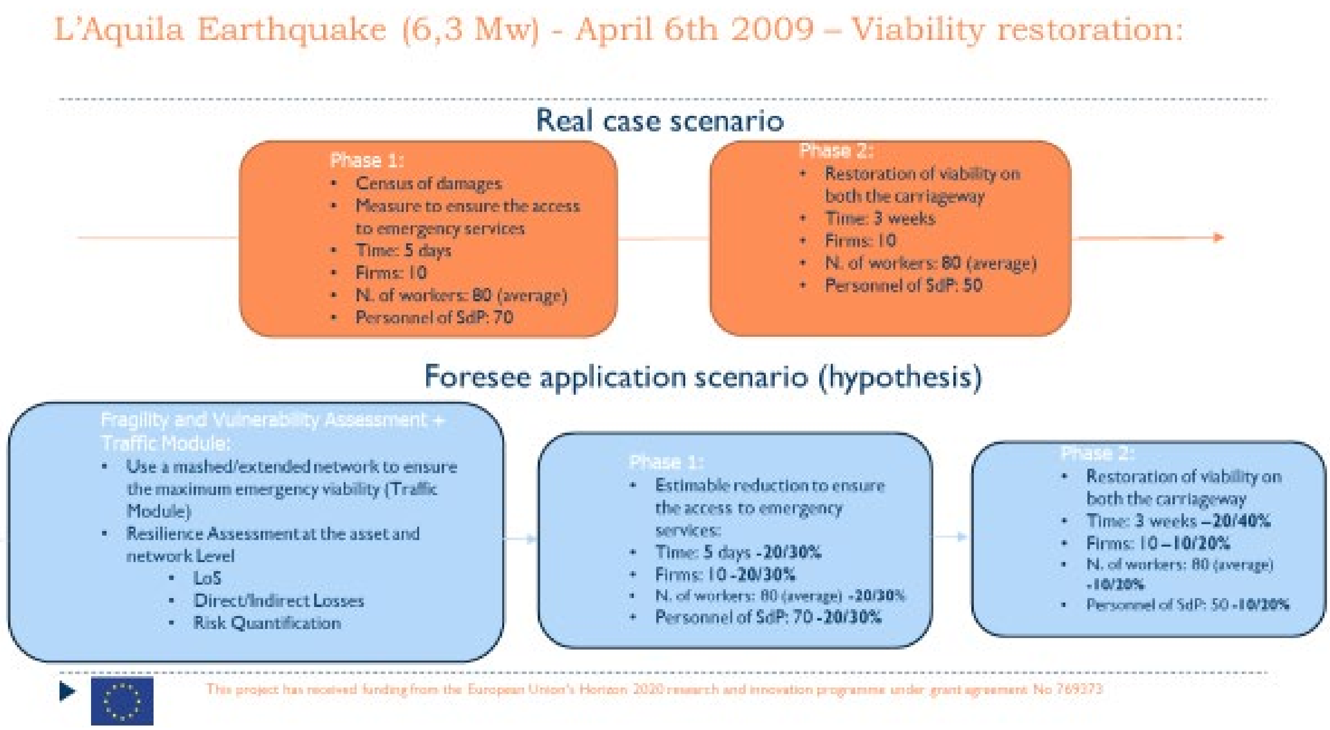
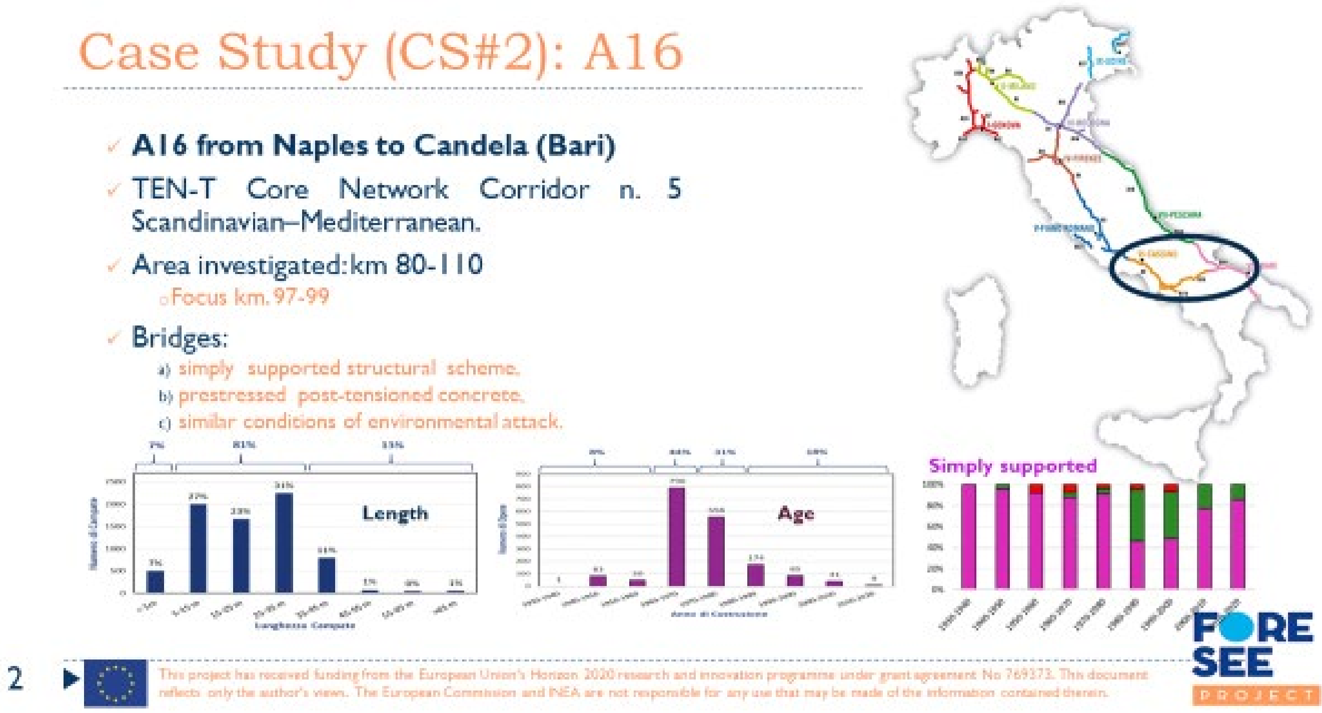


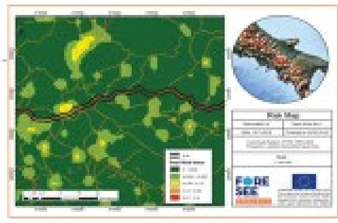


[Back to Agenda]

**11:50. A16 highway in Italy**: Livia Pardi, Autostrade per l'Italia S.p.A.

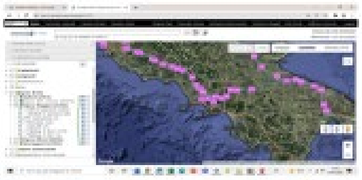



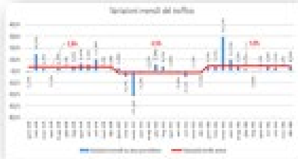
# Specific risk: landslides



GIS-based risk analysis platform generating prioritized ranked site/asset risk maps to identify strategic areas where to implement measures.

- Mountainous region, subject to landslides, earthquakes, snow and heavy traffic.
- Major event in 2005 at km. 122:
  - closure of the highway,
  - construction of a bypass.
- Traffic variations observed in the period due to re-routing.





**The "extreme" event (outside the chosen area of interest) used to increase the comprehension of all the relevant elements or factors affecting the specific event and to assess the possible consequences and actions to be undertaken.**

**Data from paper Martani C, Adey BT, Robles I et al. Estimating the resilience of, and targets for, a transport system using expert opinion. Infrastructure Asset Management, https://doi.org/10.1680/jinam.20.00029**

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FORESEE PROJECT

# Choice of FORESEE tools

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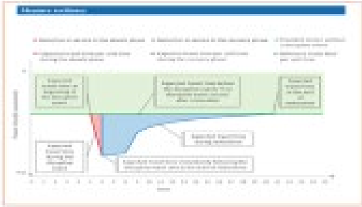
# Choice of tools (first step)



- ✓ How can the resilience of a network be modified to counteract the loss of service following a hazard?
  - Guideline to measure Levels of Service and resilience in infrastructures.
- ✓ How can specified levels of service be provided during and following the occurrence of extreme events?
  - Guideline to set target levels of service and resilience for infrastructures.

Application of the procedures and models described in the guidelines on CS#2:
- 42 indicators to represent the CS#2.
- identification of areas/parameters on which to focus actions.

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# CS#2 Scenario and Tools

| Case Study#2 | Scenario 1 | Scenario 2 |
|---|---|---|
| Life-cycle phase | Design & Construction | Operation & Maintenance |
| Risks | Landslide, L | Landslide |
| Transport | Road, R | Road |
| Scale | National and Regional | National and Regional |
| Location | Italy, IT | Italy, IT |

**Tools to be presented**

Application of T1.1 and T1.2, following event

| CS#2 | LOS as a Cost Value [10^3€] |
|---|---|
| | Impact on service |
| Interventions | 12.040 |
| Travel time | 2.970 |
| Safety | 54.000 |
| Socio-economic activities | 1.260 |

| Descrip. | Tool Dev. | KRI |
|---|---|---|
| Framework use cases, risk scenarios and analysis of impact | CEM | Framework for T 7.2/3/4 |
| Resilience Guidelines to measure Level of Service & Resilience | ETH | L1-Infrastructure<br>L2 Environment<br>L3 Organization |
| Set Targets | ETH | L1-Infrastructure<br>L2 Environment<br>L3 Organization |
| Risk Mapping tool | UC | 1.3.2<br>3.1.1<br>3.1.2 |
| Virtual modelling Platform | UEDIN | 1.3.2<br>3.1.1<br>3.1.2 |
| Alerting SAS platform | TVUK | 1.3.2<br>3.1.1<br>3.1.2 |
| Fragility and Vulnerability Analysis & Decision Support Module | RINA-C | 3.1.1<br>3.1.2 |
| Design, construction and remediation plans | CEM | 3.1.2<br>3.1.3 |
| Operational and maintenance plans | TEC | 3.1.2<br>3.1.3<br>3.2.4<br>3.2.5<br>3.2.6 |

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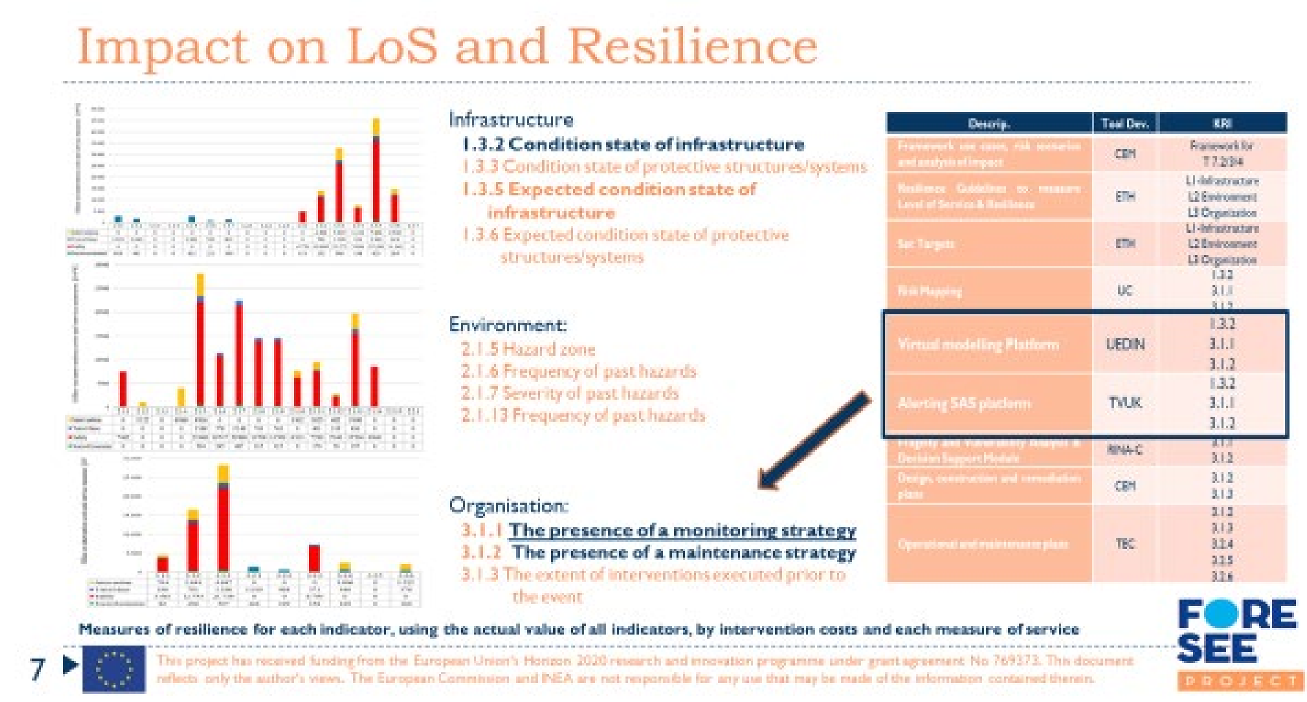
Impact on LoS and Resilience
Infrastructure
1.3.2 Condition state of infrastructure
1.3.3 Condition state of protective structures/systems
1.3.5 Expected condition state of infrastructure
1.3.6 Expected condition state of protective structures/systems
Environment:
2.1.5 Hazard zone
2.1.6 Frequency of past hazards
2.1.7 Severity of past hazards
2.1.13 Frequency of past hazards
Organisation:
3.1.1 The presence of a monitoring strategy
3.1.2 The presence of a maintenance strategy
3.1.3 The extent of interventions executed prior to the event
Descrip.
Tool Dev.
KRI
Virtual modelling Platform
UEDIN
Alerting SAS platform
TVUK
Measures of resilience for each indicator, using the actual value of all indicators, by intervention costs and each measure of service
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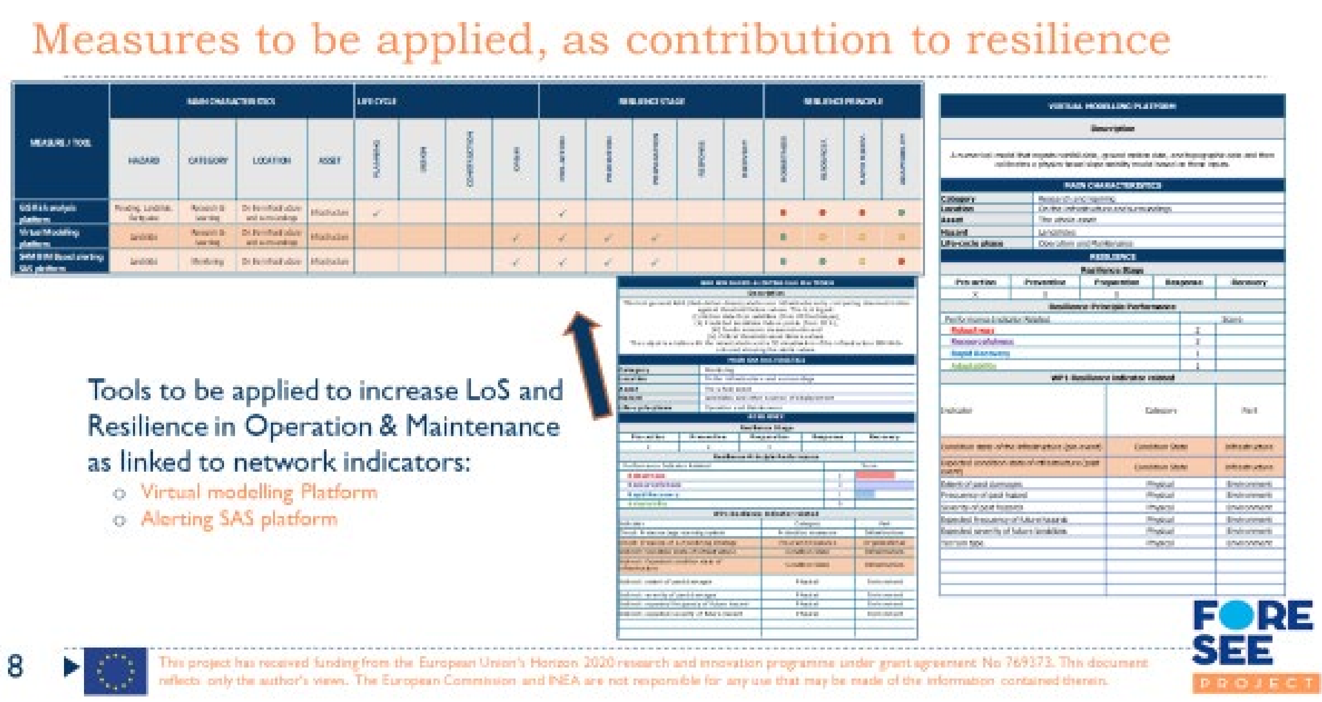
FORESEE PROJECT


Measures to be applied, as contribution to resilience
Tools to be applied to increase LoS and Resilience in Operation & Maintenance as linked to network indicators:
Virtual modelling Platform
Alerting SAS platform
8
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## Application of FORESEE tools

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## Virtual Modelling Platform and Asset Failure Prediction

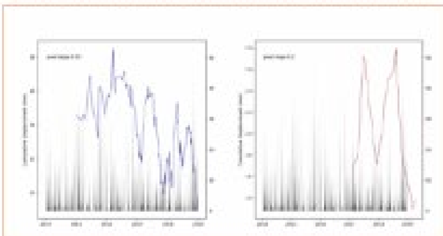
**To predict potential landslide failures along infrastructure corridors (early warning):**

- to identify warning thresholds, exceeded which, it is expected for a landslide to trigger or to reach an appreciable velocity.

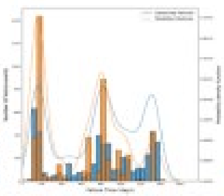
✓ **Rainfall = triggering factor** causing an increase in interstitial pressures.

✓ Landslide predictive model calibrated on topographic information, ground motion data derived from radar satellites (InSar) and precipitation data derived from satellites.

✓ Model based on historical displacement data.



Two ground motion time series from nearby points. Rainfall time series are the same, but the ground motion between the points differs.



Probability distribution of observed versus modelled failures. Peak densities of failures occur at similar times although the model over predicts failure early in the time series.

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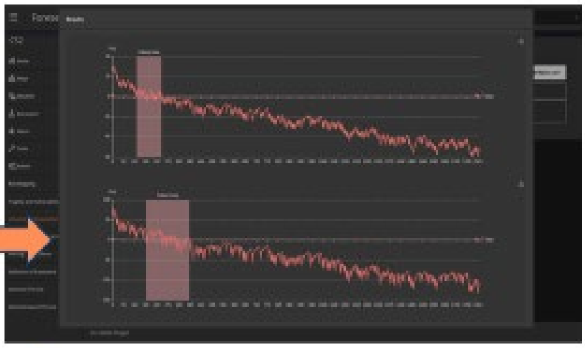
## Virtual Modelling Platform: predictive model

Identifying locations that are potentially hazardous could lead to site inspections or even to mitigation strategies.

Time interval in which to expect an event



*Integration in the FORESEE toolkit underway*

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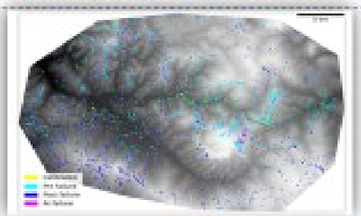
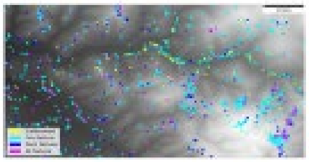
## Virtual Modelling Platform and Asset Failure Prediction

- A16: data available in the timeframe covering the period 2012-2019.
- 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.
- Expected timeframe of 25 days having to be updated from subsequent measures in time.
  - Area of interest: formations of fine/cohesive soils with landslide movements with deep sliding surfaces on which the influence of the increase in interstitial pressures, although significant, occurs over long times, due to the scarce permeability of the formations.

*For the purposes of validation, a permanent monitoring system have been installed to validate the predictive models for hazard management and integrate S-SHM.*



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.



Close up area around road with highest concentration of mapped landslides.

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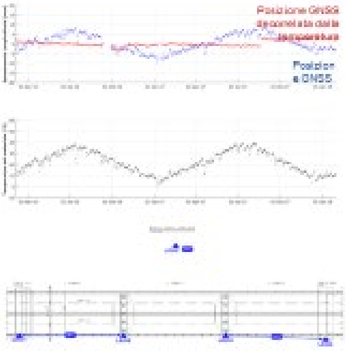
# Overview of permanent monitoring system

**Real time acquisition rate**, fundamental for alerts purposes, to complement the rate of acquisition of InSAR.

- ✓ It contributes to anchor to the ground the wide satellite images.
  - Continuous monitoring of significant points both on the structures and in the nearby landslide area.
  - A GNSS receiver/antenna is of the dual-frequency type for the monitoring of water vapour (correlated to rainfall).
  - Thermometric probe to measure the temperature with respect to different conditions of solar radiation.
  - System installed on two bridges in the area of interest.
  - The GNSS data is provided through an API (https://cloud.geoguard.eu).
  - TPZ-UK developed a new module inside S-SHM to allow the ingestion of data from external APIs.



*To be kept in service beyond end of the project.*

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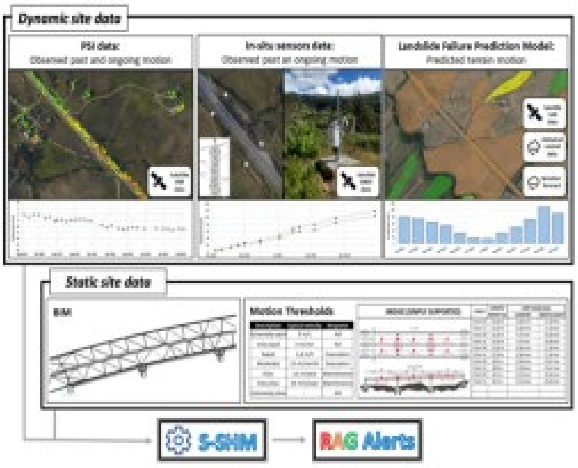
# SHM BIM based alerting SAS Platform

**To generate RAG alerts over the different elements of a BIM corresponding to a critical infrastructure.**

- ✓ Comparison of motion thresholds and motion observed along time for each BIM element.
- ✓ 3D visualization of the alerts along the critical infrastructure.




*Planned: Refinement of alerts thresholds*

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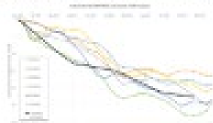
## Application to CS#2 (1/2)

- Focus: km. 97-99 based on the results of the project.
- Match of satellite data with ground benchmarks, for model calibration.
- Long time observations available.
- Integration of 2 GNSS permanent monitoring systems.
- Results confirm what is known in ASPI:
  - identification of "landslide risk" areas.
- Noted: slight rain-displacement correlation.

Descending, ascending, East-West and vertical mean velocity between Km. 97-99



Comparison of the cumulative displacement detected by the inclinometer 098+900 I2 and six PSs from the PSI analysis. The scale is in the East West direction, positive values are moving to the East and negative values are moving West

*S-SHM platform integrated in the Internet-based FORESEE Toolkit*

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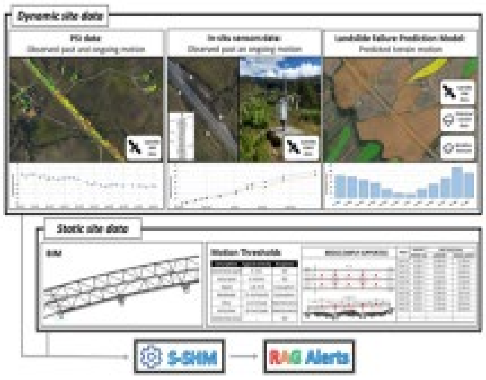
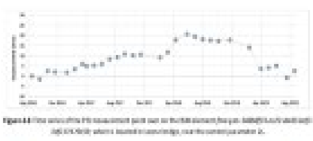
## Application to CS#2 (2/2)

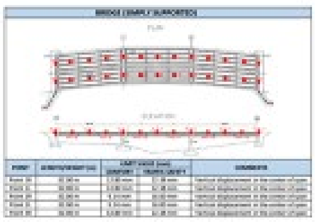
Section of the BIM used over the area of interest in Case Study #2




Theoretical range of velocities over the highways and surrounding



Permanent monitoring



Theoretical values and control points for the bridge

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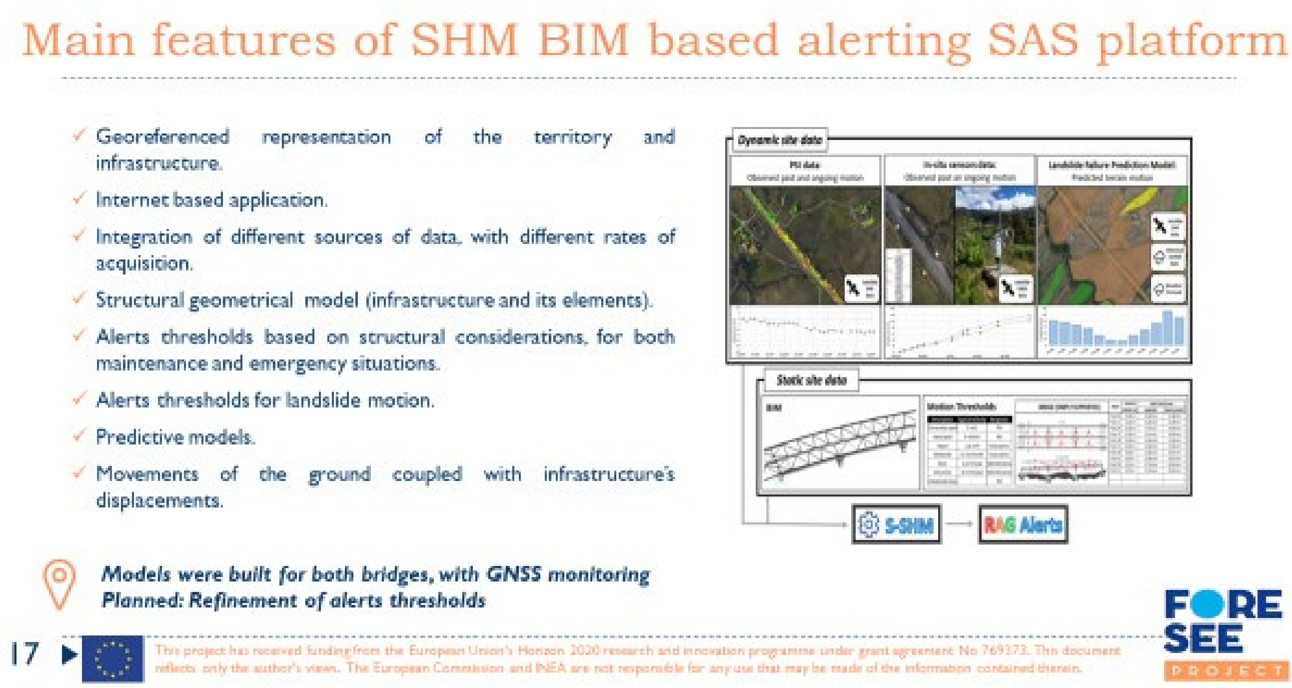
Main features of SHM BIM based alerting SAS platform
✓ Georeferenced representation of the territory and infrastructure.
✓ Internet based application.
✓ Integration of different sources of data, with different rates of acquisition.
✓ Structural geometrical model (infrastructure and its elements).
✓ Alerts thresholds based on structural considerations, for both maintenance and emergency situations.
✓ Alerts thresholds for landslide motion.
✓ Predictive models.
✓ Movements of the ground coupled with infrastructure's displacements.
Dynamic site data
PSI data
In-situ sensors data
Landslide failure Prediction Model
Static site data
BIM
Motion Thresholds
S-SHM
RAG Alerts
Models were built for both bridges, with GNSS monitoring
Planned: Refinement of alerts thresholds
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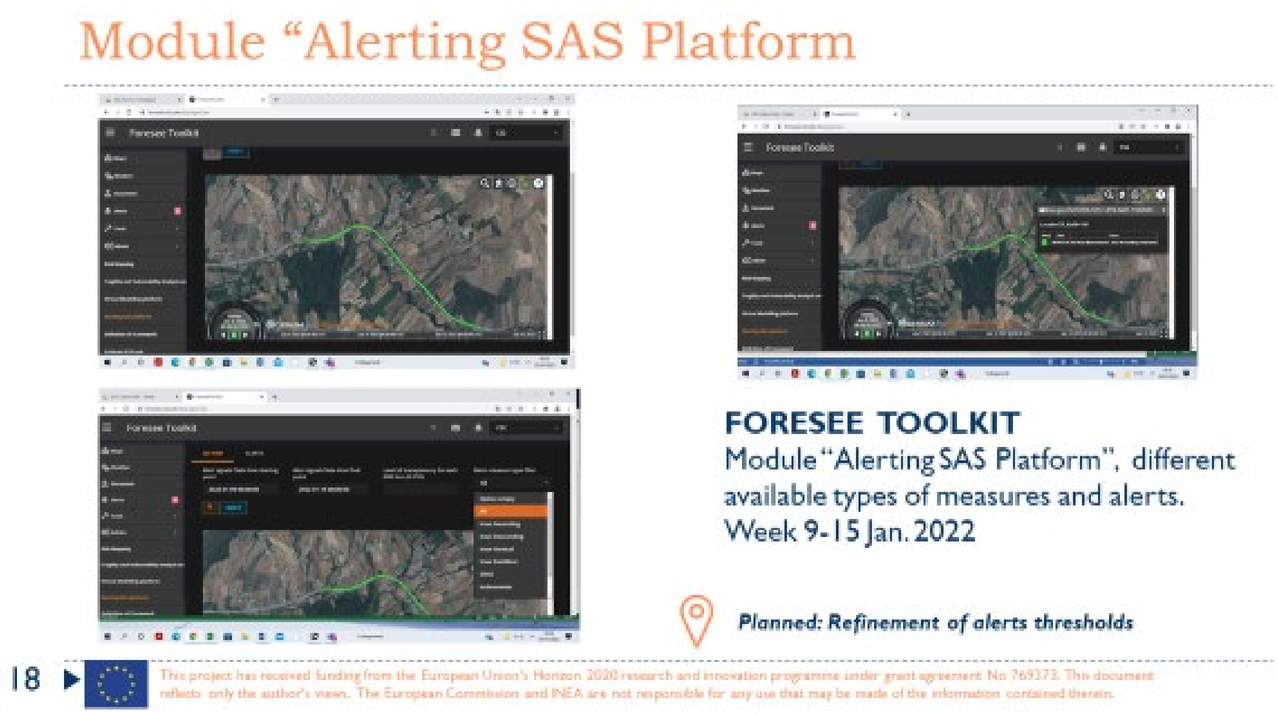
FORESEE PROJECT


Module "Alerting SAS Platform
Foresee Toolkit
FORESEE TOOLKIT
Module "Alerting SAS Platform", different available types of measures and alerts.
Week 9-15 Jan. 2022
Planned: Refinement of alerts thresholds
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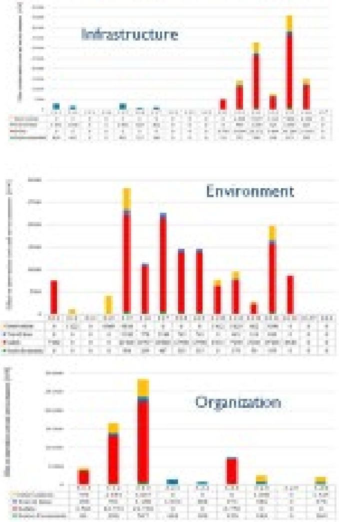
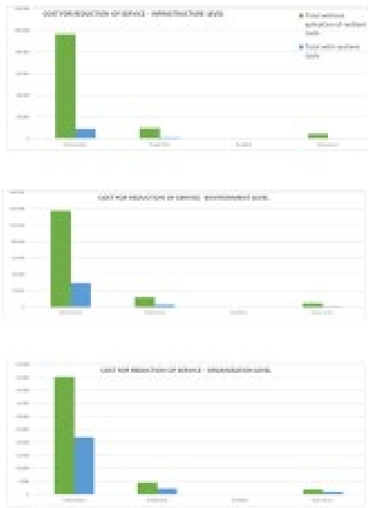
# Expected impact after application



In the hypothesis of a major event impacting on the infrastructure (data from WP1) as a result of the application of the proposed tools.

Expected: no accidents as a result of the application of the alerting platform

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# Will FORESEE results improve your management?

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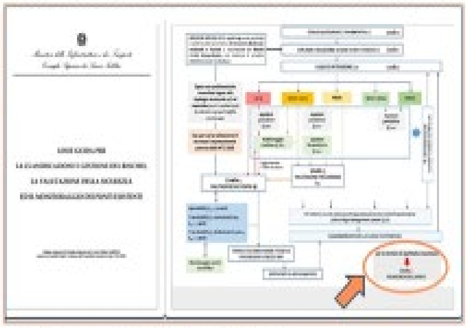
## Guidelines: How will they improve your management?

| *Infrastructure's management* | For the Future | |
|---|---|---|
| Guideline to measure Levels of Service and resilience in infrastructures. | Compliance with regulations: Guidelines for the Management of Risk, the Evaluation of Structural Safety and the Monitoring of Existing Bridges (ITA-2020). | *Common parameters with FORESEE approach.* |
| Guideline to set target levels of service and resilience for infrastructures. | | |
| Tool for governance to understand which actions to take and where to improve service and reduce negative impact. | | |



**Multi-level and multi-risk approach:**

- **Level 0:** Inventory
- **Level 1:** Inspections
- **Level 2: Class of attention** to be attributed to each bridge, defining the degree of complexity of the following steps.
- **Level 3:** Preliminary assessment
- **Level 4:** Assessment
- **Level 5: "Bridges of significant importance within the network, for which it is useful to carry out more sophisticated analyses of the resilience**

**Overall class of attention: combination of 4 distinct classes of attention, related to 4 different types of risk: structural and foundational, seismic, landslides, hydraulics. Each of them is obtained by analyzing three factors (risk, vulnerability, exposure).**

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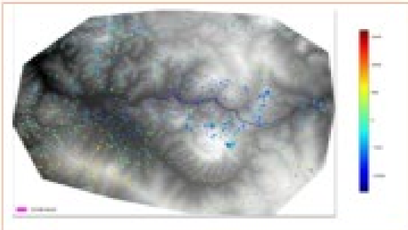
## VMP: How will it improve your management?

| *Infrastructure's management* | For the Future | |
|---|---|---|
| Improved landslide forecasting and hazard management. | Re-evaluation of the method and of thresholds values after a period of observation and collection of data from on-site monitoring, satellite interferometry, rainfall data. | *Studies in progress on the hydrogeological instability of the network.* |
| Identification of failure potentials, their mechanisms and reliable correlations between movement events and their triggering factors. | | |
| Timely warning of potential events with a positive impact on mobility and safety. | | |



**Failure points coloured by difference between day of predicted failure and day of observed exceedance of the ground motion threshold.**
**Warm colours represent failure predicted by the model occurring after observed exceedance of ground motion, whereas cool colours represent predicted failure occurring before observed ground motion.**

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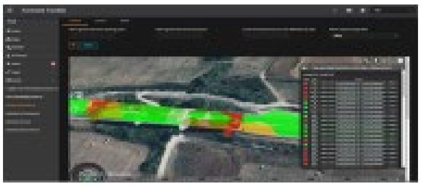
# S-SHM: How will it improve your management?

| *Infrastructure's management* | For the Future | |
|---|---|---|
| Integration of different data sources.<br>BIM model of the infrastructure and components to be kept under control. | Development of BIM for earthworks (embankments/trenches). | *Different types of risks should be integrated in the same tool.* |
| More reliable identification of warning thresholds, based on the displacements that the infrastructure is able to undergo, in the absence of damage/with acceptable damage, thus increasing resilience of the infrastructure. | In parametric form or in greater detail to make it as reliable as possible, according to a realistic behavior prediction, always for the identification of reliable warning thresholds. | |
| Used to program and design interventions. | | |
| Timely warning of potential events with a positive impact on mobility and safety. | | |



3D visualization of the alerting system over one of the bridges in CS#2.

The BIM is colored by RAG (Red-Amber-Green) alert values.

It can be navigated.

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FORESEE PROJECT

# Will FORESEE results improve your management?

| *Infrastructure's management* |
|---|
| **Integrated internet tool is not available to manage all the aspects linked to the hydrogeological risk.** |
| The use of a comprehensive internet-based 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. |
| The proposed tool could complement the Company's strategy of digitalization. |


ARGO surveillance and monitoring maintenance of the infrastructure and its elements, based on IBM-Maximo


AGE (Autostrade Google Earth) application on the Google Maps IT platform. This technology makes it possible to associate a wide variety of information relating to the infrastructure, quality indicators and territorial context to each point of the network.

Company's Command and Control Centre

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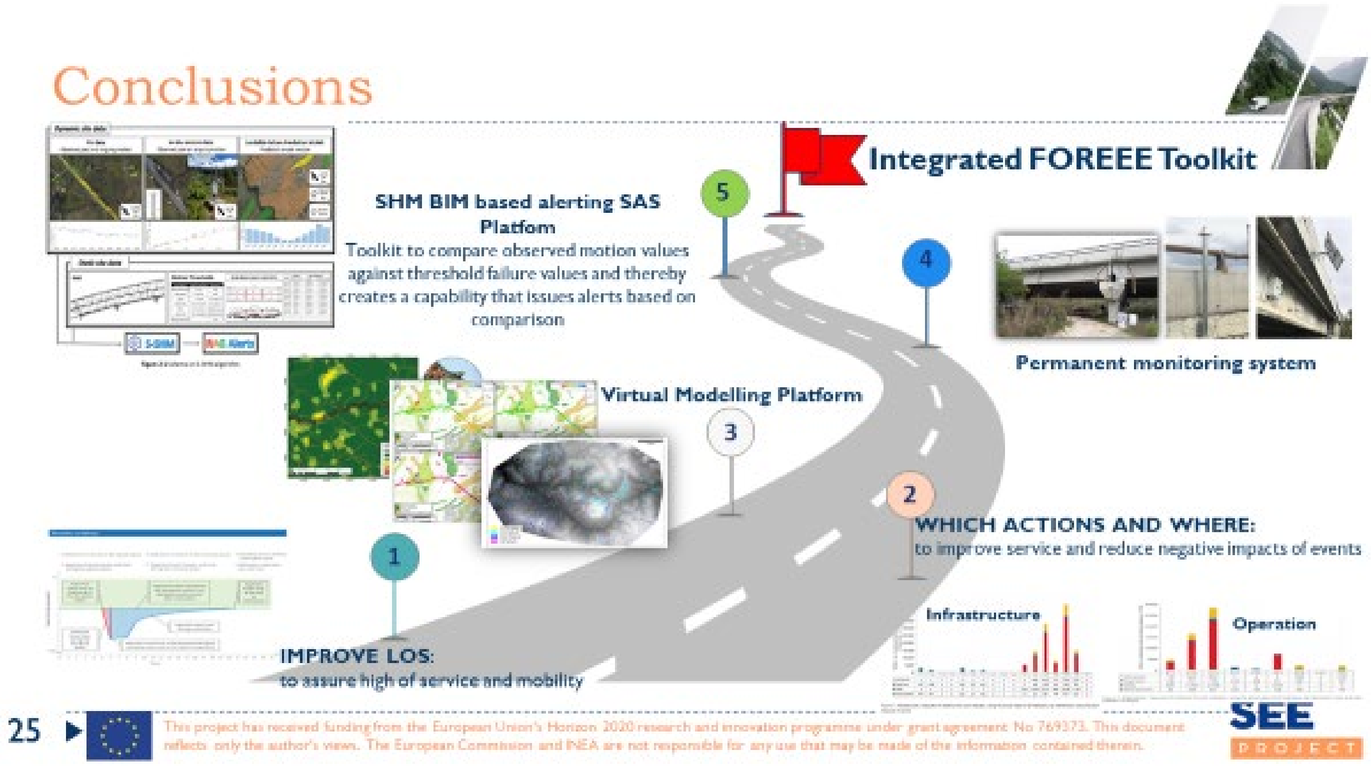
FORESEE PROJECT





Back to Agenda

12:10. Montabliz viaduct in Spain: Mª Antonia Pérez, University of Cantabria and David García-Sanchez, Tecnalia


# FORESEE RESULTS Tool: Risk Mapping

CURRENTLY

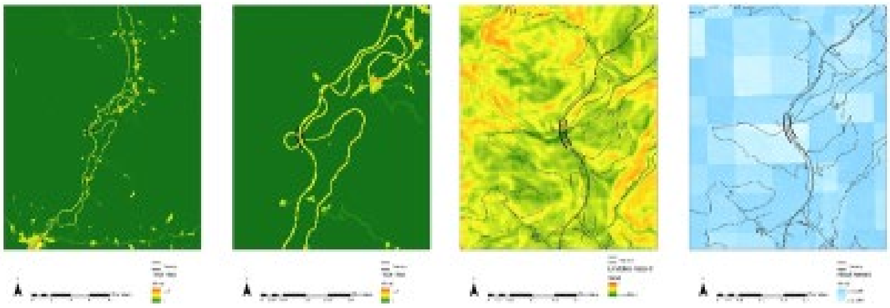
- Expert opinion

**ADVANTAGES**

- Processing and classification of large amounts of data
- 80% labor savings, at early phases of design

**RESULTS**

- Risk Map definition for:
  - WIND
  - SNOW
- POTENTIAL TO REACH THE MARKET



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# ADVANTAGES FORESEE RESULTS Tool: Risk Mapping

| ADVANTAGES Risk Mapping | |
|---|---|
| **Was this type of analysis made before FORESEE? How it was made?** | Yes. It was carried out based on historical data and expert analysis and opinions and for specific hazards (i.e. fire). |
| **How does FORESEE improve the results/analysis previously made?** | Risk Mapping has handled for this infrastructure a multitude of event data related to natural hazards, and has classified and mapped them in a very short time. The results obtained by experts did not have the answer provided by Risk Mapping, neither in detail (scale), nor in time, nor in quantity of information, nor in speed. |
| **How does this FORESEE result improve your infrastructure's management** | Risk Mapping provides information on the risks of the infrastructure especially in the design phase, such as risk prevention from the beginning of its conception. From the robustness perspective. Nevertheless, the output of the tool will be updated according to input data so the updating of the system is continuous. |
| **If it was not made, How does this FORESEE result improve your infrastructure's management ?** | Risk Mapping can also be used in the exploitation phase to foresee and plan actions against risks, in prevention and emergency plans. Easy to update and run. |
| **What cost/resource efficiencies 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%)** | 90% decrease working hours<br>80% saving maintenance costs |

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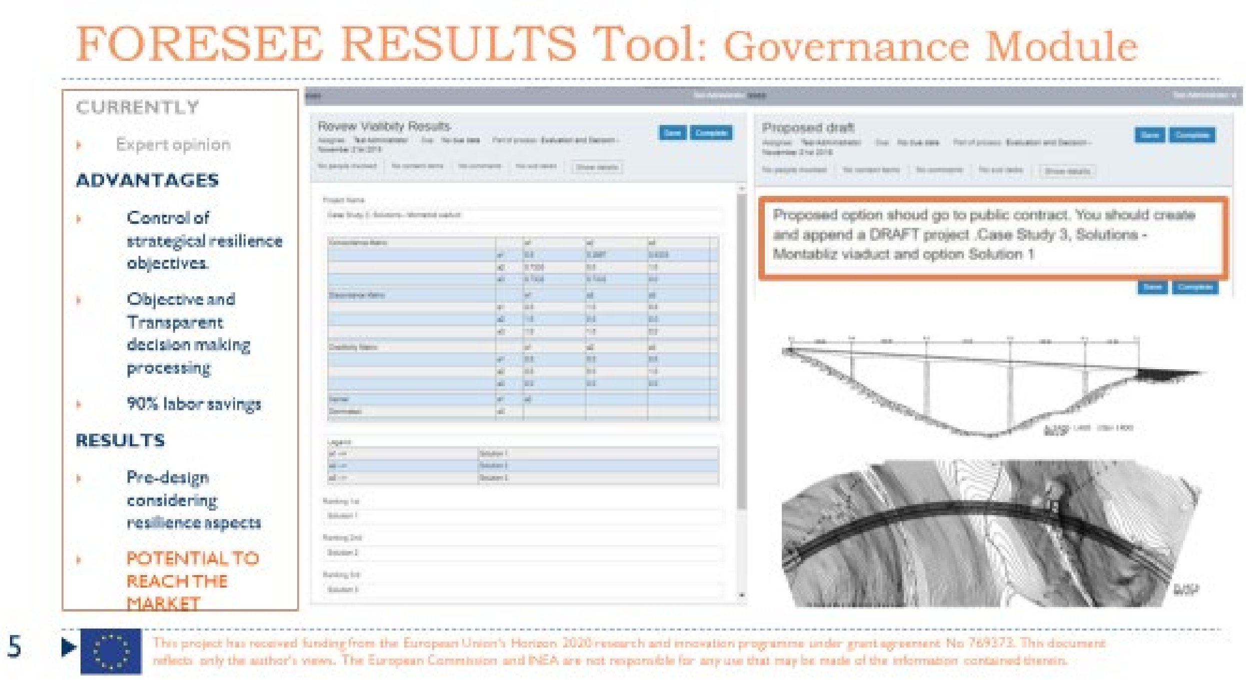


## ADVANTAGES FORESEE RESULTS Tool: Governance Module

| ADVANTAGES Governance Module | |
|---|---|
| **Was this type of analysis made before FORESEE? How it was made?** | Yes. Experts were consulted, but due to the exceptional typology of the infrastructure, no experience was available. |
| **How does FORESEE improve the results/analysis previously made?** | Helping in the decision making of InfraManagers : faster decision making, and complex decisions based on holistic approaches impossible to handle easily. |
| **How does this FORESEE result improve your infrastructure's management** | Governance Module identifies the most suitable solution in objective and transparent way considering those aspects defined by the Governance strategy of the Infrastructure in a strategic level. |
| **If it was not made, How does this FORESEE result improve your infrastructure's management ?** | Due to the multitude of studies that were carried out, costly in time and money, the typology, which was defined was the most appropriate, for its management against the hazards identified.<br>Governance Module saves time and costs, since the decision process has been automatized. |
| **What cost/resource efficiencies 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%)** | 90% decrease working hours<br>90% increase productivity |

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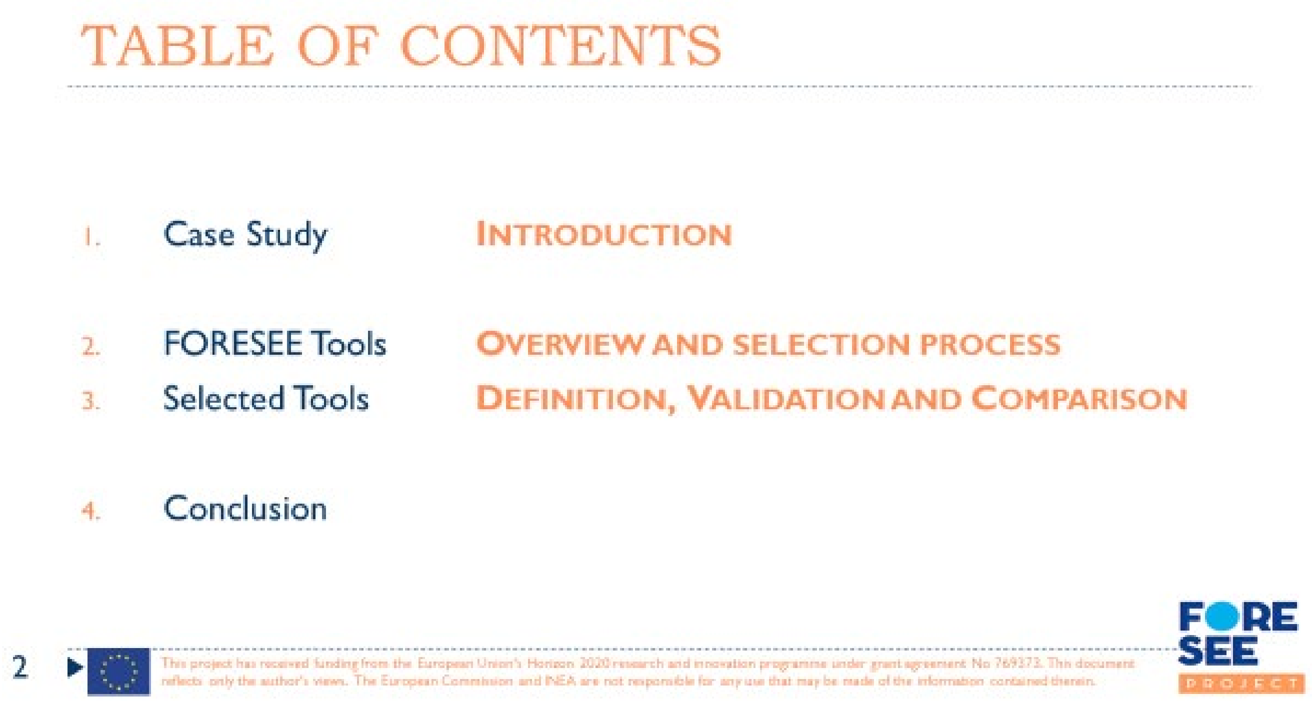
12:30. Railway track 6185 in Germany: Sebastian Kantorski, IVE

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## 1. Case Study #4 Introduction Railway track 6185 in Germany *"Numbers, data and facts."*

- track no. 6185 between Oebisfelde (267,9 km) and Berlin-Spandau (112,7 km) is part of the high-speed track Hannover – Berlin
- 150 km long
- 170 trains and 10,000 passengers per day
- first German line constructed in the 1990s as slab track (ballastless)
- several bridges that cross the river Elbe, such as the Haemerten bridge


[Wikipedia / OpenStreetMap / img.derwesten.de]


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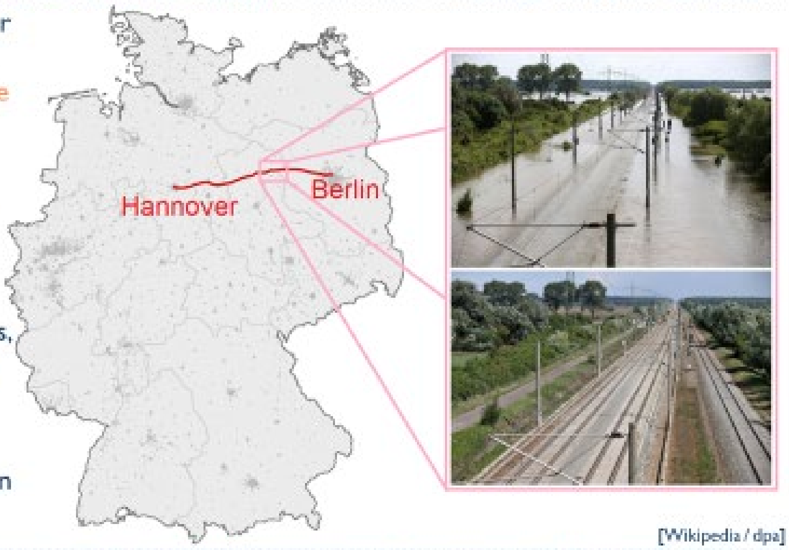
## 1. Case Study #4 Introduction Railway track 6185 in Germany

*"Elbe flood 2013."*

The Elbe flood in 2013 is used for the FORESEE tools as a benchmark and practical example for evaluation and validation:

- Data available regarding flooding risks and damages
- Haemerten bridge was closed
- Due to large-scale deviations, delays of one to two hours occurred
- Regular service was not resumed until months later in November 2013




[Wikipedia / dpa]

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## 2. FORESEE Tool Overview and Selection Process
## CS#4 Railway track 6185 in Germany *"Scenario Card."*

→ **Study scenario and parameters:**

- Heavy rain,
  Risk of moderate **flooding**.
- Heavy rain
  + river flooding,
  risk of fast and intense **flooding**.

| | Scenario |
|---|---|
| **Phase** | Operation & Maintenance |
| **Risk** | River Flooding |
| **Transport** | Railway Way |
| **Scale** | National |
| **Location** | Germany |

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## 2. FORESEE Tool Overview and Selection Process
## CS#4 Railway track 6185 in Germany *"Tool Selection."*

→ Selected FORESEE Tools (1-6) and the connection with the Key Resilience Indicators (I - III)
→ Of which Included Tools (2 of 6) selected for further presentation

| Corresponding Key Resilience Indicators | Selected FORESEE tool | Tool name |
|---|---|---|
| I. The presence of a maintenance strategy<br>II. The extent of interventions executed prior to the event<br>III. Review/update of the emergency plan | (1) | **Bridge Flooding Model** |
| | | *Resilience Guidelines to measure Level of Service & Resilience* |
| | | *Set Targets* |
| | | *Governance Module* |
| | (2) | Risk Mapping |
| | | *Virtual modeling Platform* |
| | | *Alerting SAS platform* |
| | | *Traffic Module* |
| | | *Fragility and Vulnerability Analysis & Decision Support Module* |
| | | *Flooding Methodology* |
| | | *Hybrid Data Fusion Framework* |
| | (3) | **Command and Control Center** |
| | | *Definition of framework: use cases, risk scenarios and analysis of impact* |
| | (4) | Design, construction and remediation plans |
| | (5) | Operational and maintenance plans |
| | (6) | Management and contingency plans |

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## 3a. Selected Tool Definition Bridge Flooding Model

*"Requirements."*

| | DESCRIPTION | PHASE |
|---|---|---|
| **Bridge Flooding Model** | Definition of requirements<br>Identify which of the following six defined influences have the potential to damage the assessed railway track components depending on the water level that its serviceability is no longer given and it can no longer be operated without repair work:<br>• Undercutting of foundations<br>• Softening of earthworks<br>• Overflow of electrical installations<br>• Effects of faster flowing water<br>• Positional changes of the superstructure<br>• Input of foreign substances into railway track components<br>Design of the technical system<br>Small-scale CAD model of a railway bridge over a river with earth dams in front and behind it and one DN 1000 mm culvert.<br>Implementation of the outputs<br>Outputs of the bridge model as CAD-file with visualisation of the water level. | Life Cycle phase:<br>Maintenance<br>Process phase:<br>Before the event |


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## 3a. Selected Tool Definition Bridge Flooding Model

*"Implementation."*

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

[IVE]

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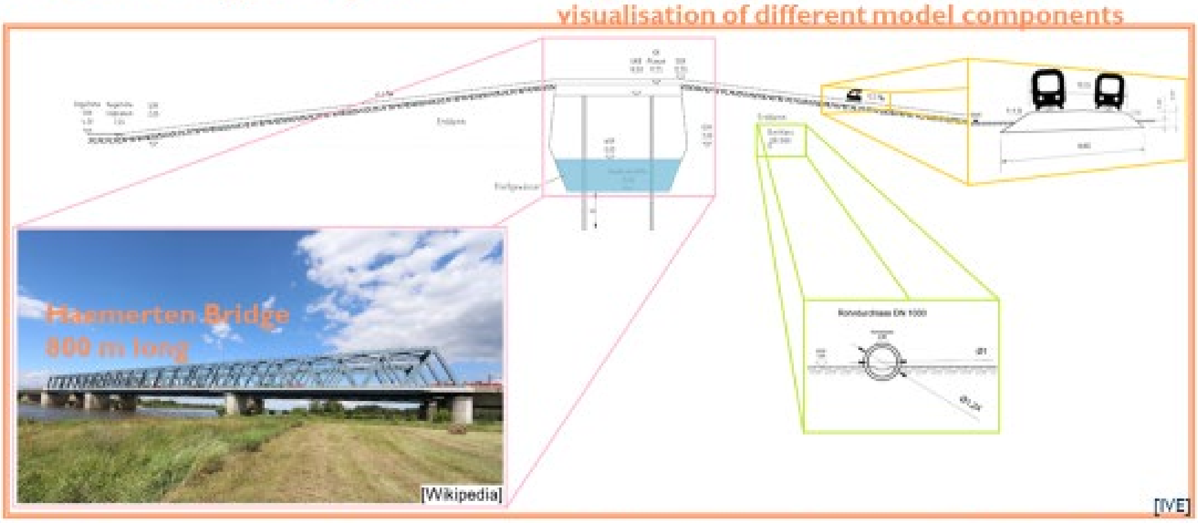
## 3a. Selected Tool Definition Bridge Flooding Model

*"Implementation."*

→ CAD-based Bridge Flooding Model: **longitudinal section** **(10x height)**
**visualisation of different model components**




[IVE]

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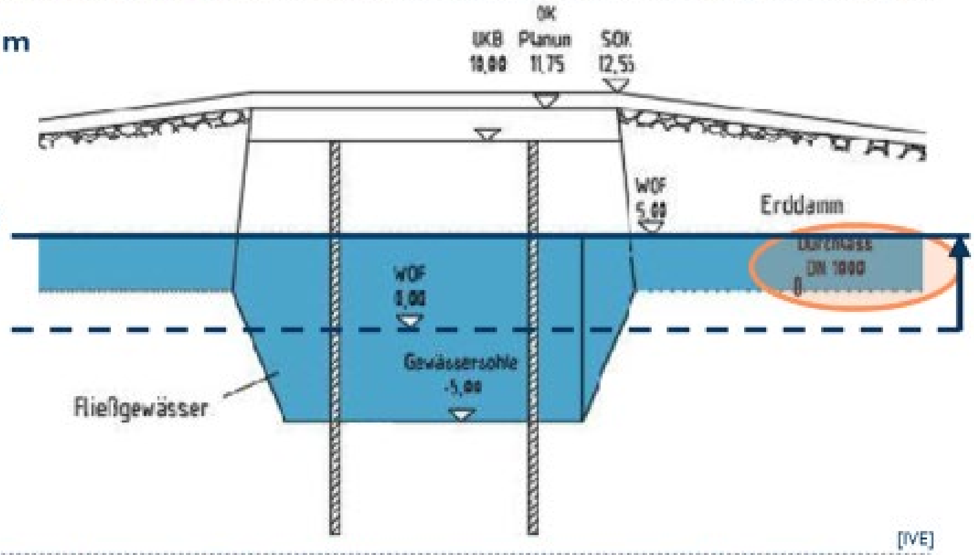
## 3a. Selected Tool Validation Bridge Flooding Model

*„Track no. 6185 at 195 km, Haemerten Bridge Flooding."*

**Water level +5,00 m**

- **Culverts are flooded**
- High pressure on the dam body

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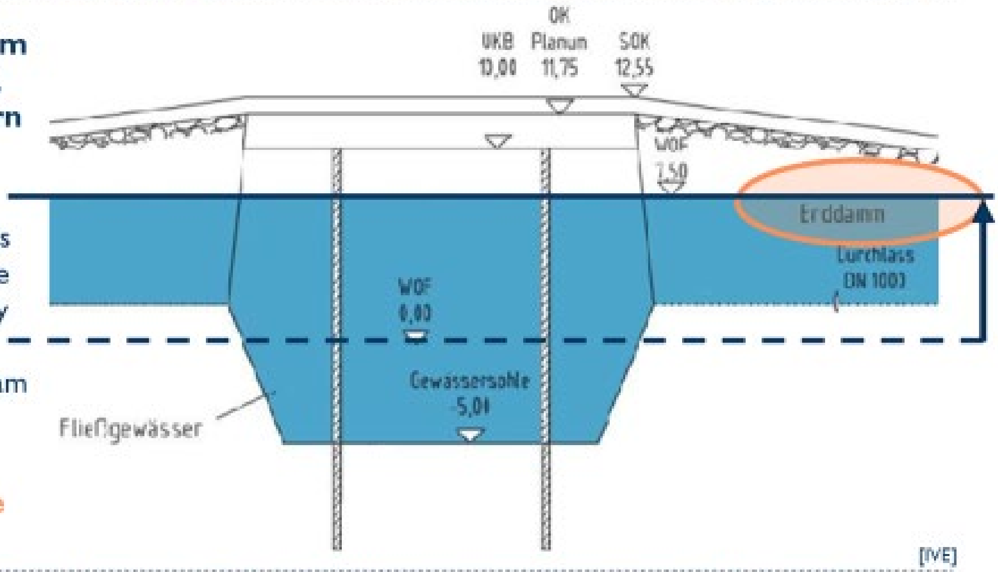
## 3a. Selected Tool Validation Bridge Flooding Model

*„Track no. 6185 at 195 km, Haemerten Bridge Flooding."*

**Water level +7,50 m (design flood level, old 100 year return period flood)**

- The Bridge itself is not affected in the model, the railway track in front of and behind the dam is flooded
- **Very high pressure on the dam body**

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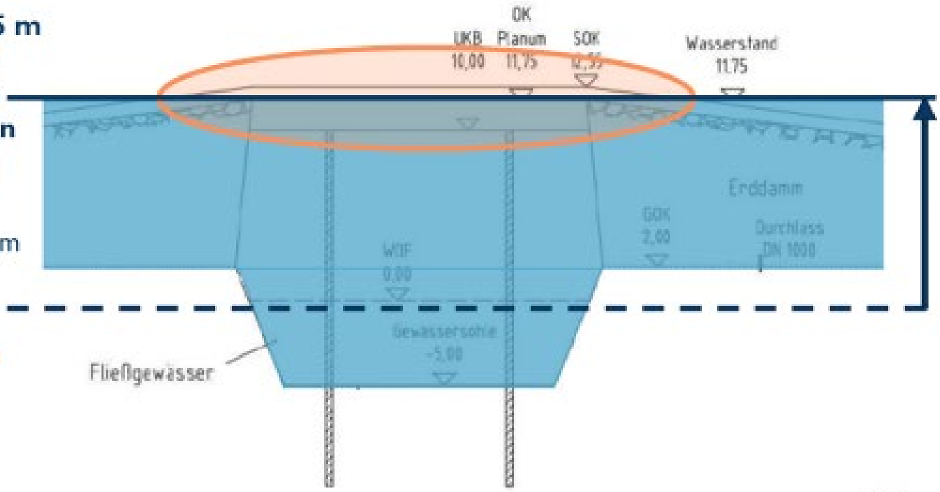
## 3a. Selected Tool Validation Bridge Flooding Model

*„Track no. 6185 at 195 km, Haemerten Bridge Flooding."*

**Water level +11,75 m (peak wave of the Elbe flood in 2013 had levels between +7 m and +10 m)**

- All areas of planum are flooded
- **Structural damage for the dam**
- **No railway operations possible**

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## 3a. Selected Tool Validation Bridge Flooding Model

*„Track no. 6185 at 195 km, Haemerten Bridge Flooding."*

[Wikipedia]

11.06.2013

[dpa]

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3a. Selected Tool Comparison
Bridge Flooding Model

*"Improvement versus before."*

| | Comparison | | |
|---|---|---|---|
| | ACTUALY / CURRENT TOOLS | FORESEE TOOL | |
| Hazard **Assess-ment** | - Design flood according to guidelines | Bridge Flooding Model | ✓ Water level dependent assessment of usability |
| | - historically based but possibly outdated design parameters | | ✓ Updatable and adaptable simulation model |
| | - Use of equipment standards depending on track category | | ✓ Track component related improvement measures |
| Rating | → "Improvement!" | | |

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3. Selected Tools — DEFINITION, VALIDATION AND COMPARISON
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4. Conclusion

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## 3b. Selected Tool Definition Command and Control Center

*"Requirements."*

| | DESCRIPTION | PHASE |
|---|---|---|
| **Command and Control Center** | Definition of requirements<br>Situation Awareness<br>Organizing big data of hazard events and summarize it, so that a human operator can handle it.<br>Anomaly / Outlier Detection:<br>Finding potentially dangerous outliers and anomalies from the normal state in Big Data of hazard events.<br>Design of the technical system<br>Software application based on an individual model and its data for each Case Study by using machine learning techniques in neural networks.<br>Implementation of the outputs<br>Issuing automatized alerts when a situation diverges from the normal state and potential danger is arising. | Life Cycle phase:<br>Operation<br>Process phase:<br>During the event |

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## 3b. Selected Tool Definition Command and Control Center

*"Implementation."*

→ **Input** – historic data:

- Water level/Discharge (green stations)
  Excel-table as provided by WSV
  (Wasserstraßen- und Schiffahrtsverwaltung)

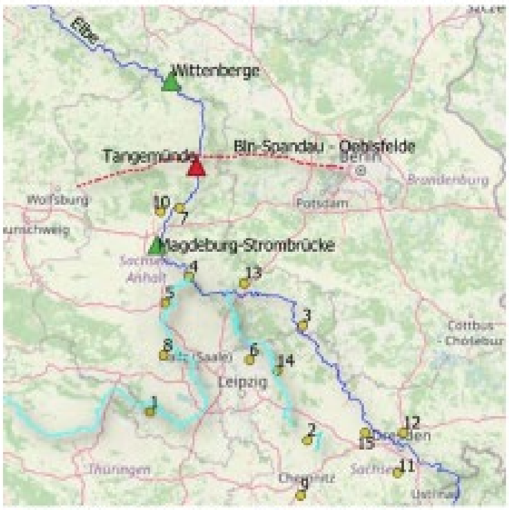
| Datum | Zeit | Q [m³/s] |
|---|---|---|
| 01.11.1997 | 00:15:00 | 254 |
| 01.11.1997 | 00:30:00 | 254 |

- Precipitation (yellow stations)
  Txt-file as provided by DWD
  (Deutschen Wetterdienst)

```
STATIONS_ID;MESS_DATUM;QN_8;  R1;RS_IND;WRTR;
        124;2006110100;   3;  0.0;   0;-999
```

→ **Output** – validation data:

- (near) Heamerten Bridge (red station)




[FRA]

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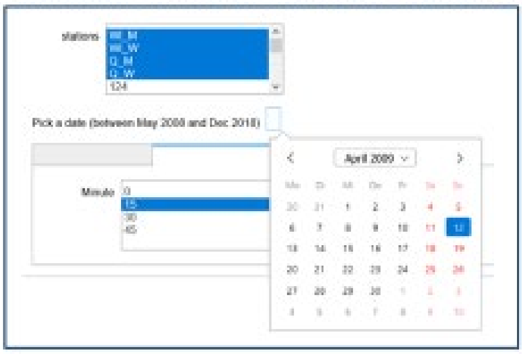
## 3b. Selected Tool Valdidation Command and Control Center

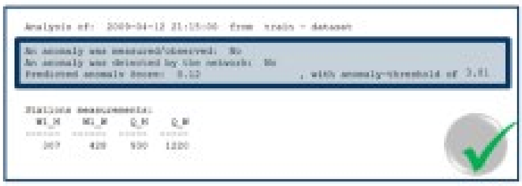
*"Failure of dam near Haemerten, 10.06.2013, 00:02."*

→ Selection of stations, date and time:

- Station:
  Magdeburg water level (WI_M)
  Wittenberge water level (WI_W)
  Magdeburg flow rate (Q_M)
  Wittenberge flow rate (Q_W)
- Date:
  12.04.2009
- Time:
  21:15

→ Output:
**No anomaly detected!**



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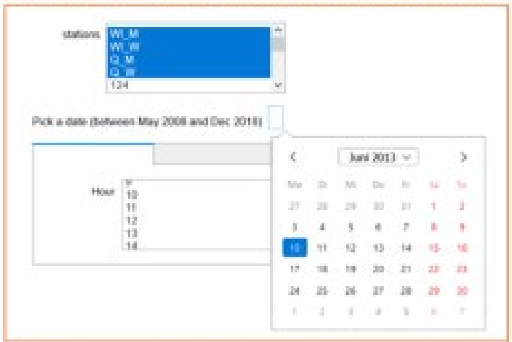
## 3b. Selected Tool Valdidation Command and Control Center

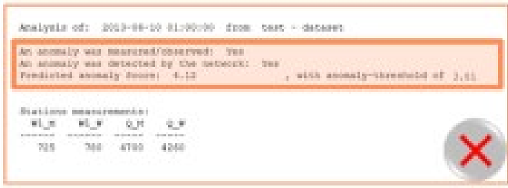
*"Failure of dam near Haemerten, 10.06.2013, 00:02."*

→ Selection of stations, date and time:

- Station:
  Magdeburg water level (WI_M)
  Wittenberge water level (WI_W)
  Magdeburg flow rate (Q_M)
  Wittenberge flow rate (Q_W)
- Date:
  10.06.2013
- Time:
  01:00

→ Output:
**Anomaly detected!**



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4b. Selected Tool Valdidation
Command and Control Center

*"Failure of dam near Haemerten, 10.06.2013, 00:02."*

09.06.2013

11.06.2013

30.06.2013

[LWH]

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3b. Selected Tool Comparison
Command and Control Center

*"Improvement versus before."*

| | Comparison | | |
|---|---|---|---|
| | *ACTUALY / CURRENT TOOLS* | FORESEE TOOL | |
| Hazard **Manage-ment** | - *No comparable tool(s) available!* | **Command and Control Center** | ✓ **Automatized alerts**<br>✓ **Predictive risk prevention**<br>✓ **AI-based hazard analysis** |
| Rating | → **"Improvement!"** | | |

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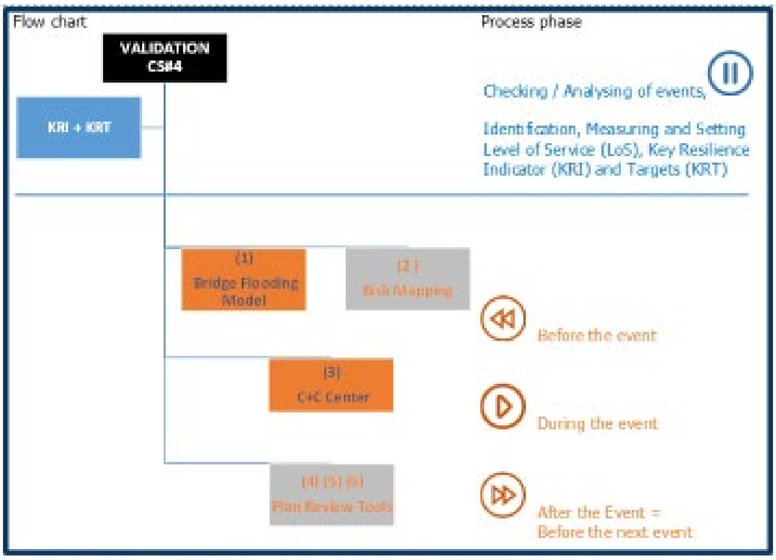
## 4. FORESEE Conclusion
## CS#4 Railway track 6185 in Germany

*"Validation chart."*

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## 4. FORESEE Conclusion CS#4 Railway track 6185 in Germany

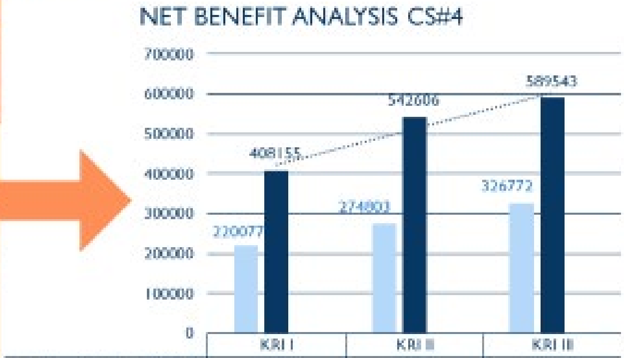
*"Net benefit analysis."*

→ Monetisation of the resilience indicators and targets as a Level of Service

→ **The key resilience targets (increase by one stage in each case) can be achieved in CS#4 through the use of the selected FORESEE tools**

| | Level of Service as a Cost Value [$10^3$€] |
|---|---|
| Intervention | 90 000 |
| Travel Time | 170 000 |
| Accident | 535 000 |
| Soc-Eco | 10 200 |

| Selected Key Resilience Indicators (KRI) | Indicator state Max/ Actual/ Target | Net benefit [$10^3$€] |
|---|---|---|
| I. The presence of a maintenance Strategy | (Actual) | 220.077 |
| | → 2 (Target) | 408.155 |
| II. The extent of interventions executed prior to the event | (Actual) | 274.803 |
| | → 2 (Target) | 542.606 |
| III. Review/update of the emergency plan | (Actual) | 326.772 |
| | → 2 (Target) | 589.543 |




| | KRI I | KRI II | KRI III |
|---|---|---|---|
| Net benefit (Actual) [1k €] | 220077 | 274803 | 326772 |
| Net benefit (Target) [1k €] | 408155 | 542606 | 589543 |
| Increase | 54% | 51% | 55% |

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## 4. FORESEE Conclusion CS#4 Railway track 6185 in Germany

*"Evaluation and potentials."*

**„Now…"**

*…the FORESEE tools of CS#4 offer infrastructure managers:*

- ✓**Resilience definition, measurement and improvement options**
  - → Measure Key Resilience Indicators and Targets
- ✓**Model-based risk assessments**
  - → Bridge Flooding Model
  - → Risk Mapping
- ✓**Automated decision support & warning systems**
  - → Command and Control Center
- ✓**Analysis, evaluation, improvement and design of construction, operational and emergency plans**
  - → Plan Review Tools

**„And in future…"**

*…improve the FORESEE tools!*

- ➢ **Further** application and feedback from practical experience of different infrastructure managers!
- ➢ **Further** validation examples to increase the tool's effectiveness, performance and accuracy!
- ➢ **Further** extension of the single case study to other railway tracks!

[flaticon]

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Back to Agenda

12:50. Tunnels at M-30 ring-road Madrid: Tobías Hanel, Ferrovial


# M-30 CASE STUDY

- The **M-30 orbital motorway circles the central districts of Madrid**. It is **32.5 km long.** Its length and the surface surrounded by the M-30 is comparable to the Boulevard Périphérique of Paris or the London Inner Ring Road.

- **The M30 is the busiest Spanish road.** It has, at least, three lanes in each direction, supplemented in some parts by two or three lane auxiliary roads. **It connects to the main Spanish radial national roads that start in Madrid. It includes several tunnels under the river Manzanares.**

M-30



FORESEE PROJECT

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# M-30 CASE STUDY

- The aim of this use case was to **implement and prove the advantages of real and accurate predictive maintenance strategies.**

- The case is quite unique in several aspects
  - it offers a **big amount of heterogeneous data suitable for testing the hybrid data fusion approach;**
  - It was the **only FORESEE case study that analyses a direct anthropogenic hazard example, the "hacking tunnel systems hazard"**

M-30



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# M-30 CASE STUDY

- **Hybrid data assessment for diagnosis and prognosis tool**
- **Novel methodology for flooding events**
- **Cyber-attack assessment**

M-30



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# CYBERATTACK ASSESSMENT

- WHAT IS A CYBERATTACK ON INFRASTRUCTURES?

A wide range of **security hazards generated by humans** that can directly or indirectly **affect the infrastructure's operational, economic and safety parameters.**

- WHAT IS THE IMPACT ON THE INFRASTRUCTURE?

Hacking events are very **different and broad in nature**. They use a wide variety of **tools and methods** to gain control or have an impact on the normal functionality of their electronically controlled targets.

- WHAT DEFENCE TOOLS ARE CURRENTLY USED?

Best management practices against cyberattack incidents involve an **organized Security Operations Center**, as well as their **technological infrastructure** and tools to defend and protect the infrastructure: **firewalls, antivirus, intrusion detection and prevention systems, etc.**

- WHAT HAPPENS WHEN AN INFRASTRUCTURE IS ATTACKED?

The potential consequences **range from a purposed malfunction** of specific systems, to disruption of the network control center, 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**.

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# CYBERATTACK ASSESSMENT

A thorough analysis of cyberattack hazard event has been performed in the study case of the M30 highway, based on three criterias:

- **Socioeconomical study** considering a cyber-attack affecting the M30 ring road. Impact on traffic and alternative routes.
- **Description of the scenarios** caused by a cyber-attack on the M30 ring road Control System and its associated response.
- **Recommendations and actions to be adopted.**


**This deep analysis will help the infrastructure manager with the maintenance and operation activities in the case of cyber-attack affecting the highway**

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# CYBERATTACK ASSESSMENT

- SOCIO-ECONOMIC IMPACTS (all the more serious the longer the duration of the incident caused by the cyber-attack)

**Environmental aspects**

- **Environmental pollution** because of the circulation of vehicles on the surface, without the corrective factor of the elimination of harmful gases through the filtering elements in the circulation tubes,
- Generation of an **increase in noise** (more surface traffic)

**Social aspects**

- **Decrease in average speed and 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,
- **Increased access times for emergency vehicles** due to traffic congestion and complexity.

**Economic impact**

- Damage caused to the management system, and the costs of restitution.
- **Possible damage caused to the infrastructure** (such as possible flooding as a consequence of the stoppage of the leakage control pumps)
- **Increase in the economic cost of travel times**
- **Possible claims** from users of the infrastructure, due to loss of capacity and **collateral damage.**

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# CYBERATTACK ASSESSMENT

- SCENARIO CAUSED BY A CYBER-ATTACK

**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)

If the cyberattack is executed by experts, 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.

For this reason, the first thing should be to **generate tools that allow to rule 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.**

The possible scenarios detail the severity of the consequences from least to greatest:

- **Is a cyberattack the control system failure reason?**
- **Does the Control Center maintain total or partial management capacity?**
- **Is the cyberattack only limiting the Control Center's ability to operate?**
- **Does the cyberattack allow the intruder to maliciously operate management systems?**

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# CYBERATTACK ASSESSMENT

- SCENARIO CAUSED BY A CYBER-ATTACK

Each of the control systems and subsystems has a supervision equipment associated with it, and an **indicator that assesses the operation, its contribution to the overall safety, and the acceptable level of operation in the event of degraded service.**

**Determination of critical facilities affected** (Increasing order of severity)

| AFFECTED EQUIPMENT | DETECTION SOURCE | IT'S A CIBER-ATTACK | BEATS STANDARDIZED INDEX | SELF-PROTECTION PLAN/ DEGRADED SERVICE FILE | CLOSED ACCESS |
|---|---|---|---|---|---|
| CLOSURE SYSTEM<br>TUNNEL / BARRIERS<br>POWER SUPPLY | | | | | |
| VENTILATION SYSTEM | | | | | |
| FIREFIGHTING CONTROL SYSTEM AND EQUIPMENT | | | | | |
| ILLUMINATION SYSTEM | | | | | |
| SIGNALING SYSTEM<br>VIDEOSURVEILLANCE SYSTEM / DAI | | | | | |
| SOS / PA/VA SYSTEMS<br>ANALYSIS AND CONTROL SYSTEM OF ENVIRONMENTAL FACTORS | | | | | |
| EVACUATION MANAGEMENT<br>INTERNAL / EXTERNAL COMMUNICATIONS EQUIP. | | | | | |

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# CYBERATTACK ASSESSMENT

- STANDARDIZED RESPONSE (FROM THE CONTROL CENTER)

A breach should trigger the systematic response and decision-making in favor of safety, in which, and in a coordinated manner, the **priority actions** are:

- Prevent access to the affected area and progressively to the entire tunnel length. (40 minutes*)
- Evacuation of vehicles that are inside (30 minutes*)
- Verification of the origin of the loss of Control.
- Divert traffic to alternative routes. (90 minutes*)

**These are indicative times, with the premise of loss of communications, so the instructions and monitoring of the First Intervention teams, Local Police, Firefighters and Health Services can only be carried out by telephone, with the consequent risk of collapse of the communications.*

**Main critical aspects: Detection and identification time, Scope identification, service restitution time determination**

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# CYBERATTACK ASSESSMENT

- ACTIONS TO BE ADOPTED

- It would be desirable to **create tools that allow rapid discrimination of the existence of a cyberattack.**
- Creating a **Safety culture**, which implies information and permanent training of the organization's participants, creating an **inventory of existing computer security risks and protected devices**, protecting passwords, paying attention to security protocols, or **web filtering.**
- **Analysis of the infrastructure control systems and their vulnerability in case of cyber attack event (**elements such as power supply system, ventilation and air pollution control system, fire fighting system, lighting system, emergency signage system, CCTV system, SOS posts, evacuation management systems, Automatic incident detection (AID), Signalling using lights and traffic signals and communications network)
- **Adaptation of Standard (regulatory framework) and elaboration of Operation Manual** that collects all recommendations and specific measures to be adopted in M-30 Ring Road will be collected.
- **The suitability of the proposal must be proven, through the execution of a DRILL**, in which the scenario is approximated to the real situation generated by a cyberattack, the results are analyzed, opportunities for improvement are provided, and finally the described actions are implemented, without forgetting the need for training and information to the operators of all its content.

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# HYBRID DATA ASSESSMENT PACKAGE

- 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 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.**

- **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.

- In this Case study #5, the tool was tested to predict the evolution of traffic flow and distribution within a network, particularly in the face of extreme events such as **cyber-attack**. **It works together with the traffic module presented earlier.**

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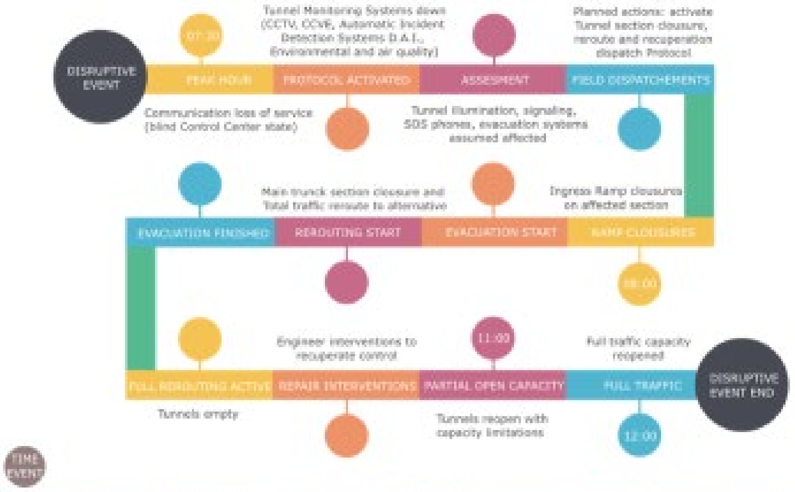
# HYBRID DATA ASSESSMENT PACKAGE

- TRAFFIC SIMULATIONS AFTER A CYBERATTACK EVENT

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# HYBRID DATA ASSESSMENT PACKAGE

- RESULTS

| # | capacity restriction | velocity |
|---|---|---|
| 1 | heavy | 70.0 |
| 2 | light | 70.0 |
| 3 | moderate | 70.0 |
| 4 | heavy | 50.0 |
| 5 | light | 50.0 |
| 6 | moderate | 50.0 |
| 7 | heavy | 30.0 |
| 8 | light | 30.0 |
| 9 | moderate | 30.0 |

*Figure 7.* **Action scenarios for this illustrative case study. In an actual setting, these possible scenarios are to be configured form the designer/operatory. It is reminded that the choice of number of lanes is here included**

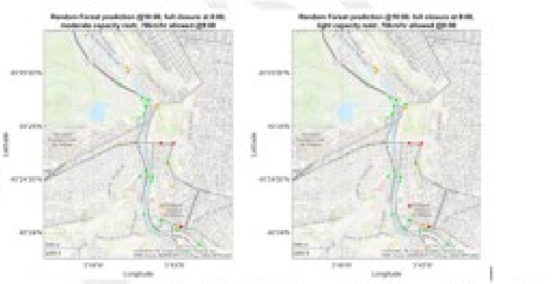


*Figure 8.* **RAG time annotation of traffic flow in terms of the index r[illegible], which quantifies the recovery of flow as compared against the traffic flow at closure time. In this plot we illustrate the effect of two separate actions scenarios, namely action set 3 versus action set 2, which relate to a change in the allowed capacity at partial 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**

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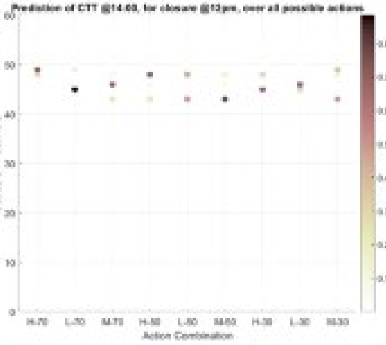
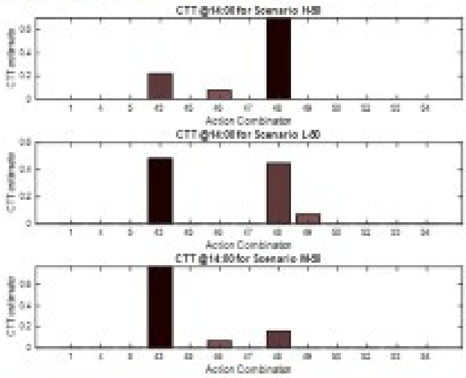
# HYBRID DATA ASSESSMENT PACKAGE

- RESULTS

We see for example that the lowest cost in this case would be achieved by a moderate capacity modification and imposition of a permissible speed limit of 50km/hr in the affected links, since this is the combination offering the most probably outcome for a relatively lower regularized travel time cost (CTT = 43).

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# HYBRID DATA ASSESSMENT PACKAGE

- USE AND ADDED VALUE FOR THE INFRASTRUCTURE'S MANAGER

Once the model is trained with data-derived information (e.g. SHM/traffic telemetry and more) and possibly with complementary data from available traffic simulations, it can be used to **predict the state of the system and to visualise the expected congestion under selection of a specific scenario of imposed flow restrictions (modifications).**

**INPUTS**

- **Traffic volume**
- **Closure time (hour)**
- **Flow speed at closure**
- **Location**
- **Nominal speed allowed on the link, as well as the number of lanes closed.**

**OUTPUTS**

- **Effects on traffic, congestion, in the face of the adoption of different alternatives, whether partial total cut-off or reduction in capacity**
- **Decision on the maximum required speed**
- **Incremental travel times.**
- **Possible impact on alternative routes in the event of diversion**

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# HYBRID DATA ASSESSMENT PACKAGE

- COMPARISON BETWEEN CURRENT TOOLS AND NEW TOOL

**This kind of study was never applied before.** It allows the simulation of the event, introducing the variables of all the critical elements of tunnel management.

It gives you **additional information to value the impact of partially or totally closing some lines or the whole section of the tunnels**.

**It allows you to predict how the traffic will be after a hazard and depending on how you manage it.**

It provides objectivity to decisions, which supports the result for third parties, specially for administrations. From a technical point of view, it allows you to combine variables and obtain results directly.

**The application of this tool can reduce the time of travel time, the traffic volume at a future time and the cost of travel time after a hazard event** (the impact in terms of cost or ROI is difficult to quantify, but it will surely have an important impact)

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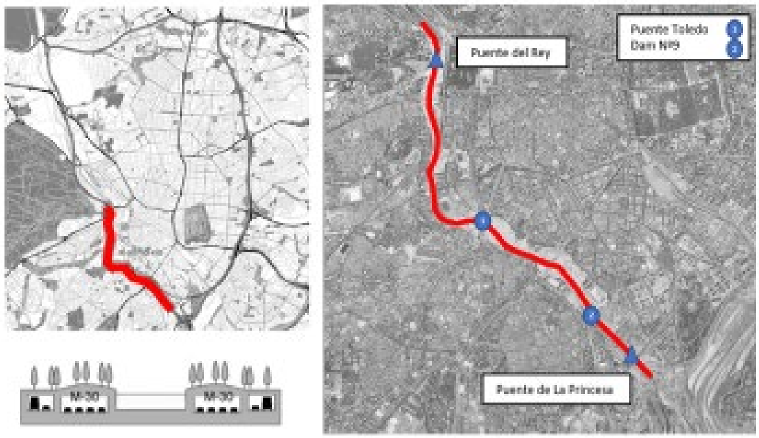
FORE SEE PROJECT

# FLOODING METHODOLOGY

- AREA OF STUDY:

The methodology has been applied to the M-30 motorway in Madrid to check its response against low frequency events at **two specific locations along the Manzanares River:**

- Upstream of "Puente de Toledo" (1)
- Upstream of Dam Nº9. (2)





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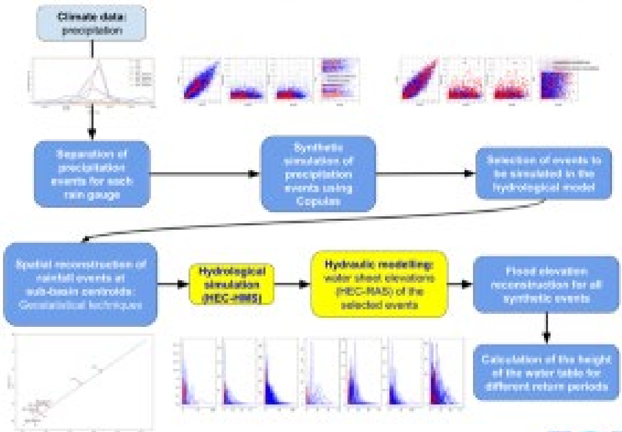
# FLOODING METHODOLOGY

- PROPOSED NOVEL METHODOLOGY (IH Cantabria) → ESTIMATION OF RETURN PERIODS OF FLOODING EVENTS.

1. hourly information on precipitation at the basin's stations.
2. characterize in detail the hyetograph corresponding to the storm events at each station.
3. simultaneously characterize the correlations between stations.
4. The stochastic generator is calibrated to reproduce the most important precipitation statistics at each station (mean rainfall, maximum rainfall, event duration, etc.).





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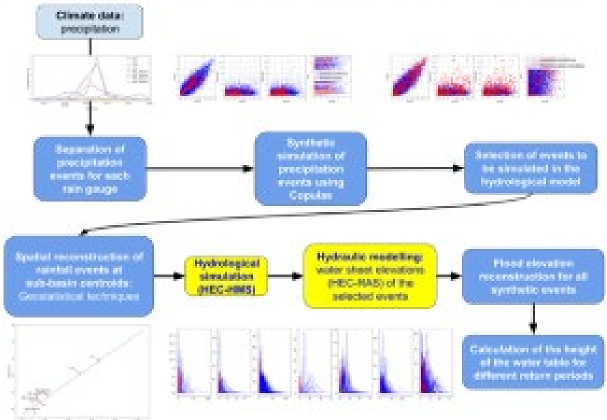
# FLOODING METHODOLOGY

- PROPOSED NOVEL METHODOLOGY (IH Cantabria) → ESTIMATION OF RETURN PERIODS OF FLOODING EVENTS.

5. The generator is 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
6. machine learning methods (statistical) are used to calculate the flood level and flow of the remaining cases.
7. Flood elevation reconstruction for all synthetic events
8. Calculation of the height of the water table for different return periods





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# FLOODING METHODOLOGY

- FINAL RETURN PERIOD

| HEC RAS XS | Left bank | Right bank | Min Height | Return Period |
|---|---|---|---|---|
| 6262 | 575.41 | 575.39 | 575.39 | 168 |
| 6282 | 575.47 | 575.46 | 575.46 | 179 |
| 6332 | 575.57 | 575.53 | 575.53 | 189 |
| 6382 | 575.65 | 575.64 | 575.64 | 209 |
| 6402 | 575.68 | 575.7 | 575.68 | 216 |
| 6432 | 575.77 | 575.78 | 575.77 | 239 |
| 6482 | 575.92 | 575.89 | 575.89 | 271 |
| 6502 | 575.98 | 575.96 | 575.96 | 289 |
| 6512 | 575.98 | 575.96 | 575.96 | 251 |
| 6532 | 576.01 | 575.98 | 575.98 | 254 |
| 6582 | 576.1 | 576.06 | 576.06 | 272 |
| 6632 | 576.18 | 576.16 | 576.16 | 301 |
| 6682 | 576.27 | 576.29 | 576.27 | 331 |
| 6732 | 576.33 | 576.39 | 576.33 | 345 |
| 6772 | 576.43 | 576.41 | 576.41 | 372 |
| 6782 | 576.46 | 576.42 | 576.42 | 373 |
| 6832 | 576.53 | 576.61 | 576.53 | 419 |
| 6882 | 576.64 | 576.68 | 576.64 | 463 |

*Table 7. Return periods for channel banks heights. Bridge sections*

Main Output: the height of the channel banks are built for return periods greater than the 100-year return period, therefore the probability of overtopping has low return periods, the infrastructure is well designed


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FORESEE PROJECT

# FLOODING METHODOLOGY

- CONCLUSIONS

The methodology requires **more computer resources and computational time** than methodologies based on the design storm, however, an **accurate and detailed flood study, and a sizing with adequate flow rates can avoid serious effects on the population during flooding episodes.**

The use of a small number of precipitation series can lead to an underestimation of the maximum flows that cause flooding and, in turn, to inadequate sizing; however, the generation of synthetic events by means of copulas makes it possible to cover the range of possible flows that cause flooding. **These flows are higher than those obtained by means of the usual methodologies, therefore, the obtained draughts would allow sizing on the safety side.**

It also happens that due to the great **uncertainty of the usual methodologies**, infrastructures are sized with low return periods. This means that in **increasingly frequent and more intense episodes caused by climate change, infrastructures may overflow, giving rise to situations of collective risk.**

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FORESEE PROJECT

# FLOODING METHODOLOGY

- COMPARISON BETWEEN CURRENT TOOLS AND NEW TOOL

✓ FORESEE flooding tool allows the creation of a better design for the infrastructure considering a new methodology that is **more accurate.**

✓ 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.**

✓ **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.**

✓ It will highly **reduce the maintenance cost** if a flooding event bigger than the calculated during the design phase is triggered

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FORESEE PROJECT

# CONCLUSIONS

- INTEREST FOR INFRASTRUCTURE MANAGEMENT: M30

✓ Understand the **impact** of major system disruptions on a critical infrastructure and **have Dynamic resilience schemes based on data.**

  ✓ **What would happen if there was a cyberattack on M30?** Analysis of impact time, behaviour of users and evolution of alerts.

  ✓ Quantify the **risk and cost** associated with the impact of eventualities on infrastructures

✓ Have an **efficient Action Plan and tools for emergencies: mitigation** such as a Decision Support System, optimization of emergency protocols and Guidelines on standards and recommendations to help **make agile decisions**

✓ **Improve awareness, response and recovery time** by implementing predictive and real- time tools to **gain back control of the Infrastructure** and mitigate consequences for final users

✓ Understand how to reduce the impact on Traffic and possible outcomes

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# CONCLUSIONS

- INTEREST FOR FERROVIAL CONSTRUCTION

✓ This tools help Ferrovial Group, as an end-to-end infrastructure provider, **understand and mitigate possible threats of different nature** that can occur **during the whole lifecycle of infrastructures**, from decision and policy making, funding, design, construction and operation and maintenance.

✓ We will be able to optimize the way we design and build infrastructures to be more efficient, moving towards a performance-based risk assessment framework that will warranty clients and citizens use **safer, resilient and sustainable assets.**

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