49th ASECAP DAYS

Decarbonizing Road Infrastructure : Challenges, Perspectives and Actions in Tough Economy

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IMPROVING RESILIENCE OF TRANSPORT INFRASTRUCTURES: THE EUROPEAN-FUNDED PROJECT FORESEE

Livia Pardi

e-mail: lpardi@autostrade.it

Autostrade per l’Italia

autostrade || per l’italia

Improving resilience of transport infrastructures: the European-funded project FORESEE

Co-authored by:

- ✓ Livia Pardi, Project Manager Dept. for Maintenance Engineering, Autostrade per l'Italia, Italy
- ✓ Federico di Gennaro, Head of Strategic Projects, Aiscat Servizi, Italy
- ✓ Bryan T. Adey, Professor for Infrastructure Management, ETH Zürich, Switzerland
- ✓ Clemente Fuggini, Head of Research & Innovation RINA, Italy
- ✓ Iñaki Beltran-Hernando, Project Manager, Tecnalia, Spain

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The European-funded project FORESEE (2018-2022)

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Mobility as a service

FORESEE

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

The functioning of society depends on the transportation of goods and people and the infrastructure is designed, built and **operated to provide the required levels of service throughout its lifetime.**

As reductions in service due to potentially disruptive events can have significant societal and economic consequences, it is important for infrastructure managers to have:

- ✓ a clear idea of the service the infrastructure is providing;
- ✓ an understanding of its resilience and how it can be modified to counteract the loss of service following an event and to provide specific levels of service during and after the occurrence of extreme events.

Objectives

1. Offer support in the management and mitigation of events that affect the transport network and its components:
   - ✓ extreme weather events (floods, landslides, heavy rains, heavy snowfalls, ...)
   - ✓ man-made hazards.
2. Provide efficient and reliable tools, also from an economic point of view, to improve the resilience of transport infrastructures, in order to reduce the extent and/or duration of the impacts of an event and increase the recovery capacity of the system.
3. Demonstrate through a cost-benefit analysis a positive return associated with the investments in resilience during the entire life cycle of the infrastructure.

https://foreseeproject.eu

Resilience: No fashion

Proposal on Union guidelines for the development of the TEN-T network (COM(2021) 812 final)

At EU Level

These aspects have gained such importance that, in the Proposal on Union guidelines for the development of the TEN-T network (COM(2021) 812 final), the European Commission has required for transport infrastructure:

- ✓ to provide safe and secure mobility;
- ✓ to improve its resilience to climate change, natural and man-made hazards since the planning phase;
- ✓ to be maintained to offer the same level of service and safety during its lifetime.

EUROPEAN COMMISSION

Strasbourg, 14.12.2021
COM(2021) 812 final

2021/0420 (COD)

Proposal for a

REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on Union guidelines for the development of the trans-European transport network, amending Regulation (EU) 2021/1153 and Regulation (EU) No 913/2010 and repealing Regulation (EU) 1315/2013

(Text with EEA relevance)

{SEC(2021) 435 final} - {SWD(2021) 471 final} - {SWD(2021) 472 final} - {SWD(2021) 473 final}

EN

CHAPTER IV-*PROVISIONS FOR SMART AND RESILIENT TRANSPORT*
Article 45-Safe and secure infrastructure
Article 46-Resilience of infrastructure
Article 48-Maintenance and project life cycle

Guidelines for risk classification & management, safety assessment & monitoring of existing bridges (D.M. 240/2022)

In Italy

The procedure is based on a multi-risk (structural and foundational, seismic, landslide and hydraulic) and multi-level approach (1-5), with successive more and more detailed levels of assessment.

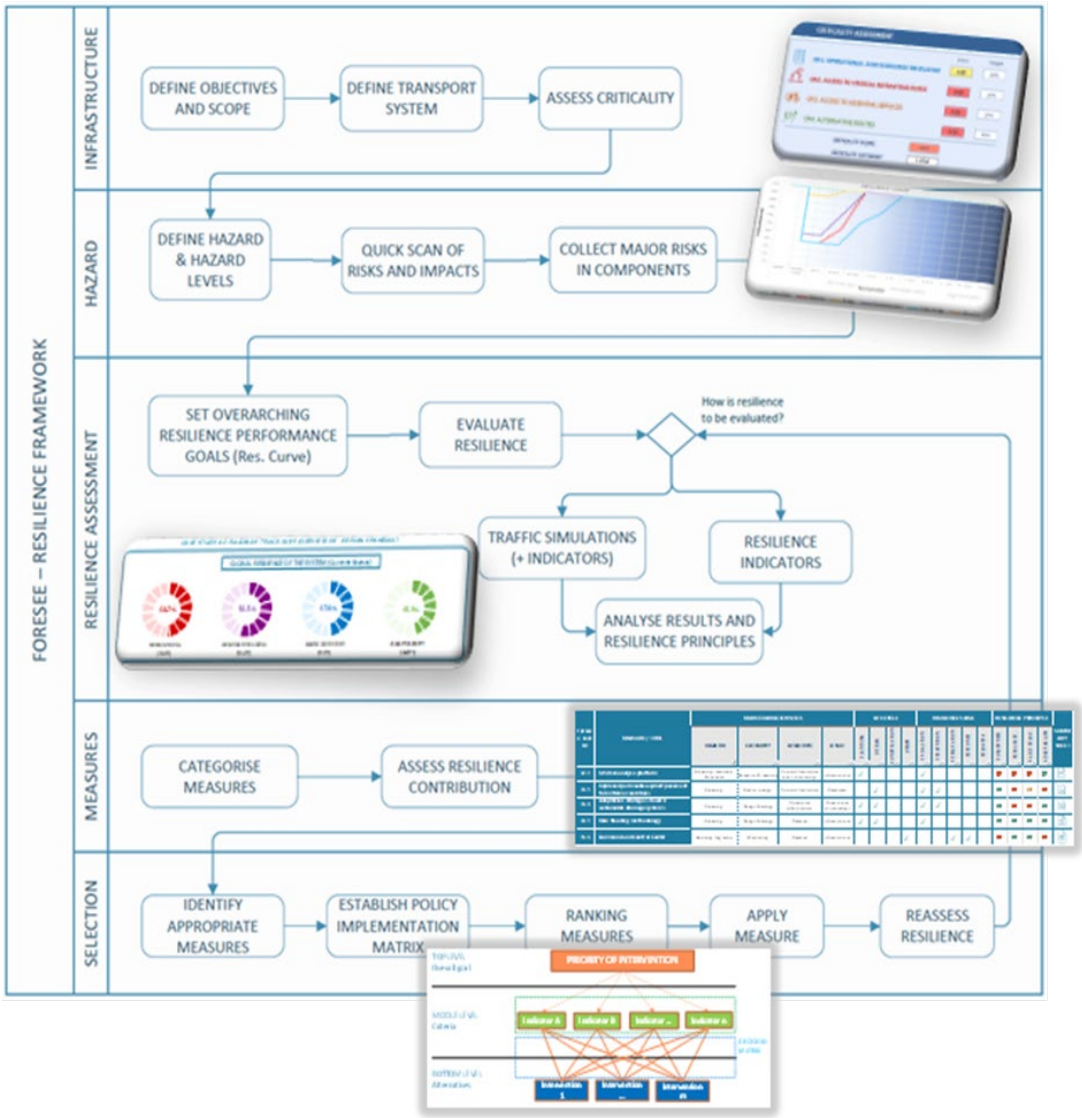
Resilience is specifically mentioned at Level 5, for those bridges considered to be of significant importance within the network, to assess their transport relevance.

Ministero delle Infrastrutture e della Mobilità Sostenibili
Consiglio Superiore dei Lavori Pubblici

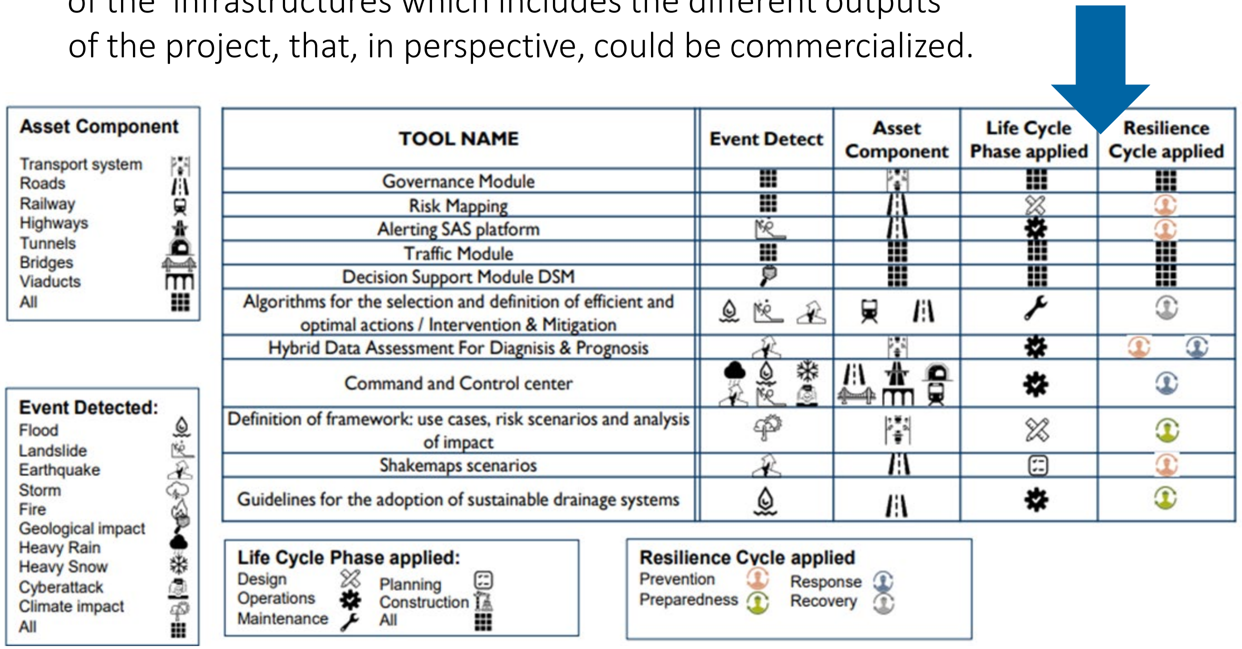
LINEE GUIDA PER
LA CLASSIFICAZIONE E GESTIONE DEL RISCHIO,
LA VALUTAZIONE DELLA SICUREZZA
ED IL MONITORAGGIO DEI PONTI ESISTENTI

Allegate al parere del Consiglio Superiore dei Lavori Pubblici n. 54/2022,
espresso dall'Assemblea Generale in data 10.06.2022.

Improving resilience of transport infrastructures: FORESEE flowchart



1) Development of a **harmonized methodology for assessing** the level of service and resilience of the networks and/or its components.
2) Modelling of the various risk scenarios, also for forecasting and alert management purposes.
3) Definition of **strategies and "adaptive" systems for the mitigation** of risks and their consequences in the short-long term (protocols for the management of emergencies in order to ensure mobility during an event and/or strategies for surveillance, monitoring and preventive maintenance).
4) Integration in a **toolkit**, a **multifunctional software** dedicated to the management of the infrastructures which includes the different outputs of the project, that, in perspective, could be commercialized.



Maintain high levels of service, safety and comfort

Improving resilience of transport infrastructures

Resilience performance-based approach to complement the current performance-based approach

Life Cycle
- Design & Construction
- Operation
- Traffic management & Emergency
- Maintenance & Upgrading

System
- Network
- Infrastructure
- Section
- Elements (bridges, tunnels, barriers, pavements,…)
- Subcomponents

Features
- Service life
- Deterioration mechanisms
- Surveillance & monitoring
- Maintenance intervention (type & duration & efficacy)

Stakeholders
- Infrastructure managers & operators (public, private, local, national…, internal organization,…)
- Demand
- Other Stakeholders

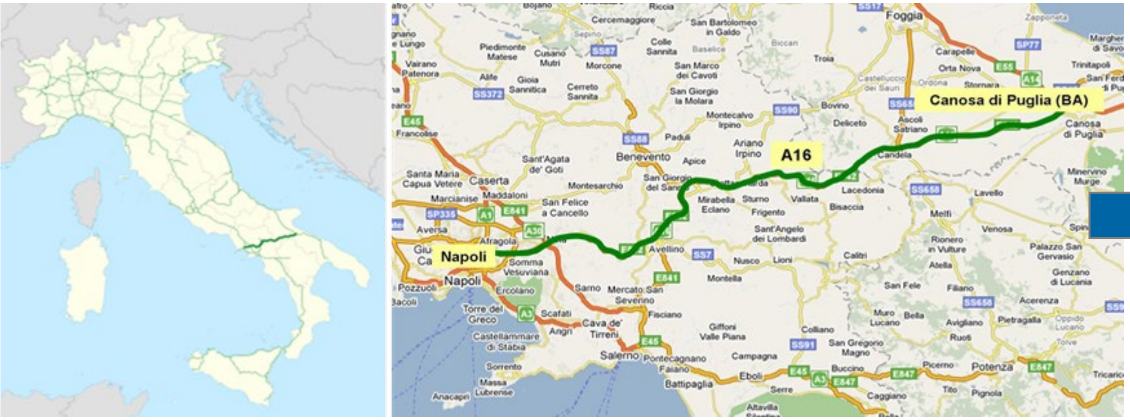
Events
- Manmade (cyber attack)
- Traffic & accidents
- Weather
- Natural (earthquakes, landslides,..)

- ✓ To understand and improve the performance of the network, face to any type of risk.
- ✓ To assess the criticality of the transport system and set resilience goals accordingly.
- ✓ To assess the resilience of the system using a wide variety of indicators.
- ✓ To analyze, define and classify potential interventions from a resilience perspective (i. e. reinforcement interventions, monitoring measures and organizational measures).
- ✓ To classify interventions in terms of greater resilience.

While
- ✓ In compliance with the risk strategies, objectives and management procedures of the organizations.
- ✓ Incorporating different parameters and data sources, at different steps in the life cycle.
- ✓ With cost efficient optimization of intervention programmes.

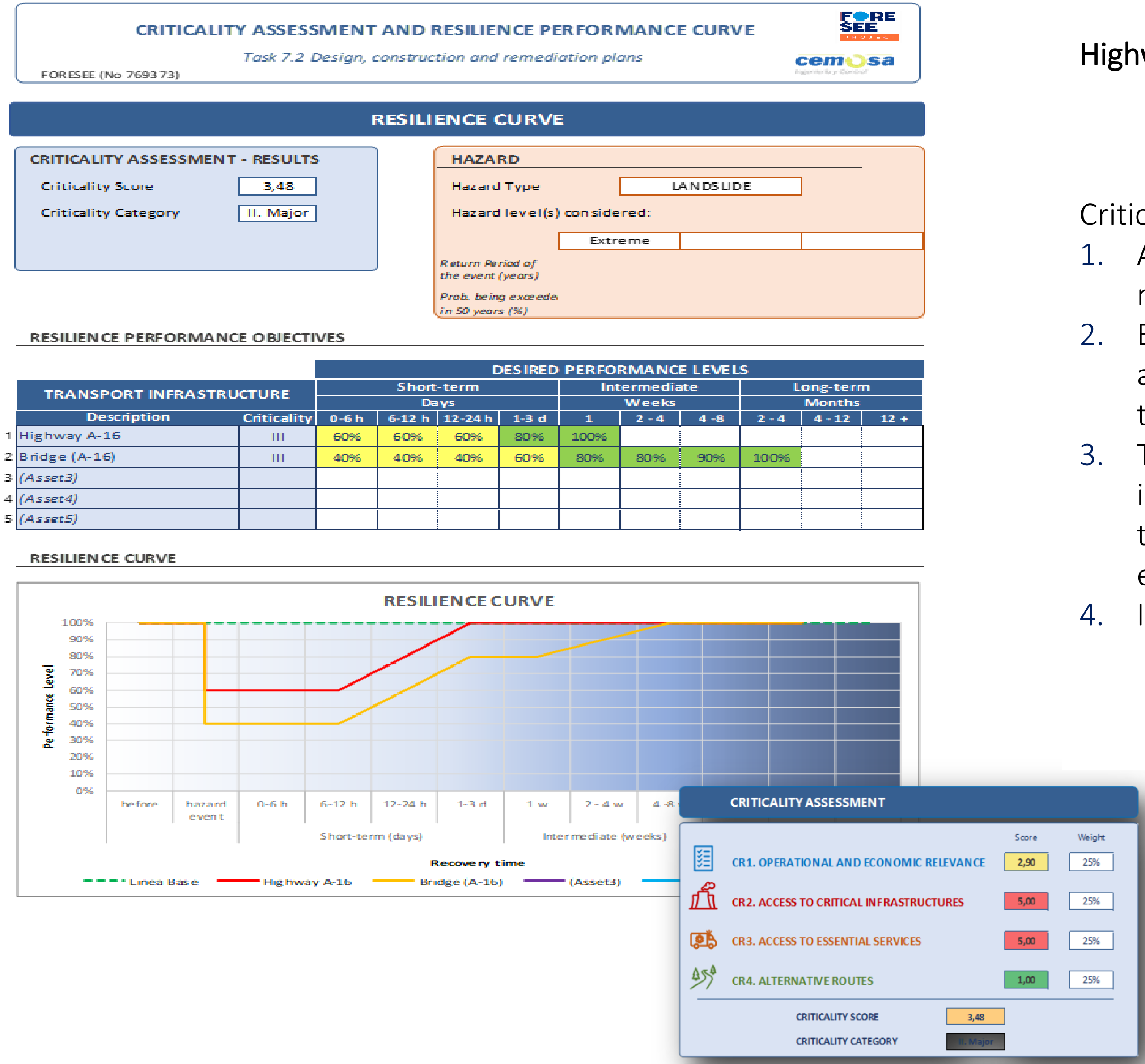
Improving resilience of transport infrastructures: Validation

	Case Study	Partner	Event/risk
#1	A24-km. 52-73 Carsoli-Torano (IT)	AISCAT	Environmental risks (earthquakes, snow)
#2	A16-km. 80-110 (IT)	ASPI	Hydrological risk (landslides)
#3	Montabliz Viaduct (ES)	Universidad Cantabria	Environmental risks(wind, snow) Accidents Fire
#4	Railway track 6185 Hannover- Berli (DE)	Ingenieurgesellschaft Für Verkehrsund Eisenbahnwesen	Flooding
#5	M-30 ring road in Madrid (ES)	Ferrovial	Flooding Cybersecurity
#6	25th April Suspended Bridge (PT)	Infraestruturas de Portugal	Environmental risks(earthquake) Accidents



1. The A16 runs from Naples to Bari along the TEN-T core network Corridor n.5 Scandinavian – Mediterranean. In the area to be investigated (km 80 to km 110) are present a total of 20 bridges (for a total length of around 3 km).
2. These bridges, generally with a simply supported structural scheme with beams and cross beams in prestressed post-tensioned concrete, are representative of a wide population of structures across Italy in similar conditions of environmental attack and hydrogeological risk.
3. **Aim of the demonstration: understanding how to increase the efficiency and efficacy of the service offered to customers in terms of safety, functionality and mobility.**

Is the infrastructure critical?



Highways = "critical infrastructures":

- ✓for daily mobility of persons and goods (as on TEN-T network),
- ✓for rescue or emergency operations.

Criticality Assessment and Resilience Performance Tool.

1. Assessment of **"criticality"** = the importance of the infrastructure for maintaining its social and economic functions.
2. Evaluation of resilience curves of the asset, in function of the hazard to be analyzed, its threshold for each hazard level (routine, design and extreme) and the desired performance objectives.
3. The tool allows for a simple visualization of resilience targets for each infrastructure being considered to highlight among different assets which are the most challenging in terms of resilience and therefore where to focus efforts.
4. It also allows to identify whether it is needed to focus:
   - ✓ on designing for strengthening the robustness of the system (minimizing service drop);
   - ✓ on strengthening the capacity to recover (speeding the recovery period).

CEN-CWA 17819/2021: result of the activities carried out in FORESEE

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Question

Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events (CWA 17819/2021)

1) Complete & systematic definition of the service level.
2) Measure of resilience.
3) Identification of the appropriate interventions to increase the levels of service and resilience.

- ✓ How can the resilience of a network be modified to counteract the loss of service following a hazard?
- ✓ How can specified levels of service be provided during and following the occurrence of extreme events?

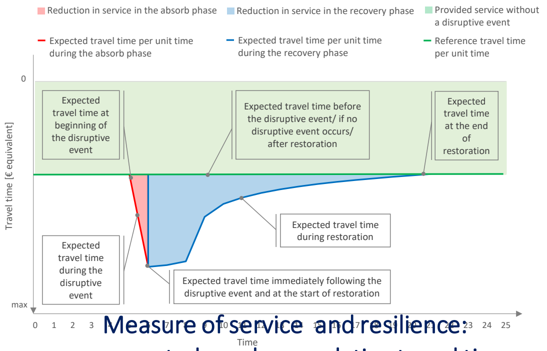
CEN-CWA 17819

- ✓ Reference document for the national CEN committees.
- ✓ It remains valid for 6 years and can be converted to the European standard.

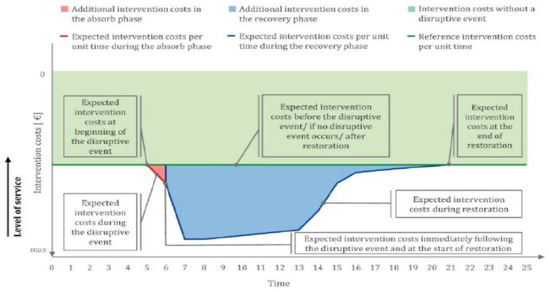
Scope

Understand how the level of service offered to users can be modified by the occurrence of natural and human events (hazard) and how negative impacts can be reduced (in terms of costs, extent and time) through the application of the concept of resilience, declined for the case of infrastructures and its elements (physical, organizational and environmental), in relation to specific risks.

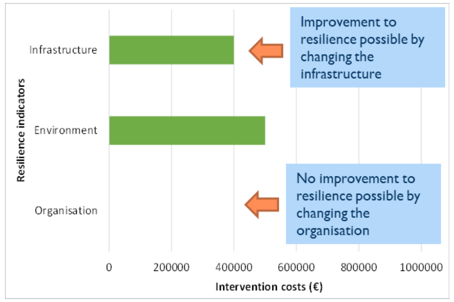
To be used by any organization that is interested in measuring resilience regardless of size or extent of infrastructure, in all situations with which the infrastructure manager is confronted, not only in the operation of the infrastructure, but since the planning stage.



Measure of service and resilience: expected yearly cumulative travel time



Measure of service and resilience in terms of intervention costs



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

Tools to be applied

Tools Descrip.	KRI
Resilience Guidelines to measure Level of Service & Resilience	L1-Infrastructure L2 Environment L3 Organization
Set Targets	L1-Infrastructure L2 Environment L3 Organization
Risk Mapping tool	1.3.2, 3.1.1, 3.1.2
Virtual modelling Platform	1.3.2, 3.1.1, 3.1.2
Alerting SAS platform	1.3.2, 3.1.1, 3.1.2
Fragility and Vulnerability Analysis & Decision Support Module	3.1.1, 3.1.2
Design, construction and remediation plans	3.1.2, 3.1.3
Operational and maintenance plans	3.1.2, 3.1.3, 3.2.4, 3.2.5, 3.2.6

Each tool is described in terms of:

- ✓ Main characteristics: location, hazard, asset and life cycle phase.
- ✓ Resilience stage: pro-action, preventative, preparation, response, recovery.
- ✓ Related performance indicators: robustness, resourcefulness, rapid recovery, adaptability.
- ✓ Related resilience indicator as in CWA (i.e. pre or post event measures, organization, environment, infrastructure).

SHM BIM BASED ALERTING SAS PLATFORM

Task	T2.5	Leader	TPZ UK	Deliverable(s)	D2.9
Name					
SHM BIM BASED ALERTING SAS PLATFORM					
Description					
This tool generat RAG (Red-Amber-Green) alerts over infrastructures by comparing observed motion against threshold failure values. The tool ingest: (i) Motion data from satellites (from PSI technique), (ii) Predicted landslides failure points (from D2.8), (iii) In-situ sensors measurements and (iv) Critical threshold asset failure values. The output is a table with the raised alerts and a 3D visualisation of the infrastructure BIM RAG-coloured showing the alerts values.					

MAIN CHARACTERISTICS

Category	Monitoring
Location	On the infrastructure and surroundings
Asset	The whole asset
Hazard	Landslides and other sources of displacement
Life-cycle phase	Operation and Maintenance

RESILIENCE

Resilience Stage

Pro-action	Preventive	Preparation	Response	Recovery
x	x	x		

Resilience-Principle Performance

Performance Indicator Related	Score	
Robustness	2	
Resourcefulness	3	
Rapid Recovery	1	
Adaptability	0	

WP1 Resilience indicator related

Indicator	Category	Part
Direct: Presence/age warning system	Protection measures	Infrastructure
Direct: Presence of a monitoring strategy	Pre-event measures	Organizational
Indirect: Condition state of infrastructure	Condition State	Infrastructure
Indirect: Expected condition state of infrastructure	Condition State	Infrastructure
Indirect: extent of past damages	Physical	Environment
Indirect: severity of past damages	Physical	Environment
Indirect: expected frequency of future hazard	Physical	Environment
Indirect: expected severity of future hazard	Physical	Environment

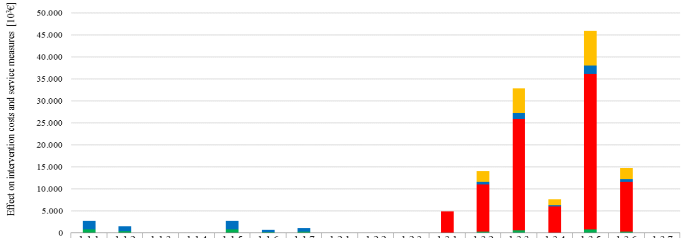
Application of the guidelines on the A16

Measures of resilience for each indicator, using the actual value of all indicators, by intervention costs and each measure of service

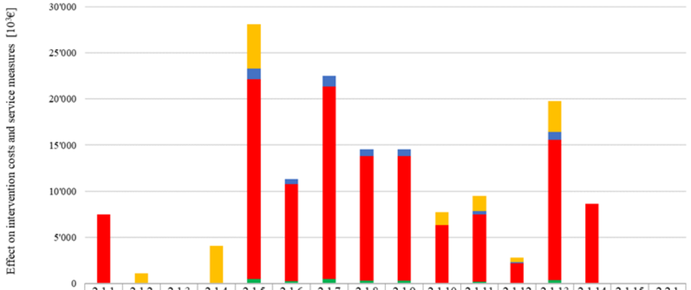
- ✓ 42 indicators to represent the highway section
- ✓ Identification of areas/parameters on which to focus actions.

Steps of the procedure:

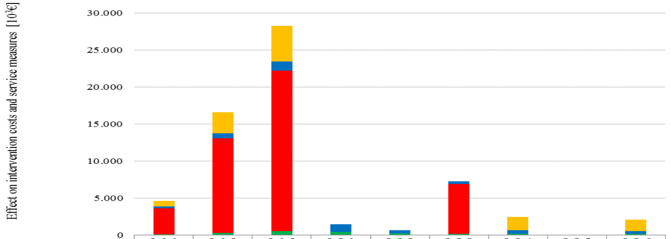
1. Identify the elements/parts of the infrastructure, relevant to the determination of resilience.
2. Choose indicators to describe the system and measure the level of service and resilience.
3. Choose the measurement mode: by means of simulations, indicators with differentiated weights, indicators with equal weights.
4. Once the measurement has been made according to the chosen method, evaluate the percentage of completion/distance from a "target" value.
5. The "actions to be taken" are identified through a cost/benefit analysis.



	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.6	1.1.7	1.2.1	1.2.2	1.2.3	1.3.1	1.3.2	1.3.3	1.3.4	1.3.5	1.3.6	1.3.7
Intervention	0	0	0	0	0	0	0	0	0	0	0	2.408	5.635	1.314	7.866	2.528	0
Travel time	1.931	1.040	0	0	1.961	520	802	0	0	0	0	594	1.390	324	1.940	624	0
Safety	0	0	0	0	0	0	0	0	0	0	4.758	10.800	25.272	5.894	35.280	11.340	0
Socio-economic	819	441	0	0	832	221	340	0	0	0	111	252	590	138	823	265	0



	2.1.1	2.1.2	2.1.3	2.1.4	2.1.5	2.1.6	2.1.7	2.1.8	2.1.9	2.1.10	2.1.11	2.1.12	2.1.13	2.1.14	2.1.15	2.2.1
Intervention	0	1'122	0	4'069	4'816	0	0	0	0	1'412	1'625	482	3'390	0	0	0
Travel time	0	0	0	0	1'188	578	1'148	743	743	0	401	119	836	0	0	0
Safety	7'462	0	0	0	21'600	10'517	20'880	13'500	13'500	6'333	7'290	2'160	15'204	8'640	0	0
Socio-Economic	0	0	0	0	504	245	487	315	315	0	170	50	355	0	0	0



	3.1.1	3.1.2	3.1.3	3.2.1	3.2.2	3.2.3	3.2.4	3.2.5	3.2.6
Intervention	794	2.844	4.847	0	0	0	1.806	0	1.525
Travel time	196	701	1.196	1.010	468	371	446	0	376
Safety	3.561	12.754	21.738	0	0	6.750	0	0	0
Socio-Economic	83	298	507	428	199	158	189	0	160

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

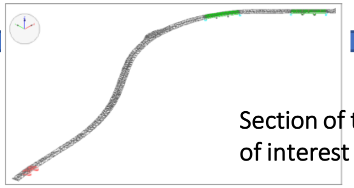
- 2.1.5 Hazard zone
- 2.1.6 Frequency of past hazards
- 2.1.7 Severity of past hazards
- 2.1.13 Frequency of past hazards

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

Risk Mapping tool | Virtual modelling Platform | Alerting SAS platform

SHM BIM based alerting SAS platform



Section of the BIM used over the area of interest on A16

Timely warning of potential events with a positive impact on mobility and safety

- ✓ Georeferenced representation of the territory and infrastructure.
- ✓ Internet based application.
- ✓ Integration of different sources of data, with different rates of acquisition.
- ✓ Movements of the ground coupled with infrastructure's displacements.
- ✓ Structural geometrical model (infrastructure and its elements).
- ✓ Alerts thresholds based on structural considerations, for both maintenance and emergency situations.
- ✓ Alerts thresholds for landslide motion.
- ✓ GIS-based risk analysis platform generating prioritized ranked site/asset risk maps to identify strategic areas where to implement measures.

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.

Location of the GNSS over the two bridges In A16

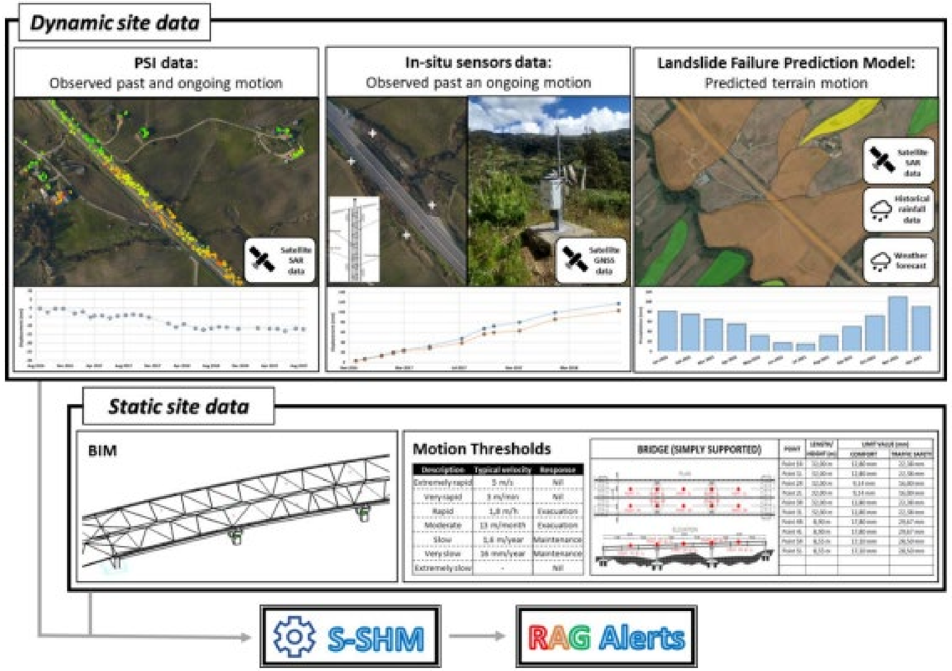
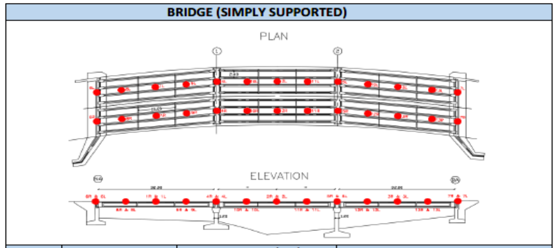


Figure 4-8 Time series of the PSI measurement point over on the BIM element *fme-gen-348b8f33-ec22-4a83-bef1-3ef117479c59*, which is located in Leone bridge, near the control parameter 2L.

Velocity class	Description	Velocity (mm/s)	Typical velocity	Response
7	Extremely rapid	5,000	5 m/s	Nil
6	Very rapid	50	3 m/min	Nil
5	Rapid	0.5	1,8 m/h	Evacuation
4	Moderate	0.005	13 m/month	Evacuation
3	Slow	0.00005	1,6 m/year	Maintenance
2	Very slow	0.0000005	16 mm/year	Maintenance
1	Extremely slow	-	-	Nil

Theoretical range of velocities over the highways and surroundings

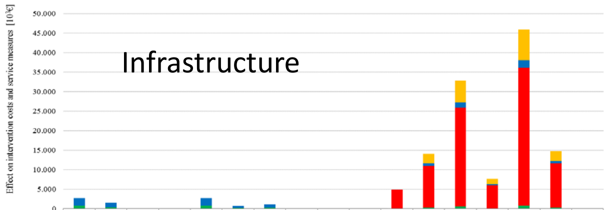
VERTICAL DISPLACEMENT IN CENTER OF SPAN					
Simply supported (one span)		Simply supported (several spans)			
		Side span		Center span	
Comfort	Traffic safety	Comfort	Traffic safety	Comfort	Traffic safety
$\frac{L}{1750}$	$\frac{L}{1000}$	$\frac{L}{2500}$	$\frac{L}{1430}$	$\frac{L}{3500}$	$\frac{L}{2000}$



POINT	LENGTH/HEIGHT (m)	LIMIT VALUE (mm)		COMMENTS
		COMFORT	TRAFFIC SAFETY	
Point 1R	32.00 m	12.80 mm	22.38 mm	Vertical displacement in the center of span
Point 1L	32.00 m	12.80 mm	22.38 mm	Vertical displacement in the center of span
Point 2R	32.00 m	9.14 mm	16.00 mm	Vertical displacement in the center of span
Point 2L	32.00 m	9.14 mm	16.00 mm	Vertical displacement in the center of span
Point 3R	32.00 m	12.80 mm	22.38 mm	Vertical displacement in the center of span

Theoretical values and control points for the bridge

Expected impact after application



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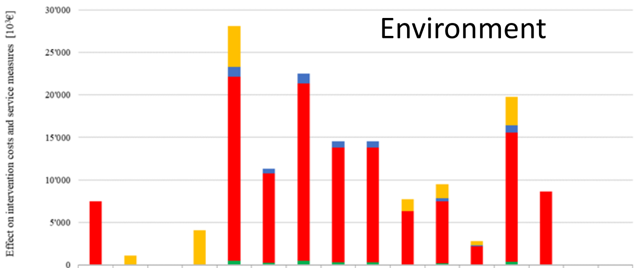

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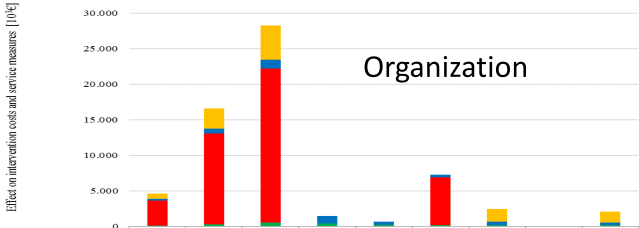

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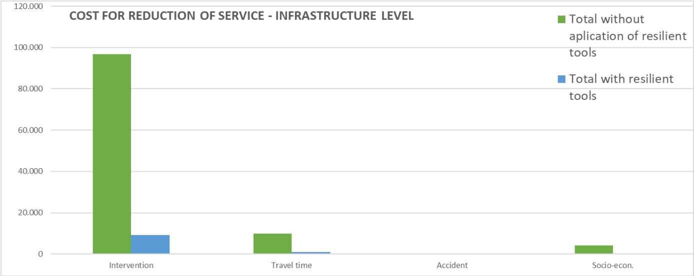
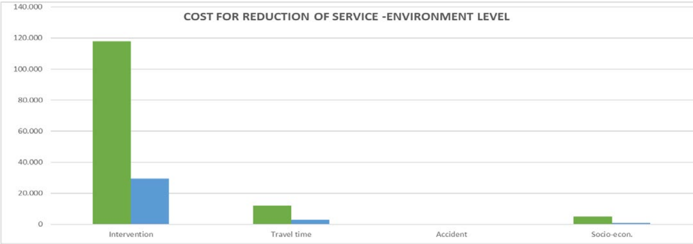
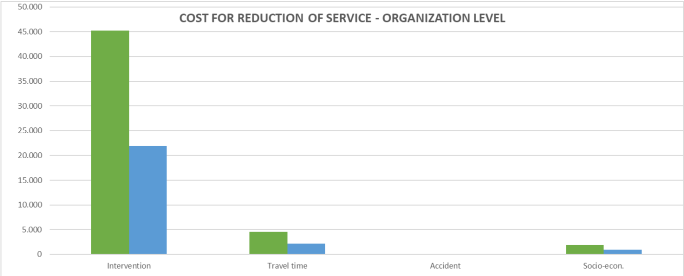
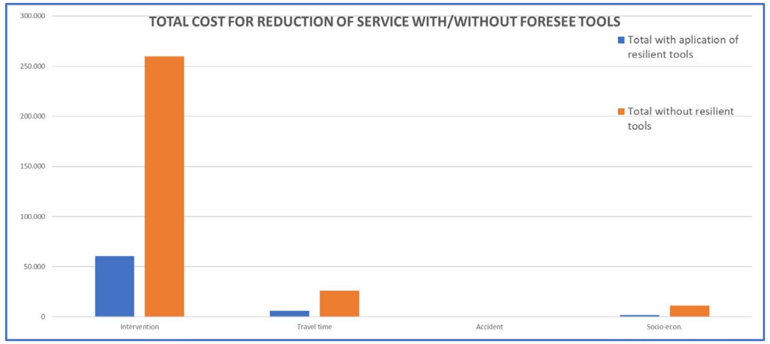








In the hypothesis of a major event impacting on the infrastructure (data from WP1) as a result of the application of the proposed tools.

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

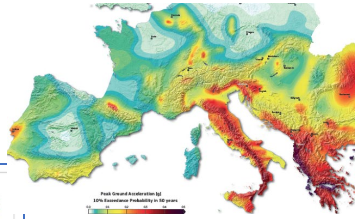
Fragility and Vulnerability Analysis & Decision Support Module TOOL

Tools Descrip.	KRI
Resilience Guidelines to measure Level of Service & Resilience	L1-Infrastructure L2 Environment L3 Organization
Set Targets	L1-Infrastructure L2 Environment L3 Organization
Risk Mapping tool	1.3.2, 3.1.1, 3.1.2
Virtual modelling Platform	1.3.2, 3.1.1, 3.1.2
Alerting SAS platform	1.3.2, 3.1.1, 3.1.2
Fragility and Vulnerability Analysis & Decision Support Module	**3.1.1, 3.1.2**
Design, construction and remediation plans	3.1.2, 3.1.3
Operational and maintenance plans	3.1.2, 3.1.3, 3.2.4, 3.2.5, 3.2.6

Methodology steps:

- ✓ Network characterization (layout, assets description through geometrical and mechanical parameters, traffic parameters for transport assessment)

- ✓ Hazard description through curves or georeferenced maps



- ✓ Risk, Vulnerability and Loss assessment

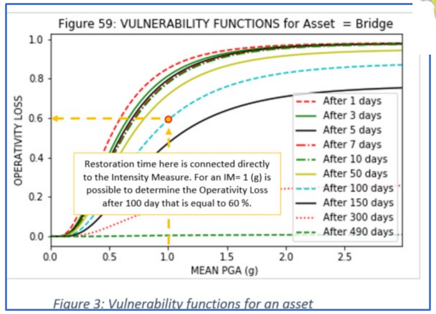


Figure 3: Vulnerability functions for an asset

- ✓ Resilience assessment at the Asset and Network Level

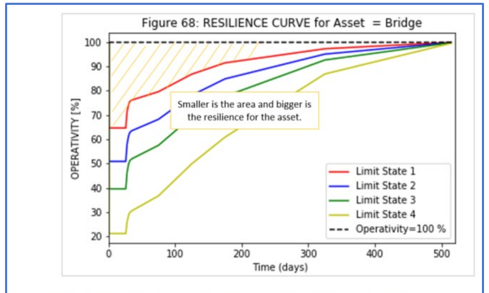


Figure 8: resilience estimation of the different assets of the network

Fragility and Vulnerability Analysis & Decision Support Module (I & II Case Studies)

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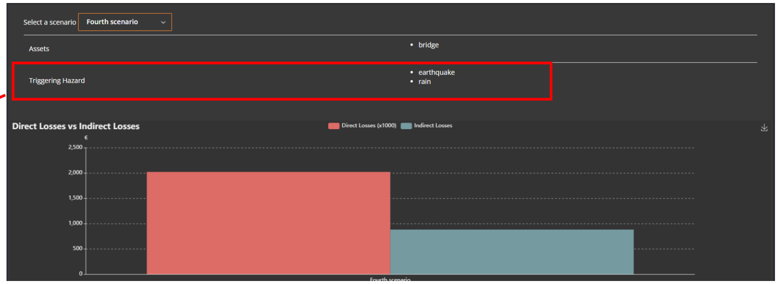
TOOLs OUTPUTS:

- ✓ Direct Losses (Economic losses derived from structural damages)
- ✓ Indirect Losses (Economic losses induced by service interruption)
- ✓ Resilience Assessment (description of the infrastructure recovery phase day per day after the event occurrence and Resilience assessment for each section of the network)
- ✓ Level of Service (description of the infrastructure Level Of Service before and after the event)

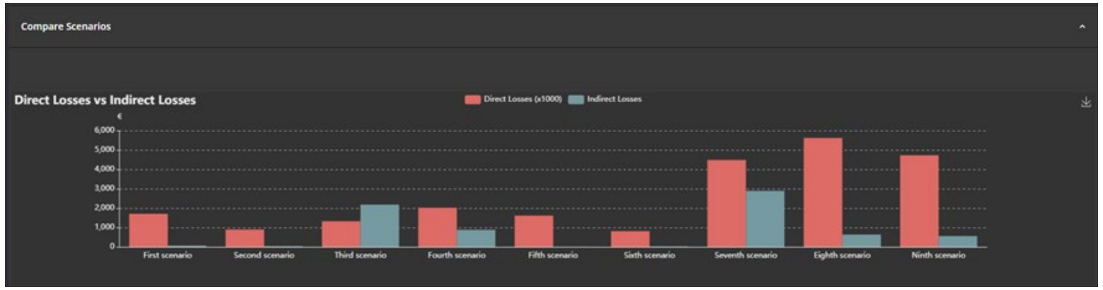
From FORESEE Toolkit

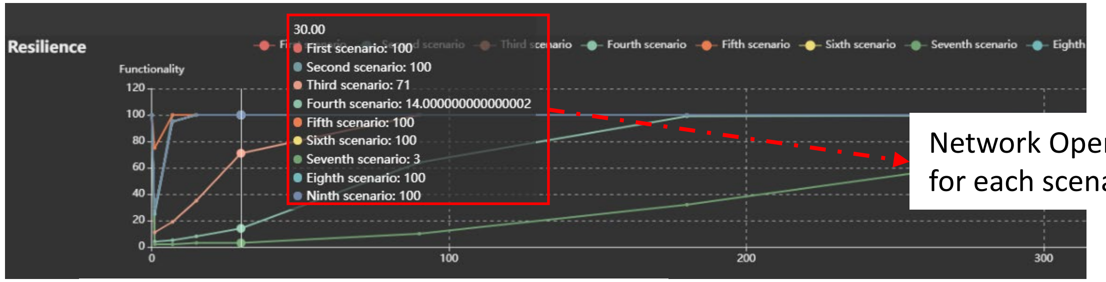


Scenario description

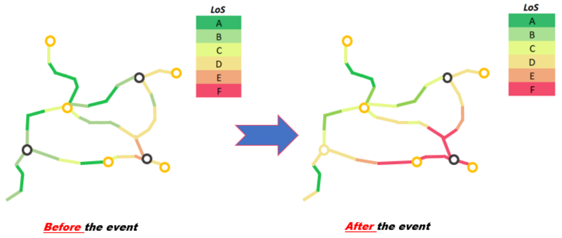
1 scenario

all scenarios





Network Operativity for each scenario



Methodology for prioritizing resilience-enhancing measures: decision making

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.

Based on Analytic Hierarchical Process (AHP) theory: systematic engineering method transforming qualitative analysis into quantitative analysis.

HIERARCHICAL MODEL

TOP LEVEL

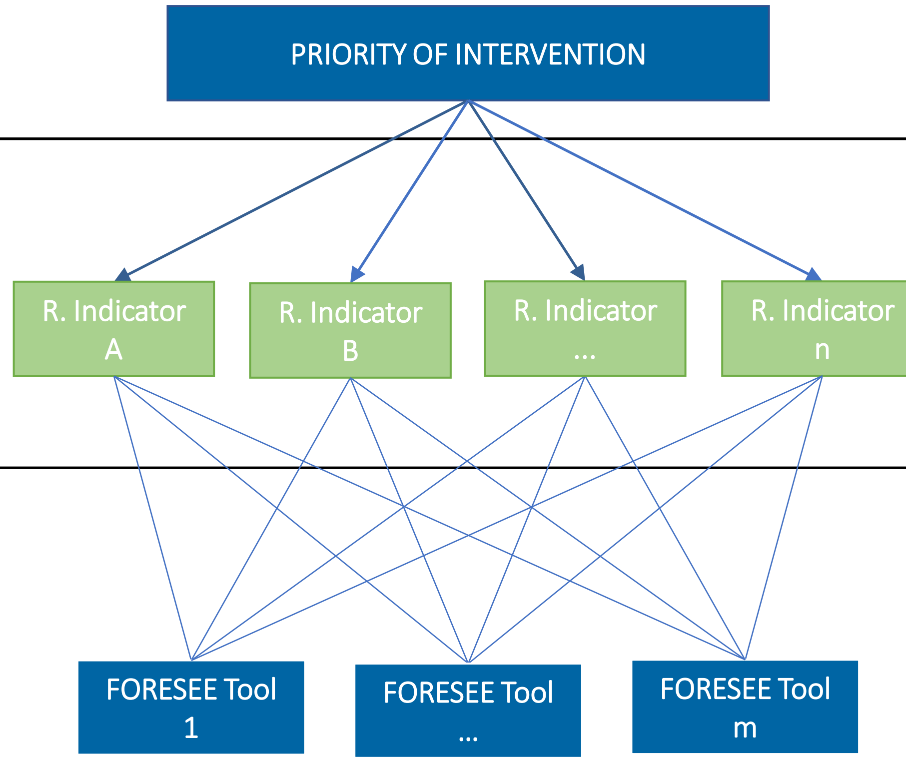
Overall goal: to determine the optimal interventions in terms of increased resilience.

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.



Conclusions

The **different** tools may be used separately or as a whole (toolkit) **to improve asset management** (i. e identifying the areas where to focus attention, new monitoring systems, new Internet-based alert system, novel network representation via GIS/BIM, fragility and vulnerability analysis), or **to concentrate economic effort to increase service and resilience** for design, maintenance and operation purposes.

Impact on infrastructure's management

- ✓ The **guidelines and methodology** allow to provide a unique measure, also toward the other stakeholders, and a tool for governance to understand actions to take and where to improve service and reduce negative impact.
- ✓ The use of a **comprehensive tool**, covering, different sources of data and functions, allows an integrated control "in real time" of the infrastructure and its elements both in terms of maintenance and traffic conditions.
- ✓ The **timely warning of potential events** has a positive impact on mobility and safety and the identification of warning thresholds, based on the displacements that the infrastructure is able to undergo will be much more reliable, thus increasing resilience of the infrastructure.

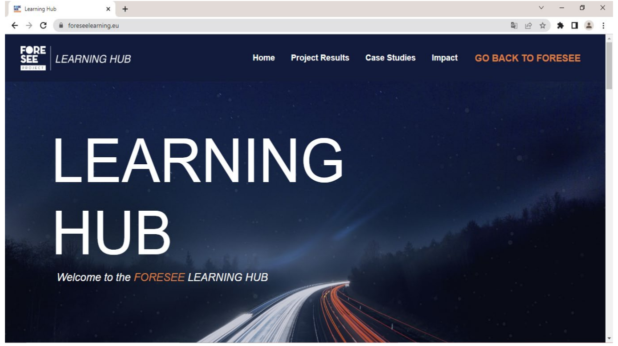
Impact on day-to-day business

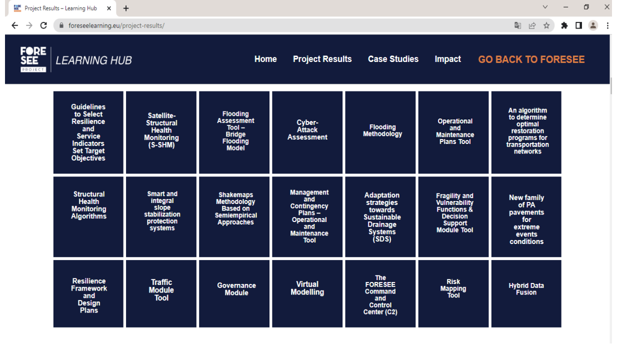
- ✓ Optimized use of economic resources.
- ✓ Increased efficacy of maintenance inventions.
- ✓ Reduced impact of traffic flow due to the reduction in the number of subsequent interventions.
- ✓ Reduced impact on mobility for emergency situations.

Some references

H2020 FORESEE Project Partner (www.foreseeproject.eu)

FORESEE Learning Hub (project results) https://foreseelearning.eu/





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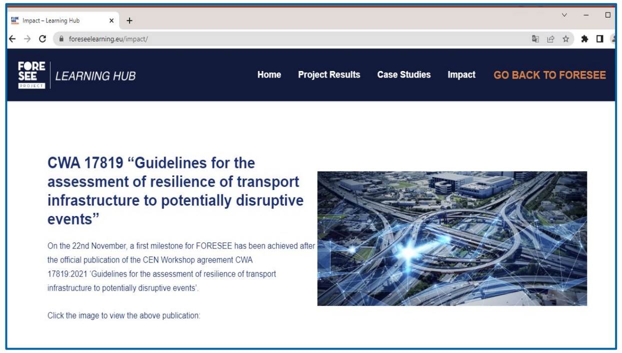
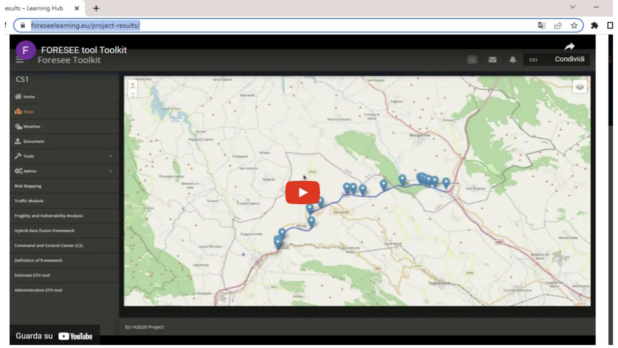
- ✓ https://foreseelearning.eu/impact/
- ✓ https://www.cencenelec.eu/news-and-events/news/2021/eninthespotlight/2021-11-22-infrastructure-systems-resilience/



FORESEE toolkit
https://foreseelearning.eu/project-results



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THANK YOU FOR YOUR ATTENTION

Livia Pardi
Autostrade per l’Italia
Via A. Bergamini 50, 00159 Rome, Italy
e-mail: lpardi@autostrade.it
mob.: +39 335 1052247