- FORESEE -

Future proofing strategies FOr RESilient transport networks against Extreme Events

– Deliverable 6.7 –

PT Case Study #6
25 de Abril Bridge (Lisbon)

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	Participant Legal Name	Country
1	FUNDACION TECNALIA RESEARCH & INNOVATION (TEC)	Spain
2	RINA CONSULTING SPA (RINA-C)	Italy
3	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. (FRAUNHOFER)	Germany
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8	CENTRO DE ESTUDIOS DE MATERIALES Y CONTROL DE OBRA SA (CEMOSA)	Spain
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17	THE UNIVERSITY OF EDINBURGH (UEDIN)	United Kingdom
18	Ingenieurgesellschaft für Verkehrs- und Eisenbahnwesen mbH (IVE)	Germany

Author's list		
André Costa	IP	andre.costa@infraestruturasdeportugal.pt
Francisco Godinho	IP	francisco.godinho@infraestruturasdeportugal.pt
Pedro Abegão	IP	pedro.abegao@infraestruturasdeportugal.pt

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1. INTRODUCTION

This deliverable will consist in the test and validation of the project outcomes in Case Study (CS) *#25 de Abril* Bridge (Lisbon) to select and design the best technical solutions for preventive maintenance to plan future maintenance, contingency, and emergency interventions/planning and to set up of procedures for events management to ensure user's safety. Basically, in the assumption is to select and design the best technical solutions before (preparation and preventive maintenance), during (event management and control centre) and after a hazard event (predictive maintenance, emergency planning and practice).

2. CASE STUDY #6 DESCRIPTION

The case study focusses on earthquake hazard on the bridge, to evaluate and select, through the Foresee Tools, the best technical solutions for preventive maintenance to plan and integrate future maintenance into actual procedures, the enforcement of the contingency plan and the emergency procedures, using the tools for a comparative analysis with the actual procedures.

Worldwide transport infrastructure deal with new challenges.

Resilience of transportation systems has been of growing interest in recent years since an efficient and reliable transport system is essential for the wellbeing and the growth of society, providing services for the transport of people and goods, with direct repercussions over work and economy.

Therefore it´s critical to develop "greener" and "smarter" transport systems, considering the benefits for citizens and society while respecting the environment, assuring "smooth" conditions of travel, reducing the number of accidents and disruptions from networks jamming and their impact on transport, energy, and trade.

Transport infrastructure must function continually and safely against increasing hazards and extreme events, which are increased around the world mainly because of climate change.

Improving the level of service and resilience offered, by highly efficient management, construction and operation of networks with the use of the latest technologies and throughout their life cycle, is a requirement. Economic and social investments are needed to preserve the existing infrastructure inheritance, by maintaining and upgrading it, and by reducing the negative impacts and consequences of increased mobility.

The aim of the demonstration is to understand how to increase the efficiency and efficacy of the service offered to customers in terms of safety, functionality and mobility, as well to test some of the provided reliable methodologies and tools that were conceived to improve the resilience of transport networks, this case a bridge, as well as the ability to reduce the magnitude and/or duration of disruptive events.

2.1. INFRASTRUCTURES / NETWORK DESCRIPTION

The *25 de Abril* Bridge is a suspension bridge connecting the city of Lisbon to the city of Almada and the South of the country, across the Tagus River. It was opened in 1966. The upper deck carries six car lanes, while the lower deck carries a double track railway electrified at 25 kV AC. It is a road and rail bridge used by over 100 million people per year.

This structure has a socio-economic role at local, regional and national level.

Figure 1. CS#6, *25 de Abril* Bridge (Lisbon) by Ferreira, Jorge (2016).

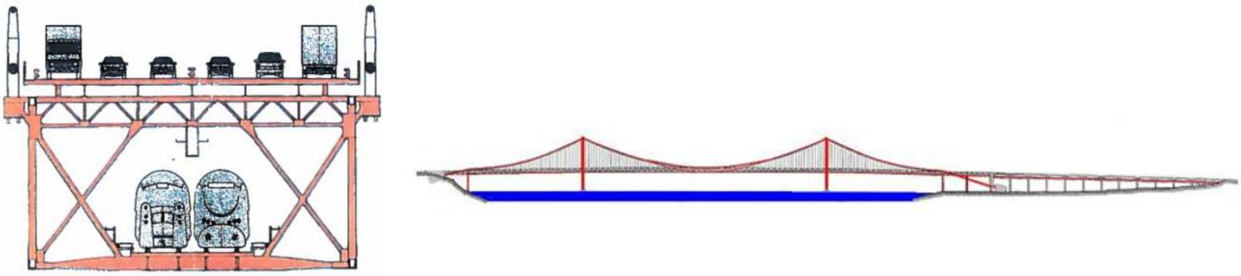


Figure 2. 25 de Abril Bridge (Lisbon) – Cross Section.

The *25 de Abril* Bridge construction started in 1962 and it opened to service in 1966.

On this date, the cross section of this bridge only contemplated a highway (2x2 lanes in each direction).

However, the project also predicts and contemplated the possibility of a future enlargement (although for only one more way) and inclusion of the train.

On July 29, 1999 (1994-1999), the works for the installation of railway and the enlargement of the roadway platform (cross section) was completed (3x3 lanes in each direction), which included the reinforcement and general improvement of this infrastructure.

This bridge has 55 (fifty-five) years old.

Some characteristics of this bridge:

Table 1. CS#6, Bridge Characteristics.

Number of spans of main bridge:	*6*
Main span length:	*1.012,88m*
Anchorage to anchorage length:	*2.227,64m*
Clearance referred to water level	*70m*
Height of main towers referred to water level	*190,5m*
Primary cables diameter	*58,60cm*
N. of wires per cable	*11.248un*
Total length of cables wires	*54.196km*
Secondary cables diameter	*35,44cm*
N. of wires per cable	*4.104un*
Total length of cables wires	*20.000km*
Depth of south main tower below water level	*80m*
Depth of north main tower below water level	*25m*

The bridge between August 1966, date of opening to traffic and March 1995 was managed exclusively by a state-owned company called *Junta Autónoma de Estradas*.

On March 24th, 1995, the concession contract between the Portuguese State and *Lusoponte* started.

This contract aimed at the conception, design and construction of the *Vasco da Gama* Bridge and respective financing and the operation and maintenance of the *Vasco da Gama* Bridge and the road deck of the *25 de Abril* Bridge.

In April 1994, rail traffic began operating on the *25 de Abril* Bridge. As of this date, the bridge has three entities with responsibilities in its management, namely *Refer*, in terms of the superstructure of the bridge and the railway structure, *Lusoponte*, in terms of road deck and the *Instituto de Estradas de Portugal*, in terms of management of the concession contract signed between the Portuguese State and *Lusoponte*.

The coexistence of road and railway operation on the bridge, the responsibility of different entities – *Refer*, *Lusoponte* and *Instituto de Estradas de Portugal* – raised the question of coordination between these entities in terms of safety and security.

The *25 de Abril* Bridge Security Authority was then created.

In 2008, through the Decree-Law n. º 95/2008, of June 6th, the Portuguese State decided to centralize in *Estradas de Portugal* the control and articulation of a set of actions, namely in terms of maintenance, improvement, or major repairs and in terms of safety and security of road and railway operations. Consequently, the *25 de Abril* Bridge Security Authority is extinguished.

The management of the *25 de Abril* Bridge – structure, rail and road operation – continues to be divided between three different entities, namely *Estradas de Portugal*, *Refer* and *Lusoponte*, but whose attributions and competences change.

Estradas de Portugal assumes the management of the bridge's structure and the coordination of safety and security in road and railway operations within an integrated management logic of the *25 de Abril* Bridge.

Refer kept the management of railway equipment (inspection, maintenance, improvements, major repairs, etc.) and railway operation.

Lusoponte kept the maintenance of the road deck and the road operation.

In 2015, through the Decree-Law n. º 91/2015, of May 29th, another change takes place in the management of the *25 de Abril* Bridge. By decision of the Portuguese State, *Estradas de Portugal* and *Refer* were merged, creating *Infraestruturas de Portugal* (IP).

Currently, the management of the *25 de Abril* Bridge is characterized by:

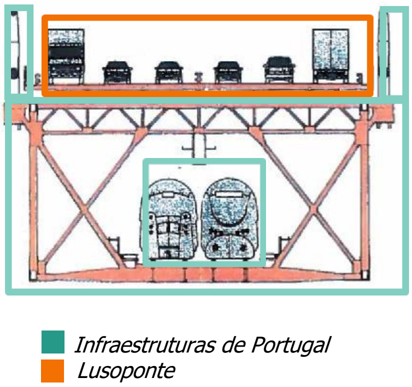


Figure 3. Current Management System – Entities Responsibilities.

Infraestruturas de Portugal

Superstructure:

- Inspection, maintenance, improvement, major repair and overhaul of characteristics.
- Studies, projects, supervision, assistance to economic and technical quality of the works.
- Coordination and integrated management of operation's safety and security.

Rail Infrastructure:

- Inspection, maintenance, improvements, major repair and renovation.

LUSOPONTE LISBOA

Road concession:

- Maintenance of the road deck, traffic management, assistance to users and collection of tolls, according to the concession contract.

IMT INSTITUTO DA MOBILIDADE E DOS TRANSPORTES, I.P.

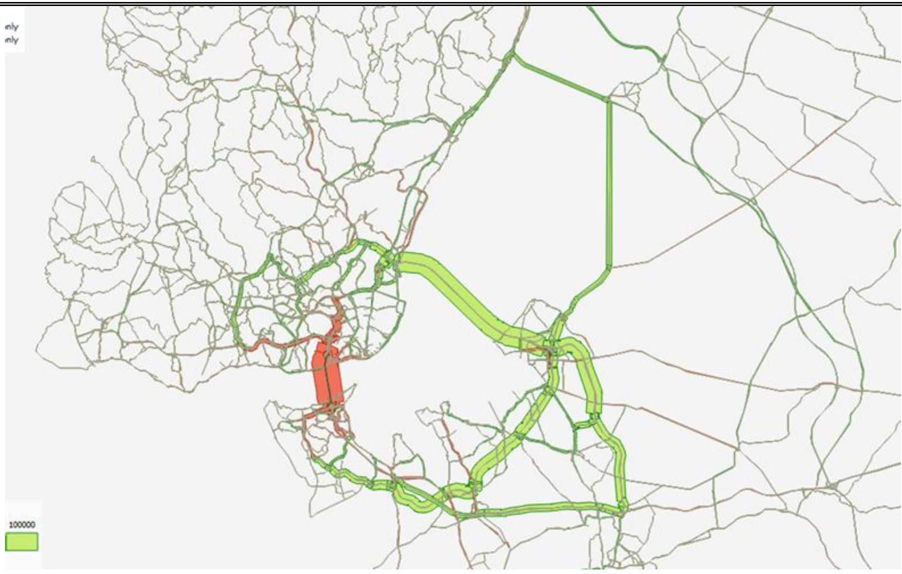
Road Concession:

- Manage the *Lusoponte* concession contract.

In the table below, some information regarding *Infraestruturas de Portugal* management and usage/traffic conditions:

Table 2. CS#6, Maintenance procedures and traffic conditions.

Inspection, Maintenance and Repair	*Infraestruturas de Portugal carried out permanently on the bridge an inspection, maintenance and repair program which is based on routine inspection, routine maintenance, special inspection, special maintenance, inspection of damage, according to needs and major repair, improvement or overhaul of characteristics works, including the preparation of studies and projects, supervising and monitoring of the work and verification of its technical quality.*
Structural Monitoring	*Infraestruturas de Portugal has a cooperation protocol with the Portuguese Nacional Civil Engineering Laboratory to monitor the overall structural behavior and implementation of permanent monitoring system.*
Usage conditions	*It is a road and rail bridge used by over 100 million people per year* *± 150.000 vehicles per day* *± 4.500.000 vehicles per month* *± 54.000.000 vehicles per year* *± 150 trains per day* *± 4.500 trains per month* *± 54.000 trains per year* *The bridge allows transposition over Tagus River, connecting Lisbon to the South of Portugal and it is one of the main links between the North and South. This infrastructure has an important socio-economic role at local, regional and national level.* ***Road traffic:*** *In normal conditions, if this bridge would close to traffic (which would result in the termination of the respective tolls, contemplated in the Lusoponte concession contract), estimated travel time by alternative routes, based on the National Traffic Model (EMME), would increase an average of about 22.2 minutes.* *traffic gains (green) and losses (in red) if the bridge was suppressed.*

	 *The value of the bridge benefit, defined through "HEATCO - Developing Harmonized European Approaches for Transport Costing and Project Assessment (Deliverable 5)", is €10.70 per hour.* *Regarding Lusoponte tolls, as the traffic would be transferred to Vasco da Gama Bridge (alternative to 25 de Abril Bridge crossing the Tagus River), its tolls exceed the current revenues of 25 de Abril Bridge.* *Just considering the saving of time achieved, road traffic, with the service of the 25 de Abril Bridge, it reaches the value of €300 million per year.* ***Railway**:* *The closure of the bridge would mean the suspension of the Fertagus concession contract and the closure of the direct connection between Lisbon and Porto to the Algarve, Évora and Beja (CP trains).* *Regarding Fertagus, the concession contract´s suspension gives rise to the obligation for the State to provide compensation to maintain the company's financial balance. On the other hand, the service provided by Fertagus provides IP revenue from the use rate of about €4,2 million, which would not be received.* *Also, the direct connection to the Algarve, Évora and Beja affects about 6,400 trains per year. An alternative route would consist of crossing Tagus River by boat and then take the railroad in Barreiro. IP revenue from the usage fee would be reduced by around €400 thousand.*

The bridge superstructure and rail infrastructure, as described above, is currently managed by *Infraestruturas de Portugal*, a state-owned company that manages the Portuguese road and rail network infrastructure.

To fulfil its responsibilities and achieve its goals, *Infraestruturas de Portugal* has implemented a management system that consists of:

2.2. INSPECTION, MAINTENANCE, IMPROVMENT, MALOR REPAIR, OVERHAUL CHARACTERISTICS

Routine inspection and routine maintenance are performed by a multidisciplinary full-time team of 16 (sixteen) persons.

The routine inspection is carried out daily according to a pre-defined schedule, in which each bridge element has a defined inspection frequency (monthly, quarterly, annually).

A monthly report results from the routine inspection that, in addition to recording the state of conservation of the structure and installed equipment, identifies and quantifies the maintenance work to be carried out and the materials/consumables to be acquired for these maintenance work.

Routine maintenance results from prioritizing the anomalies detected in the routine inspection that can be carried out in the short term with the human resources and means of access available. For this reason, routine maintenance is also usually referred to as small maintenance. These are welding, painting, bolts, nuts and washer's replacement or small metal parts replacement.

Anomalies that cannot be eliminated through routine maintenance are grouped together and subject to a major repair work contract to be performed by a contractor.

Also works that correspond to improvements and overhaul of the bridge characteristics that cannot be eliminated through routine maintenance will be carried out by a contractor, through a contract to be signed for this purpose.

Special inspection can be determined in case of unforeseen circumstances, with or without visible damage to the bridge, such as accidents, extreme events, etc., or it is a specific inspection with an execution frequency exceeding one year.

In this bridge, the underwater inspection of the foundations of the pillars located on the riverbed, the experimental determination of the forces deployed in the suspension cables hangers and the inspection of the suspension cable clamp bolts are identified as specific inspections. These special inspections are carried out every 5 (five) years.

Anomalies detected on a special inspection are eliminated through routine maintenance, special maintenance, or repair work contracts, depending on their specificities.

Special maintenance, like some special inspections, is associated with regular maintenance but with a usually more spaced execution interval.

The preventive maintenance of bearings and expansion joints, road and railway and the tightening of the suspension cable clamp bolts (activity connected with special inspection to the same kind of bolts) are examples of maintenance considered special.

2.3. INTEGRATED SAFETY AND SECURITY OPERATION

The coexistence of road and railway operation on the bridge, whose management is ensured by different entities, *Lusoponte* in the case of the roadway and *Infraestruturas de Portugal* in the case of the railway, determined the need to clarify the specific attributions and competences of each of the entities.

Infraestruturas de Portugal, in terms of safety and security of the bridge operation, centralizes and coordinates in an integrated bridge management logic.

The activities carried out by *Infraestruturas de Portugal* in this matter are:

- Systematically and continuously adopt measures in terms of preventing the risks inherent to existence and operation of the *25 de Abril* Bridge.
- Check, adapt and make the procedures compatible operations and the conservation and maintenance of the structure, equipment and devices adopted by the different entities, identifying any gaps or deficiencies and following the implementation of the consequent action's correctives.
- Manage the integrated safety manual and the integrated emergency plan of the *25 de Abril* Bridge, proceeding to the reviewing, updating it and checking for compatibility and complementarity with the emergency plans of the different entities involved.
- Promote, exclusively within the scope of its activities of operating safety, the performance of audits to check the safety conditions in that the road and railway operation is carried out in the bridge.
- Promote the carrying out of investigations and technical investigations of accidents or incidents occurring on the bridge, ensuring the implementation of the necessary corrective and preventive actions.
- Develop an annual safety program, which includes the objectives to be achieved, the means to be involved and the planned phasing for the different actions and elaborate a semi-annual monitoring report for the annual safety program.
- Propose to the Government the creation, modification, or revision of legal or regulatory instruments, to guarantee the conditions for the proper exercise of its powers.
- Act in conjunction with the entities responsible for all aspects associated with restrictions, or prohibition, on the transport of hazardous materials on the *25 de Abril* Bridge.
- Promote plan and coordinate the realization of real or office exercises to test the integrated safety manual and integrated emergency plan of the bridge.
- Promote plan and coordinate the implementation of training actions for the personnel of the competent authorities in matters of safety and security.
- Encourage the preparation of contingency plans for alternative transport in situations of prolonged unavailability of road or rail traffic on the *25 de Abril* Bridge, in conjunction with public transport operators, as well as road infrastructure concessionaires.
- Order the suspension or restriction of road or rail traffic, whenever the safety of people and goods crossing the *25 de Abril* Bridge justifies it.
- Manage emergency situations, as provided for in the integrated emergency plan for the *25 de Abril* Bridge.
- Authorize the reopening to road or rail traffic, after the resolution of emergency situations.

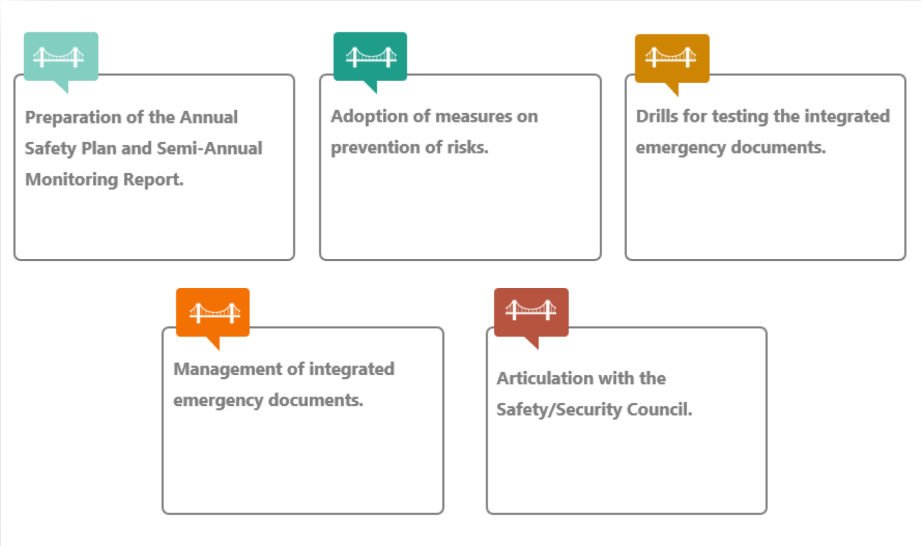


Figure 4. Main Activities and Documents within the Integrated Operational Safety and Security.

2.4. ANNUAL COST – ASSET MANAGEMENT

*Infraestruturas de Portugal*s investment in the management of the *25 de Abril* Bridge assumes, on average, an annual value of € 1’220’000.

This amount does not include the investment made with contracts for improvement works, major repairs or overhaul of the characteristics of the *25 de Abril* bridge.

The breakdown of the average annual investment between inspection, maintenance, acquisition of materials and equipment and studies, projects and consultancy, developed by *Infraestruturas de Portugal*, takes the following form:

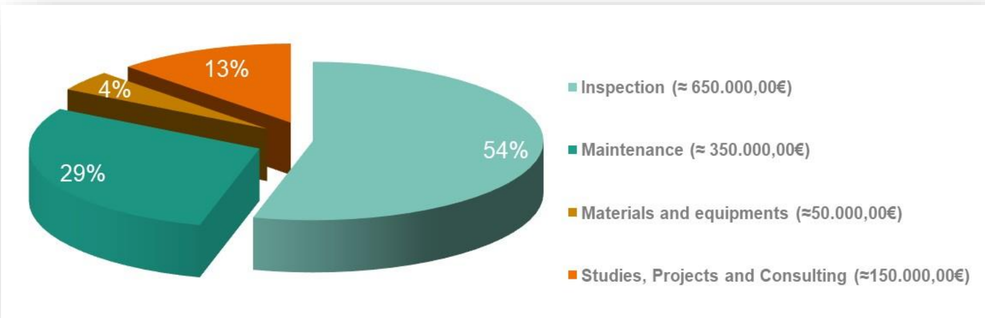


Figure 5. Annual Cost - Bridge Management.

2.5. HAZARD DESCRIPTION

The *25 de Abril* Bridge has been studied in two different scenarios, which can affect regular traffic service (road and railway):

- Earthquake: risk of moderate of severe events which may bring to partial or total closing of the bridge to evaluate, through the Foresee Tools, the enforcement of the operational, maintenance, contingency plan and the emergency procedures.
- Simulation of a train accident with a special focus on the management of people (communication, contingency, emergency and evacuation) during and after the event, using the tools for a comparative analysis with actual procedures and a previous disruptive event.

2.5.1 EARTHQUAKE

Earthquakes are a global problem and are considered one of the most important natural disaster worldwide. They result into serious socio-economic impacts, causing loss of lives, population displacement, business bankruptcy.

3. SCENARIO CARD & VALIDATION CONDITIONS

3.1. SCENARIO CARD FOR CASE STUDY #6 - *25 DE ABRIL* BRIDGE (LISBON)

As the *25 de Abril* Bridge (Lisbon) is an existing bridge, corresponding to the life cycle (LC) only the operating and maintenance phase, in relation of the management and contingency plans, is considered in the following.

Two different scenarios have been studied as mentioned above (Section 2.5.).

Table 3. CS#6, Scenario Card.

CS #6	**scenario**	
LC phase	Operation & Maintenance,	**M**
risk	Earthquake; Train Accident	**E;TA**
transport	Road and Railway	**RR**
scale	National,	**N**
location	Portugal,	**P**
	LC phase (M), risk (E;TA), transport (RR), scale (N), location (P)	

The disruptions in the *25 de Abril* Bridge cause delays, traffic jams and have very relevant social-economic impact that will be studied in this case study, as it affects the daily commuting of an important percentage of the Lisbon Metropolitan Area.

The main investigation topics regarding the considered operating and maintenance phase are earthquake impact on bridge structural behaviour/assessment as well operations in combination with maintenance and contingency plans.

The outcomes of the project will implement the advantages of real and accurate predictive maintenance strategies as well the best technical solutions for preventive maintenance to plan future maintenance as well event management and contingency procedures.

Current guidelines, recommendations for action, procedures of *Infraestruturas de Portugal* for major incident management are used here for the tool comparison. In this context, existing maintenance, operational and contingency plans are also analysed and compared.

3.2. VALIDATION METHODOLOGY AND PROCEDURE

Key Resilience Indicator (KRI) and Key Resilience Targets (KRT) are defined in the first step (see Section 3.3.) and used for the selection of the FORESEE Tools for this CS#6 (see Section 3.3.) as well as an evaluation benchmark in the further procedure.

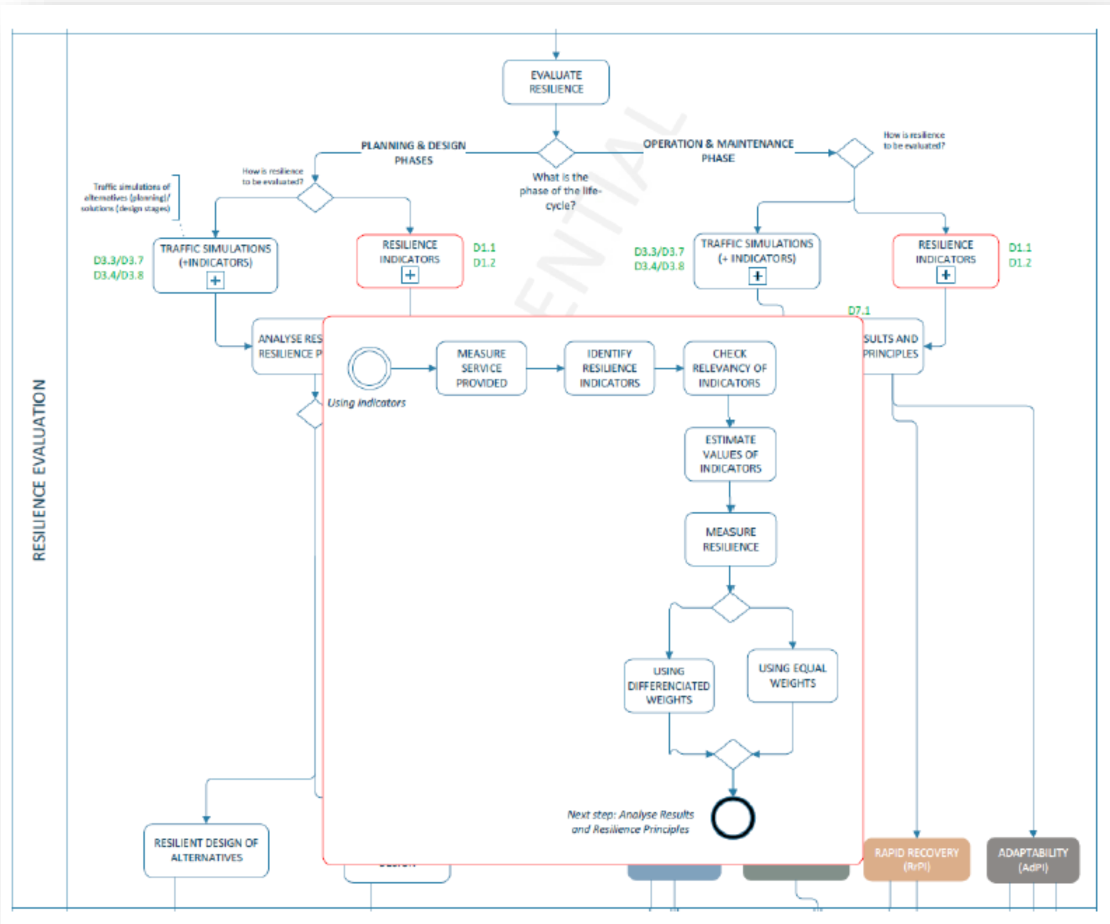


Figure 6. Evaluating Resilience using Indicators.

The tool validation shown on Section 4. is a procedure performed on Deliverable D6.1. The linear approach is basically divided into the phases of requirements analysis, implementation and validation.

The selected FORESEE Tools are additionally subdivided according to the time phase in which they are used (before, during or after an event) (see Section 4.).

The information regarding the requirements, modelling and output will be theoretically validated mainly based on the deliveries of the individual FORESEE Tools in the first step (see Section 5.).

In the second step, the subsequent validation of the implementation of the requirements will also include comparisons with the current situation (see Section 6.).

In the final evaluation, possible suggestions for improvements for a real use and commercialization of the FORESEE Tools are pointed out (see Section 7.) and the results of the validation of CS#6 are summarised once again as a conclusion (see Section 8.).

The approach to validate, theoretical, the tools have been the following:

1 Definition of the main KPIs that each tool uses as an input and gives as an output.

2 Relation between the previously mentioned selected KPIs with the ones obtained from the tools.

3 Analysis of the KPIs that will improve the resilience of the infrastructure by using each tool.

4 Executive analysis and conclusions of each tool developed by the infrastructure manager

5 The infrastructure is digitized through Indicators, KPI and thresholds KRT – Deliverables D1.1 and D1.2.

6 The Traffic Module is a stochastic algorithm that predict the most probable input data before using it in a traffic simulation software.

7 The Tool Command and Control Centre represents graphically the indicators and the thresholds.

8 The Tool Definition of framework: use cases, risk scenarios and analysis of impact, defines the potentials risks.

The following main project outcomes will be applied and validated from a theoretical point of view and some of them from practical point of view.

- Assessment of the Level of service and resilience (Work Package WP1).
- Risk Mapping (Work Package WP2).
- Traffic Module (Work Package WP3).
- Control and Command Centre (Work Package WP5).
- Design & Construction plans (Work Package WP7).
- Operational and maintenance plans (Work Package WP7).
- Contingency and Evacuation plans (Work Package WP7).

3.3. KEY RESILIENCE INDICATOR (KRI) AND TARGETS (KRT)

The functioning of society depends on the transportation of goods and persons.

As reductions in service due to natural hazards (i.e. earthquakes, floods, wind, etc.) can affect mobility of persons and goods, it is fundamental to provide cost effective and reliable tools to improve the service and resilience of the infrastructure, as it promotes:

- Holistic approach.
- Unique measure to consider all these factors and their weight.
- Tool for governance to understand which actions to take and where to improve service and reduce negative impacts.

To do so, however, it is necessary for transport infrastructure managers to:

a. On one side, have a clear idea of the service that the infrastructure is providing and an understanding of its resilience if it is affected by natural hazards.

b. On the other side, to understand how the resilience of a network can be modified to balance the loss of service following a hazard and to provide the specified levels of service during and following the occurrence of extreme events, that is, to set resilience targets. (Martani et al.)

A methodology to measure the resilience of a transport infrastructure with respect to a defined service and set resilience targets have been proposed in the European research project FORESEE- Future proofing strategies FOr RESilient transport networks against Extreme Events (Adey et al., 2020).

According to Deliverable D1.1 "Guideline to measure Levels of Service and resilience in infrastructures" and Deliverable D1.2 "Guideline to set target levels of service and resilience for infrastructures" the KRI and KRT are identified in preparation for the following validation of the FORESEE Tools in phase 0 of the flow chart (see Section 4., Figure 9).

The guideline is to be used by managers to establish targets for the service provided by and the resilience of transportation infrastructure, especially when the desire is to have a standardised, repeatable and comparable process.

The guideline is a valuable support in understanding the impact of the different factors on the daily operation of the infrastructure.

Service is defined as the ability to perform an activity in a certain way, provided by transport infrastructure and in the project, four types of service are proposed:

- Travel time.
- Safety: the cost of repairing damaged property, the number of injuries and deaths due to people travelling across the proposed section.
- Interventions: the cost of keeping the infrastructure in, or restoring it to, an acceptable state.
- Socio economic activities: the costs for the society due to the additional travel time for all the people and goods travelling after a hazard.

Resilience is defined as the "ability to continue to provide service if a hazard event occurs and when considering extreme events, resilience is therefore measured as the difference between the service provided by the infrastructure if no hazard event occurs and the service provided by the infrastructure if a hazard event occurs and the costs of intervention if no hazard event occurs and the costs of interventions if a hazard event occurs. It may be measured in terms of travel time, expected cumulative injuries and fatalities or intervention costs".

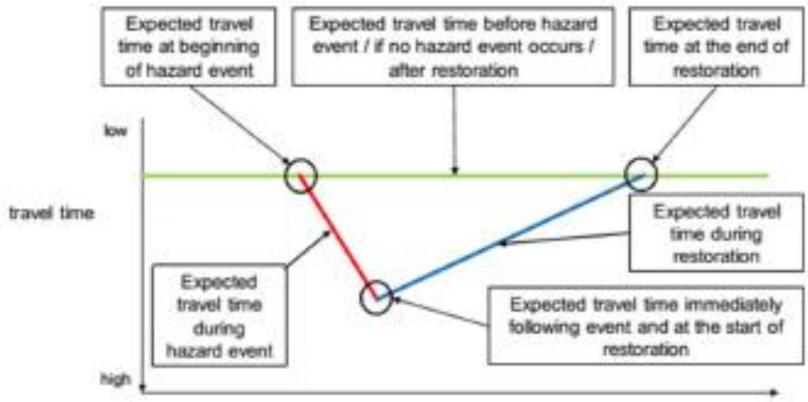


Figure 7. Resilience and Service (from Deliverable D1.1), measured in Travel Time.

The KRI and KRT for CS#6 are determined with the help of an excel file provided by ETH, which reflects the methodology from Deliverables D1.1 and D1.2. The application and methodological correlations of the Excel file were taught by ETH in a "Resilience Index & Target Training Workshop" on 2021.03.24.

In the first step, the input variables for the measuring the service are defined. These are classified between event-independent, such as the annual maintenance cost, number of people travelling per day, goods travelled per day, leisure and socio-economic cost per person and others (see Annex 1 - Section 1.1) and event-dependent inputs (see Annex 2 - Section 1.2), on the outcome of the event have been included, such as the cost of intervention after the event, days to recover normal service and the outcome on people and property.

The event-independent parameters include general theoretical data from the literature, real data and expert knowledge from *Infraestruturas de Portugal*, as a manager of this asset.

The event-dependent inputs to measure the service are related to the hazard event of earthquake for CS#6. The comparative data for the hazard assessment are provided here on the one hand by available practical cost and recover data from previous events and experience.

On the other hand, the estimation of the average delay (per train and per car) after an event is again compared with the results by previous experience as well with the results of the *Infraestruturas de Portugal* traffic simulation model (EME) and Planning Department of *Infraestruturas de Portugal*.

For instance, this transport infrastructure is managed along its life cycle, to provide service, in the best safety conditions, service that allows:

- To a road and rail user travel between North and South Tagus riverbank within specific amount of time (travel time).
- To a road or rail user to travel between the North and South Tagus riverbank without having his/her property damaged or being hurt or losing his/her life (safety).
- to an infrastructure manager to be able properly maintain the infrastructure within the best use of resources, to guarantee a safe utilization of the infrastructure during its life cycle.
- to the inhabitants of the region served to be able to ship and have shipped goods between the North and South Tagus riverbank (socio-economic activities).

To measure these characteristics of the service, we have therefore established and assessed journey times, safety, the cost of interventions and the impact on socio-economic activities.

In the tables contained in Deliverable D1.1 (Annex 1), we have defined the measure of the expected loss in the level of service after an event, in this case an earthquake.

As a result of the first step, the determined inputs are combined or multiplied to represent the loss of service (LOS) after the hazard in the form of a (maximum) cost value as a measured value. As shown in Table 4 (and Annex 1 - Section 1.2), a distinction is made between intervention, travel time, accident/safety and socio-economic costs.

Table 4. CS#6, LOS as Cost Value.

CS #6	**LOS as a Cost Value [10^3€]**
Intervention	**5 693**
Travel Time	**3 448 170**
Safety	**4 187 346**
Socio-Economic	**77 394**

In the second step of the Key Resilience Indicator (KRI) and Key Resilience Targets (KRT) determination, the current condition state of the CS#6 infrastructure and hazard prevention strategies are estimated for the influencing variables provided by the ETH and others defined by IP in post-stage. For this purpose, we have selected 54 (fifty-four) indicators of resilience that are compliant on managing the earthquake hazard, as presented on Table 5. These indicators were selected to capture the performance of all relevant aspects of the transport system, in this case a bridge. It is included an explanation of each indicator and the reasons why it has been chosen.

The total of 54 (fifty-four) indicators for measuring Earthquake Resilience (E) are categorised hierarchically into eight levels of detail. At the top level "0", a distinction is made between Infrastructure (E1), Environmental (E2), Organisational (E3), Structural Health Monitoring (E4), Inspection (E5), Small/Current Maintenance (E6), Structural Analysis (E7) and Evacuation and Traffic Management (E8) indicators. In the lowest level, the current condition state and with it the optimizable is defined for each of the 54 (fifty-four) indicators.

For each indicator, a set of possible values are available as a scale. The measure for the current indicator state is defined in CS#6 based on expert knowledge (Stakeholders) together with the *Infraestruturas de Portugal* (see Annex 1 - Section 1.2).

At level "1", these indicators have been grouped into the following groups:

- **Operation: Those aspects related fundamentally to the infrastructure and its condition.**
- **Protective Measures: Those aspects related to the safety of the operation.**
- **Preventive Measures: All those related to the legal requirements applied to the maintenance and management of the infrastructure.**
- **Pre-Event Activities.**
- **Post-Event Activities.**
- **Structural Health Monitoring.**
- **Inspection Procedures.**
- **Structural Analysis.**
- **Small Maintenance Procedures that contribute for reliable structure.**
- **Direct and Immediate Response.**
- **Long Term Response Measures.**

We have considered and pointed out that it would be convenient to relate these factors to the existence of a management and quality plan that helps in the permanent monitoring of the established indicators.

Relevant is the analysis of indicators related to the organisation of operation management, inspection, maintenance, structural analysis as well Evacuation and Traffic Management, with indicators defined prior to the event, highlighting the strategy and existence of a maintenance plan, as well as others related to the activities to be carried out in the presence of the event and afterwards, indicating the existence and practices of the emergency plan, as well as the forecasts for the timely restoration of normality in the service.

The assignment of the values of the resilience indicators considers the state of the infrastructure in the phases before, during and after the event, the protection measures, which include alternative routes, the existence of a warning system, a permanent Structural Health Monitoring, inspection plan, proper maintenance, coordination between services, availability of on-site resources and evacuation and contingency measures.

Finally, the indicators relating to the environment and the value of the effect on different past events are assessed and related to the indicators described above.

For the final analysis of the service and intervention costs regarding the indicators and targets, two further factors are considered.

On the one hand, the intervention, travel time, accident and socio-economic cost value presented in Table 4 are only considered if an increase in the value of the resilience indicator is likely to lead to lower or higher expected costs - the case of same expected costs is not taken into account (see Annex 1 - Section 1.3).

On the other hand, the influence of the individual indicators on the service is assessed by using differentiated weights / percentages according to the expert knowledge of the infrastructure manager (see Annex 1 - Section 1.4).

As an interim, the following Table 5 shows the evaluation of the LOS as a cost value, considering the two weighting factors and depending on the resilience indicators and targets.

Table 5. CS#6, LOS as Weighted Cost Values for the Resilience Indicators.

ID	Level 1	ID	Indicator	Costs [€]				
				Intervention	Travel time	Accident	Socio-econ.	Total
E1.1	CS of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	0	0	697 881	13 732	711 613
		E.1.1.2	Age / Age of replacement of safe shut down system	0	0	628 093	12 359	640 451
		E.1.1.3	Condition state of infrastructure (pre-event)	1 107	62 232	814 596	16 028	893 963
		E.1.1.4	Condition state of protective structures/systems (pre-event)	703	39 532	517 466	10 182	567 883
		E.1.1.6	Expected condition state of infrastructure (post-event)	1 415	79 508	1 040 735	20 478	1 142 135
		E.1.1.7	Expected condition state of protective structures/systems (post-event)	1 179	66 237	867 028	17 060	951 504
E1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	0	68 593	0	17 667	86 259
		E.1.2.2	The possibility of using another means to satisfy transport demand	0	143 409	0	36 936	180 345
		E.1.2.3	The number of possible existing alternative ways to deviate vehicles	0	0	0	0	0
		E.1.2.4	The presence of a warning system	0	16 176	0	4 166	20 342
		E.1.2.5	The presence of a safe shutdown system	0	0	0	0	0
		E.1.2.6	The presence of emergency / evacuation paths	0	0	0	0	0
		E.1.2.7	The presence of special measures to help evacuate persons	0	52 572	0	13 540	66 112
E1.3	Preventive measures	E.1.3.1	Complience with the current seismic design code	2 219	124 721	1 632 559	32 123	1 791 622
		E.1.3.2	Presence of systems to reduce seismic effects	2 209	124 112	1 624 591	31 966	1 782 877
		E.1.3.3	Adequate systems to reduce seismic effects	5 200	292 243	3 825 377	75 269	4 198 089
E2.1	Context	E.2.1.1	Accessibility	5 600	0	0	0	5 600
		E.2.1.2	Presence of persons/property below the infrastructure	0	0	2 872 517	0	2 872 517
		E.2.1.3	Extent of past damages due to hazards	0	0	0	0	0
		E.2.1.4	Hazard zone	552	31 016	405 994	7 988	445 550
		E.2.1.5	Duration of past down time due to hazards	228	0	0	0	228
		E.2.1.6	Land type	5 289	0	3 890 209	0	3 895 498
		E.2.1.7	Budget availability	0	0	0	0	0
		E.2.1.8	Traffic	1 127	63 332	828 999	16 312	909 769
		E.2.1.9	Hazards goods traffic	0	0	1 277 908	0	1 277 908
		E.2.1.10	Flammable goods traffic	0	0	3 516 032	0	3 516 032
E3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	0	0	0	0	0
		E.3.1.2	The presence of an maintenance strategy	0	0	0	0	0
		E.3.1.3	The extent of interventions executed prior to the event	267	14 980	196 085	3 858	215 190
E3.2	Post event activities	E.3.2.1	The presence of an emergency plan	0	0	0	0	0
		E.3.2.2	Practice of the emergency plan	0	130 803	0	33 689	164 492
		E.3.2.3	Review/update of the emergency plan	0	306 846	4 016 530	79 030	4 402 407
		E.3.2.4	Expected time for tendering	3 771	211 923	0	54 582	270 277
		E.3.2.5	Expecetd time for construction	447	25 106	0	6 466	32 019
E.4.1	SHM Availability	E.4.1.1	Continuous vibration monitoring	2 122	0	1 561 102	0	1 563 224
		E.4.1.2	Continuous stress and displacement monitoring of resistance elements	1 423	0	1 046 821	0	1 048 244
		E.4.1.3	Continuous relative displacement monitoring of moving components	2 122	0	1 561 102	0	1 563 224
E.4.2	SHM Reliability and operation	E.4.1.4	Autonomous short-term electrical supply to the monitoring system installed on site	4 245	0	3 122 204	0	3 126 448
		E.4.1.5	Permanent fail-safe communication of monitoring relevant information	2 122	0	1 561 102	0	1 563 224
		E.4.1.6	SHM data analysis	949	0	697 881	0	698 830
		E.4.1.7	Update rate on the feedback of the structural condition	4 245	0	3 122 204	0	3 126 448
E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan	0	0	0	0	0
		E.5.1.2	Repair plan of damaged components	0	0	0	0	0
E.5.2	Inspection operation	E.5.2.1	Visual inspections	0	0	0	0	0
		E.5.2.2	Technical measurements	0	0	0	0	0
E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	0	0	0	0	0
		E.6.1.2	Corrective maintenance interventions	2 135	119 959	1 570 232	30 896	1 723 222
E.7.1	Structural analysis	E.7.1.1	Structural model	0	0	0	0	0
E.7.2	Seismic risk studies	E.7.1.2	Seismic risk studies	2 846	159 945	0	41 195	203 987
E.8.1	Direct and immediate response	E.8.1.1	Coordination between services	0	79 973	0	0	79 973
		E.8.1.2	Availability of resources on site	2 135	119 959	0	0	122 094
		E.8.1.3	Availability of safe-through equipment	0	0	0	0	0
E.8.2	Response for long term disrupt	E.8.2.1	Long-term contingency plans	0	239 918	0	0	239 918
		E.8.2.2	Long-term traffic/mobility plans	0	239 918	0	0	239 918

In the third and final step, the resulting LOS cost values of the resilience indicators in the hazard event of earthquake are compared with the necessary cost values for implementing the resilience targets.

The comparative costs and targets are also based on the expert knowledge of the road-railway infrastructure manager (*Infraestruturas de Portugal*) and consider (if necessary) legal requirements as a minimum target.

In terms of a cost-benefit analysis, the resilience indicators and targets shown in Table 6 provide by far the maximum benefit and are consequently selected as key resilience indicators and targets for CS#6 (the complete comparison can be found in Annex 1).

To set the target levels of service and resilience for infrastructures of the transport system in Case Study 6 (CS#6): the *25 de Abril* Bridge, some input information is required or have been considered, namely:

- The expected reduction in the level of service following an earthquake,
- The resilience indicators following an earthquake, and
- The maximum expected reduction in the level of service for specific indicators, estimated considering differentiated weights.

Taking into consideration the outputs coming from the previous study, we can obtain the following key resilience indexes (21), whose values are under the maximum possible level. In result, these are the indicators we could improve using the tools developed as part of the FORESEE Project.

Table 6. CS#6, Key Resilience Indicators to be Improved.

ID	Indicator
E.1.2.1	The possibility of building a temporary alternative route for vehicles
E.1.2.2	The possibility of using another means to satisfy transport demand
E.1.2.4	The presence of a warning system
E.1.2.7	The presence of special measures to help evacuate persons
E.2.1.9	Hazards goods traffic
E.2.1.10	Flammable goods traffic
E.3.2.2	Practice of the emergency plan
E.3.2.3	Review/update of the emergency plan
E.3.2.4	Expected time for tendering
E.4.1.1	Continuous vibration monitoring
E.4.1.2	Continuous stress and displacement monitoring of resistance elements
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site
E.4.2.2	Permanent fail-safe communication of monitoring relevant information
E.4.2.3	SHM data analysis
E.4.2.4	Update rate on the feedback of the structural condition
E.6.1.2	Corrective maintenance interventions
E.7.2.1	Seismic risk studies
E.8.1.1	Coordination between services
E.8.2.1	Long-term contingency plans
E.8.2.2	Long-term traffic/mobility plans

All framework and calculations that were performed, explanations as well that are related with this practical application is shown on Annex 1.

3.4. SELECTED FORESEE TOOLS AND ITS POSSIBLE CONNECTION WITH THE PREVIOUS KRI FOR CS#6

For the KRIs selected in the previous Section 3.3., possible applications are now identified from the pool of developed FORESEE Tools that support the implementation of the KRTs, which are also defined beforehand. It should be mentioned here that the majority of the ("available") FORESEE Tools can only be analysed at the time of the present validation of CS#6 based on the existing deliveries without practical application.

The FORESEE Tools selected for CS#6 to improve the resilience of this road-railway infrastructure (bridge) are:

Table 7. CS#6, Foresee Tools including Solutions Catalogue

Deliverable (D) / Tool (T)	*Name*	*Developer*	*CS #6*	
			Selected FORESEE tool	**Corresponding KRI**
D1.1	**Resilience Guidelines to measure Level of Service & Resilience**	**ETHZ/IP**	√→	*KRI Identification*
D1.2	**Set Targets**	**ETHZ/IP**	√→	*KRI Identification*
D1.3	**Governance Module**	**UC**		
D2.7/ T 2.1	**Risk Mapping**	**UC**	√→	**E.7.2.1**
D2.8/T2.4	**Virtual modelling Platform**	**UEDIN**	Not Developed for CS#6	
D2.9/T2.5	**Alerting SAS platform**	**TVUK**	Not Developed for CS#6	
D3.3/D3.7/T3.4.1	**Traffic Module**	**WSP**	√→	**E.1.2.1 E.1.2.2 E.2.1.9 E.2.1.10 E.8.2.2**
D3.8/T3.4.2	**Fragility and Vulnerability Analysis & Decision Support Module**	**RINA-C**	Not Developed for CS#6	
D4.1	**Flooding Methodology**	**IH**		
D4.4	**Hybrid Data Fusion Framework**	**ETH**	Not Developed for CS#6	
D5.3/D5.6/ T 5.5	**Command and Control Center**	**FRA**	√	**E.4.1.1 E.4.1.2 E.4.1.3**

				E.4.2.1 E.4.2.2 E.4.2.3
D7.1/ T.7.1	**Definition of framework: use cases, risk scenarios and analysis of impact**	**CEM**	→	*Framework for T 7.2/3/4*
D7.2/D7.5/ T 7.2	**Design, construction and remediation plans**	**CEM**	√→	E.1.2.4 E.1.2.7 E.3.2.2 E.3.2.3 E.3.2.4 E.4.2.4 E.6.1.2 E.8.1.1 E.8.2.1 E.8.2.2
D7.3/D7.6/ T 7.3	**Operational and maintenance plans**	**TEC**	√→	E.1.2.4 E.1.2.7 E.3.2.2 E.3.2.3 E.3.2.4 E.6.1.2 E.8.1.1 E.8.2.1 E.8.2.2
D7.4/ T 7.4	**Management and contingency plans**	**ICC**	√→	E.1.2.4 E.1.2.7 E.3.2.2 E.3.2.3 E.6.1.2 E.8.1.1 E.8.2.1 E.8.2.2
Solutions catalogue				
D 4.2	Earthquake Platform	CEM	√→	E.1.2.4 E.3.2.2 E.3.2.3 E.4.2.4 E.8.2.1 E.8.2.2
D 3.3	Sustainable Drainage System	CEM		
D 4.7	Development of algorithms for the selection and definition of efficient and optimal actions	ETHZ/CEM	√→	E.3.2.2 E.3.2.3 E.4.2.4 E.8.2.1
D 3.5	New Family of PA-pavements	UC		
D 3.6	Smart & Integral slope	UC		

	stabilization system			
D 4.4	SHM Algorithms	TEC	√→	E.4.1.1 E.4.1.2 E.4.1.3 E.4.2.1 E.4.2.2 E.4.2.3 E.4.2.4

4. SYSTEM VALIDATION IN CASE STUDY #6

The tool validation follows the procedure in the Figure 6 and is basically divided into the phases of requirements analysis (**1.**), implementation (**2.**) and validation (**3.**).

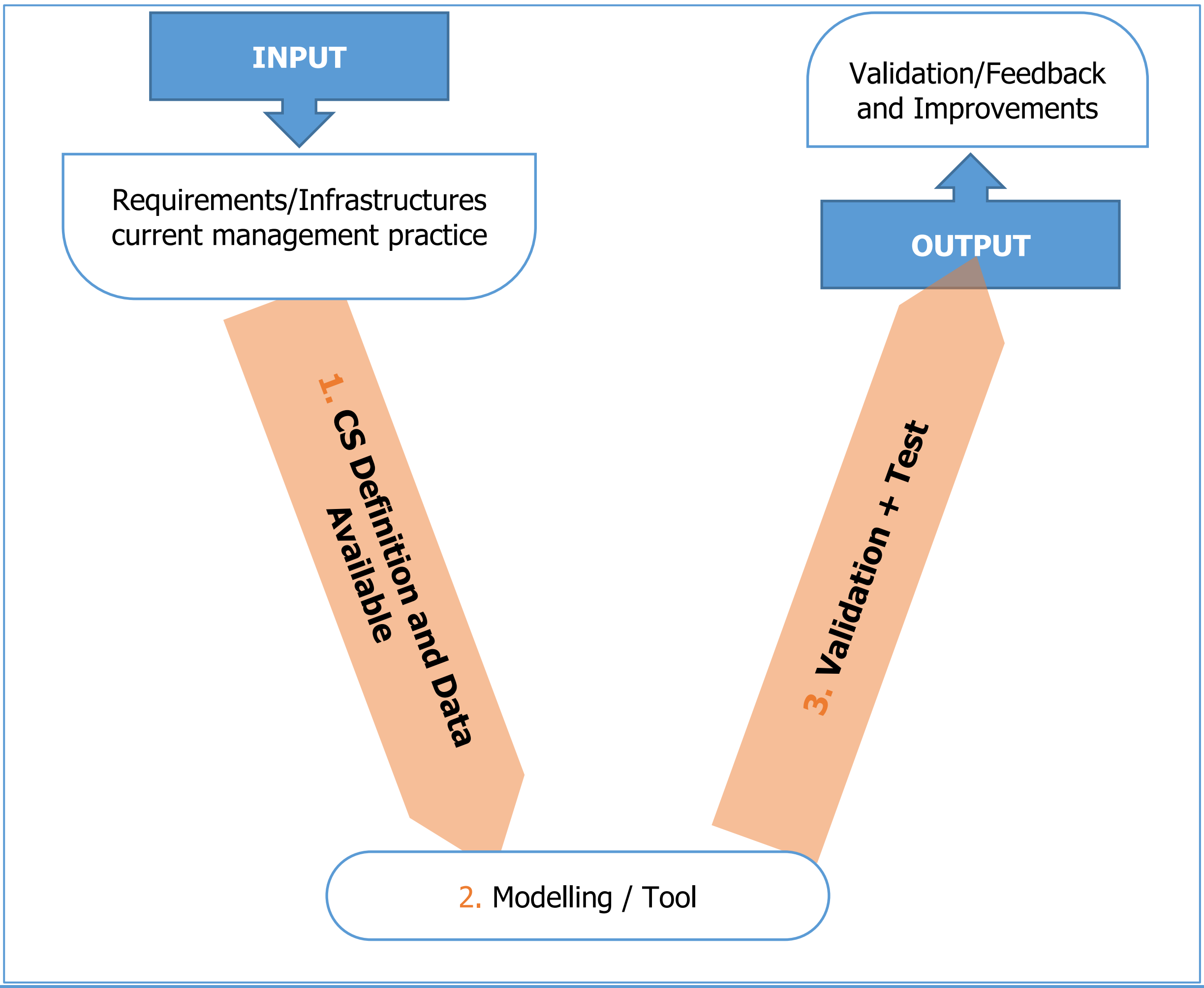
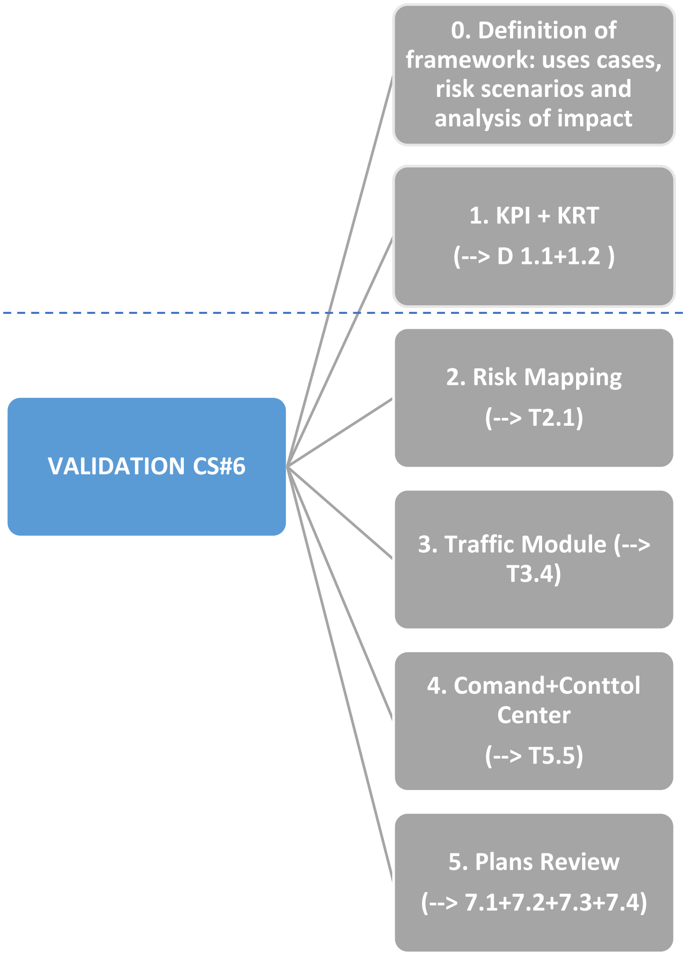
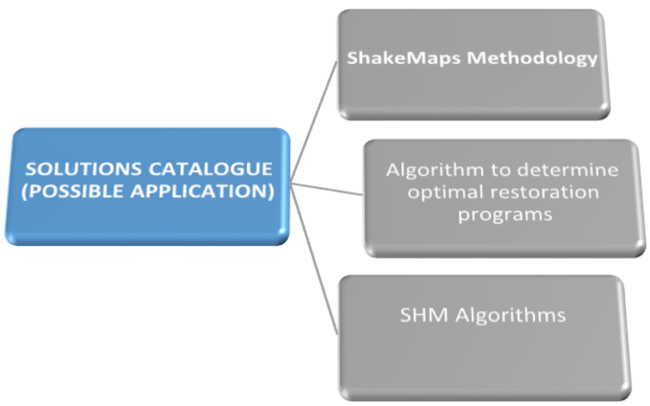


Figure 8. CS#6, FORESEE Tool Validation model

The FORESEE Tools selected in Section 3.4 for resilience improvement are thematically grouped into the process phases before, during and after a possible earthquake hazard.

Flow chart





Process phase

Checking / Analysing of events
+ Identification and Setting KPI / KRT

Before the event

During the event

After the Event = Before the next event

Explanation

0. The infrastructure and event are digitized and identificated through Indicators, KPI and thresholds KRT – Deliverables D1.1 and 1.2 as an evaluation benchmark
1. The Tool "**Risk Mapping**" analyses the risks.
2. The Tool "**Command and Control (C+C) Centre**" represents graphically the indicators and the thresholds.

3. The **<u>Traffic Module</u>** is an stochastic algorithm that predict the most probable input data before using it in a traffic simulation software
4. The Tool "**<u>Definition of framework</u>**" defines the use cases, risk scenarios and analysis of impact and potentials risks for the asset and defines the potentials hazards.
   <u>Tool</u> "**Plan Review**" which analyses, evaluates, updates and improves maintenance and contingency plans.

Figure 9. CS#6, FORESEE Tool Validation Flow chart and Process phase

The tool validation is a procedure that is basically divided into the phases of requirements analysis (**1.**), implementation (**2.**) and validation (**3.**).

In the following two sections, the FORESEE Tools selected for resilience improvement in CS#6 are categorised according to the previously defined process phases and validated in accordance with the model.

To this end, the input factors of the selected FORESEE Tools are first described and clustered in section 5 in the form of a brief requirements analysis with an increasing level of detail. In the subsequent validation and test phase in Section 6, the possible improvements through the selected FORESEE Tools are determined. In this context, a comparison is also made with the current situation regarding hazard prevention and management plans at *Infraestruturas de Portugal*.

The approach to validate the tools have been the following:

1. To better understand each tool without reading their specific deliverable, a summarize of the tool has been provided.
2. Definition of the main KPIs that each tool uses as an input and gives as an output.
3. Relation between the previously mentioned selected KPIs with the ones obtained from the tools (point 2).
4. Analysis of the KPIs that will improve the resilience of the infrastructure by using each tool.
5. Analysis and conclusions of each tool developed by the infrastructure manager (*Infraestruturas de Portugal*).

5. REQUIREMENTS OF THE FORESEE TOOLS IN CS#6

As a basis for the subsequent validation and test phase, the selected FORESEE Tools are briefly described below in the form of a requirements analysis. All the information required for this is taken from the deliveries provided. The subsequent validation and testing phase can therefore only be theoretical in some cases and practical in others. For a clear structure, the tools are also assigned to their Life Cycle and process phases according to their future use.

In the following, additional indications for the requirements analysis of the individual tools are given. The summary of the comparative analysis of the collected requirements can be found in the subsequent Table 8.

5.1. DEFINITION OF A FRAMEWORK TO DEVELOP THE RESILIENCE PLANS

The guideline presented in Deliverable D7.1 offers a useful insight to the different aspects linked to the evaluation of resilience, from its understanding down to the consequences of events and associated recovery measures, indicating the main steps to follow in the assessment of resilience plans.

A set of use cases covering a wide range of transport infrastructure and risk scenarios, to guarantee a holistic approach, is proposed. Use 02: Highway (with bridges) is relevant for CS#6. Results have been built by interaction with the different partners and by shared questionnaires. The validation is made from a theoretical point of view.

5.2. RESILIENCE GUIDELINES TO MEASURE LEVEL OF SERVICE & RESILIENCE AND TARGETS

The needed requirement is to have a tool to assess the level of service of the infrastructure and to understand on which parameters/aspects to intervene to increase resilience and, if possible, to predict future performances face to a set of constraints and boundary conditions to the covered in the analysis (risks, ageing assets, company's policies, socio political context, etc).

Different are the results produced in Work Package WP1 (Deliverables D1.1. and D1.2):

- The guidelines are to be used to determine how to measure, the service provided by and the resilience of, transport infrastructure, with their associated target levels to attain. It promotes different levels of analysis, starting with indicators, but a more sophisticated approach based on traffic analysis is possible.
- Cost benefit analysis allows the choice of optimal solutions.
- Excel file implementing the above-mentioned approach which allows infra managers to make a sensitivity analysis as it is possible to test the excel file with the data.
- Implemented toolkit internet based interfaced with the other tools. In this case it is only possible to analyse the application in test phase done by the developers as well by *Infraestruturas de Portugal*.

Close contact among CS#6 leader and the ETH has been carried out. In addition, the results have been presented together with the tool developers to the FORESEE 4th SRG WEBINAR on 2021.01.21.

As forementioned, the steps to determine the resilience of the system using indicators are developed in detailed in Deliverable D1.1, which can be summarizes as follows:

1. Measure the service provided by the transport system.
2. Identify parts of the transport system that are likely to influence resilience (infrastructure, environment, organisation among others that were defined by *Infraestruturas de Portugal* in a post-stage).
3. Identify resilience indicators: they should be selected to give an adequate representation of how difference between the service provided, and the intervention costs, with and without the occurrence of the hazard event.

4. Check relevancy of indicators to ensure that all indicators are appropriate, and that there are indications for all relevant aspects of the service provided by the infrastructure and intervention costs.
5. Estimate values of the indicators.
6. Measure resilience (using differentiated resilience weights), correlating the values of the indicators to the reductions of service with and without the occurrence of the hazard event.

5.3 REQUIREMENTS OF THE FORESEE TOOL "RISK MAPPING" (T2.1 – D2.5)

The requirements identified for the "Risk Mapping" tool derive from the deliverable provided. The associated appendix shows that the tool provides specific outputs for the present CS#6 in the form of colour-coded risk and hazard maps (see Annex 2 - Section 2.1).

These outputs are predefined by the tool developers and can therefore not be edited and applied independently for validation in this report for CS#6.

5.4 REQUIREMENTS OF THE FORESEE TOOL "TRAFFIC MODULE" (T3.4.1 – D3.7)

The FORESEE traffic module refers to a multi-scenario software script intended to proof how existing traffic simulations, using commercial traffic analysis tools, can help evaluate resilience even with uncertain inputs. The claim is that resilience can be better understood by simulating stochastically the loss of service through the combination of the uncertainty values associated to the disruptive events, the mitigation strategies, or the recuperation interventions.

Traffic module applies Monte Carlo simulation methodologies to narrow down and define the uncertainty of the outcomes that result from a given risk assessment that affects the resiliency of transport systems, following the best practices on asset management (see ISO 55000). The benefits of incorporating these probabilistic methodologies into the traffic simulations would be that measuring the future transport system resilience can increase in quality and likelihood.

The purpose of the Traffic Module is to enable resilience measurements with traffic simulations even when some uncertain input parameters are present.

The traffic forecasting capability - assuming some underlying future parameter changes- is what makes traffic simulations interesting. For example, assuming a different future capacity or speed condition of a section, traffic simulations can forecast the non-linear traffic flow changes expected over the network.

Traffic simulations work best for average traffic forecasts, but they are challenged by special cases. Generally, there is not enough background data or examples of disruptive events, to calibrate and simulate such behaviours accurately. However, if the disruptive event scenarios and planned measures affect only to a limited set of input parameters, the outcome can provide reasonable measures of LOS and therefore enable the desired resilience assessment.

However, as with any forecast model, "accuracy" will depend on the robustness of the assumptions and their relationships. Therefore, when the input parameters are questionable some amount of sensitivity tests must be carried out on the areas of uncertainty. To avoid over or understatement of the range of potential deviations on this type of analysis, it is good practice to use probabilistic algorithms such as Monte Carlo simulations. Unfortunately, most common traffic simulation tools do not have this capacity.

This module demonstrate how Monte Carlo simulations can be used together with a well-known traffic simulation tool to narrow down the outcome uncertainty of the resilience assessments by using traffic simulations.

Measuring resilience for a transport system should be a combination of measuring the services without a hazard and measuring the loss of service when withstanding difficulties and while intervening to recover quickly afterwards (as explained in Deliverables D1.1 and D1.2).

There are many ways to evaluating the "resiliency" of transport systems, considering the varying scope of factors and the different disruptive events and their effects on the service they provide. From the methodologies and definitions described in Work Package WP1 we can characterize the methods as a combination of "qualitative vs quantitative", with the "based on indicators vs the based-on simulations". Following this characterization, the traffic module aim is to help assess the resiliency on wide scope transport network scenarios using quantitative methods able to measure volume, speed and trip duration, based on traffic simulations.

The LOS for traffic purposes can be measured by estimating the time required to transport good and persons for a specific volume demand.

For this CS#6 specifically, *Infraestruturas de Portugal* have a traffic model (of road vehicles only – EMME Model) that is of the whole country. A scope of this traffic model was delivered to WSP.

As referred on Deliverable D3.7 (page 39), the implementation of the module in a traffic simulation model depends on the traffic tools available and the interfaces these provide. Also, the selection of the best suited tool for a traffic analysis will depend on the case study characteristics and objectives of the traffic model. In general, there are transport simulations tools that are more adequate than others for macro scope analysis than for micro analysis, mono-mode vs multimode studies, or depending on the different transport management systems that want to be processed (i.e.: Toll highways, public transport, etc.).

For FORESEE's Transport Module being able to embed the processes through scripts and the good management of the scenarios are the most valuable characteristics and based on all considerations that were made on Deliverable D3.7, the Traffic Tool selected to implement the module was PTV VISUM.

The snapshot shown on Table 2 (*Infraestruturas de Portugal* traffic model) was provided by EMME Software.

As presented on Deliverable D6.7 - Final version of the Traffic Module, regarding CS#6, some constraints were stated:

- *MODEL: The Use Case does not have a Transport demand model available to FORESEE, though the infrastructure manager informs that one exists for the road (not rail) section in EMME.*
- *TRAFFIC DATA: 2019-07-05: The Case Study (IP) send and extract of their EMME transport demand model holding the traffic only over the 25th Abril Bridge, including the original zonification that corresponds to the whole of Portugal. There are two issues with this information: the extract holds no data of the alternative routes (empty roads never causes congestion) and the country wide size is not readable by the size limited licence*

available for WSP. 2020-04-30: the Case Study technically understands that a simple extraction of the Lisbon area would solve both issues, unfortunately it was not available.

- *SCENARIO/PROBABILISTIC DATA: 2020-06-23: WP6 provided the Scenario Card details indicating the scenarios will be probabilistic based on the earthquake risks, stating the increase on average travel time should the bridge close (22.2minutes) - which can only come from running such scenario of the transport demand model. At the current state of the deliverable the Use Case is considered Not applicable.*

5.5 REQUIREMENTS OF THE SOLUTION CATALOGUE "SHAKEMAPS METHODOLOGY" (T.4.2 – D4.5)

The requirements identified for the "Shakemaps methodology" tool derive from the deliverable provided.
In case of CS#6, this was not applied in practical terms, but only in theoretical. Therefore, some considerations are made, by infrastructure manager, regarding the potential use of this tool.

5.6 REQUIREMENTS OF THE SOLUTION CATALOGUE "ALGORITHM TO DETERMINE OPTIMAL RESTORATION PROGRAMS" (T.4.3 – D4.2 & D4.7)

The requirements identified for the " Algorithm to determine optimal restoration programs" tool derive from the deliverable provided.
In case of CS#6, this solution was not applied in practical terms, but only in theoretical. Therefore, some considerations are made, by infrastructure manager, regarding the potential use of this tool.

5.7 REQUIREMENTS OF THE SOLUTION CATALOGUE "SHM ALGORITHMS" (T.4.5 – D4.4 & D4.9)

The requirements identified for the " SHM Algorithms" tool derive from the deliverable provided.
In case of CS#6, this solution was not applied in practical terms, but only in theoretical. Therefore, some considerations are made, by infrastructure manager, regarding the potential use of this tool.

5.8 REQUIREMENTS OF THE FORESEE TOOL "COMMAND AND CONTROL CENTRE" (T5.5)

The definition and design of the tool "Command and Control Centre" are taken from the overall deliverable of the FORESEE Toolkit, of which the Command-and-Control Centre is an essential part. The actual outputs and deliverable of this tool were explained in a workshop on 2021.11.18 for the CSs involved.

In case of CS#6, this tool was not applied in practical terms, but only in theoretical. Therefore, some considerations are made, by infrastructure manager, regarding the potential use of this tool.

5.9 REQUIREMENTS OF THE FORESEE TOOLS "PLANS REVIEW" (T7.2, T7.3, T7.4)

The tools developed under Tasks T7.x are grouped together for this validation, as the result is always an improvement and review of existing plans. For this tool collection, the most information is available in the framework of the requirements and input-output analysis compared to the others selected FORESEE Tools.

On the one hand, all individual deliverables are available for the theoretical part of the requirement definition.

Design, construction and remediation plans may be validated from a theoretical point of view. These plans are based on resilience-based performances criteria and offer a view on new design procedures to adapt and increase the LOS and resilience of existing and future infrastructures.

Moreover, the Task T7.2 tool can be tested in practice to some extent. For this purpose, the tool developers provide form-based Excel tables, which the users (in this case the CS leaders) can fill with input values by their selves and determine the outputs independently (in this case Performance-based design resilience curves - see Annex 2 - Section 2.3). In addition, the results were discussed together with the tool developers in a workshop on 2021.07.21 and the tool could be further improved.

In particular, the practical applicability compared to the purely theoretical analysis of the deliverable significantly increases the understanding of the tools and thus also the subsequent testability and ability for real application and commercialization.

At this stage, operational and maintenance plans may be validated from a theoretical point of view. These plans should provide a process to determine optimal intervention programs to increase the level of reliability and service of the infrastructures covering methodologies, systems, procedures and materials to increase factors such as safety, efficiency, or productivity.

Therefore, the main objective of Work Package WP7 lies in the definition of operational resilience schemes, covering the whole life cycle of the infrastructures and resilience phases, able to reduce the impact and consequences of extreme events and considering the demands and behaviours (including psychological aspects) of all end users of transport networks (infrastructure owners and operators, passengers, drivers, logistic operators, etc.), by:

- Defining a framework regarding the use cases and assets to be considered, risk scenarios to be considered in the resilience schemes and impacts (due to extreme events) to be analysed.
- Deploying different plans for the whole life cycle of infrastructure and resilience phases, considering the achievements of the previous WP of the project.

- Defining general schemes of resilience, in terms of strategical plans, to improve the LOS and the resilience, at tactical and operational decisions implemented level, in transport infrastructures.
- Structuring the plans in a use-case driven way, considering the diverse test cases selected.
- Obtaining resilience plans, based on the selected use cases, which will be used as patterns during the implementation of the resilience guides into the FORESEE Toolkit.

As mentioned on Deliverable D7.6, the main objective is to provide an adequate framework to increase factors as important as safety and efficiency. In this regard, the new methodologies, systems, procedures and materials developed in Work Package WP3 and Work Package WP4, along with other existing ones, will be incorporated to the current plans and based on the framework and KPIs defined in Deliverable D7.1, covering a wide range of transport infrastructure and identifying what are the main risks and impacts that a hazard may cause in transport infrastructure.

Table 8. CS#6, Requirements of the selected FORESEE Tools.

CS#6	***REQUIREMENTS***	***Life Cycle + Process Phase***
T 2.1 Risk Mapping	0. Source of information: Deliverable 2.5 "Datasets/maps hot spots, risks and impact ranking" 1. Definition of requirements Identification and prioritising of areas of high vulnerability of disruption caused by extreme natural events. The tool provides a risk occurrence assessment for the most significant natural disasters (floods, landslides, and earthquakes). Hazard maps and risk maps of the infrastructure's area to identify the risks prior to the more accurate and more local scale quantification 2. Design of the technical system (Arc-)GIS-based software application GIS-based methodology providing strategic areas where to implement measures to mitigate the impacts of extreme natural events. 3. Implementation of the outputs Colour-coded risk and hazard maps as tif-file (see annex 2 – Section 2.1)	Life Cycle phase: Planning & Design Operation & Maintenance, M Process phase: Before the event
T3.4.1 Traffic Module	0. Source of information: Deliverable 3.7 "Traffic Module"	Life Cycle phase: Planning & Design Operation &

	1. Definition of requirements Allows several scenario-based traffic simulations before and after the event occurrence, in order to evaluate the effects of disruptive events. 2. Design of the technical system 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. Inputs: O-D matrices Traffic flows 3. Implementation of the outputs Traffic volumes Travel times Travel Speeds ***(→ *Practical implementation unavailable)***	Maintenance, M Process phase: Before the Event After the Event / Before the next event
T 4.2 Solutions Catalogue – Shakemaps Methodology	0. Source of information: Deliverable 4.5 1. Definition of requirements The methodology is based on the generation of shakemaps scenarios through the combination of two developments: simulation of synthetic time history records and characterization of site-effects based on empirical and semiempirical approaches. These semi-empirical Shakemaps are integrated into a GIS platform as a representation of the ground motion parameters distribution produced by a set of realistic simulated seismic events. 2. Design of the technical system Integrating additional layers into the GIS platform, such as data related to existing infrastructures or population density, together with the information provided by these semi-empirical shakemaps, will allow to perform different risk assessment 3. Implementation of the outputs Semi-empirical shakemaps scenarios integrated into a GIS platform ***(→ *Practical implementation unavailable)***	Life Cycle phase: Planning & Design Operation & Maintenance, M Process phase: Before the Event After the Event / Before the next event
T.4.3 Solutions Catalogue - Algorithm to Determine Optimal Restoration Prograi	0. Source of information: Deliverable 4.2 and Deliverable 4.7 1. Design of the technical system The use of the algorithm will help	Life Cycle phase: Operation & Maintenance, M Process phase:

	infrastructure network managers develop improved restoration programs for their networks, resulting in minimum overall costs during the restoration period. The reduction in overall costs enhances the resilience of infrastructure networks. Moreover, the algorithm is beneficial for infrastructure managers in charge of the determination of the resilience of critical infrastructures to extreme events 2. Implementation of the outputs The algorithm to determine the optimal restoration programs contains a description of all required inputs, a complete mathematical model and a search algorithm to determine optimal restoration programs, for all objects in a network based on the minimization of the overall direct and indirect costs ***(→ *Practical implementation unavailable)***	Before the Event After the Event / Before the next event
T.4.5 Solutions Catalogue - SHM Algorithms	0. Source of information: Deliverable 4.4 and Deliverable 4.9 1. Design of the technical system Data-driven algorithms, model-based algorithms and data-driven algorithms supervised by FE models are implemented with successful results consisting of: Reliable alert systems of damage existence independent from environmental variability. Damage identification (location and severity estimation) by the combination of data-driven and model-based techniques. 2. Implementation of the outputs - Reliable alert algorithms which, once trained, could be included in a real-time alert system given their computational agility. - New paradigm for damage identification using FE models with the standard complexity of engineering practice combined with Deep Learning techniques (→ *Practical implementation unavailable)	Life Cycle phase: Operation & Maintenance, M Process phase: Before the Event After the Event / Before the next event
T 5.5 Command +Control Center	0. Source of information: Deliverable 5.1 "1st version of the FORESEE toolkit" 1. Definition of requirements Situation Awareness (SA) Organizing big data of hazard events and summarize it, so that a human operator can handle it. Anomaly / Outlier Detection: Finding potentially dangerous outliers and	Life Cycle phase: Operation & Maintenance, M Process phase: During the event / After the Event

	anomalies from the normal state in big data of hazard events 2. Design of the technical system Software application based on an individual model and its data for each CS by using machine learning techniques in neural networks. 3. Implementation of the outputs Issuing automatized alerts when a situation diverges from the normal state and potential danger is arising. ***(→ *Practical implementation unavailable)***	
Plans Review **T 7.1** Definition of framework: use ca risk scenarios and analysis of impa **T 7.2** Design, construction and remediation plans **T 7.3** Operational and maintenance plar **T 7.4** Management and contingency pla	0. Source of information: Deliverable 7.2 (for T.7.2) - "Design, construction and remediation plans" Deliverable 7.3 (for T.7.3) - "Operational and Maintenance Plans" Deliverable 7.4 (for T.7.4) - "Management and contingency plans**"** 1. Definition of requirements Developing three different Resilience Plans, that aim to reduce the impact and consequences of extreme events as well as to increase the ability to recover from them. T7.2 - Developing design, construction and remediation plans in order to adapt and increase the resilience of the infrastructure T7.3 - increase transport infrastructures' safety, efficiency and productivity factors regarding the occurrence of extreme events T7.4 - how people respond to different Communication strategies in emergency situations to study the reaction time of the users, based on different parameters 2. Design of the technical system Software based tools by using Microsoft Excel to calculate the criticality (T.7.2) and risk assessment with net-benefit analysis (T.7.3). Online study to determine the warning conditions and crowd behaviours; computer aided models for evacuation and fire simulations (T.7.4) 3. Implementation of the outputs **Design, construction, and remediation plans:** These plans will include new design approaches based on performance-based design procedures to adapt and increase the LOS and resilience of existing and future infrastructures. (see Annex	Life Cycle phase: Operation & Maintenance, M Process phase: After the Event / Before the next event

	2 – Section 2.2) **Operational and maintenance plans:** These plans will provide a process to determine optimal intervention programs to increase the level of reliability and service of the infrastructures. These plans will also include methodologies, systems, procedures, and materials to increase factors such as safety, efficiency, or productivity. **Management and contingency plans:** These plans will develop new and more effective contingency and communication strategies in order to enhance the resilience of the transport system. Communication plans are key to mitigate the adverse consequences, by instigating the evacuation of users in a safe way, as well as by helping recover the normal service as quickly as possible.

6. OUTPUTS COMING FROM THE VALIDATION PHASE AND IMPROVEMENTS VIA THE FORESEE TOOLS. COMPARISON WITH CURRENT SITUATION REGARDING ASSET MANAGEMENT PLANS

Based on the previous requirements analysis and the additional indications, the validation of the selected FORESEE Tools for the improvement of the defined KRI and KRT in CS#6 can be evaluated in the following.

As explained in the previous section, for most tools only descriptions of incoming requirements and outgoing outputs are available from the deliverables. As the newly developed tools can currently mostly be applied theoretically instead of practically, the validation is only qualitative by comparison with the current situation in the form of a tendential rating of the improvement.

The structural approach is identical to the previous requirements analysis. Firstly, additional indications are pointed out regarding the improvements using the selected FORESEE Tools. The comparison of the identified improvements with the current situation and the tools used is summarised in Section 6.2.2.

Furthermore, the validation will be critically assessed by checking the Current Management Asset Principles and Resilience Principles in Section 6.2 and by performing a net benefit analysis in section and presenting the resilience factors after using the selected FORESEE Tools in Annex 1 (Section 1.10).

6.1 FORESEE TOOL OUTPUTS

6.1.1 RISK MAPPING – (T2.1 – D2.5)

6.1.1.1 Guidebook

As mentioned on several FORESEE deliverables, one of the challenges when evaluating the resilience of infrastructures is the decision-making at a certain moment of adopting measures to face possible natural disasters. This is a task of great responsibility and importance since these events affect society on a constant basis in different parts of the European territory.

Because of this, the need for using available resources as efficiently as possible to mitigate the adverse effects of natural disasters has become a priority. Having as much information as possible is key to help meet this challenge and tools such as geographic information systems (GIS) are a great option capable of analyzing large amounts of data visually and efficiently. Therefore, the evaluation of the risks involved in these natural disasters is proposed via the implementation of a GIS. Some of the main innovations of this tool includes the consolidation of different natural disasters into the same information package and the use of different satellite measurement techniques that help geophysical monitoring of these catastrophes such as the Synthetic Aperture Radar Interferometry (InSAR) or the Normalized Difference Vegetation Index (NDVI) provided by the Copernicus program.

Therefore, as mentioned on Deliverable D2.5, the main objective of the tool developed in Task T2.1 is to identify and assess the risk of natural disasters in different areas of study using an application implemented in GIS. This application analyzes, evaluate, identify and consolidate the risks to improve decision-making. Using the ArcGIS software platform, the process has been automated by creating a tool capable of calculating the risk of different natural disasters such as landslides, floods and earthquakes in a specific area within the European territory, considering the impact of these potential events on population and infrastructures.

So, the Risk Mapping tool developed in Task T2.1 of the FORESEE Project is aimed at the early large-scale identification of the risks to extreme natural disasters to which road infrastructures are exposed as well as to approach the vulnerability of these infrastructures.

This application is a key element to be considered at the early phases of an infrastructure project will be the identification, in terms of probability and consequences, of the different risks that must be considered, as infrastructures will have to be designed to resist with the highest resilience level as possible (resilience as robustness). Two main outcomes can be obtained from running the tool: hazard and risk maps at a European scale.

All the actions carried out for the development of a GIS-based application for the identification and prioritizing of areas of high vulnerability of disruption caused by extreme natural events is described.

Large scale data in relation to weather (rainfall and temperature), elevation, geology, land cover or lithology, among others, are used to identify areas that are vulnerable to climate-related hazards: floods, landslides and earthquakes.

For this, an empirical approach based on regression modelling has been considered that can be applied at early phases of the projects design, where risks can be identified at a larger scale, prior to a more detailed data collection for a given impending regional or local extreme natural event.

The resultant GIS risk analysis considers the importance of traffic and population at the time of assessing the impact caused by the extreme natural events.

Therefore, the purpose of this tool, vulnerability of roads concentrated the greatest effort. In this sense, for the vulnerability assessment of the different types of roads (motorways, primary, secondary and tertiary roads) a MCDM analysis was carried out that made use of different criteria: traffic, length, costs and accidents rate.

As the vulnerability of transport infrastructures is also related to the people living around them, potential personal damage must have an impact on the vulnerability factors defined. Therefore, population density was set to weight the general vulnerability factors. A synoptic diagram of the process followed for the risk mapping is in Figure 10.

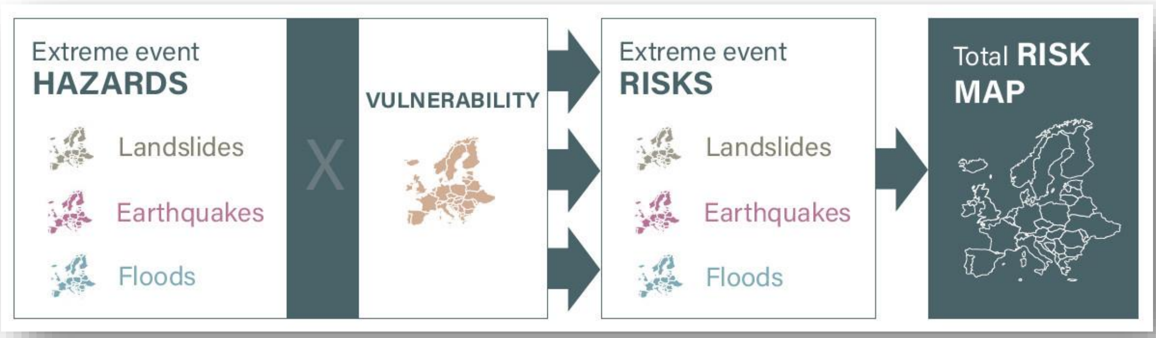


Figure 10. Synoptic Diagram of the Risk Maps Generation.

We can now see that there is a direct link between this tool and the next previously mentioned KRIs (Section 3.3.):

- E.4.1.1 - Continuous vibration monitoring.
- E.4.1.2 - Continuous stress and displacement monitoring of resistance elements.
- E.4.1.3 - Continuous relative displacement monitoring of moving components and anti-seismic devices.

Indirect way:

- E.3.2.2 - Practice of the emergency plan.
- E.3.2.3 - Review/update of the emergency plan.
- E.8.2.1 - Long-term contingency plans.

6.1.1.2 Results

As for the study case here referred, some risk and hazard map generated in the context of the analysis of the *25 de Abril* Bridge, regarding earthquakes, are shown at Annex 2 (Section 2.1).

6.1.1.3 Improvements via the FORESEE TOOL "Risk Mapping"

For the Risk Mapping tool developed in Task T2.1, no comparable systems are available from the infrastructure manager itself. But the sources freely available from the national and European authorities, public databases and research institutions provide similar results to the colour-coded risk and hazard maps of the FORESEE Risk Mapping.

Therefore, a possible improvement, as a result of Task T2.1, is rated as equal in total (with a slight tendency towards the tools that are currently freely usable online and perhaps provide more detailed outputs for the CS#6 local area in Portugal).

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 9. Questions & Impacts for Task T2.1 (Deliverable D2.5)

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	For the Risk Mapping tool developed, no comparable systems are available from the infrastructure manager itself. But the sources freely available from the National IPMA (Portuguese Institute of the Sea and Atmosphere), Lisbon City Hall, Universities, among others) and European authorities/entities, as well public databases, Eurocodes (Eurocode 8) and National guidelines and research institutions provide similar results to the colour-coded risk and hazard maps of the FORESEE Tool.
How does FORESEE improve the results/analysis previously made?	Compared to the national standardised maps according to RSA (Structural Safety and Loads Regulations) and National Annex of Eurocode 8 with detailed information only for Portugal, the FORESEE Tool applies large scale rapid risk analysis based on past real extreme natural events occurred all over Europe for a general overview.
How does this FORESEE result improve your infrastructure's management	This tool contributes to enhance the extent of interventions executed prior to the event based on a software-supported risk assessment.
If it was not made, how does this FORESEE result improve your infrastructure's management?	The main added value of the tool is identification and prioritising of areas of high vulnerability of disruption caused by extreme natural events.
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 tool provides a GIS-based risk occurrence assessment for the most significant natural disasters - not only earthquakes, as in this case, but also landslides and floods.

the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	80% decrease working hours. Perhaps 20% saving maintenance costs

6.1.2 TRAFFIC MODULE (T3.4.1 – D3.7)

6.1.2.1 Guidebook

As aforementioned, the Traffic Module describes a conceptual framework and methodology designed for the development of the FORESEE Traffic Module. It includes a stochastic multi-scenario Python script algorithm called Monte Carlo, that makes use of existing traffic simulations, through a traditional traffic analysis tool called PTV VISUM. The purpose of the traffic module is to enable the resilience assessment over transport demand models when probabilities or uncertain input parameters are present.

The purpose of the traffic module is to enable resilience measurements with traffic simulations even when there are some uncertain input parameters.

"*To measure resilience, we not only need to consider the probability and possible consequences of disruptive events, but also the different ways in which service is restored, either temporarily through alternative routes or with restrictions during interventions. Traffic simulations are very powerful tools to measure and compare the service provided with and without events and interventions. The use of traffic simulations is required to obtain good estimates of service delivery and resilience of transport systems as explained in D1.1 and D1.2 (Annexes 1 and 2)*".

The space between "inverted commas" belongs to the Executive Summary of the deliverable. So, the objective of this module/tool is to provide infrastructure managers with a system to help them make decisions in the case of extreme events, and to study and train Control Centre Operators, through the possibility of using simulations under normal operating conditions.

All of this contributes to improve the resilience of the infrastructure and ensure that the expected level of service is maintained, even in the face of the disruption caused by extreme events, by adapting operating procedures.

It includes a description of the scope, variables and data management requirements needed to assess resilience in transport models when some input variables are questionable.

It explains the methodology used, and the practical description of the traffic simulation tool in which the FORESEE traffic module will be implemented, which allows the explicit quantitative connection between the service provided by transport infrastructure systems and their resilience.

Service indicators for traffic purposes can be measured by estimating the time needed to transport goods and people for a specific volume demand.

To measure resilience, it´s important and needed to compare a base case reference with conditions during and after the disruptive event, using simulations.

The objective of the traffic module is to simulate traffic scenarios considering variables with uncertainty. It intends to make use of existing traffic simulations and demonstrate that it is possible to generate statistical results related to uncertainty input parameters by applying stochastic methods.

As previously mentioned, the traffic module is a Python script that creates a multi-scenario set of inputs to be used in existing traffic analysis tools. It allows to predict the future traffic volume considering the available set of traffic data and different scenarios, such as the total closure of the bridge or some lanes during some specific time on recover phase when a hazard occurs.

Therefore, we can now see that there is a direct link between this tool and the next previously mentioned KRIs (Section 3.3.):

- E.1.2.1 - The possibility of building a temporary alternative route for vehicles.
- E.1.2.2 - The possibility of using another means to satisfy transport demand.
- E.2.1.9 - Hazard's goods traffic.
- E.2.1.10 - Flammable goods traffic.
- E.8.2.2 - Long-term traffic/mobility plans.

6.1.2.2 Results

No practical results have been provided for this tool.

6.1.2.3 Potential Improvements via the FORESEE TOOL "Traffic Module"

For the Traffic Module developed in Task T3.4.1, comparable systems are available from the infrastructure manager (*Infraestruturas de Portugal*) itself, as already above mentioned.

The objective of the traffic model is to produce different simulation scenarios for the desired hazard, to deliver simulated data of the network performance (flows, travel times) and assess the consequences of such hazards over regular road and railway traffic. These results yield important information regarding the evolution of traffic parameters with and without, p.e earthquake hazard occurrence, or between different hour simulations. These differences in travel time and traffic volume provide the keystone indicators for the indirect costs the hazards and their resilient strategies might have to society.

We consider this tool - Traffic Module – might respond to the requirements that the infrastructure manager can expect in the event of an extreme event, in terms of traffic management, through the experience acquired in simulations prior to the event, and using indicators as input variables related to traffic, such as hourly intensity, travel times, speed, and others.

It would be an advantage to have simulation modules in the Control Centre to study the results of the application of different management strategies based on different scenarios.

As above-mentioned, traffic models balance transport demand with the infrastructure system networks to create traffic simulations that mimic the behaviour of traffic.

Since the definition of resilience relies in the evaluation of the transport services, and the main transport service indicator can be measured in terms of traffic, it is logical to extract data and incorporate traffic simulations when available. The traffic simulations facilitate assessing the resilience on wide scope transport network scenarios by using quantitative methods able to measure the traffic volume, speed and trip duration (Robles, et al. 2020) which represent some of the most relevant aspects of the measure of services the transport system provides. The resilience can be evaluated by comparing the cases with and without the potential disruptive events (Deliverable D3.7).

Traffic simulations are not only applicable to existing transport systems, as CS#6, but can also provide useful information during planning and design phases. Simulations can be used to evaluate the resilience of different alternatives as well as preliminary designs (both with and without disruptive events). Then, results can be used to compare and select the best alternative (at planning stage) or the best design consideration (at design phase).

Furthermore, results from evaluating the resilience at early stages of the project will help to define. The type of design strategies that might be considered. For example, results from traffic simulations with and without disruptive events could reveal a high criticality of a link; in such case, it could be considered designing in extra redundancy or provide above normal reserve capacity.

The availability of a tool in which the Manager can immediately introduce different variables to solve the questions indicated below, and which the methodology explained in the Traffic Module of the Foresee Project allows, will be decisive for its application:

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

In conclusion, this tool will give the infrastructure manager a very important information to be able to predict the traffic volume and the duration of the closure time after an earthquake event. However, in Case Study 6, this task was not performed. Therefore, a possible improvement because of Task T3.4.1 is rated as equal in total.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 10. Questions & Impacts for Task T3.4.1 (Deliverable D3.7)

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	This tool gives us the possibility to improve the input data given to a traffic simulation model by using stochastic algorithms of Montecarlo. This kind of analysis is already performed by *Infraestruturas de Portugal* regarding this bridge or other crucial assets.
How does FORESEE improve the results/analysis previously made?	It might improve the input data for all traffic simulations, and therefore, the quality of the output data coming from those models. It also allows the simulation of the event, and its consequences on the specifically infrastructure and the incidence in the corridor/metropolitan area. It helps to define new possibilities of building a temporary alternative route for vehicles or the possibility of using another means to satisfy

	transport demand as well improve re-route Hazards and Flammable goods traffic. It can be used to define long-term traffic/mobility plans to achieve or improve the resilience of this bridge.
How does this FORESEE result improve your infrastructure's management	We have previous studies/reports regarding this bridge and training of the operators/stakeholders, for the application of measures during an event.
If it was not made, how does this FORESEE result improve your infrastructure's management?	It provides objectivity to decisions, which supports the results for third parties, especially for administrations/governments. From a technical point of view, it allows you to combine variables and obtain results directly. However, as already said *Infraestruturas de Portugal* have this kind of analysis incorporated on Asset Management Policy due to the importance of this bridge.
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%)	It is difficult to assess the individual contribution of each tool, in this case the "Traffic Module", but it will probably significantly reduce the costs associated with a traffic cut in the event of an event, reducing cut-off time and travel times on alternative routes. Given the high average daily intensity (ADI) of this infrastructure, only by obtaining a 5% -10 % reduction in time and its associated cost, we would be facing a substantial advance.

6.1.3 SOLUTION CATALOGUE – EARHQUAKE PLATFORM/SHAKEMAPS METHODOLOGY (T.4.2 – D4.5)

6.1.3.1 Guidebook

A seismic hazard assessment methodology has been developed in FORESEE to characterise the seismic action including directivity and local effects, based on data obtained from small seismic records and geotechnical field tests.

The methodology is based on the generation of shakemaps scenarios through the combination of two developments: simulation of synthetic time history records and characterization of site-effects based on empirical and semiempirical approaches. These semi-empirical Shakemaps are integrated into a GIS platform as a representation of the ground motion parameters distribution produced by a set of realistic simulated seismic events. The integration of the results into a GIS platform increases the exploitability of the characterization of the seismic action.

Through this methodology the following outputs are achieved:

- Realistic seismic records of a target seismic event are obtained from real seismic records of a small event. This semi-empirical development allows to simulate historical events of high magnitude and for which there are only descriptions of the consequences (e.g. collapse of the bell tower and cracks in most buildings).

- Site effects characterization through soil properties obtained from field tests. This empirical development helps to obtain the shear wave velocity profile depending on the depth. From this property, ground dynamic amplification is obtained as a frequency dependent function that modifies the amplitude of the incident seismic waves. These outcomes study site effects in a deeper detail than current regulations, in which soil properties are considered only as a variation of tabulated parameters in elastic response spectrum construction.
- The outcomes from these two different developments are compounded to generate simulated shakemaps scenarios. In order to describe the seismic action distribution for a target seismic event, three different procedures are applied:
    - Firstly, an analysis of historical seismicity in the seismogenic area is performed to set target events, depending on the return period established by regulation.
    - Then, time history records from seismic station are extrapolated to those locations where the structure of the soil is obtained by means of field test. This extrapolation is done following a methodology developed by CEM in D4.7.
    - Once ground motion parameters are obtained from time history records in seismic stations and field test locations, continuous maps are elaborated through interpolation functions.
- Finally, all this information that describes shakemaps scenarios, such as ground motion parameters distribution, is integrated in a GIS platform which increases the exploitability of the data of seismic action characterization. The integration of the information in a GIS platform allows to manage and analyse ground motion parameters together with any other socioeconomical information which may help to plan response actions to increase the infrastructure resilience.

INPUTS NEEDED

To be able to develop these semi-empirical shakemaps the following information would be needed:

- Geotechnical data: results from SPT and/or SPAC tests on the area of study.
- Seismic records.
- Focal mechanisms.

OUTPUTS

Semi-empirical shakemaps scenarios integrated into a GIS platform.

This methodology falls under the resilience category **"Research and Learning"** according to the classification provided in D7.5 of FORESEE.

This methodology provides a better understanding of the likelihood and consequences of the risks from extreme hazard events (in this case, earthquakes) and will allow for better planning of **response** activities.

Regarding the different principles of resilience, this methodology will contribute mainly to the **Adaptability** of the system: the methodology is based on gathering information from past events and understanding the likelihood and consequences of the events. Also, the simulations carried out allows for better planning response activities, therefore, increasing the **Resourcefulness** of the system. Additionally, a better definition of seismic parameters will improve the structural design of the infrastructures, making them more **Robust**.

Therefore, we can now see that there is a direct link between this tool and the next previously mentioned KRIs (section 3.3):

- E.1.2.4 - The presence of a warning system
- E.3.2.2 - Practice of the emergency plan
- E.3.2.3 - Review/update of the emergency plan
- E.4.2.4 - Update rate on the feedback of the structural condition
- E.8.2.1 - Long-term contingency plans
- E.8.2.2 - Long-term traffic/mobility plans

6.1.3.2 Results

No practical results have been provided for this tool.

6.1.3.3 Potential Improvements via the FORESEE TOOL " Shakemaps Methodology"

For the Shakemaps Methodology developed in T.4.2, no comparable systems are available from the infrastructure manager (Infraestruturas de Portugal) itself.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 11. Questions & Impacts for T4.2 (D4.5)

Question	***Impact***
Was this type of analysis made before FORESEE? How it was made?	The methodology implies a novel technique. Conventional seismicity maps of the area are usually consulted if necessary.
How does FORESEE improve the results/analysis previously made?	Current procedures to characterize the seismic action according to current regulations and seismic codes have the following weaknesses, which are overcome by this novel methodology: • Fault is considered as punctual in far field and seismic attenuation laws are based on radial interpolations. • Near field effects, like directivity, are not considered. It may lead to underestimation of seismic action and variations in its frequency content. • Hypocentre depth is not considered. It may lead to greater effects due to the vertical component of accelerations. The weaknesses on seismic action characterisation in regulations and the uncertainty regarding extreme earthquake events in zones of medium seismicity could lead to catastrophes when it comes to critical infrastructures such as transport infrastructures. This innovative methodology will

	mitigate and it´s very important for this particular bridge located in a high seismic zone.
How does this FORESEE result improve your infrastructure's management	The shakemaps integrated into a GIS platform allows infrastructure manager to manage and analyse the information provided by the shakemaps (related to different return periods) together with any other information, such as socioeconomic information. These developments provide a better understanding of the local seismicity as simulations are associated to feasible seismic magnitudes of the seismogenic area in terms of return periods. In this way, potential consequences due to seismic events can be assessed more precisely and be associated to probability of occurrence, which may help to plan response operations as well as better planning in the design phase. On the other hand, a better understanding of the local seismicity will be useful for making more robust designs of infrastructures as well their management.
If it was not made, How does this FORESEE result improve your infrastructure's management?	Once seismic action is characterised through this methodology, the infrastructure manager will be able to plan response actions oriented to increase the resilience of the infrastructure in case of an expected seismic event associated with a specific return period.
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%)	It is difficult to assess the individual contribution of each tool. On the one hand, if the methodology is used for better planning response operations, it would lead to reducing disruptions as well as damages. On the other hand, if the methodology is used during the design phase, it would lead to more robust designs according to the expected seismic magnitudes.

6.1.4 SOLUTION CATALOGUE - ALGORITHM TO DETERMINE OPTIMAL RESTORATION PROGRAMS (T.4.3 – D4.2 & D4.7)

6.1.4.1 Guidebook

The algorithm to determine the optimal restoration programs contains a description of all required inputs, a complete mathematical model and a search algorithm to be used to determine optimal restoration programs, for all objects in a network based on the minimization of the overall direct and indirect costs.

This algorithm enables the digital generation of optimal restoration programs in general. More specifically, it determines the optimal sequence and the restoration level/priority with which the damaged objects in the network should be restored so that it would result in minimum overall costs and a satisfactory level of service. These restoration programs are developed considering time, budget, and resource constraints.

The use of the algorithm will help infrastructure network managers develop improved restoration programs for their networks, resulting in minimum overall costs during the restoration period. The reduction in overall costs enhances the resilience of infrastructure networks. Moreover, the algorithm is beneficial for infrastructure managers in charge of the determination of the resilience of critical infrastructures to extreme events.

The algorithm to determine the optimal restoration programs contains a description of all required inputs, a complete mathematical model and a search algorithm to determine optimal restoration programs, for all objects in a network based on the minimization of the overall direct and indirect costs.

This study was an essential step in the field of risk-informed decision-making for complex infrastructure systems. Especially in the context of future resilience of infrastructures, the presented work forms the basis for numerous applied and scientific extensions. This includes investigating the application of reinforcement learning or a hybrid heuristic algorithm in the proposed model and comparing the results with SA and PSO. Or increasing the applicability of the proposed model by extending the scope of the study to interdependent networks as well as multi-hazard scenarios.

Therefore, we can now see that there is a direct link between this tool and the next previously mentioned KRIs (section 3.3):

- E.3.2.2 - Practice of the emergency plan
- E.3.2.3 - Review/update of the emergency plan
- E.4.2.4 - Update rate on the feedback of the structural condition
- E.8.2.1 - Long-term contingency plans

6.1.4.2 Results

No practical results have been provided for this tool.

6.1.4.3 Potential Improvements via Solution Catalogue " Algorithm to Determine Optimal Restoration Programs"

For the Algorithm to Determine Optimal Restoration Programs developed in T.4.3, no comparable systems are available from the infrastructure manager (Infraestruturas de Portugal) itself.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 12. Questions & Impacts for T4.3 (D4.2 & D4.7)

Question	***Impact***
Was this type of analysis made before FORESEE? How it was made?	For this bridge, restoration programs have always been developed, using prioritization rules based on economic or engineering criteria, such as prioritization based on the level of damage, on the importance or the criticality of the objects, etc.

How does FORESEE improve the results/analysis previously made?	This tool compared the efficiency of various heuristic algorithms in a real-world case study and used the most suitable one (PSO) in a novel double staged approach. Using the proposed model developed on this tool, a near-optimal solution can be found relatively quickly after the natural hazard event occurs. This is significant because when investigating real-world scenarios, the possible solution space can quickly become so large that it will not be possible to find the optimal result within a finite time. Additionally, the approach has the advantage of providing better solutions in comparison to using prioritization rules which is the benchmark model that is mostly implemented in practice. Due to its efficiency, the proposed model can be applied in this bridge, for different natural hazard events, such as earthquakes.
If it was not made, How does this FORESEE result improve your infrastructure's management?	The proposed model can be applied in networks of any size and for a variety of infrastructure types as well as for different natural hazard events. It is also beneficial for infrastructure managers who are responsible for determining the resilience of infrastructures to disruptive events. The model can provide estimations on the time that is required to recover the desired level of service following a disruptive event and provide insights on various possible restoration programs and the trade-offs between the direct and indirect costs. It´s a very interesting model, because includes constraints, such as limits on the available budget, resources and the type of intervention that can be executed per damage state, as well as varying traffic assignments caused during the implementation of the restoration program.
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%)	The successful implementation of this algorithm into appropriate software where the results will be the reduction in overall direct and indirect costs associated with intervention programs. The improvement in efficiency expected is 10-15% on average (in terms of reduction in costs, but the exact difference depends on the organization and its current processes. Additionally, it is expected that there will be 50% reduction in the number of hours required to generate and modify the restoration programs (compared to using other optimization approaches).

6.1.5 SOLUTION CATALOGUE - SHM ALGORITHMS (T.4.5 – D4.4 & D4.9)

6.1.5.1 Guidebook

Data-driven algorithms, model-based algorithms and data-driven algorithms supervised by FE models are implemented with successful results consisting of:

- Reliable alert systems of damage existence independent from environmental variability.

- Damage identification (location and severity estimation) by the combination of data-driven and model-based techniques.

The developed SHM algorithms for bridge structures, if integrated in a wider system, could detect damage and quantify it by its severity or by a deviation from the characterized reference behavior, thus they provide an insight of structural robustness before and after an event, and slightly contribute to resourcefulness, rapid recovery and adaptability, as they can quickly assess if an structure has not suffered damage or significative damage (so it can be used). As any other SHM algorithms, they do not imply physical actuation on the structure, only monitoring and quick assessment, which means a solid starting point for any resilience framework.

Results obtained and potential improvements

- Reliable alert algorithms which, once trained, could be included in a real-time alert system given their computational agility.

- New paradigm for damage identification using FE models with the standard complexity of engineering practice combined with Deep Learning techniques.

We can now see that there is a direct link between this tool and the next previously mentioned KRIs (needed to be improved):

- E.4.1.1 - Continuous vibration monitoring
- E.4.1.2 - Continuous stress and displacement monitoring of resistance elements
- E.4.1.3 - Continuous relative displacement monitoring of moving components and anti-seismic devices
- E.4.2.1 - Autonomous short-term electrical supply to the monitoring system installed on site
- E.4.2.2 - Permanent fail-safe communication of monitoring relevant information
- E.4.2.3 - SHM data analysis
- E.4.2.4 - Update rate on the feedback of the structural condition

6.1.5.2 Results

No practical results have been provided for this tool.

6.1.5.3 Potential Improvements via the Solution Catalogue "SHM Algorithms"

For the SHM Algorithms developed in T.4.5, comparable systems are available from the infrastructure manager (Infraestruturas de Portugal) itself, meanwhile they are not completely automated system but required always manual/technical responsible intervention/assessment.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 13. Questions & Impacts for T4.5 (D4.4&D4.9)

Question	***Impact***
Was this type of analysis made before FORESEE? How it was made?	Comparable analysis is available for this bridge. Infraestruturas de Portugal has a cooperation protocol with the Portuguese Nacional Civil Engineering Laboratory to monitor the overall structural behaviour and implementation of permanent monitoring system. The structural health monitoring system and framework is composed of 200 sensors with the capability of acquiring and processing data in real time. This system provides over 8500 million measurements per day, comprising accelerations, displacements, rotations, traffic, wind, ground acceleration, strain and temperature and can issue alerts in **near real-time**.
How does FORESEE improve the results/analysis previously made?	FORESEE D4.9 algorithms provide: (i) reliable and auto explainable artificial intelligence anomaly detection, (ii) a combined framework with the inclusion of commercial FE models at a consultancy standard engineering practice. Reliable alert algorithms which, once trained, could be included in a real-time alert system given their computational agility. - New paradigm for damage identification using FE models with the standard complexity of engineering practice combined with Deep Learning techniques.
If it was made, How does this FORESEE result improve your infrastructure's management?	The two SHM approaches developed in Deliverable 4.9 - algorithms and improved for the subsequent publications provide the infrastructure owner/operator with the ability to infer structural damage existence and to estimate its location and degree of severity within the bridge (asset level) in real time. The algorithms provide the infrastructure owner/operator, the ability to infer the structural state (existence of damage from a reference) if included in a SHM continuous monitoring framework. This will give the operator/owner the capacity of transcend the standard periodic maintenance framework for this type of

	bridges. The mixed approach combining calculation models and Deep Learning provides an estimation of the location and severity of the damage to guide visual inspections. For further developments and future improvements: - Reduction of the required monitoring data to trigger a reliable alert using data-driven algorithms. - More detailed consideration of uncertainty (measurement error and environmental variability) in FE models when supervising artificial intelligence algorithms. - Improve required computational time in both approaches. - Integration in an in-house SHM tool for real-time deployment.
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%)	There would be a benefit in security by the anticipation to structural collapse and also the actuation in an early state of damage progression, which makes the reparations less expensive and extends structure lifetime. A reliable SHM anomaly detection technique, if implemented in a continuous SHM system, means permanent control of the monitored asset that facilitates its inspection by demand, constituting a development that goes beyond periodic maintenance and conducts to an improvement for the safety and maintenance of the bridges.

6.1.6 CONTROL AND COMMAND CENTRE (T5.5 – D5.3/D5.6)

6.1.6.1 Guidebook

The Command Control Centre serves for training purposes to increase situation awareness of the users in the FORESEE Toolkit.

It provides interactive real time visualization and natural human computer interaction by using big data analytics and machine learning.

It uses neural networks to achieve efficient anomaly detection by learning the normal behavior of the infrastructure. This allows the neural networks to detect when new data points lay outside of this normal behavior and issue meaningful alerts.

It uses a supervised machine learning approach, using historical data randomly split into trainset and test set (80% - 20%). While the model is trained and built on trainset of historical data, the model ix fixed, tested and validated on the test set of historical data.

Once the model is trained and tested, whenever it is fed with new data (live data or near real time data), it can give prediction for anomalies such as earthquake events.

For the particular scenario of the *25 de Abril* Bridge, no tasks have been developed and no results have been provided for this tool.

However, we can now see that there is a direct link between this tool and the next previously mentioned KRIs (needed to be improved):

- E.1.2.4 - The presence of a warning system.
- E.1.2.7 - The presence of special measures to help evacuate persons.
- E.2.1.9 - Hazard's goods traffic.
- E.2.1.10 - Flammable goods traffic.
- E.4.1.1 - Continuous vibration monitoring.
- E.4.1.2 - Continuous stress and displacement monitoring of resistance elements.
- E.4.1.3 - Continuous relative displacement monitoring of moving components and anti-seismic devices.
- E.4.2.1 - Autonomous short-term electrical supply to the monitoring system installed on site.
- E.4.2.2 - Permanent fail-safe communication of monitoring relevant information.
- E.4.2.3 - SHM data analysis.
- E.4.2.4 - Update rate on the feedback of the structural condition.
- E.8.1.1 - Coordination between services.

6.1.6.2 Results

No practical results have been provided for this tool.

6.1.6.3 Potential Improvements via the FORESEE TOOL "Control and Command Centre"

One of the most interesting aspects of this tool is that it gives us an anomaly detection strategy on tabular sensor or multimedia data of critical transport infrastructure assets that can be done with machine learning techniques. The alarms raised using anomaly detection are meaningful and enhance the situational understanding of the infrastructure operators, leading to a faster detection time when problems occur, compared to a manual observation of the sensor data.

The outputs are a module based on raising automatically alerts of anomaly detections from sensors or multimedia data.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 14. Questions & Impacts for Task T5.5 (Deliverables D5.3/D5.6)

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	Currently, *Infraestruturas de Portugal* has a cooperation protocol with the Portuguese Nacional Civil Engineering Laboratory (LNEC) to monitor the overall structural behaviour and implementation of permanent monitoring system. Also, *25 de Abril* Bridge has implemented a Traffic and Emergency Control Centre that takes the decisions and updates dynamic traffic panel messages in roads as well on railway, for example, such as: traffic restrictions, alternative ways, reversible lanes, speed management, preferred vehicle treatment, emergencies, and other important and vital information. Procedures for critical reaction in the event of a hazard are available in the form of incident management, but no automated machine learning methods are provided for predictive warning.
How does FORESEE improve the results/analysis previously made?	It might improve. The current tools do not provide a complete analysis and overview of all the different factors and elements, and consequently a rapid response when needed.
How does this FORESEE result improve your infrastructure's management?	It makes easier and accurate. An anomaly recognized by the Command and Control itself with the aid of the Big Data analysis (using interpretable machine learning for Data Driven Decision Support using SHM data, traffic data and vulnerability of network), could generated an automated warning, which improves bridge reliability and resilience.
If it was not made, how does this FORESEE result improve your infrastructure's management?	It provides objectivity to decisions, which supports the results for third parties, especially for administrations/governments. The main factor is the capability to define asset's vulnerability/fragility against a specific hazard type and magnitude: the result of this activity can be used to asset's operability losses for different damage levels scenario make a vulnerability analysis to quantify the potential losses in terms of operability and traffic continuity or even if the bridge could be on service after a hazard.
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%)	It is difficult to assess the individual contribution of each tool, in this case the "Command-Control Centre", but it will probably significantly reduce the costs associated with post-analysis, event management, reducing cut-off time and travel times on alternative routes. Given the high average daily intensity (ADI) of this infrastructure, only by obtaining a 5% reduction in time and its associated cost, we would be facing a substantial advance.

6.1.7 PLANS REVIEW" (T7.2, T7.3, T7.4)

6.1.7.1 Framework for Application of Foresee Resilience Plans (D7.1)

6.1.7.1.1 Summary of the tool

Here we present the main conclusions extracted from Deliverable D7.1:

Work Package WP7 is focused on developing resilience plans, covering the whole lifecycle of the infrastructures, with the aim of:

1. **Reducing the impact and consequences of extreme events.**
2. **Increasing the ability to recover from them.**

According to Deliverable D7.1, one of the outcomes of the Work Package WP7 are three different resilience plans that will enable reducing the impact and consequences of extreme events; in other words, that will improve the resilience of the system.

These plans will cover the whole life cycle of the infrastructure as well as the resilience principles and phases should include:

1. **Design, construction, and remediation plans.**

   These plans will include new design approaches based on performance-based design procedures to adapt and increase the Level of Service (LOS) and resilience of existing and future infrastructures.

2. **Operational and maintenance plans.**

   These plans will provide a process to determine optimal intervention programs to increase the level of reliability and service of the infrastructures. These plans will also include methodologies, systems, procedures and materials to increase factors such as safety, efficiency or productivity.

3. **Management and contingency plans.**

   These plans will develop new and more effective contingency and communication strategies to enhance the resilience of the transport system. Communication plans are key to mitigate the adverse consequences, by instigating the evacuation of users in a safe way, as well as by helping recover the normal service as quickly as possible.

Figure 11 illustrates the principles and stages of resilience together with the three Resilience Plans to be developed in the FORESEE Project. As it can be inferred, the first two plans are more focused on increasing the physical resilience of the systems and maintaining some/all the transport capacity offer, so that when an extreme event occurs, people and goods are still able to continue their trips. Also, these plans are focused on providing monitoring strategies and procedures to restore services as quickly as possible. On the other hand, Management and Contingency plans are more focused on the transport demand, ensuring clear and effective communication to users so that the impact of the extreme event is minimized.

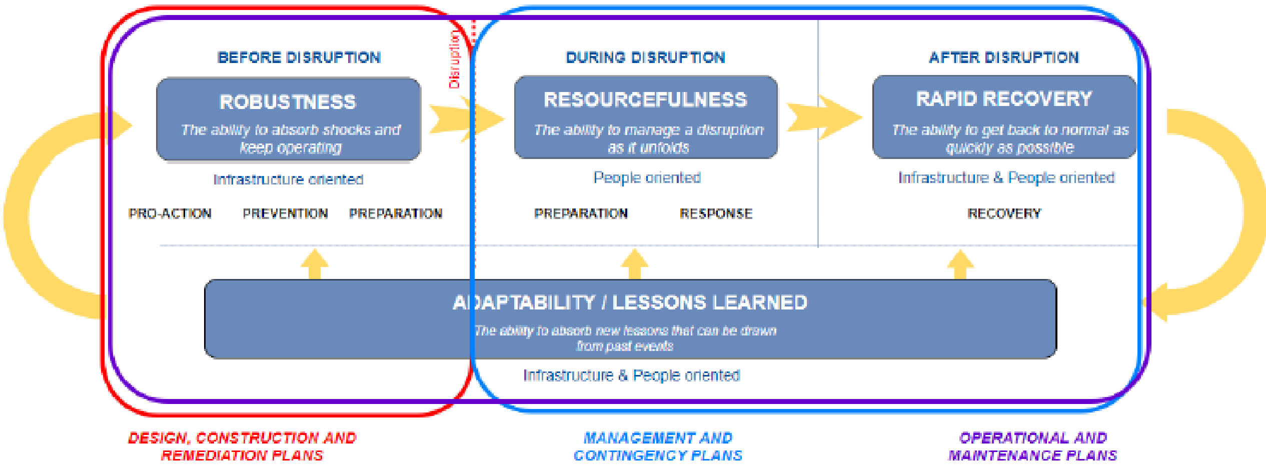


Figure 11. Resilience Concepts and FORESEE Resilience Plans (from Deliverable D7.1).

Resilience Plans may serve as a guideline to help infrastructure owners and operators in understanding not only the underlying meaning of resilience, but also to understand how it develops over time and how it can be improved/modified during the infrastructure's life cycle.

Resilience can be measured with two different procedures, developed in the project, assumed traffic simulations or indicators as in Deliverables D1.1 and D1.2.

In the proposed approach, resilience indicators may be assembled in function of the four fundamental concepts underlining resilience:

1. Robustness: the ability for transport infrastructure to overcome and absorb disruptive event shocks and continue operating. This concept is mainly (oriented toward the physical parts of the infrastructure.
2. Resourcefulness: the ability to skilfully manage a disruption as it unfolds. It is primarily people oriented as it is related for example to prioritizing what should be done.
3. Rapid recovery: the ability to get "back to normal" as quickly as possible after a disruption.It is oriented towards people as well as towards the infrastructure.
4. Adaptability: the ability to absorb new lessons that can be drawn from past events to improve resilience.

This would lead to understand where to concentrate efforts possibly also in function of the organization's strategies and objectives.

The procedure would be particularly useful in the phase of conception and planning of the infrastructure where design may be modified because of the "resilient approach".

The Deliverable D7.1 promotes a Resilience Plan Framework based on four steps:

- System definition.
- Hazard definition and potential impacts from the point of view of the operation, as well as from an economic, social, and environmental perspective.
- Resilience evaluation.
- Resilience plans application.

Apart from being applicable in different stages in the life cycle, the different resilience plans are focused on the different elements that contribute to the "system infrastructure" with the aim of assuring safe and seamless, even if reduced, mobility, in the presence of an event.

It has to be noticed, however, that the stages do not represent steps in the service life of the infrastructure but are defined with reference to the resilience approach (Deliverable D7.1):

a) Pro-action: activities aimed at avoiding the occurrence of the disaster (disruptive event).
b) Prevention: activities aimed at minimising the vulnerability of an element to a given hazard.
c) Preparation: activities carried out in preparation of an extreme event to reduce consequences.
d) Response: activities developed during an extreme event.
e) Recovery: activities developed after a disruption to restore services as soon as possible.

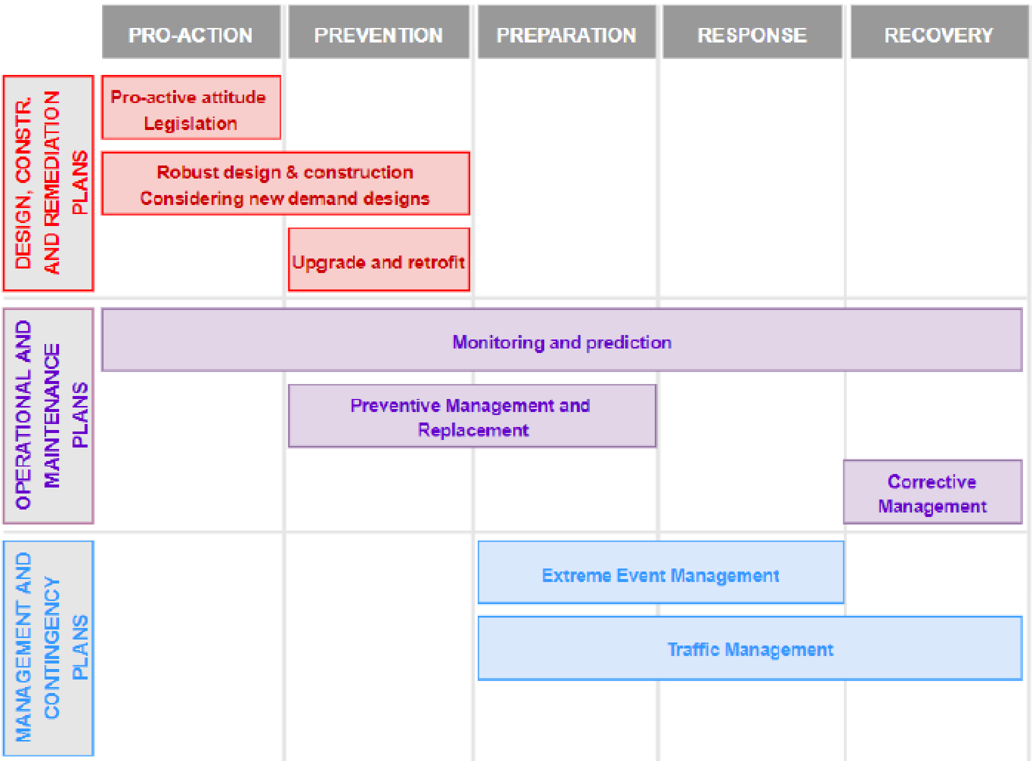


Figure 12. Resilience Stages and FORESEE Resilience Plans (from Deliverable D7.1)

Resilience plans are developed according to the following scheme, where the actions to be done for each step are indicated and how resilience contributes to the definitions of the different resilience plans.

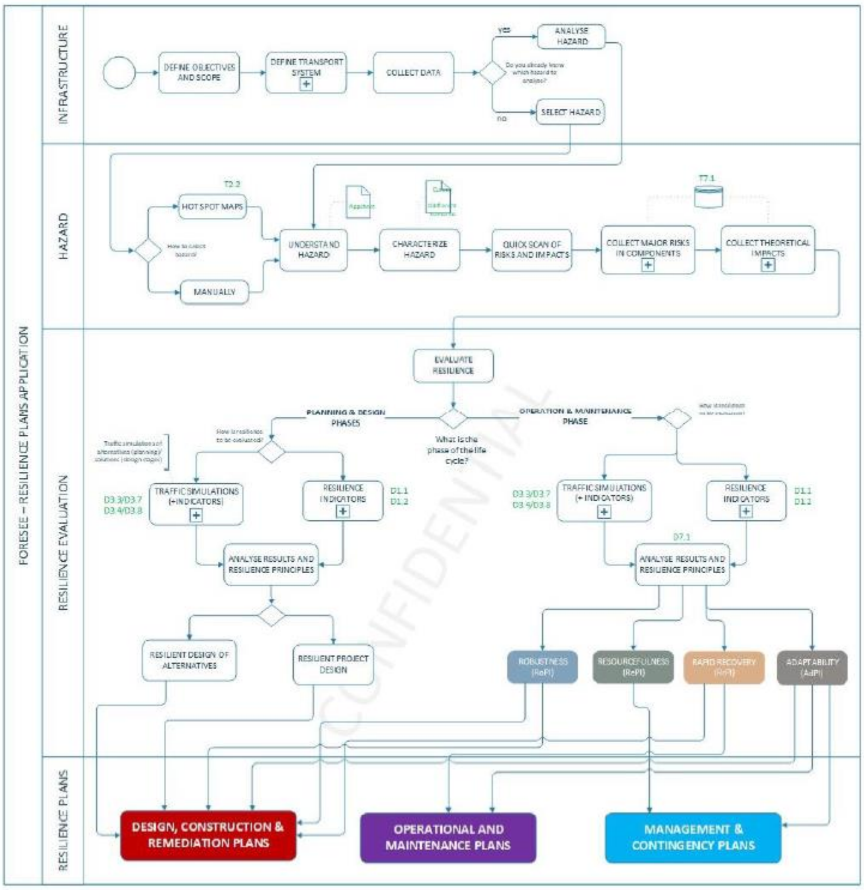


Figure 13. Resilience Plans Application (from Deliverable D7.1)

A set of use cases has been defined covering a wide range of transport infrastructure and identifying what are the main risks and impacts that a hazard may cause in a transport system.

As far as it concerns to roads and railways, the system infrastructure is identified by the following physical components (Figures 14 and 15).

These elements represent, in general, a set of possible components that should be detailed or reduced in function of the specific risks addressed.

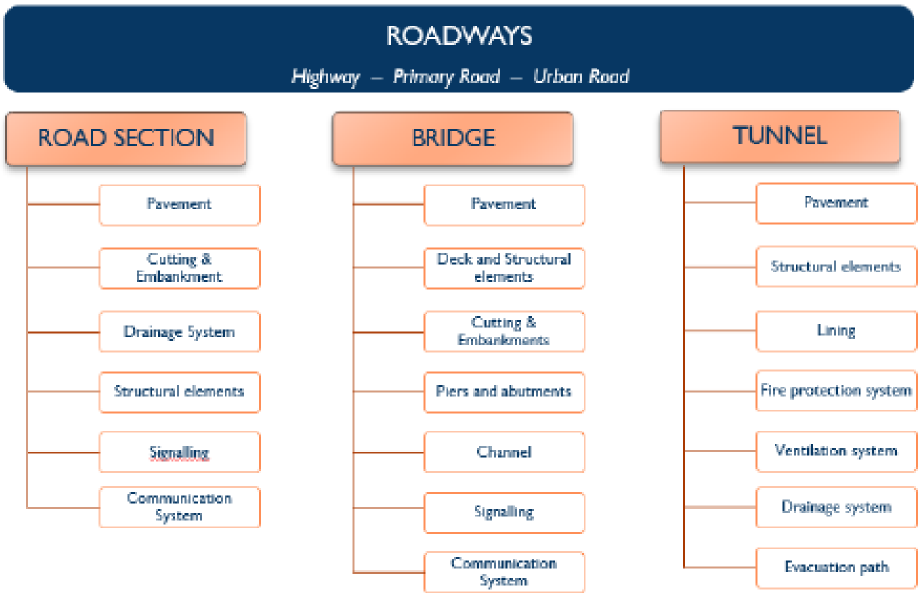


Figure 14. Roadway Networks, Systems and Components (from Deliverable D7.1).

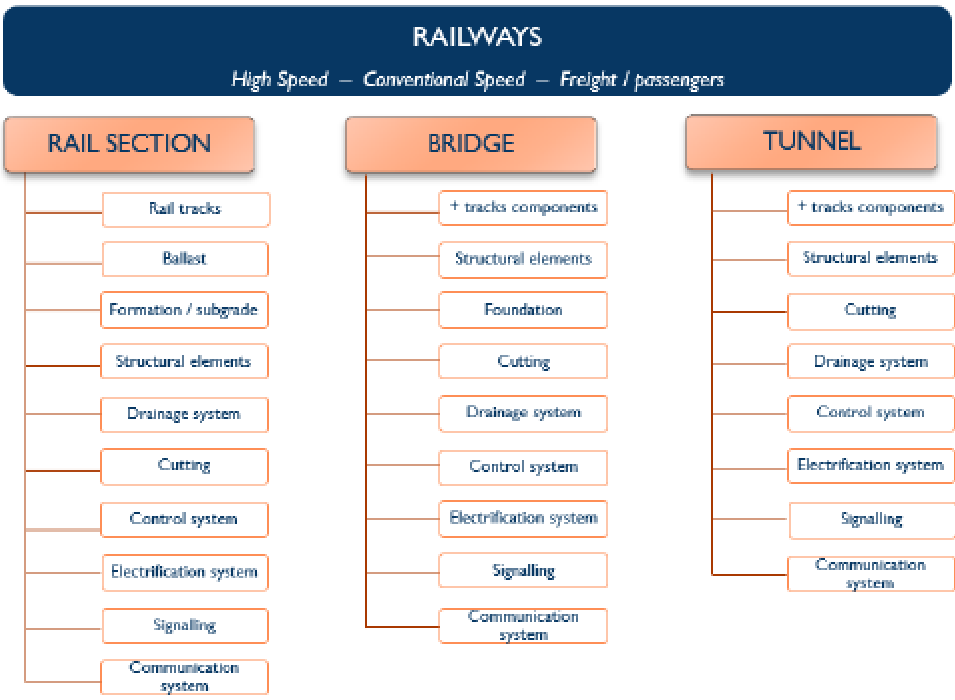


Figure 15. Railway Networks, Systems and Components (from Deliverable D7.1).

As far as it concerns CS#6, the most relevant use-case for the development of resilience plans is "use case 02 - Highway (with bridges) for earthquakes".

For each component, a set of possible general risks is defined that may be triggered by an earthquake, independently from the main components. The same applies to the definition of the theoretical impacts because of an earthquake. The process should therefore be tailored to the specific problem at hand.

In this particular use case 02, as shown on Deliverable D7.1, it has been considered for analysis the route of a highway with bridges that is located in high seismicity area.

- **What can happen?**

Similarly, each of the components that assemble the highway were analyzed to identify which are the major risks that an earthquake may cause.

In this case, additionally to the components from the highway section (i.e.: pavement) it was also included the components of a bridge (i.e.: piers).

Table 15 shows the obtained results: the first column indicates the component considered and, on the right, the major risks that could happen.

Table 15. Use Case 02: Risks on Components (from Deliverable D7.1).

ROADWAYS - GENERAL		EARTHQUAKE
ROAD COMPONENT	RISK ID	MAJOR RISKS
Pavement	PV.01	Cracking
	PV.02	Loss of capabilities
	PV.03	Loss of integrity
Communication system	CM.01	Equipment failures
Drainage system	DR.02	Obstruction
	DR.03	Structural damages and erosion
	DR.04	Collapse
Embankment / cutting (slope)	EC.01	Erosion
	EC.02	Lack of stability
	EC.03	Retaining walls tilting and bulging
Formation / subgrade	FS.01	Lack of stability
Material	MA.01	Loss of loading capacity
Pavement, structure and foundation (global)	PSF.01	Increase of uplift pressures
Signalling	SI.01	Equipment failures
	SI.02	Damage to signs, lighting and supports
	SI.03	Collapse
Structural elements (global)	ST.01	Loss of loading capacity
	ST.02	Cracking
	ST.03	Collapse
BRIDGE COMPONENTS		
Foundation	FO.01	Erosion
	FO.02	Settlement
	FO.03	Lack of stability
Piers and abutments	PA.01	Elements burn or melt
	PA.02	Excessive displacement
	PA.03	Settlement
Channel	CH.01	Erosion
	CH.02	Reduced clearance under bridge
	CH.03	Debris flow
Deck and structural elements	DE.01	Instability
	DE.02	Unfastening of expansion joints
	DE.03	Additional load

- **If it does happen, what are the consequences?**

Next, theoretical impacts following an earthquake are analyzed. Table 16 shows the results obtained: the first column indicates the type of impact identified (operational, safety, etc.) and, on the right, the theoretical impacts.

Table 16. Use Case 02: Theoretical Impacts (from Deliverable D7.1)

ROADWAYS		*EARTHQUAKE*
TYPE OF IMPACT	IMPACT ID	IMPACT DESCRIPTION
Operational	OP.01	Reduced traffic capacity
	OP.02	Temporary closure
	OP.03	Collapse / long-time closure
	OP.04	Traffic restrictions
	OP.05	Travel delays
	OP.06	Infrastructure lifespan decrease
	OP.07	Difficult traffic management
Safety	SF.01	Accidents (vehicles)
	SF.02	Accidents (objects)
	SF.04	Involuntary vehicle displacement
	SF.05	Passage obstruction
	SF.07	Vehicle immobilization
Social - safety	SS.01	Direct loss of lives
	SS.02	Indirect loss of lives
	SS.03	Difficulty for response operations
Social	SO.01	Quality of transport service
	SO.02	Loss of reputation
Economic	EC.01	Maintenance costs
Socio - economic	SE.01	Isolation of areas
	SE.02	Reduced access to destinations
	SE.03	Disruption of economic activity
	SE.04	Increment of travel time
Environmental	EN.01	Pollution
	EN.02	Hazardous products release
Environmental - economic	EE.01	Pollution costs increase

An earthquake is the shaking of the surface of the Earth resulting from a sudden release of energy in the Earth's Lithosphere that creates seismic waves.

- **Types – What kinds of earthquake hazards can occur?**

An earthquake can take place mainly according to one or more of the following processes:

- **Tectonic Earthquakes (natural)**: The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an earthquake that releases energy in waves that travel through the earth's crust and cause the shaking that we feel.

  A huge tremor occurs when two moving tectonic plates slide over one another. Tectonic earthquakes are the most prevalent kinds of earthquakes in the world.

- **Volcanic Earthquakes (natural)**: Volcanic earthquakes come in two forms: long-period volcanic earthquakes and volcano-tectonic earthquakes. Volcano-tectonic earthquakes usually happen after a volcanic eruption.

- **Explosion Earthquakes (manmade)**: These are caused by nuclear explosions. They are, essentially, man triggered kind of earthquakes.

- **Collapse Earthquakes (manmade)**: These kinds of earthquakes are generally smaller and most commonly occur near underground mines. They are sometimes referred to as bursts mines.

As shown above, earthquakes can be natural or man triggered, however, the most common are natural ones.

- **Main causes - What can an earthquake be due to?**

An earthquake can be caused mainly by one of the following aspects or by a combination of several of them:

- **Natural forces:** Earthquakes are caused by the sudden release of energy within some limited region of the rocks of the Earth. The energy can be released by elastic strain, gravity, chemical reactions, or even the motion of massive bodies. Of all these the release of elastic strain is the most important cause, because this form of energy is the only kind that can be stored in sufficient quantity in the Earth to produce major disturbances.

  Earthquakes associated with this type of energy release are called tectonic earthquakes.

- **Volcanism:** The disturbance is the result of a sudden slip of rock masses adjacent to the volcano and the consequent release of elastic strain energy.

  The stored energy, however, may in part be of hydrodynamic origin due to heat provided by magma moving in reservoirs beneath the volcano or to the release of gas under pressure.

- **Artificial/human induction:** Earthquakes are sometimes caused by human activities, including:
  - **The injection of fluids into deep wells (Fracking, gas storage, etc.),**
  - **The detonation of large underground nuclear explosions,**
  - **The excavation of mines,**
  - **And the filling of large reservoirs.**

In the case of deep mining, the removal of rock produces changes in the strain around the tunnels. Slip on adjacent, pre-existing faults or outward shattering of rock into the new cavities may occur. In fluid injection, the slip is thought to be induced by premature release of elastic strain, as in the case of tectonic earthquakes, after fault surfaces are lubricated by the liquid.

6.1.7.1.2 Conclusions

The guideline presented in Deliverable D7.1 offers a useful insight to the different aspects linked to the evaluation of resilience, from its understanding down to the consequences of events and associated recovery measures, indicating the main steps to follow in the assessment of resilience plans.

A set of use cases covering a wide range of transport infrastructure and risk scenarios, to guarantee a holistic approach, is proposed. Results have been built by interaction with the different partners and by shared questionnaires.

The validation is made from a theoretical point of view.

As the document is built upon the results from other Work Packages of the project, it would have been interesting to apply the computation of the Resilience-principles Performance Indicators to the set of data resulting from the application of the Deliverables D1.1 and D1.2 to the different case study where the level of service, the resilience and related targets have been calculated.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 17. Questions & Impacts for Deliverable D7.1.

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	This type of analysis has not been performed. Sometimes, depending on the asset characteristics/importance, risk, and planning management, as well Cost-Benefit Analysis are carried out, where risks, impacts, profits and actions to the undertaken are identified.
How does FORESEE improve the results/analysis previously made?	The proposed approach could be used to guide the definition of framework resilience plans for operation purposes in compliance with the risk strategies, objectives, and management procedures of the organization. Also, it gives to an infrastructure manager a clear framework that will serve on the one hand, as a tool to drive the steps to evaluate the resilience of a transport system facing an extreme event, considering a risk assessment (risks and impacts that a hazard may cause in the transport system) and, on the other hand, to guide the application of the FORESEE Resilience Plans according to the results from the resilience evaluation.
How does this FORESEE result improve your infrastructure's management?	Improved traffic flow, increased mobility, preparedness response pre/during and after an event.
If it was not made, how does this FORESEE result improve your infrastructure's management?	It provides objectivity to response capacity, which supports the results for third parties, especially for administrations. From a technical point of view, we will be able to obtain a resilience value for each of the critical elements, and as a whole infrastructure/transport system.
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%)	Expected outputs would result in an optimization of resources (economic, personnel travel time). However, it´s complex to assess the individual influence of each tool, in this case the "Plans Based on use cases, risk scenarios and 7.1 impact analysis", but it will undoubtedly reduce infrastructure management costs, increasing its capacity. response to extreme events.

	Being a tool to be used to assess a strategy to approach risk and resilience, a positive ROI. between 5%-10% in reduction costs would be a substantial advance.

Deliverable D7.1 includes the framework that will serve on the one hand, as a tool to drive the steps to assess the resilience of a transport system to an extreme event and, on the other hand, to guide the implementation of the FORESEE Resilience Plans according to the results of the resilience assessment.

6.1.7.2 Design, Construction and Remediation Plans (T7.2 - D7.5)

6.1.7.2.1 Summary of the tool

In Deliverables D7.2 and D7.5, resilience was characterized using the following four principles, which are: **robustness** (i.e.: the ability to absorb shocks and keep operating), **resourcefulness** (i.e.: the ability to manage a disruption as if unfolds), **rapid recovery** (i.e.: the ability to get back to normal as quickly as possible) and **adaptability** (i.e.: the ability to absorb new lessons that can be drawn from past events).

The objective of this deliverable is to present a design resilient aware approach based on **performance criteria**, which will allow evaluating the functionality of a transport infrastructure under different **risk scenarios**, to set different performance objectives during and after an extreme event, according to the needs of the community and stakeholders.

To be able to analyze the variation in performance during an extreme event, performance measures are needed. Since resilience is a combination of service quality and recovery time during and after a hazard event, the following performance metrics have been defined:

- **Performance Levels:** this parameter encompasses both the level of damage observed in the infrastructure after a hazard event and the level of service that the system can provide (e.g.: fully operational, partially closed, etc.).
- **Recovery Time:** this parameter represents the period of time needed to restore the service to a desired level. It can typically range from hours to months.

The proposed performance-based design approach consists of setting objectives for these two measures (performance level and recovery time).

Nevertheless, setting performance objectives is only meaningful if the level of hazard against which they are being set is also specified.

For this reason, **three hazard levels** have been defined: **routine, design and extreme** and performance objectives will be established for those hazard levels.

In this document, a methodology has been developed to objectively assess the criticality of a route/bridge.

The methodology consists of a separate assessment of the following four criteria:

- **Criterion 1: Operational and economic relevance.**

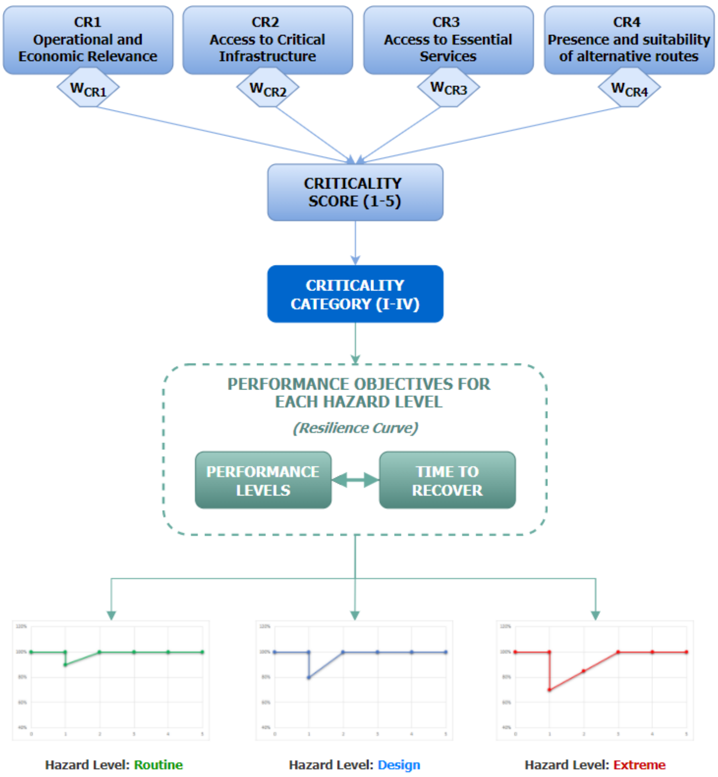
- **Criterion 2: Access to critical infrastructure.**
- **Criterion 3: Access to essential services.**
- **Criterion 4: Presence and suitability of alternative routes.**

For each criterion, a score is obtained in a 1-5 scale (where 5 means high criticality). Then, a weight is allocated to each criterion and a global criticality score is obtained. According to this final score, the route is classified as follows:

- Category I: Vital.
- Category II: Major.
- Category III: Significant.
- Category IV: Normal.

Once the "Criticality category" of the infrastructure is defined, the next step is to set performance objectives in terms of performance levels and recovery time.

This tool allows to calculate the criticality of the infrastructure as well as to build the resilience curves obtained for each route analyzed, based on the objectives set for performance levels and recovery times.



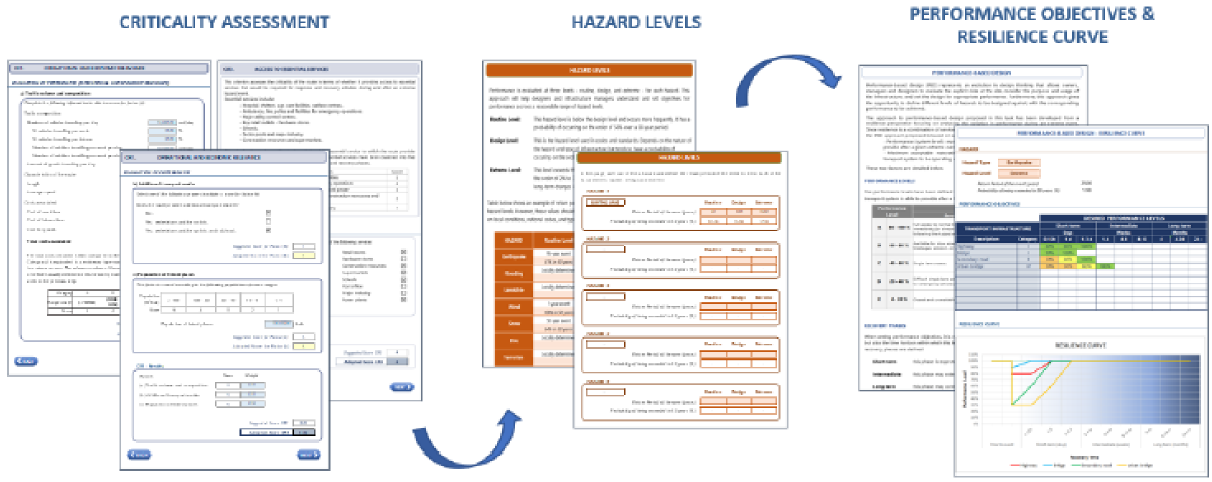


Figure 16. Tool Overview (from Deliverable D7.5).

6.1.7.2.2 Results of practical application on CS#6

The results performed *Infraestruturas de Portugal* with CEMOSA collaboration are presented on Annex 2 (Section 2.2).

6.1.7.2.3 Improvements via the FORESEE TOOL D7.2 - Summarize and related key resilience indexes

The main input data is the following:

- **Traffic composition (number and type of vehicles).**
- **Characteristic of the route (length and average speed).**
- **Cost of travel time.**
- **Additional transport modes.**
- **Population.**
- **Presence of critical infrastructure (energy, water, transportation hubs…).**
- **Presence of critical services (hospitals, fire station, police stations…).**
- **Return period of the event and probability of exceedance.**

The output data is the following:

- **Performance level.**
- **Recovery time.**

Let us remember all the Key Resilience Indexes that were previously selected:

ID	Indicator
E.1.2.1	The possibility of building a temporary alternative route for vehicles
E.1.2.2	The possibility of using another means to satisfy transport demand
E.1.2.4	The presence of a warning system
E.1.2.7	The presence of special measures to help evacuate persons
E.2.1.9	Hazards goods traffic
E.2.1.10	Flammable goods traffic
E.3.2.2	Practice of the emergency plan
E.3.2.3	Review/update of the emergency plan
E.3.2.4	Expected time for tendering
E.4.1.1	Continuous vibration monitoring
E.4.1.2	Continuous stress and displacement monitoring of resistance elements
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site
E.4.2.2	Permanent fail-safe communication of monitoring relevant information
E.4.2.3	SHM data analysis
E.4.2.4	Update rate on the feedback of the structural condition
E.6.1.2	Corrective maintenance interventions
E.7.2.1	Seismic risk studies
E.8.1.1	Coordination between services
E.8.2.1	Long-term contingency plans
E.8.2.2	Long-term traffic/mobility plans

Therefore, we can now see that there is a direct link between this tool and the next previously mentioned KRIs:

- E.1.2.4 - The presence of a warning system.
- E.1.2.7 - The presence of special measures to help evacuate persons.
- E.3.2.2 - Practice of the emergency plan.
- E.3.2.3 - Review/update of the emergency plan.
- E.3.2.4 - Expected time for tendering.
- E.4.2.4 - Update rate on the feedback of the structural condition.
- E.6.1.2 - Corrective maintenance interventions.
- E.8.1.1 - Coordination between services.
- E.8.2.1 - Long-term contingency plans.
- E.8.2.2 - Long-term traffic/mobility plans.

6.1.7.2.4 Conclusions

This work seeks to identify tools to ensure the resilience of infrastructure in its different phases, from the Evaluation/Decision Phase, Design to the in-service phase.

As shown in Figure 17, the different phases of the life cycle of an infrastructure can be summarized and grouped into three phases: (1) evaluation and decision, (2) design and construction, and (3) operation and maintenance.

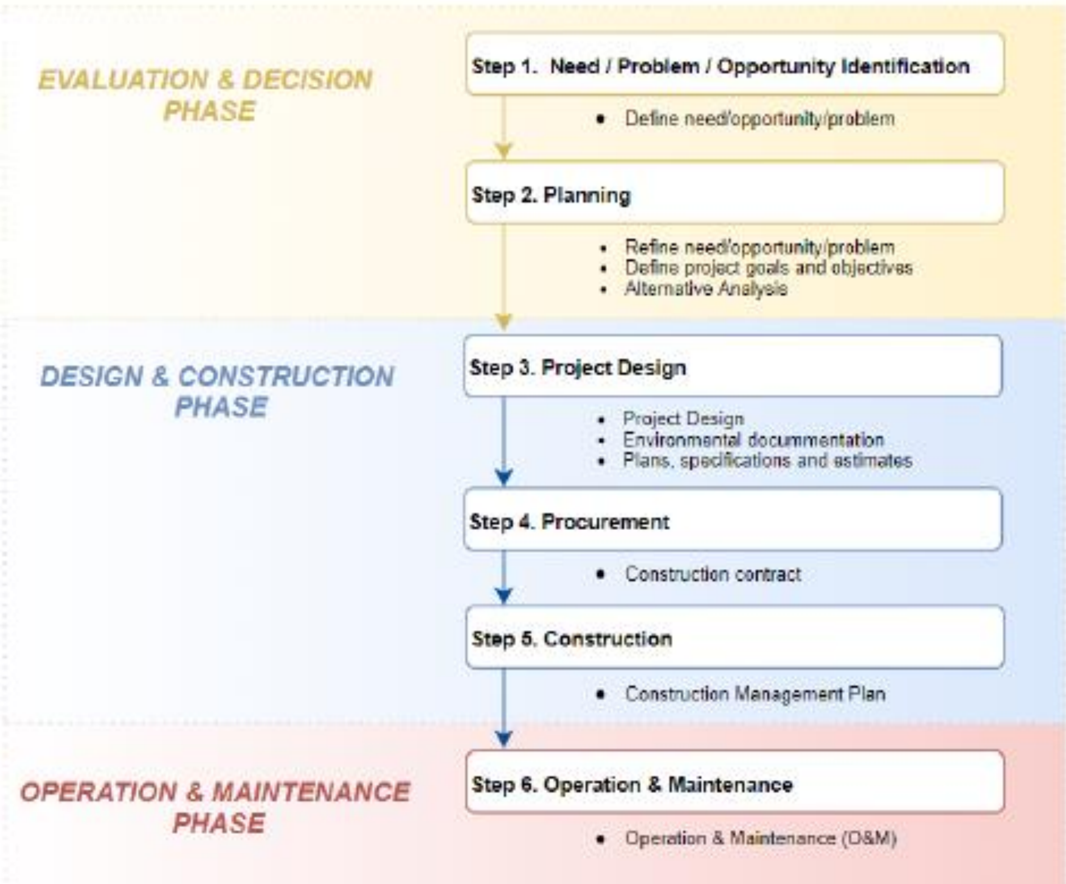


Figure 17. Infrastructure's Life Cycle (Deliverable D7.5).

Deliverable D7.5 explains all the main steps involved in the development of an engineering project, with the aim of highlighting the importance of a robust planning process and the role of resilience during early design phases.

As shown on Deliverable D7.5, the objective of the Task T7.2 was to present a design resilient aware approach based on **performance criteria**, which will allow evaluating the functionality of a transport infrastructure under different **risk scenarios**, to set different performance objectives during and after an extreme event, according to the needs of the community and stakeholders. Furthermore, Deliverable D7.5 also presents a catalogue of measures to improve the resilience of the infrastructure.

An excel tool has been defined and developed to assess the criticality of the infrastructure.

25 de Abril Bridge, which is the case in point, despite her age, has gone through all the steps foreseen in the existing road and railway regulations in Portugal, which are listed in this tool, and which are specified as follows:

- Stage 1: Identification of a demand/problem/opportunity.
- Stage 2: Planning.
- Stage 3: Project design.
- Stage 4: Tendering / competition.
- Stage 5: Construction.
- Stage 6: Operation and maintenance phase.

The Foresee Project provides that, from the analysis of the preliminary planning and design and the successive steps, it can be extracted that it is at this stage that the general characteristics of the new infrastructure are defined, such as location, alignment or grade level, which can have a great influence on the final design of the infrastructure components, as well as on the resilience of the infrastructure.

The work for *25 de Abril* Bridge has focused more directly on the analysis and assessment of indicators related to the Operation & Maintenance phase, other indicators have been included that refer to other processes related to the aforementioned stages, for example when dealing with the age of the infrastructure or the replacement, values of the damage suffered in the event of an earthquake, the replacement time and others, all of them determining factors for the assessment of the resilience capacity of the infrastructure.

We have considered as decisive those indicators that allow monitoring of compliance with the provisions of current regulations and concession contract between *Infraestruturas de Portugal* and Portuguese Government, indicators subject to constant monitoring through the Management and Quality Plan and both internal and external audits.

As known, acceptable levels of performance of the transport system, in this use-case, a bridge, during and after extreme events can be perceived differently by the community and by the managing authority of the infrastructure. Thus, this section is focused on developing a procedure to assess the role that the transport asset plays during day-to-day and emergency activities, as well as the interdependence with other sector's infrastructure. This will allow to objectively establish minimum performance levels and recovery times.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 18. Questions & Impacts for Task T7.2 (Deliverable D7.5).

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	This type of analysis with resilience as a criterion has not been performed. As far as it concerns the evaluation & decision, design & construction and operation & maintenance stages, different standards and procedures are available, and the process is clearly defined by *Infraestruturas de Portugal*.

	For instance, the process of planning and/or assessing the needs of a new infrastructure is quite complex and see the involvement of different stakeholders from public authorities (i.e Ministry of Infrastructures and Transport) down to local communities. Regarding Design & Construction phase, National and European Regulations as well law-decrees and national legislation are considered. Once the transport infrastructure has been built, it begins the phase of the Operation & Maintenance, usually considered together, which defines activities as **Operations** (day-to-day activities required to provide service delivery to the users of the transport system/bridge) and **Maintenance**: permanent functional checks, monitoring testing, measuring, servicing, repairing or replacing of necessary equipment, infrastructure, and supporting utilities so that assets can perform the required functions and achieve the intended service objectives throughout the expected life of the asset.
How does FORESEE improve the results/analysis previously made?	This tool tries to determine procedures that make possible to guarantee the resilience of the infrastructure in its different phases, from the evaluation/design to the in-service phase. It introduces the concept of resilience and the calculation procedures for its evaluation.
How does this FORESEE result improve your infrastructure's management	The added value of the methodology developed is that it provides a systematic evaluation to ensure that the level of service or performance expected by the different stakeholders is considered. This allows infrastructure managers to include resilience aware approaches from the early design phases to maintenance/operation phase. Furthermore, the methodology provides useful information on the different performance requirements (in terms of resilience) of the asset considered, in this case a vital infrastructure (bridge). It also presents a methodology for classifying measures to build resilience. This procedure provides a useful method to systematically identify, categorize, and assess measures in terms of their contribution to the resilience. It can help on the improved traffic flow and increased mobility.
If it was not made, how does this FORESEE result improve your infrastructure's management?	It helps with the audit in the different phases in order to achieve adequate resilience of the infrastructure, with a process that guarantees the achievement of the planned service objectives.
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%)	Expected outputs would result in an improvement and optimization of resources (economic, personnel travel time) for management of the emergency situation and pro-active interventions. As part of the tools that make up the Foresee Project, in this case it is about guaranteeing the service objective, and as has been said repeatedly, achieving a cost reduction of 5% would mean a notable improvement in general results.

As aforementioned stated, Deliverable D7.5 contains an analysis of the entire procedure (design-approach based on resilience performance criteria) proposed in the Foresee Project for the different phases of the infrastructure, relating the decisions and solutions adopted with the expected resilience, expressed in quantitative terms.

As mentioned on Deliverable D7.5:

"*(…) the design approach allows evaluating the transport infrastructure behaviour under different risk scenarios, in order to set different resilience performance objectives during and after an extreme event, according to the needs of the community and stakeholders. To this end, a methodology has been developed to objectively assess the criticality of transport infrastructures and to set resilience performance objectives. Criticality is assessed by evaluating a number of criteria that encompass economic or traffic relevance as well as social needs. Then, this assessment forms the basis for setting resilience objectives in terms of performance targets and associated recovery time.*

The theory and practice of the performance-based design is not new to engineering, since for example it is currently being used in seismic design of buildings. However, this approach is seldom used or even non-existent in design phases considering other extreme hazard events (such as floods or high winds) taking into account the resilience perspective. Therefore, the added value of the methodology developed here is the attempt to formalize this decision-making process related to the expected performance on the transport infrastructure design process. It allows designers and infrastructure managers to include resilience aware approaches from the early design phases as well as to consider the criticality of the infrastructure. Furthermore, the way the information is represented (in the form of resilience curves) facilitates the understanding of the different performance requirements of each asset under different levels of hazards. This allows infrastructure managers to easily identify where to focus efforts for enhancing resilience, that is, whether it is needed to focus on designing for strengthening the robustness of the system or for strengthening the capacity to recover. It also presents a methodology for classifying measures to build resilience. This procedure provides a useful method to systematically identify, categorize, and assess measures in terms of their contribution to the resilience. The methodology has been applied to the different procedures and tools developed in FORESEE project. The information has been collected in a data sheet form and a FORESEE Tool Catalogue has been created.

The procedure for the application of the Design, Construction and Remediation plan brings together the two methodologies presented (together with other FORESEE outcomes) in order to provide infrastructure managers a systematic structure to (i) introduce resilience from early stages of project development; (ii) to establish overall resilience performance goals taking into account infrastructure owners/managers as well as community needs; and (ii) to define, categorize and rationally rank interventions according to their contribution to system's resilience."

In the opinion of those responsible for this report, resilience is very crucial and is a distinctive characteristic of the infrastructure because any infrastructure manager pretends, after an event, to avoid the decreasing of the expected level of service, and consequently lose an important part of the usefulness of the infrastructure.

In conclusion, we considered both the methodology developed and the tool useful for infrastructure managers to have an overview of the resilience of the system and to analyse the criticality of the infrastructure.

Therefore, this tool will give the infrastructure manager a very important information to be able to predict the duration of the closure time after the earthquake event, and very a useful information to update and manage the emergency and the contingency plans.

6.1.7.3 Operational and Maintenance Plans (T7.3 - D7.6)

6.1.7.3.1 Summary of the tool

The main goal of this tool is the definition of operational and maintenance resilience schemes to reduce the impact and consequences of extreme events onto civil infrastructures as rail, road, hubs and networks, covering their whole life cycle and for all end users: IM and operators, drivers, passengers, freight.

The application of resilience schemes is directed through the development of a tool that centralises, as an interactive catalogue tool, the indications and guidelines required to implement the resilient schemes developed in FORESEE defining the infrastructure type and hazard related. To do so, in this tool the main line of work is focused in:

- First, collect the infrastructure definition and information with all the data available of the asset studied.
- After the data collection, a Risk assessment follows in order to prioritize and identify actions and main hazards associated to the infrastructure.
- The new operational and maintenance plans are developed focused in giving the guidelines on how to implement the new FORESEE Tools and strategies into the service life of the asset.
- A resilience assessment where the methodology is going to follow the available strategies presented in FORESEE. The target is to compare the resilience of the system in two scenarios, an initial one where no new methodologies developed in FORESEE are applied to the Operational and Maintenance Plans of the asset, comparing the resilience of the infrastructure once the new FORESEE developments are applied to the Operational and Maintenance Plans.
- A cost-benefit analysis follows, looking to prove the economic benefits of incorporating the new strategies and tools into the Operational and Maintenance Plans.
- Final graphs are given to support the infrastructure manager to have a quick overall view of the analysis made, where mainly it is compared the resilience of the system with and without the application of the FORESEE developments, for each kind of indicator.

The operational and maintenance plans will be based on risk assessment and mitigation strategies, establishing the strategic priorities to increase the level of reliability and service of the selected use cases for the given and diverse risk scenarios considered. For that purpose, a set of restrictions must be taken into consideration such as limiting economic resources, admissible level of risk or environmental conditions.

6.1.7.3.2 Results of practical application on CS#6

The results performed by *Infraestruturas de Portugal* are presented on Annex 2 (Section 2.3).

6.1.7.3.3 Improvements via the FORESEE TOOL D7.6 - Operational and Maintenance Plans and Conclusions

In Deliverable D7.3, the general and specific strategies are designed, in detail, to guarantee the resilience of the infrastructure, and which basically coincide with the standards and benchmarks that *Infraestruturas de Portugal* follows and applied in the asset management throughout the successive stages.

We can see that there is a direct link between this tool and the next previously mentioned KRIs:

- E.1.2.4 - The presence of a warning system.
- E.1.2.7 - The presence of special measures to help evacuate persons.
- E.3.2.2 - Practice of the emergency plan.
- E.3.2.3 - Review/update of the emergency plan.
- E.3.2.4 - Expected time for tendering.
- E.6.1.2 - Corrective maintenance interventions.
- E.8.1.1 - Coordination between services.
- E.8.2.1 - Long-term contingency plans.
- E.8.2.2 - Long-term traffic/mobility plans.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 19. Questions & Impacts for Task T7.3 (Deliverable D7.6).

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	Some of them are made, through compliance with current regulations, Quality Plan, Maintenance and Inspection Contract/Plan.
How does FORESEE improve the results/analysis previously made?	In Deliverables D7.3 and D7.6, the general and specific strategies are designed, in detail, to guarantee the resilience of the infrastructure.
How does this FORESEE result improve your infrastructure's management?	It makes easier the description of scenarios, a risk assessment for a specific hazard, the study of the socio-economic impact, and the measures to be adopted before and after the event (regarding maintenance protocol and operation planning).

If it was not made, how does this FORESEE result improve your infrastructure's management?	From the Technical point of view, it offers a complete guide that can be add on operational and maintenance plans already implemented, that supposes the exhaustive monitoring of the critical elements to be managed, measures as well regarding operation planning.
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%)	Due to its overall vision, it will have a positive effect that, as a cautious assessment, we can estimate 5% of each of the aspects mentioned in the question.

6.1.7.4 Contingency Plans (T7.4 - D7.4)

6.1.7.4.1 Summary of the tool

In general, a contingency plan is a set of **alternative procedures and instructions to the normal operating conditions** in the development of the infrastructure's own activity (at a strategic, organizational, operational and personnel level), **so that the operation of this, despite the fact that some of its activities stop doing so due to external conditions**.

In general, a contingency plan is a set of **alternative procedures and instructions to the normal operating conditions** in the development of the infrastructure activity itself (at the strategic, organizational, operational and personnel level**), in a way that allows the operation of this, despite the fact that some of its activities stop due to an internal or external accident**.

The main function of a contingency plan is the continuity of infrastructure operations.

In general terms, any contingency plan includes four stages:

1. Evaluation.
2. Planning.
3. Testing.
4. Execution.

<u>Specific action procedures</u>

This point will be of great importance in the contingency plan since it is where all the response procedures to any emergency are collected. All the actions to be developed and the team in charge of carrying out those actions will be defined to give a quick and effective response to emergencies.

These procedures will have a general basis with similar characteristics based on the following points:

- I Emergency Detection and Alert.
- II Alarm Mechanisms.
- III Emergency Response Mechanisms.
- IV Evacuation and / or Confinement.
- V Provision of First Aid.
- VI Ways of receiving external aid.

As part of Deliverable D7.4, there has been developed a study to check the performance of each kind of infrastructure user when they must evacuate it.

Objective

The purpose of this study is to be able to determine the impact of these factors on human behavior to obtain an adequate interpretation of the evacuation phenomenon and to be able to improve communication systems based on the reaction time of users.

During the execution of the project, the impact of the following factors will be analyzed:

- Disruption in evacuation routes by blocking certain exits, to modify user routes.
- Movement of the occupants right after the alarm is activated and until they decide to look for an exit.
- Process for choosing evacuation routes known, unknown and indicated.
- Characteristics of the occupants, emphasizing multiculturalism.

The evacuation process is developed in four phases, each with an execution time, which can vary depending on a multitude of conditions. The sum of these partial times will determine the total evacuation time:

1. **Detection time**: time it takes to discover and confirm an emergency (**tD**).
2. **Alarm**: The time of emission of the corresponding messages by the means of public address, lights or sounds encoded (**tA**).
3. **Reaction**: Time elapsed since the evacuation decision is communicated until the first person begins to leave (**tR**).
4. **Evacuation time**: The proper evacuation time begins when the first person begins to use the evacuation routes to move to a safer place until the last arrives to this place(**tE**).

The present study aims to **analyze the factors of the communication strategies that directly affect the alarm time (tA) and consequently the reaction time (tR), to arrive at a more effective communication plan in the process evacuation**.

6.1.7.4.2 Results of practical application on CS#6

No practical application was performed for CS#6.

6.1.7.4.3 Improvements via the FORESEE TOOL D7.4 - Contingency Plans

We can see that there is a direct link between this tool and the next previously mentioned KRIs:

- E.1.2.4 - The presence of a warning system.
- E.1.2.7 - The presence of special measures to help evacuate persons.
- E.3.2.2 - Practice of the emergency plan.
- E.3.2.3 - Review/update of the emergency plan.
- E.6.1.2 - Corrective maintenance interventions.
- E.8.1.1 - Coordination between services.
- E.8.2.1 - Long-term contingency plans.
- E.8.2.2 - Long-term traffic/mobility plans.

COMPARISON BETWEEN CURRENT SITUATION AND THE POSSIBLE APPLICATION OF THE TOOL

Table 20. Questions & Impacts for Task T7.4 (Deliverable D7.4)

Question	***Impact***
Was this type of analysis made before FORESEE? How was it made?	Integrated safety manual and the integrated emergency plan of the *25 de Abril* bridge have already this type of procedures that are implemented in case of an anormal or accident situation. Those manuals and correlated procedures are permanently review, updating and checking in terms of compatibility and complementarity with the emergency plans of the different entities/stakeholders involved. The plans and their feasibility are tested periodically to identify the planning deficiencies and solve them. Also, all resources (technical and human) are evaluated. All these procedures are analysed to verify the adequacy of the procedures and the overall effectiveness of the plans.
How does FORESEE improve the results/analysis previously made?	It aims to transform real static emergency and contingency plans into dynamic plans adapted to more variables. It is about incorporating the benefits of moving to "dynamic" approaches which considers/investigate user response and reactions/behaviours and new concepts in emergency simulations.
How does this FORESEE result improve your infrastructure's management?	With a set of procedures and instructions at a strategic, organizational, operational and personnel level that arise in an extraordinary situation that puts the continuity of the infrastructure at risk. In terms of a train accident, during and after the event, it can help to increase the preparedness of the infrastructure manager and all entities responsible for emergency and operational procedures to act and respond immediately with safeness.

If it was not made, how does this FORESEE result improve your infrastructure's management?	The nine sections that make up Deliverable D7.4, represent an exhaustive compendium of the applicable regulations, the knowledge and the experience acquired in the matter, which together with the rest of the tools, guarantees the management of extreme events.
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%)	We consider that the timely management of extreme events can improve, as a whole, by 5%, based on saving resolution time and reducing associated costs.

6.1.7.4.4 Conclusions

In Deliverable D7.4, the general and specific strategies are designed, in detail, to guarantee the resilience of the infrastructure, from the point of view of the provision of management and contingency plans, which basically, in some features, coincide with the standards and benchmarks that *Infraestruturas de Portugal* follows and applied in the asset management throughout the emergency and contingency protocols during maintenance and operation phase.

6.2 CURRENT ASSET MANAGEMENT, RAAMSSHEEP AND RESILIENCE PRINCIPLES FOR CS#6.

The implementation of the selected FORESEE Tools should make the infrastructure (more) resilient. In addition to the improvement rating described in the previous sections, the terms of RAMSSHEEP and resilience principles are introduced to validate resilience in an also qualitative but structured method.

Within the FORESEE Project, resilience has been defined as the ability to continue to provide service if a hazard event occurs (compare Deliverable D1.1).

There is a very extensive available information about the comparison between the existing management plans of *25 de Abril* Bridge and the updated ones developed as part of the Foresee Project.

This information has been extensively analyzed as part of the Section 5.

Based on the previous requirements analysis and the additional indications, the validation of the selected FORESEE Tools for the improvement of the defined KRI and KRT in CS#6 can be evaluated in the following.

As explained in the previous section, for most tools only descriptions of incoming requirements and outgoing outputs are available from the deliverables at the current time. As the newly developed tools can currently only be applied theoretically instead of practically, the validation is only qualitative by comparison with the current situation in the form of a tendential rating of the improvement.

The structural approach is identical to the previous requirements analysis. First of all, additional indications are pointed out regarding the improvements through the use of the selected FORESEE Tools. The comparison of the identified improvements with the current situation and the tools used is summarised in Table 21 which follows.

Furthermore, the validation will be critically assessed by checking the RAMSSHEEP and Resilience Principles in the Table 22 and by performing a net benefit analysis and presenting the resilience factors after using the selected FORESEE Tools in Annex's 1 and 2.

6.2.1 CURRENT ASSET MANAGEMENT SYSTEM (*25 DE ABRIL* BRIDGE)

This topic is explained on Section 2.2. and Section 2.3.

6.2.2 RAMSSHEEP AND RESILIENCE PRINCIPLES FOR CS#6

The well-known RAMS (Reliability, Availability, Maintainability, and Safety) analysis can be seen as a risk concept that describes the primary performance and resilience of all the functions of a system. In comparison to a basic RAMS analysis, the new extended RAMSSHEEP analysis also takes more social, ecology and economy aspects into account. In this project resilience consists of four outcome-focused abilities which are described as resilience principles in the following. Since infrastructure resilience relies on these four concepts, improving any of them improves the overall resilience of the infrastructure (compare Deliverable D7.1).

Table 21. CS#6, Improvements via the FORESEE Tools in comparison with current situation regarding Asset Management Plan.

CS#6	***Comparison***		
	ACTUALY / CURRENT TOOLS	**FORESEE TOOL**	
Hazard Assessment	- Risk and hazard maps freely available and editable online (databases…)	T2.1 Risk Mapping	✓ Risk and hazard maps prepared and predefined by the tool developers (→ see Annex 2 Section 2.1)
	- National standardised maps with detailed information only for Portugal and online databases		✓ large scale rapid risk analysis based on past real extreme natural events occurred all over Europe for a general overview
Rating	**=** *"Equal"*		

Hazard ***Assessment***	- *Traffic simulations using EME software adapted to 25th Abril Bridge needs* - *Variable input data* - *Cameras* - *Sensors – traffic sensors* - *Expert's opinions* - *Lessons learned*	T3.4 Traffic module	✓ Accurate input data as stochastic Montecarlo algorithms are performed
Rating	= *"Equal"*		
Hazard ***Management***	- *Cameras* - *Structural sensors located on several elements of the bridge* - *Traffic and Railway Control Centre* - *Automatic detection of incidents that is already implemented on the cameras* - *Permanent presence of authorities (police)*	T.5.5 C+C Centre	✓ Automatized alerts ✓ Predictive risk prevention ✓ AI-based hazard analysis
Rating	→ *"Slight Improvement!*		
Hazard ***Planning/ Management***	- *Subjective,* *based on Expert knowledge/Regulations*	T7.2 T7.3 T7.4 Plan Review	✓ Objective, science-based
	- *Static,* *based on Eu-wide and national regulations/frameworks*		✓ Dynamic, adapted to more variables and simulations
	- *Incomparable and fixed,* *no reference or benchmark for possible optimisation available*		✓ Comparable and scalable, monetize resilience / LOS to identify optimal investment decisions
	- *Robustness quality*		
Rating	→ *"Improvement!*		

In the following, it is qualitatively validated whether the FORESEE Tools selected in CS#6 affect the RAMSSHEEP and resilience principles.

Table 22. CS#6, RAMSHEEP & Resilience Principles.

S#6 *TOOL*	*OUTPUT*												
	RAMSHEEP									RESILIENCE PRINCIPLES			
	R	A	M	S	S	H	E	E	P	*Robust-nes*	*Resources-fulness*	*Rapid-Recovery*	*Adaptability*
T2.1 Risk Mapping	-	-	-	√	√	-	√	√	√	-	-	-	√
T3.4 Traffic Module	-	-	√	-	-	√	-	√	√	√	√	√	√
T5.5 C+C Centre	√	√	√	√	√	√	√	√	√	-	√	√	-
T7.2 **T7.3** **T7.4** Plan Review	√	√	√	√	√	√	√	√	√	√	√	√	√

For a better understanding, the terms and components of the RAMSHEEP and resilience principles, both are described in more specific way as follow:

The acronym of **RAMSSHEEP** stands for [extracted from "RAMSSHEEP analysis: A tool for risk-driven maintenance. Applied for primary flood defence systems in the Netherlands"]:

- **R**eliability:

  The probability that a system/structure will fulfil its function under certain circumstances and during a specific time interval.

  → **T5.5 C+C Centre, T7.x Plan Review**

- **A**vailability:

  The probability that a system/structure can fulfil its function at any random moment under certain circumstances.

  → **T5.5 C+C Centre, T7.x Plan Review**

- **M**aintainability:

  The probability that a system/structure fulfils its function under certain circumstances during maintenance within the established time frame.

  ➔ **T3.4 Traffic Module, T5.5 C+C Centre, T7.x Plan Review**

- **S**afety:

  The absence of unacceptable risks in the system/structure in terms of human injuries.

  ➔ **T2.2 Risk Mapping, T5.5 C+C Centre, T.7.x Plan Review**

- **S**ecurity:

  The guarantee of a safe system/structure with respect to vandalism, terrorism

  and human errors (including all kinds of sabotage of the system).

  ➔ **T2.2 Risk Mapping, T5.5 C+C Centre, T7.x Plan Review**

- **H**ealth:

  The feeling of good health with respect to the physical, mental and societal views. This does not implement if an individual is feeling well or not (subjective argument).

  ➔ **T5.5 C+C Centre, T7.x Plan Review**

- **E**nvironment:

  To meet certain requirements which have been secured in Environmental Acts one suffices the rules of a good and clean environment. The environment can be seen as a physical environment wherein human life is even possible.

  ➔ **T.2.2 Risk Mapping, T5.5 C+C Centre, T7.x Plan Review**

- **E**conomics:

  The Cost-Benefit will form a central position in the aspect of Economy. The increase the performance of the RAMS aspects will lead also to an increase of the direct costs. A serious reflection in terms of a Cost-Benefit Analysis must be made to provide more insight for an economical choice.

  ➔ **T2.2 Risk Mapping, T5.5 C+C Centre, T7.x Plan Review**

- **P**olitics:

  A rational decision has to be made based on the aspects above, also including some political aspects.

  ➔ **T2.2 Risk Mapping, T5.5 C+C Centre, T7.x Plan Review**

The **Resilience Principles** stand for [extracted from Deliverable D7.1]:

- **Robustness:**

  This concept refers to the ability for transport infrastructure to overcome and absorb disruptive event shocks and continue operating. This concept is mainly oriented toward the physical parts of the infrastructure. At first sight, robustness could be misunderstood if it is assimilated simply as "resistance" and only translated into designing structures that are strong enough to resist a shock.

Nevertheless, this concept goes beyond being able to stand the hazard's punch; robustness could also be translated to redundant systems, so if something important stops working there is a substitute or an alternative path that would allow to keep operating. Robustness also relates to reliability: the capability to operate under a range of conditions. Finally, robustness also entails investing and maintaining elements of critical infrastructures.

➔ **T3.4.1 Traffic Module, T7.x Plan Review**

- **Resourcefulness:**

  This concept refers to the ability to skilfully manage a disruption as it unfolds. Resourcefulness might depend on the resources available to overcome difficulties, but it is primarily people oriented as it is related for example to prioritizing what should be done, how to communicate an emergency message, how to manage people to evacuate the network, etc. This includes financial, social, physical, technological, information and environmental resources. This ability relies more on people, rather than on the infrastructure itself.

  ➔ **T3.4.1 Traffic Module, T5.5 C+C Centre, T7.x Plan Review**

- **Rapid recovery:**

  This concept refers to the ability to get "back to normal" as quickly as possible after a disruption. It is oriented towards people as well as towards the infrastructure. With regards to people, this concept entails to carefully develop contingency plans, emergency plans, and counting with the right people and resources at the right place. With regards to the infrastructure orientation, it entails designs and constructions that provide the ability to recover from disruptions (e.g.: modular infrastructures that enables single components to be easily replaced, minimising the disruption or the loss of service, or flexible designs, such as bidirectional roads, that enable operators to temporarily adapt better to the required recuperation restrictions).

  ➔ **T3.4.1 Traffic Module, T5.5 C+C Centre, T7.x Plan Review**

- **Adaptability:**

  More than the quality of being able to adjust to new conditions, which is already included in the rapid recovery ability, this concept refers to the ability to absorb new lessons that can be drawn from past events to improve resilience. Engineers, emergency planners, transport operators, owners, etc. are able to learn from experience and past failures. This concept is oriented towards people as it involves revising plans, procedures, and introducing new tools and technologies to improve the other three resilience concepts (robustness, resourcefulness, and rapid recovery). Learning from the past will allow to be better prepared for the next crisis.

  ➔ **T2.2 Risk Mapping, T3.4.1 Traffic Module, T.5.5 C+C Centre, T7.x Plan Review**

Regarding the considerations that have been made on the application of the FORESEE Tools, it can be said that:

- Case study leader considers that they are of great importance for the management of resilience.
- Case study leader considers that they are fast, automatic and transparent, which facilitates and benefits their governance carried out so far based on expert judgment and lessons learned.
- Case study leader proposes that these tools should be integrated into a single management platform to improve the existing one, if available.

7. POTENTIAL IMPROVEMENTS OF THE TOOLKIT FOR REAL COMMERCIALIZATION

The Foresee Project recommendations for transportation infrastructures management have been used for *25 de Abril* Bridge. Not only in terms of earthquake hazard also for normal operation/management and emergency situations as also for simulation of a train accident with a special focus on the management of people (communication, contingency, emergency and evacuation) during and after the event, taking special consideration on resilience improvement. The conclusions of this study are shown in the following paragraphs.

- **Does FORESEE's results improve the quality of your analysis and infrastructure's management?**

After the study it is obvious the vital importance of the *25 de Abril* Bridge infrastructure for the community, as critical assessment performed on Task T7.2 shown (score: 4.55/5.0).

Therefore, using the FORESEE recommendations it is possible to improve the management and operation quality.

54 (fifty-four) indicators were set and analysed to measure the level of resilience. It has been shown that 21 (twenty-one) of the 54 (fifty-four) indicators can be improved by FORESEE Decision-Making methodology and related tools.

- **What could be improved for the final release of the components/Tool?**

All documents that were developed on FORESEE Project explain the main procedures, the objective of each tool that will be used to assess resilience as well to increase that resilience.

In our opinion, it is important to develop a tool dialogue/interaction between the tools themselves and the user, so just introducing the data agreed for the operation/management of the system, it will be possible to acquire rapid and direct answers for decision-making, especially in the face of extreme events.

Also, and maybe, these tools should be integrated into a single management platform to improve the existing one, if available.

Regarding this case study, we think that it would be interesting to assess the structural resilience (before and after an extreme event) with machine learning techniques to assess and define repair/retrofitting and maintenance procedures (pre and post event) on key structural elements. This strategy could lead in a resilience improvement of this type of asset.

- **Would you pay for this kind of tool/service?**

Decisions in the case of an extreme event, based on objective data and experienced with previous simulations, are definitive supports in the infrastructure management.

As aforementioned in this document, the tools provided by the FORESEE Project give answers to important questions depending on the situation.

These are examples:

- **Effects on traffic, congestion. It helps to adopt properly decision of different alternatives, whether partial or total close or capacity reduction of the infrastructure load.**
- **Decision on the maximum required speed.**
- **Increase of travel time.**
- **Possible impact on alternative routes.**
- **Decision making procedures for preventive maintenance and operation planning.**
- **Decision making for retrofit/reinforcement procedures.**
- **Dynamic Contingency and Emergency procedures.**
- **Impact of the improvements that are made on the resilience.**

Therefore, probably we would pay for this kind of tool/service.

- **Was this type of analysis made before FORESEE? How was it made? How does FORESEE improve the results/analysis previously made? How does this FORESEE result improve your infrastructure's management?**

Infraestruturas de Portugal methodologies and internal regulations, such as Maintenance and Operating Manuals, cover most of the points included by the FORESEE Project. However, the main difference is that it is not applied from the point of view of resilience as understood by FORESEE.

As mentioned on Sections 2.1, 2.2 and 2.3. the maintenance and operation of this bridge is ensured by different entities, *Lusoponte* in the case of the roadway and *Infraestruturas de Portugal* in the case of the railway, with specific attributions and competences of each of the entities.

Infraestruturas de Portugal, in terms of safety and security of the bridge operation, centralizes and coordinates in an integrated bridge management logic, which enhances the regulatory and contract requirements, demanding service indicators such as response time, and time to return to normality.

The FORESEE Project involves all phases from the initial study (planning/design) to the commissioning (exploration) of the infrastructure as a whole, and always with the objective of improving resilience.

Furthermore, it allows measuring this resilience and evaluates different scenarios of management options in order to improve the results of management in different events, especially those considered extreme.

Therefore, all the above improves and ensures management quality.

The actual comparison of the improvements as a result of the selected FORESEE Tools described in Section 6 shows that in CS#6 the most significant potential for optimisation at the time of the study is provided by the Plan Review applications in Tasks T7.x.

These instruments of the Plan Review primarily influence the maintenance, safety and satisfaction of the transport system. The positive effects in terms of break- and downtime reduction as well as productivity increase can also be achieved retrospectively (after the event / before the next one) by reviewing the construction and maintenance plans by using the applications of Tasks T7.x.

Also, Guidelines to measure Level of Service and Resilience in Infrastructures (D1.1 and D1.2) could be, in near future, complied with actual regulations and guidelines for risk management, evaluation/assessment of structural safety and monitoring of existing bridges.

- **Does this tool/result facilitate your work? How? Can it be measured in working hours or €? 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% (check D8.6)**

From the preliminary study to their management in the service phase, the Foresee Tool/service is a general compendium of regulations with a compilation of good practices that are applied to infrastructures. Consequently, it has an immediate effective application, and together with the definition of different indicators included in the Management and Quality Plans, it allows a permanent monitoring of the management, also the requirements needed to keep the ideal level of resilience.

Initially, it is difficult to quantify what the application of the Foresee Tool represents in terms of working hours, maintenance costs, return of investment and increased productivity, but applying it we would be looking at a very positive scenario. A series of improvements are proposed to be implemented in the FORESEE Tool, in view of the results obtained for the CS#6.

- Improvement of technical indicators, in the Operation & Maintenance, M.
- Express the results of decision-making in economic terms to achieve a better integration of the Resilience Plan with the Asset Management Plan.
- GUI output of the Tool, for a faster and easy understanding.
- Integration tool dialogue/interaction between the tools themselves and the user.
- Integrated into a single management platform to improve the existing one, if available.

Table 23. FORESEE Tool CS#6 COMMERCIALIZATION

Case Study#6 FORESEE TOOL	REAL COMMERCIALIZATION
RISK MAPPING	√
TRAFFIC MODULE	√
COMMAND CONTROL CENTER	√
DESIGN, CONSTRUCTION AND REMEDIATION PLANS	-

OPERATIONAL AND MAINTENANCE PLANS	-
CONTINGENCY PLANS	-

Table 24. FORESEE Solutions Catalogue CS#6 COMMERCIALISATION

Case Study#6 FORESEE SOLUTIONS CATALOGUE	REAL COMMERCIALISATION
EARTHQUAKE PLATFORM	√
DEVELOPMENT OF ALGORITHMS FOR THE SELECTION AND DEFINITION OF EFFICIENT AND OPTIMAL ACTIONS	√
SHM ALGORITHMS	√

8. CONCLUSIONS

In recent decades, interest in infrastructure resilience against the impacts of natural and man-made threats has been considerably in focus. Because of that, it is important to include the resilience concept in all decision-making in all phases of the life cycle of a transport system/infrastructure (from planning, design, operation, maintenance, and conservation).

The general objective of FORESEE Project is to provide reliable tools to improve/enhance the resilience of transportation infrastructure, such as the ability to reduce the impact, magnitude and / or duration of disruptive events.

The present validation is related to CS#6 – *25 de Abril* Bridge and concludes that an implementation of selected FORESEE Tools can increase, in some way, the resilience of the road-railway infrastructure (bridge) and that a real implementation could be beneficial.

This is clarified in the present deliverable as follows:

- By defining the LOS in Section 3.3., the current state of the infrastructure studied in CS#6 can be monetised. On this base the optimal indicators (KRI) and targets (KRT) for improvement can be found. For the possible achievement of the set targets, various software and process tools newly developed in the FORESEE Project are presented in Section 3.4., of which the tools for The Risk mapping (Task T2.1), Traffic Module (Task T3.4.1), Command and Control Centre (Task T5.5) and Plan Review (Tasks T7.x) are most suitable for the present case. However, others could be applied, eventually in terms of planning and design phase.
- The system validation described structurally in Section 4 based on a V-model in the form of a requirements analysis of the inputs in Section 5 and validation of the improvements through the outputs in Section 6 identifies the most significant **issue** of the present study. Most of the (selected) FORESEE Tools only can be evaluated theoretically based on the existing deliverables.

However, practical and qualitative validation was performed, essentially on Plan Review tools in Tasks T7.x, which are those that can provide the most potential for improvement for CS#6. In the case of the Traffic Module (Task T3.4.1) and Command and Control Centre in Task T5.5, unfortunately no profound validation could be performed at all.

Furthermore, if the selected FORESEE Tools can help to achieve the defined improvements of the indicator state one level up (enhance the resilience), the consideration of RAMSHEEP and resilience principles in Section 6.2 as well as the net benefit analysis of the LOS in Annex 1 (Section 1.10) and Annex 2 (Section 2.3.1.5) show that the resilience of the infrastructure considered in CS#6 can be increased by using the selected FORESEE Tools in general.

Perhaps other FORESEE Tools, than the ones mentioned, could be applied in this Case Study, in terms of practical application, p.e: Fragility and Vulnerability Analysis & Decision Support Module (Asset's fragility characterization against the considered hazards depending on the criticality levels of the asset's main features and functionality to evaluate asset's operativity losses for different damage levels scenario), Hybrid Data Fusion Framework (developing algorithms to determine optimal restoration and risk reduction intervention programs) as well SHM BIM based alerting SAS (This tool generates 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 Deliverable 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 visualization of the infrastructure BIM RAG-colored showing the alerts values).

The Fragility Functions, Vulnerability Functions and Decision Support Module could be a valuable instrument for the infrastructure manager, as *Infraestruturas de Portugal*, in addressing the economic resources in the achievement of the safety levels required. Perhaps, using the tool, maybe it would be possible to obtain a bigger picture of the infrastructure vulnerability and possible restoration cost. The connection with resilience is given from the multiple lists of parameters obtained through the proposed tool, starting from possible losses in case of event occurrence, and the Level of Service assessment before and after the event to have a picture of the event consequences over the infrastructure mobility. Furthermore, the resilience has been defined for different interruption events through Recovery Curves that determine the infrastructure functionality over the days after the event occurrence. Of course, this type of analysis for this bridge would be very specific, mainly because of the inputs regarding infrastructure mechanical and geometric characterization for the analysis's performance.

The Hybrid Data Fusion tool aims to support resilient decisions for infrastructure assets, when extreme events occur, provided measurements form diverse sources are available. As mentioned on Deliverable D5.2.1, the tool is called "hybrid" due to its capacity to incorporate two sources of inputs, namely simulation models and actual monitoring data. Data stem from monitoring measurements, that is collected via use of telemetry and appropriate sensors; simulated data can be generated via use of appropriate models, depending on the case study at hand (e.g. structural analysis module for the case of a bridge, or traffic simulation model for the case of a highway). Perhaps, it would be interesting to apply this tool in order to allow infrastructure managers to forecast the behavior of an asset, in this case *25 de Abril* Bridge, e.g. performance/possible damage on a bridge, or traffic behavior in a critical portion of a road network, when an event (e.g. earthquake) occurs.

Therefore, this type of analysis could lead to identify the probability for an existing or impending occurrence of faults, and accordingly decide on important actions for intervention and repair (e.g. road/bridge closure, repair of bridge deck, foundations, joints, bearings, etc).

Unfortunately, some constraints between data available, interaction between tools, type of infrastructure (suspension bridge which leads to specific analysis due to fragility functions and type of damage) or some minor information during the performed tasks and at the time of the investigation, made the application not possible.

Therefore, applying the FORESEE Tools to the Case Study CS#6 provide the infrastructure leader.

1. The Resilient, objective, transparent, automatic decision-making, encompassing all reputational qualities and aspects
2. The selection of the resilient infrastructure against its specific hazards, which complies with the Resilience Plan and subsequently, will be the resilient infrastructure for the Operation and Maintenance Plan.
3. The Path of Resilient Infrastructure Governance.
4. The definition of Operation & Maintenance Plan, based on a resilient design in front of specific hazards.
5. In addition, obtain a better benefit, introducing the FORESEE Tool, along of the life cycle of the infrastructure.

Resilience is more than simply preventing a disaster from occurring; resilience involves how a system plans and prepares to withstand and absorb, recover and adapt to disruptions and hazards (Linkov, Trump and Hynes 2019).

As a recommendation for followed EU projects regarding this subject:

- As we know, bridges are usually the most critical and vulnerable component of road and rail transport systems, while bridge damage due to earthquake results in substantial direct and indirect losses. Therefore, perhaps the development of a tool for rapid evaluation of bridge seismic performance for different levels of earthquake intensity is valuable for resilience assessment of road and rail networks and bridge retrofit prioritization. The key requirements for an effective vulnerability assessment tool are the broad application range and the acceptable accuracy in the estimation of structure-specific parameters.

  As a suggestion, an online database for developing fragility analysis of as built and retrofitted bridges, i.e. fragility curves for specific bridges, as a suspension bridge, could be performed. This type of framework would be useful to prioritize maintenance strategies, optimal restoration and risk reduction intervention programs as well operational procedures for a vital and particular infrastructure, such as *25 de Abril* Bridge.
- Improve the FORESEE Tools in terms of application and feedback from practical experience by other infrastructure managers and operators and hereby further validation in more case studies/examples to increase the tool´s effectiveness performance and accuracy.

In terms of challenges for the operation and maintenance of this infrastructure, the following figure intends to show how the infrastructure manager (*Infraestruturas de Portugal*) will ensure the existence and continuance of appropriate use conditions of this infrastructure.

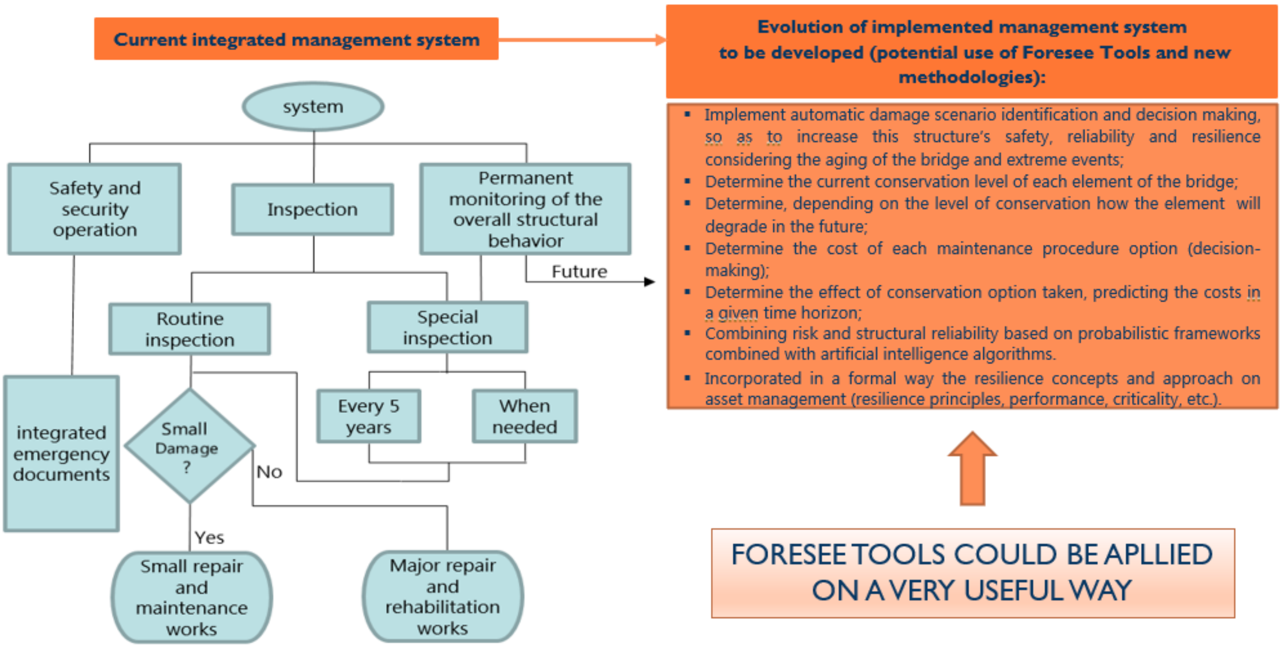


Figure 18. Challenges – Asset Management (25th Abril Bridge).

ANNEX 1. TOOL VERIFICATION WP1 - IDENTIFICATION OF KPI AND KRT

1.1 MEASURE OF SERVICE

As aforementioned (Section 2.1.), the requirements for the provision of the service are conditioned primarily by legislation and concession contract.

By way of summary, the indicators chosen for this section are detailed below, referring to the occurrence of the event:

- Interventions for restoration.
- Impact on travel times.
- Impact on safety (accident).
- Impact on socio-economic activities.

The case study application shows how the service and resilience objectives can be set for the *25 de Abril* Bridge in Lisbon.

The service provided by the transport system is measured as the ability of road and railway users to travel between North and South Tagus riverbank within a specific amount of time (travel time) and without having their property damaged or being hurt or losing their lives (safety), and the inhabitants of the area to be able to ship and have shipped goods on the highway (socio-economic activities).

The service provided by the infrastructure (in absence of any earthquake) is measured as shown in Table 27, where in the last column it is shown how the annual service is estimated, using inputs on the infrastructure, environment and organization and the variables affecting the service (Tables 25 and 26). Table 27 should be read as follows: the measure of travel time (€6’927’000) is estimated as the amount of minutes a vehicle spend on average on the bridge, which is computed as the ratio of length of the infrastructure in km (Li = 2’227/1’000) and the speed limit (Sl = 70km/h) and converted in minutes (i.e. multiplied by 60 min/h), multiplied by the cost of that time for the users in one year, estimates as the sum of the average number of people traveling for work in a day (Pw = 471’429) for the cost of work time (Cwt = €0.421/min) and the average number of people traveling for leisure in a day (Pl = 117’857) for the cost of leisure time (Clt = €0.122/min), for 365 days.

This number is used as reference number to measure deviations that are caused due to the reference earthquake. It is not a measure of the value of the bridge.

The formulas to estimate the costs for safety, interventions and socio-economic activities reported in Table 27 follow a similar logic. In total the measures of service have a value of €1’376’330’000.

Table 25. CS#6, Event-independent Inputs to Measure the Service [ETH/IP].

Inputs	Symbol	Value
Annual cost of regular maintenance [€/m]	Cm	500
Length of the infrastructure [m]*	Li	2277
N. of people traveling per day	P	589286
N. of people traveling per work in a day	Pw	471429
N. of people traveling per leisure in a day	Pl	117857
Goods travelling per day [trains]	G	150
Cost of work time [€/min]	Cwt	0,421
Cost of leasure time [€/min]	Clt	0,122
Socio economic costs per person [€/p.p.]	SECp	0,009
Socio economic costs for goods [€/train]	SECg	0,011
Impact of injuries per person [10^3€/p.p.]	Ip	397,6
Impact of death per person [10^3€/p.p.]	Dp	2617,8
Speed limit (average between weather condition) [km/h]*	Sl	70
Delay per unit (person or train) per day with no hazard event [min/p.u.]	Dpud_0	45
Property damage probability with no hazard event [%]	Ppd_0	0
Injury probability with no hazard event [%]	Pi_0	1,00E-04
Death probability with no hazard event [%]	Pd_0	1,00E-05
Property damage per person in case of accident [10^3€/p.p.]	PDp_0	5

Table 26. CS#6, Event-dependent Inputs to Measure the Service [ETH/IP].

Inputs	Symbol	Earthquake [_e]
Cost of intervention after the event [€/m]	Ci	2500
Delay per unit (person or train) per day after an event [min/p.u.]	Dpud	180
Days to recover in case of accident	D	90
Property damage probability per event [%]	Ppd	50
Injury probability per event [%]	Pi	0,5
Death probability per event [%]	Pd	0,1
Property damage per person in case of accident [10^3€/p.p.]	PDp	5

Table 27. Annual estimated Measure of Service, along with the way it is Computed.

Type of Service	Measure	Annual Estimate [10^3€]	Estimated Annual Service
Travel time	the travel time for all the people travelling between the North and South Tagus riverbank	6'927	((Li/1'000)/Sl)* ((Pw*Cwt)+(Pl*Clt))
Safety	the cost of repairing damaged property, the number of injuries and deaths due to people travelling between the North and South Tagus riverbank	4'808	(((Ppd_0/100)*P* PDp_0) + ((IPi_0/100)*P* Ip) + ((Pd_0/100)*P* Dp))
Interventions	The cost of keeping the infrastructure in, or restoring it to, an acceptable state	1'138'500	(Cm*Li)
Socio economic activities	This service is measured as the costs for the society due to the additional travel time for all the people and goods travelling from the North and South Tagus riverbank after a hazard. It is estimated the same way that the travel time is, except that here the socio-economic costs of delays are considered, instead of the costs for travel time.	226'095	(P*Dpud_0*SECp)+ (G*Dpud_0*SECg)
Total		1'376'330	

1.2 RESILENCE INDICATORS

The infrastructure manager (*Infraestruturas de Portugal*) determined that there were 54 (fifty-four) relevant indicators for the example transport system and defined their possible ranges of values (Table 28 to Table 35). The indicators were selected to give an indication of the difference between the intervention costs and the service provided if no earthquake occurs and if the reference earthquake occurs, from the start of the hazard to the time when service is again provided at the level it was before the earthquake.

The indicators were grouped at the highest level as Infrastructure (**E1**), Environment (**E2**), Organizational (**E3**), Structural Health Monitoring (**E4**), Inspection (**E5**), Small Maintenance (**E6**), Structural Analysis (**E7**) and Evacuation and Traffic Management (**E8**) indicators.

Infrastructure indicators (E1) (Table 28) are considered those related to the physical man-made parts of the transport system (bridge). They consisted of condition state, protective measure, and preventive measure indicators. Protective measure indicators pertained to how well the physical man-made parts of the transport system can protect the infrastructure providing the service. Preventive measure indicators pertained to how well the physical man-made parts of the transport system can withstand the reference hazard. Condition indicators pertained to how well the physical man-made parts of the transport system can provide the service it was originally designed to provide.

Environment indicators (E2) (Table 29) were those related to the physical natural parts, and the non-physical man-made parts of the transport system (bridges). An example of the former is the exposure to hazards. An example of the latter would be the available budget.

Organization indicators (E3) (Table 30) are those related to non-physical man-made parts of the transport system (bridge), i.e. the activities of the organisation managing the infrastructure. They consisted of pre-event and post-event activities indicators, whereas pre-event and post-event referred to the start of the earthquake.

Structural Health Monitoring indicators (E4) (Table 31), **Inspection indicators (E5)** (Table 32), **Small Maintenance indicators (E6)** (Table 33), **Structural Analysis indicators (E7)** (Table 34) and **Evacuation and Traffic Management indicators (E8)** (Table 35) indicators were considered, since they are very specific and important indicators in this case study. They impact in a relevant way in the management, maintenance and operation of a bridge of this nature. They may be considered as organization indicators, but in very particular manner.

Table 28. CS#6, Proposed Infrastructure Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.1	Infrastructure	E.1.1	Condition state of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	The older the warning systems, the more obsolete their performances and therefore the higher it is the probability of accidents due to a lack of signaling the danger in case of an earthquake.
				E.1.1.2	Age / Age of replacement of safe shut down system	The older the safe shut down system, the more obsolete their performances and therefore the higher is the probability of accidents due to a lack of stopping the traffic in case of an earthquake.
				E.1.1.3	Condition state of infrastructure	The better the condition state of the infrastructure, the lower is the probability of the infrastructure to be damaged following up with an earthquake and the lower the consequences are in case it occurs.
				E.1.1.4	Condition state of protective structures/systems	The more deteriorated the protection barriers, the lower is the probability that it can provide the LOS for which it was designed, and the higher the expected consequences are in case of earthquakes.
				E.1.1.5	Expected condition state of infrastructure (after the event)	The expected share of the infrastructure in excellent (i.e. CS1) good (i.e. CS1 and 2), decent (CS 3 or 4) or bad (CS5) after an event, is an indication of its ability to withstand the earthquake and, therefore, of higher resiliency.
				E.1.1.6	Expected condition state of protective structures/systems (after the event)	The expectation of theprotective structure to be in excellent (i.e. CS1) good (i.e. CS1 and 2), decent (CS 3 or 4) or bad (CS5) after an event, is an indication of its ability to function after an earthquake and, therefore, of higher resiliency of the infrastructure.
		E.1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	The possibility of re-routing the traffic through temporary paths reduces the consequences of an infrastructure being out of service after an earthquake.
				E.1.2.2	The possibility of using another means to satisfy transport demand	The possibility of re-routing people and goods using temporary means reduces the consequences of an infrastructure being out of service.
				E.1.2.3	The number of possible existing alternative ways to deviate vehicles	The possibility of re-routing the traffic through existing temporary paths reduces the consequences of an infrastructure being out of service after an earthquake.
				E.1.2.4	The presence of a warning system	The presence of a warning system to prevent users to pass by a road section in case of danger, reduces the consequence of an earthquake.
				E.1.2.5	The presence of a safe shutdown system	The presence of a safe shut down system to prevent users to access a road section in case of danger, reduces the consequence of an earthquake.
				E.1.2.6	The presence of emergency / evacuation paths	The presence of an emergency path to allow users to escape a road section in case of danger, reduces the consequence of an earthquake.
				E.1.2.7	The presence of special measures to help evacuate persons	The possibility of using extraordinary measures (e.g. helicopter) to allow users to escape a road section in case of danger, reduces the consequence of an earthquake.
		E.1.3	Preventive measures	E.1.3.1	Compliance with the current seismic design code	The more recent the seismic regulation's level of compliance, the lower the impact of an earthquake on the infrastructure.
				E.1.3.2	Presence of systems to reduce seismic effects	The presence of systems to reduce seismic effects prevent the road section to be hit in case of earthquakes.
				E.1.3.3	Adequate systems to reduce seismic effects	The adequate functioning of systems to reduce seismic effects prevent the road section to be hit in case of earthquakes.

ID	Indicator	Number of possible values	Number of possible values Possible values and meaning	
E1.1.1	Age / Age of replacement of the warning system	3	0/3	> 80% of the minimum service life achieved**
			1/3	> 50%,< 80% of the minimum service life achieved**
			2/3	> 20%,< 50% of the minimum service life achieved**
			3/3	< 20% of the minimum service life achieved**
E1.1.2	Age / Age of replacement of safe shut down system	3	0/3	> 80% of the minimum service life achieved**
			1/3	> 50%,< 80% of the minimum service life achieved**
			2/3	> 20%,< 50% of the minimum service life achieved**
			3/3	< 20% of the minimum service life achieved**
E1.1.3	Condition state of infrastructure (pre-event)	5	0/5	Condition State 5: Very bad (unable to provide the service)
			1/5	I don't know
			2/5	Condition State 4: Bad (the service is provided but heavily impacted by the conditions)
			3/5	Condition State 3: Good (the service is provided and only lightly impacted by the conditions)
			4/5	Condition State 2: Very good (with minor deterioration, not impacting the service)
			5/5	Condition State 1: Excellent (in perfect conditions)
E1.1.4	Condition state of protective structures/systems (pre-event)	5	0/5	Condition State 5: Very bad (unable to provide the service)
			1/5	I don't know
			2/5	Condition State 4: Bad (the service is provided but heavily impacted by the conditions)
			3/5	Condition State 3: Good (the service is provided and only lightly impacted by the conditions)
			4/5	Condition State 2: Very good (with minor deterioration, not impacting the service)
			5/5	Condition State 1: Excellent (in perfect conditions)
E1.1.5	Expected condition state of infrastructure (post-event)	3	0/3	Collapsed, requires rebuilding
			1/3	Out of service, requires repair/rebuilding
			2/3	In service but repairs are necessary
			3/3	In service and no repairs necessary
E1.1.6	Expected condition state of protective structures/systems (post-event)	3	0/3	Collapsed, requires rebuilding
			1/3	Out of service, requires repair/rebuilding
			2/3	In service but repairs are necessary
			3/3	In service and no repairs necessary

ID	Indicator	Number of possible values	Number of possible values Possible values and meaning	
E1.2.1	The possibility of building a temporary alternative route for vehicles	2	0/2	No alternative path
			1/2	1 alternative path
			2/2	Multiple alternative paths
E1.2.2	The possibility of using another means to satisfy transport demand	2	0/2	No alternative means
			1/2	1 alternative mean
			2/2	Multiple alternative means
E1.2.3	The number of possible existing alternative ways to deviate vehicles	2	0/2	No alternative ways
			1/2	1 alternative way
			2/2	Multiple alternative ways
E1.2.4	The presence of a warning system	2	0/2	No warning systems
			1/2	1 warning system
			2/2	Multiple warning systems
E1.2.5	The presence of a safe shutdown system	1	0/1	No safe shut down
			1/1	1 safe shut down
E1.2.6	The presence of emergency / evacuation paths	2	0/2	No emergency path
			1/2	1 emergency path
			2/2	Multiple emergency paths
E1.2.7	The presence of special measures to help evacuate persons (i.e. helicopters)	2	0/2	No extraordinary measures
			1/2	1 extraordinary measure
			2/2	Multiple extraordinary measures

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.1.3.1	Complience with the current seismic design code	2	0/2	Below current regulation, e.g. designed according to an old design code that is less restrictive than the current one
			1/2	According to current regulation
			2/2	Above current regulation
E.1.3.2	Presence of systems to reduce seismic effects	1	0/1	Absence of the system
			1/1	Presence of the system
E.1.3.3	Adequate systems to reduce seismic effects	1	0/1	Not adequate
			1/1	Adequate

Table 29. CS#6, Proposed Environment Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.2	**Environment**	**E.2.1**	**Context**	E.2.1.1	Accessibility	The more the road is accessible, the less expensive it is to conduct the intervention on it.
				E.2.1.2	Presence of persons/property below the infrastructure	The possibility to affect third parties below the infrastructure rises the consequences of an earthquake when it occurs.
				E.2.1.3	Extent of past damages due to hazards	The higher the past damages connected to earthquakes, the higher is its probability of suffering strong events also in the future.
				E.2.1.4	Hazard zone	The more the road is in a zone exposed to frequent and high magnitude earthquakes, the higher is its probability of being hit.
				E.2.1.5	Duration of past down time due to hazards	The highest the Nº of days per year that earthquakes have interrupted the service, the higher is its probability of suffering interruptions also in future.
				E.2.1.6	Land type	The harder the material of the landslides, the higher are the consequences in case of a landslide following up with an earthquake.
				E.2.1.7	Budget availability	The higher the budget availability is, the higher is the probability and effectiveness of the executing the interventions to recover the disruption of an earthquake.
				E.2.1.8	Traffic	The more traffic is on a road the higher is the exposition to consequences in case an earthquake occurs.
				E.2.1.9	Hazards goods traffic	The presence of dangerous goods transported on the road raises the consequences in case of accident.
				E.2.1.10	Flammable goods traffic	The presence of inflammable goods transported on the road raises the consequences in case of accident.

ID	Indicator	Number of possible values	Number of possible values Possible values and meaning	
E.2.1.1	Accessibility*	3	0/3	Accessible with telescopic crane
			1/3	Accessible with truck mounted crane
			2/3	Accessible with steps
			3/3	Accessible without equipments
E.2.1.2	Presence of persons/property below the infrastructure*	1	0/1	Yes
			1/1	No
E.2.1.3	Extent of past damages due to hazards*	3	0/3	Infrastructure's collapse, or no information available
			1/3	Serious damage
			2/3	Minor damage
			3/3	Aesthetic damages
E.2.1.4	Hazard zone*	3	1/3	High
			2/3	Medium
			3/3	Low
E.2.1.5	Duration of past down time due to hazards*	2	0/2	2 weeks per year, or no information available
			1/2	1-2 weeks per year
			2/2	1 day -1 weeks per year
E.2.1.6	Land type*	3	0/3	Rock mass
			1/3	Clayey
			2/3	Loose rocks
			3/3	Sandy
E.2.1.7	Budget availability	2	0/2	Enough for <50% of the intervention
			1/2	Enough for >50%,<100% of the intervention
			2/2	Enough for >100% of the intervention
E.2.1.8	Traffic*	3	0/3	>80% of capacity
			1/3	>50%,<80% of capacity
			2/3	>20%,<50% of capacity
			3/3	<20% of capacity
E.2.1.9	Hazards goods traffic*	2	0/2	Frequent dangerous goods
			1/2	Rare dangerous goods
			2/2	No dangerous goods
E.2.1.10	Flammable goods traffic*	1	0/1	Yes
			1/1	No

Table 30. CS#6, Proposed Organization Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because…)
E.3	Organization	E.3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	The presence of a monitoring plan raises the awareness of the IM on the state of the road and his preparedness to react when necessary. A prepared IM is trusted to be more reactive and reduces the consequences of an earthquake on traffic.
				E.3.1.2	The presence of a maintenance strategy	The presence of an intervention strategy lowers the probability that an infrastructure ends up in a deteriorated state.
				E.3.1.3	The extent of interventions executed prior to the event	The more it is spent on regular maintenance before the event, the lower is the probability that the infrastructure will suffer a drop in LOS following up with an earthquake.
		E.3.2	Post event activities	E.3.2.1	The presence of an emergency plan	The presence of an emergency plan reduces the time between the occurrence of an earthquake and the moment an IM reacts.
				E.3.2.2	Practice of the emergency plan	The regular execution of the emergency plan raises the ability of the IM to apply it when needed, reducing the time for execution and the risk of failure.
				E.3.2.3	Review/update of the emergency plan	The highest the Nº years since the last review/update of the emergency plan the less the plan is trust to be effective.
				E.3.2.4	Expected time for tendering	The longer the time for the for public tender the loger the infrastructure stay out of service.
				E.3.2.5	Expected time for construction	The longer the time for construction the loger the infrastructure stay out of service.

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.3.1.1	The presence of a monitoring strategy	2	0/2	No CS monitoring
			1/2	Periodic monitoring of the CS
			2/2	Constant (i.e. instrumented) monitoring of the CS
E.3.1.2	The presence of an maintenance strategy	2	0/2	No intervention strategy
			1/2	Only responsive interventions conducted
			2/2	Preventive interventions strategies is conducted
E.3.1.3	The extent of interventions executed prior to the event	2	0/2	<50% of the benchmark budget
			1/2	>50%,<80% of the benchmark budget
			2/2	> 80% of the benchmark budget
E.3.2.1	The presence of an emergency plan	2	0/2	No plan
			1/2	Generic plan
			2/2	Operative plan (with tasks, resources, ...)
E.3.2.2	Practice of the emergency plan	4	0/4	No exercise
			1/4	1 exercise every > than 2 years
			2/4	1 exercise every 2 years
			3/4	1 exercise every year
			4/4	1 exercise every 6 months
E.3.2.3	Review/update of the emergency plan	2	0/2	>5 years ago
			1/2	<5 years ago
			2/2	<2 years ago
E.3.2.4	Expected time for tendering	3	0/3	> 1 year
			1/3	> 8 months and < 1 year
			2/3	> 4 months and < 8 months
			3/3	< 4 month
E.3.2.5	Expected time for construction	3	0/3	> 1.5 year
			1/3	> 1 year and < 1.5 year
			2/3	> 6months and < 1 year
			3/3	< 6 month

Table 31. CS#6, Proposed Structural Health Monitoring Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because…)
E.4	Structural Health Monitoring	E.4.1	SHM Availability	E.4.1.1	Continuous vibration monitoring	A monitoring system permanently installed for capturing the natural modes' frequencies and shapes allows assessing, in real-time, important changes in the stifness and boundary conditions.
				E.4.1.2	Continuous stress and displacement monitoring of resistance elements	A monitoring system permanently installed for measuring stress and displacements during and after na earthquake allow for the direct comparison of values obtained from seismic design.
				E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	Moving components and seismic devices should include relative displacement monitoring to assess, during operation and after na earthquake, the presence of possible discontinuities in structural supports / boundary conditions as well as possible obstacles to traffic circulation.
		E.4.2	SHM Reliability and operation	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	In case of a seismic event the monitoring system needs to function in the subsequent hours to allow for the estimation of modal features, stresses and displacements, and posterior comparison with the pre-event baseline
				E.4.2.2	Permanent fail-safe communication of monitoring relevant information	In case of a seismic event, and in case conventional data and cellular networks fail, the results obtained from the monitoring system should be consulted remotely and in real-time.
				E.4.2.3	SHM data analysis	The analysis of the data acquired should allow for the extraction of information regarding the structural behaviour and the health condition
				E.4.2.4	Update rate on the feedback of the structural condition	The SHM system should be capable of providing feedback on the structural condition with the fastest cadency possible without compromising the sensitivity to damages nor the resolution against false alerts

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.4.1.1	Continuous vibration monitoring	2	0/2	Non existent
			1/2	Ability to identify global natural modes
			2/2	Ability to identify local natural modes in the major structural elements
E.4.1.2	Continuous stress and absolute displacement monitoring	2	0/2	Non existent
			1/2	Ability to characterize stresses or absolute displacements in one or more major structural elements
			2/2	Ability to characterize stresses or absolute displacements in all major structural elements
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	0/2	Non existent
			1/2	Ability to characterize relative displacements in one or more movable components
			2/2	Ability to characterize relative displacements in all movable components
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0/2	No uninterruptable power supply (UPS) system
			1/2	Uninterruptable power supply (UPS) system with capacity for autonomous operation during hours
			2/2	Uninterruptable power supply (UPS) system with capacity for autonomous operation during days
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2	0/2	No direct access to SHM data by technical staff
			1/2	Direct access to SHM data by technical staff, using conventional communications
			2/2	Direct access to SHM data by technical staff, using special fail-safe communication systems (satellite, other)
E.4.2.3	SHM data analysis	3	0/3	No real-time automatic analysis
			1/3	Automatic comparison of data to corresponding limits defined using limit states
			2/3	Automatic comparison of data to limits defined statistically from baseline of monitoring data
			3/3	Automatic comparison of data with numerically generated damage scenarios considered likely to occur in case of earthquake
E.4.2.4	Update rate on the feedback of the structural condition	3	0/3	No automatic feedback
			1/3	Daily feedback
			2/3	Hourly feedback
			3/3	Feedback on-demand

Table 32. CS#6, Proposed Inspection Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.5	Inspection	E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan	An inspection and testing plan of the critical components (screw faults, bridge moorings, bearings, joints, suspension cables) must be defined and implemented to evaluate diferences between the last and current inspection, based on pre-defined damage indicators to allows for the monitoring of component
				E.5.1.2	Repair plan of damaged components	A repair plan of damage components observed during the inspection should be defined and will improve and speed up maintenance intervertions. A contigency repair plan of critical components should be in place in case of a seismic event.
		E.5.2	Inspection operation	E.5.2.1	Visual inspections	The implementation of regular visual inspection of components (bridge moorings, bearings, joints) allows detecting unexpected damage in an early stage.
				E.5.2.2	Technical measurements	The measurement of parameters to assess and quantify the deviation of structural components from their standard functioning, between inspections and after a seismic safety coeficient.

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.5.1.1	Component inspection and testing plan	2	0/2	No plan
			1/2	Generic plan
			2/2	Operative plan (with tasks, resources, ...)
E.5.1.2	Repair plan of damaged components	2	0/2	No plan
			1/2	Generic plan
			2/2	Operative plan (with tasks, resources, ...)
E.5.2.1	Visual inspections	2	0/2	No visual inspection
			1/2	Periodic visual inspection
			2/2	Permanent visual with team permanently on site
E.5.2.2	Technical measurements	2	0/2	No measurements
			1/2	Periodic measurements
			2/2	Permanent visual with team permanently on site

Table 33. CS#6, Proposed Small Maintenance Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	The implementation of maintenance intervention (welding repair, retightening and screws replacing, etc) increases structural performance in case of seismic event and lowers probability of accident in case of seismic hazards.
				E.6.1.2	Corrective maintenance interventions	The adequate and timely execution of corrective maintenance, prior to any hazardous event, increases structural performance in case of seismic event and lowers probability of accident in case of seismic hazards.

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.6.1.1	Periodic routine maintenance interventions	2	0/2	No routine maintenance contracted
			1/2	Routine maintenance contracted and available on demand
			2/2	Routine permanent maintenance team available on site
E.6.1.2	Corrective maintenance interventions	2	0/2	No corrective maintenance contracted
			1/2	Corrective maintenance contracted and available on demand
			2/2	Corrective permanent maintenance team available on site

Table 34. CS#6, Proposed Structural Analysis Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	Structural model	A structural model calibrated to reproduce the structural response should be developed and calibrated to the structural response using on site measurement. In case of seismic occurrence it can be used to compared against structural measruements and analysis the structural condition.
		E.7.2	Seismic risk studies	E.7.1.2	Seismic risk studies	Using the structural model as well as information from site geology and seismic action, seismic risk studies should be conducted to allow for precise and rapid estimations of the wxpected damage scenarios on the structural system

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.7.1	Structural model	3	0/3	No model developed
			1/3	Simplified model for static analyses
			2/3	Detailed model previously callibrated for non linear static analysis
			3/3	Detailed model previously callibrated for time-history dynamic non-linear analysis
E.7.2	Seismic risk studies	3	0/3	No studies conducted
			1/3	Seismic vulnerability studies for earthquake events
			2/3	Seismic risk studies for earthquake events
			3/3	Probablistic studies for seismic hazard, vulnerability and risk

Table 35. CS#6, Proposed Evacuation and Traffic Management Resilience Indicators.

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)
E.8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	Coordination between services	While working on a complex infrastructure, with a diferente environment from the normal road/street, and where operational hazards are a strong reality, the quality and quantity of communication between the police, the concession operator, emergency services and civil protection is of paramount imporance.
				E.8.1.2	Availability of resources on site	The availability of police and concession operator resources in the vacinity of the bridge and/or dedicated police officers to the bridge trafic control have a strong influence on the rapidness and the acuracy of the police dispatch/deployment.
				E.8.1.3	Availability of safe-through equipment	The availability of equipment especially designed to ensure the minimum/critical operation of a long-span bridge in case of earthquake can prove very important, especially to aid in emergency services and disaster management. Examples consist of plates to cover damaged joints.
		E.8.2	Response for long term disruption	E.8.2.1	Long-term contingency plans	Coherent crise managment plans, in case of long term unavailability of the bridge, should be defined and ready to be implemented.
				E.8.2.2	Long-term traffic/mobility plans	Specific alternative mobility plans in case of long term unavailability of the bridge, with specific focus on the mobility of emergency services, should be designed and ready to implement

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning	
E.8.1.1	Coordination between services	2	0/2	Informal coordination between elements of one or more intervenient emergency and response services
			1/2	Formal coordination and communication between a subset of intervenient emergency and response services
			2/2	Formal coordination and communication between a all intervenient emergency and response services thgough dedicated channels
E.8.1.2	Availability of resources on site	2	0/2	No resources available
			1/2	Resources available in one side of the bridge (river margin)
			2/2	Resources available in both sides of the bridge (river margins)
E.8.1.3	Availability of safe-through equipment	1	0/1	No safe-through equipment.
			1/1	Safe-through equipment available.
E.8.2.1	Long-term contingency plans	1	0/1	No long-term contingency plans
			1/1	Existence of long-term contingency plans
E.8.2.2	Long-term traffic/mobility plans	1	0/1	No long-term traffic/mobility plans
			1/1	Existence of long-term traffic/mobility plans

1.3 SCALE AND MEASURES OF RESILIENCE INDICATORS FOR EARTHQUAKE

Table 36. CS#6, Scale and Measures of Resilience Indicators for Earthquake [ETH/IP].

ID	Level 0	ID	Level 1	ID	Indicator	Scale	Measure	Impact				Meaning of the measure Value for the current indicator state
								Intervention	Travel time	Accident	Socio-econ.	
E1	Infrastructure	E1.1	CS of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	3	2			X	X	> 50%,< 80% of the minimum service life achieved**
				E.1.1.2	Age / Age of replacement of safe shut down system	3	2			X	X	> 20%,< 50% of the minimum service life achieved**
				E.1.1.3	Condition state of infrastructure (pre-event)	5	3	X	X	X	X	Condition State 3: Good (the service is provided and only lightly impacted by the conditions)
				E.1.1.4	Condition state of protective structures/systems (pre-event)	5	3	X	X	X	X	Condition State 3: Good (the service is provided and only lightly impacted by the conditions)
				E.1.1.5	Expected condition state of infrastructure (post-event)	3	2	X	X	X	X	In service but repairs are necessary
				E.1.1.6	Expected condition state of protective structures/systems (post-event)	3	2	X	X	X	X	In service but repairs are necessary
		E1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	2	1		X		X	1 alternative path
				E.1.2.2	The possibility of using another means to satisfy transport demand	2	1		X		X	1 alternative mean
				E.1.2.3	The number of possible existing alternative ways to deviate vehicles	1	1		X		X	1 alternative way
				E.1.2.4	The presence of a warning system	2	1		X		X	1 warning system
				E.1.2.5	The presence of a safe shutdown system	1	1		X		X	1 safe shut down
				E.1.2.6	The presence of emergency / evacuation paths	2	2		X		X	Multiple emergency paths
				E.1.2.7	The presence of special measures to help evacuate persons	2	0		X		X	No extraordinary measures
		E1.3	Preventive measures	E.1.3.1	Complience with the current seismic design code	2	1	X	X	X	X	According to current regulation
				E.1.3.2	Presence of systems to reduce seismic effects	1	0	X	X	X	X	Absence of the system
				E.1.3.3	Adequate systems to reduce seismic effects	1	0	X	X	X	X	Not adequate
E2	Environment	E2.1	Context	E.2.1.1	Accessibility	3	0	X				Accessible with telescopic crane
				E.2.1.2	Presence of persons/property below the infrastructure	1	0			X		Yes
				E.2.1.3	Extent of past damages due to hazards	3	3	X				Aesthetic damages
				E.2.1.4	Hazard zone	2	1	X	X	X	X	High
				E.2.1.5	Duration of past down time due to hazards	3	2	X				1-2 weeks per year
				E.2.1.6	Land type	3	0	X		X		Rock mass
				E.2.1.7	Budget availability	2	2	X	X	X	X	Enough for >100% of the intervention
				E.2.1.8	Traffic	3	0	X	X	X	X	>80% of capacity
				E.2.1.9	Hazards goods traffic	2	0			X		Frequent dangerous goods
				E.2.1.10	Flammable goods traffic	1	0			X		Yes
E3	Organization	E3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	2	2	X	X	X	X	Constant (i.e. instrumented) monitoring of the CS
				E.3.1.2	The presence of an maintenance strategy	2	2	X	X	X	X	Preventive interventions strategies is conducted
				E.3.1.3	The extent of interventions executed prior to the event	2	1	X	X	X	X	>50%,<80% of the benchmark budget
		E3.2	Post event activities	E.3.2.1	The presence of an emergency plan	2	2		X		X	1 exercise every 2 years
				E.3.2.2	Practice of the emergency plan	4	0		X		X	No exercise
				E.3.2.3	Review/update of the emergency plan	2	0		X	X	X	>5 years ago
				E.3.2.4	Expected time for tendering	3	0	X	X		X	> 1 year
				E.3.2.5	Expecetd time for construction	3	0	X	X		X	> 1.5 year
E4	Structural health monitoring	E.4.1	Availability	E.4.1.1	Continuous vibration monitoring	2	1	X		X		Ability to identify global natural modes
				E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2	1	X		X		Ability to characterize stresses or absolute displacements in one or more major structural elements
				E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	1	X		X		Ability to characterize relative displacements in one or more movable components
		E.4.2	Reliability and operation	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0	X		X		No direct access to SHM data by technical staff
				E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2	1	X		X		Direct access to SHM data by technical staff, using conventional communications
				E.4.2.3	SHM data analysis	3	2	X		X		Automatic comparison of data to limits defined statistically from baseline of monitoring data
				E.4.2.4	Update rate on the feedback of the structural condition	3	2	X		X		Hourly feedback
E5	Inspection	E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan	2	2			X	X	Operative plan (with tasks, resources, ...)
				E.5.1.2	Repair plan of damaged components	2	2			X	X	Operative plan (with tasks, resources, ...)
		E.5.2	Inspection operation	E.5.2.1	Visual inspections	2	2	X	X	X	X	Permanent visual with team permanently on site
				E.5.2.2	Technical measurements	2	2	X	X	X	X	Permanent visual with team permanently
E6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	2	2	X	X	X	X	Detailed model previously callibrated for non linear static analysis
				E.6.1.2	Corrective maintenance interventions	2	1	X	X	X	X	Corrective maintenance contracted and available on demand
E7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	Structural model	3	3	X	X		X	Detailed model previously callibrated for time-history dynamic non-linear analysis
		E.7.2	Seismic risk studies	E.7.2.1	Seismic risk studies	3	0	X	X		X	No studies conducted
E8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	Coordination between services	2	1		X			Formal coordination and communication between a subset of intervenient emergency and response services
				E.8.1.2	Availability of resources on site	2	1	X	X			Resources available in one side of the bridge (river margin)
				E.8.1.3	Availability of safe-through equipment	1	1	X				Safe-through equipment available.
		E.8.2	Response for long term disruption	E.8.2.1	Long-term contingency plans	1	0		X			No long-term contingency plans
				E.8.2.2	Long-term traffic/mobility plans	1	0		X			No long-term traffic/mobility plans

1.4 RESILIENCE ESTIMATION

The measures of resilience used were the cumulative differences in interventions costs and the reductions in service if each indicator had its worst and current values.

This was determined by first estimating the maximum restoration intervention costs and reductions in service (Table 37) considering the transport system characteristics (Tables 25 and 26), and then the expected intervention costs and reductions in measures of service if each indicator had worst possible value (Table 39).

An example of the former is the maximum reduction in the travel time for work measure of service (€3’215’237’000), which is estimated by multiplying the number of workers traveling per day (321’429), by the average delay per person per day (180 minutes), by the cost of working time (€0.421/min) by the average number of days in which the traffic is delayed due to the restoration interventions (90 days).

An example of the latter is that the value of the safety measure of service between the Review/Update of the emergency plan (3.2.3) – Table 38 having its worst value is €4’016’589’000, which is 96% of the maximum expected reductions in safety if all indicators have their worst possible values, i.e. €4’187’346’000. The total measure of resilience is €7’718’603’000. The review/update of the emergency plan (3.2.3) is expected to have no effect on the restoration intervention costs.

Table 37. CS#6, Loss of Service after an Earthquake Hazard as a Cost Value [ETH/IP].

Impact level 1	Symbol	Description	Impact level 2	Symbol	Costs [10^3€]			
					Estimate	Computation	Estimate	Computation
Interventions	Ii_e	The impact of executing interventions			5693	(Ci_e*Li)	5693	(Ii_e)
Travel time	Itt_e	The impact of the additional travel time on passengers	Work	Itt.w_e	3215237	(Pw*Dppd_e*Cwt*D_e)	3448170	(Itt.w_e+Itt.l_e)
			Leisure	Itt.l_e	232933	(Pw*Dppd_e*Clt*D_e)		
Safety	Is_e	The impact on the users and affected public due to the user being involved in an accident	Property damage	Is.pd_e	1473214	((Ppd_e/100)*PDp_e*P)	4187346	(Is.pd_e+Is.i_e+Is.d_e)
			Injury	Is.i_e	1171500	((Ppd_e/100)*Ip_e*P)		
			Death	Is.d_e	1542632	((Ppd_e/100)*Dpp_e*P)		
Socio-economic activities	Ise_e	The contribution of the road operation to socio-economic development, i.e. the socio and economical costs of people and goods not being able to travel	Persons	Ise.p_e	76371	(P*Dppd_e*D_e*SECp)	77394	(Ise.p_e+Ise.g_e)
			Goods	Ise.g_e	1023	(P*Dppd_e*D_e*SECg)		
Total					7718603	(Ii_e+Itt_e+Is_e+Ise_e)		

Table 38. CS#6, Impact Factor for using differentiated Resilience Weights [ETH/IP].

Impact on the service	ID	Impact on the service	Costs and reductions in service [10^3€]				
			Intervention Costs	Measures of Service			Total
				Travel time	Accident	Socio-econ.	
50%	E.1.1.1	Age / Age of replacement of the warning system	2 846	1 724 085	2 093 673	38 697	3 859 302
45%	E.1.1.2	Age / Age of replacement of safe shut down system	2 562	1 551 677	1 884 306	34 828	3 473 372
49%	E.1.1.3	Condition state of infrastructure (pre-event)	2 769	1 677 021	2 036 520	37 641	3 753 950
31%	E.1.1.4	Condition state of protective structures/systems (pre-event)	1 759	1 065 314	1 293 683	23 911	2 384 666
75%	E.1.1.5	Expected condition state of infrastructure (post-event)	4 245	2 571 090	3 122 249	57 708	5 755 293
62%	E.1.1.6	Expected condition state of protective structures/systems (post-event)	3 536	2 141 956	2 601 122	48 076	4 794 690
43%	E.1.2.1	The possibility of building a temporary alternative route for vehicles	2 441	1 478 749	1 795 745	33 191	3 310 125
90%	E.1.2.2	The possibility of using another means to satisfy transport demand	5 104	3 091 673	3 754 428	69 393	6 920 597
71%	E.1.2.3	The number of possible existing alternative ways to deviate vehicles	4 066	2 463 116	2 991 128	55 285	5 513 595
10%	E.1.2.4	The presence of a warning system	576	348 725	423 480	7 827	780 607
43%	E.1.2.5	The presence of a safe shutdown system	2 451	1 484 631	1 802 888	33 323	3 323 293
93%	E.1.2.6	The presence of emergency / evacuation paths	5 278	3 196 953	3 882 277	71 756	7 156 264
16%	E.1.2.7	The presence of special measures to help evacuate persons	936	566 684	688 162	12 719	1 268 501
78%	E.1.3.1	Complience with the current seismic design code	4 439	2 688 778	3 265 166	60 350	6 018 732
39%	E.1.3.2	Presence of systems to reduce seismic effects	2 209	1 337 827	1 624 614	30 028	2 994 678
91%	E.1.3.3	Adequate systems to reduce seismic effects	5 200	3 150 144	3 825 433	70 705	7 051 482
98%	E.2.1.1	Accessibility	5 600	3 391 970	4 119 099	76 133	7 592 803
69%	E.2.1.2	Presence of persons/property below the infrastructure	3 905	2 365 477	2 872 559	53 093	5 295 035
12%	E.2.1.3	Extent of past damages due to hazards	692	419 345	509 239	9 412	938 688
19%	E.2.1.4	Hazard zone	1 104	668 660	811 999	15 008	1 496 772
12%	E.2.1.5	Duration of past down time due to hazards	685	415 008	503 973	9 315	928 981
93%	E.2.1.6	Land type	5 289	3 203 532	3 890 266	71 904	7 170 990
12%	E.2.1.7	Budget availability	710	430 152	522 363	9 655	962 880
20%	E.2.1.8	Traffic	1 127	682 669	829 011	15 323	1 528 129
31%	E.2.1.9	Hazards goods traffic	1 737	1 052 339	1 277 927	23 620	2 355 623
84%	E.2.1.10	Flammable goods traffic	4 780	2 895 402	3 516 083	64 988	6 481 253
81%	E.3.1.1	The presence of a monitoring strategy	4 608	2 791 173	3 389 511	62 648	6 247 940
86%	E.3.1.2	The presence of an maintenance strategy	4 886	2 959 754	3 594 230	66 432	6 625 302
9%	E.3.1.3	The extent of interventions executed prior to the event	533	322 947	392 176	7 249	722 904
8%	E.3.2.1	The presence of an emergency plan	451	273 203	331 768	6 132	611 554
41%	E.3.2.2	Practice of the emergency plan	2 328	1 409 950	1 712 198	31 646	3 156 122
96%	E.3.2.3	Review/update of the emergency plan	5 460	3 307 556	4 016 589	74 238	7 403 843
66%	E.3.2.4	Expected time for tendering	3 771	2 284 364	2 774 057	51 273	5 113 465
8%	E.3.2.5	Expected time for construction	447	270 623	328 636	6 074	605 780
75%	E.4.1.1	Continuous vibration monitoring	4 245	2 571 090	3 122 249	57 708	5 755 293
50%	E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.4.1.3	Continuous relative displacement monitoring of moving components	4 245	2 571 090	3 122 249	57 708	5 755 293
75%	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	4 245	2 571 090	3 122 249	57 708	5 755 293
75%	E.4.2.2	Permanent fail-safe communication of monitoring relevant information	4 245	2 571 090	3 122 249	57 708	5 755 293
50%	E.4.2.3	SHM data analysis	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.4.2,4	Update rate on the feedback of the structural condition	4 245	2 571 090	3 122 249	57 708	5 755 293
50%	E.5.1.1	Component inspection and testing plan	2 846	1 724 085	2 093 673	38 697	3 859 302
50%	E.5.1.2	Repair plan of damaged components	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.5.2.1	Visual inspections	4 269	2 586 128	3 140 510	58 046	5 788 953
50%	E.5.2.2	Technical measurements	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.6.1.1	Periodic routine maintenance interventions	4 269	2 586 128	3 140 510	58 046	5 788 953
75%	E.6.1.2	Corrective maintenance interventions	4 269	2 586 128	3 140 510	58 046	5 788 953
75%	E.7.1.1	Structural model	4 269	2 586 128	3 140 510	58 046	5 788 953
50%	E.7.2.1	Seismic risk studies	2 846	1 724 085	2 093 673	38 697	3 859 302
50%	E.8.1.1	Coordination between services	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.8.1.2	Availability of resources on site	4 269	2 586 128	3 140 510	58 046	5 788 953
50%	E.8.1.3	Availability of safe-through equipment	2 846	1 724 085	2 093 673	38 697	3 859 302
75%	E.8.2.1	Long-term contingency plans	4 269	2 586 128	3 140 510	58 046	5 788 953
75%	E.8.2.2	Long-term traffic/mobility plans	4 269	2 586 128	3 140 510	58 046	5 788 953

Table 39. CS#6, Expected Intervention Costs and Reductions in Measures of Service if each Indicator had worst possible Value [IP].

ID	Impact on the service	Costs and reductions in service [10^3€]				
		Intervention Costs	Measures of Service			Total
			Travel time	Accident	Socio-econ.	
E.1.1.1	50%	-	-	2 093 673	38 697	2 132 370
E.1.1.2	45%	-	-	1 884 306	34 828	1 919 133
E.1.1.3	49%	2 769	1 677 021	2 036 520	37 641	3 753 950
E.1.1.4	31%	1 759	1 065 314	1 293 683	23 911	2 384 666
E.1.1.6	75%	4 245	2 571 090	3 122 249	57 708	5 755 293
E.1.1.7	62%	3 536	2 141 956	2 601 122	48 076	4 794 690
E.1.2.1	43%	-	1 478 749	-	33 191	1 511 939
E.1.2.2	90%	-	3 091 673	-	69 393	3 161 066
E.1.2.3	71%	-	2 463 116	-	55 285	2 518 401
E.1.2.4	10%	-	348 725	-	7 827	356 552
E.1.2.5	43%	-	1 484 631	-	33 323	1 517 954
E.1.2.6	93%	-	3 196 953	-	71 756	3 268 709
E.1.2.7	16%	-	566 684	-	12 719	579 403
E.1.3.1	78%	4 439	2 688 778	3 265 166	60 350	6 018 732
E.1.3.2	39%	2 209	1 337 827	1 624 614	30 028	2 994 678
E.1.3.3	91%	5 200	3 150 144	3 825 433	70 705	7 051 482
E.2.1.1	98%	5 600	-	-	-	5 600
E.2.1.2	69%	-	-	2 872 559	-	2 872 559
E.2.1.3	12%	692	-	-	-	692
E.2.1.4	19%	1 104	668 660	811 999	15 008	1 496 772
E.2.1.5	12%	685	-	-	-	685
E.2.1.6	93%	5 289	-	3 890 266	-	3 895 555
E.2.1.7	12%	710	430 152	522 363	9 655	962 880
E.2.1.8	20%	1 127	682 669	829 011	15 323	1 528 129
E.2.1.9	31%	-	-	1 277 927	-	1 277 927
E.2.1.10	84%	-	-	3 516 083	-	3 516 083
E.3.1.1	81%	4 608	2 791 173	3 389 511	62 648	6 247 940
E.3.1.2	86%	4 886	2 959 754	3 594 230	66 432	6 625 302
E.3.1.3	9%	533	322 947	392 176	7 249	722 904
E.3.2.1	8%	-	273 203	-	6 132	279 335
E.3.2.2	41%	-	1 409 950	-	31 646	1 441 596
E.3.2.3	96%	-	3 307 556	4 016 589	74 238	7 398 383
E.3.2.4	66%	3 771	2 284 364	-	51 273	2 339 407
E.3.2.5	8%	447	270 623	-	6 074	277 144
E.4.1.1	75%	4 245	-	3 122 249	-	3 126 494
E.4.1.2	50%	2 846	-	2 093 673	-	2 096 519
E.4.1.3	75%	4 245	-	3 122 249	-	3 126 494
E.4.2.1	75%	4 245	-	3 122 249	-	3 126 494
E.4.2.2	75%	4 245	-	3 122 249	-	3 126 494
E.4.2.3	50%	2 846	-	2 093 673	-	2 096 519
E.4.2,4	75%	4 245	-	3 122 249	-	3 126 494
E.5.1.1	50%	-	-	2 093 673	38 697	2 132 370
E.5.1.2	50%	-	-	2 093 673	38 697	2 132 370
E.5.2.1	75%	4 269	2 586 128	3 140 510	58 046	5 788 953
E.5.2.2	50%	2 846	1 724 085	2 093 673	38 697	3 859 302
E.6.1.1	75%	4 269	2 586 128	3 140 510	58 046	5 788 953
E.6.1.2	75%	4 269	2 586 128	3 140 510	58 046	5 788 953
E.7.1.1	75%	4 269	2 586 128	-	58 046	2 648 443
E.7.2.1	50%	2 846	1 724 085	-	38 697	1 765 628
E.8.1.1	50%	-	1 724 085	-	-	1 724 085
E.8.1.2	75%	4 269	2 586 128	-	-	2 590 397
E.8.1.3	50%	2 846	-	-	-	2 846
E.8.2.1	75%	-	2 586 128	-	-	2 586 128
E.8.2.2	75%	-	2 586 128	-	-	2 586 128

1.5 MEASURES OF RESILIENCE PER INDICATOR

The measures of resilience per indicator were computed as the expected intervention costs and reductions in the measures of service taking into consideration the value of the indicator (Table 28 to Table 35 and Table 36).

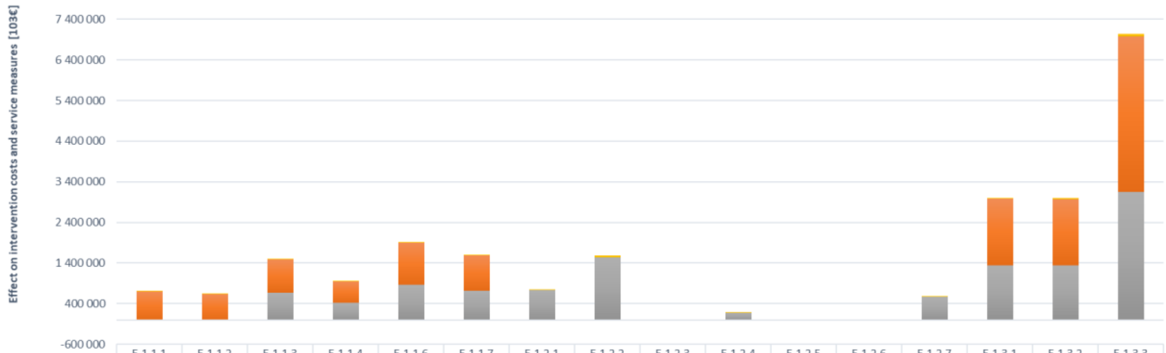
The exact numbers are shown for a subset (**E4 - Structural Health Monitoring**) of these in Table 40, in terms of both the maximum possible value, the actual expected value and the difference between the two.

The figure shows, for example, that the measures of SHM Data Analysis (E4.2.3) in terms of intervention costs and safety measures of service using the worst indicator value (0/3), i.e. the max measures, are €2’846’000 and €2’093’673’000 and using the actual indicator value (2/3), are €949’000 and €697’891’000.

The former of these values means that if the SHM Data Analysis indicator had its worst possible values the consequences of the reference earthquake would be €2’846’000 in restoration interventions and €2’093’673’000 in terms of injuries and fatalities. The latter of these values mean that in the actual situation, the consequences of the reference earthquake would be €949’000 in restoration interventions and €697’891’000 in terms of injuries and fatalities.

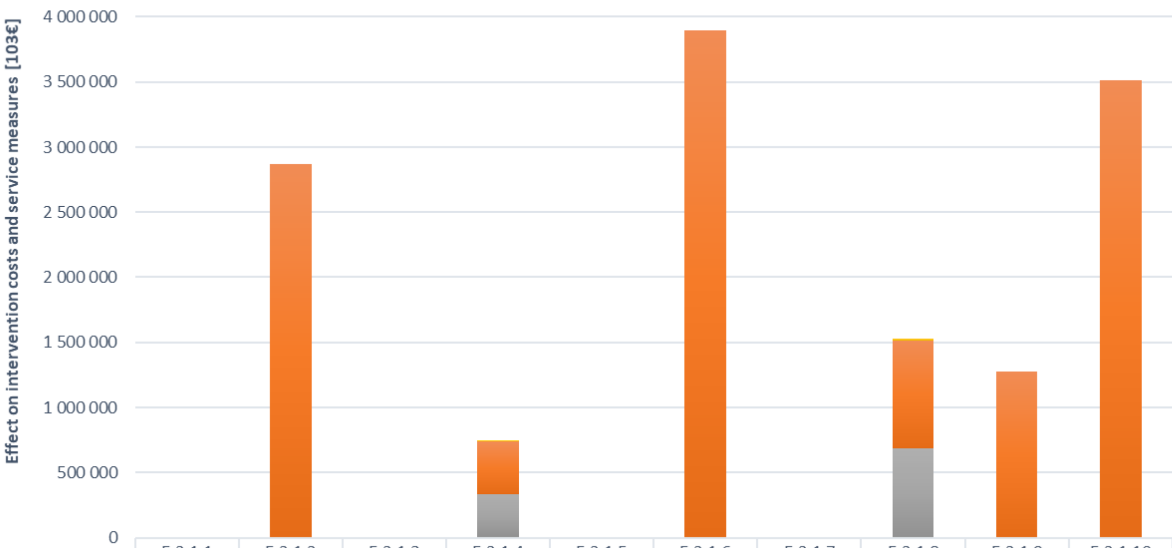
Table 40. CS#6, Expected Intervention Costs and Reductions in Measures of Service if each Indicator had worst possible Value [IP].

ID	Indicator	Item	Measures of Resilience [10^3€]				
			Intervention Costs	Reductions in Service			Total
				Travel time	Safety/Accident	Socio-econ.	
E.4.1.1	Continuous vibration monitoring	Max	4 245	Not Relevant	3 122 249	Not Relevant	3 126 494
		Actual	2 122		1 561 125		1 563 247
		Difference	2 122		1 561 125		1 563 247
E.4.1.2	Continuous stress and displacement monitoring of resistance elements	Max	2 846	Not Relevant	2 093 673	Not Relevant	2 096 519
		Actual	1 423		1 046 837		1 048 260
		Difference	1 423		2 122		3 545
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	Max	4 245	Not Relevant	3 122 249	Not Relevant	3 126 494
		Actual	2 122		1 561 125		1 563 247
		Difference	2 122		1 561 125		1 563 247
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	Max	4 245	Not Relevant	3 122 249	Not Relevant	3 126 494
		Actual	4 245		3 122 249		3 126 494
		Difference	0		0		0
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	Max	4 245	Not Relevant	3 122 249	Not Relevant	3 126 494
		Actual	2 122		1 561 125		1 563 247
		Difference	2 122		1 561 125		1 563 247
E.4.2.3	**SHM data analysis**	**Max**	**2 846**	**Not Relevant**	**2 093 673**	**Not Relevant**	**2 132 370**
		Actual	**949**		**697 891**		**698 840**
		Difference	**1 898**		**1 395 782**		**1 397 680**
E.4.2.4	Update rate on the feedback of the structural condition	Max	4 245	Not Relevant	3 122 249	Not Relevant	3 859 302
		Actual	4 245		3 122 249		3 126 494
		Difference	0		0		0
Total		Max	26 915	Not Relevant	19 798 593	Not Relevant	19 825 508
		Actual	17 228		12 672 600		12 689 828
		Difference	9 687		7 125 993		7 135 680



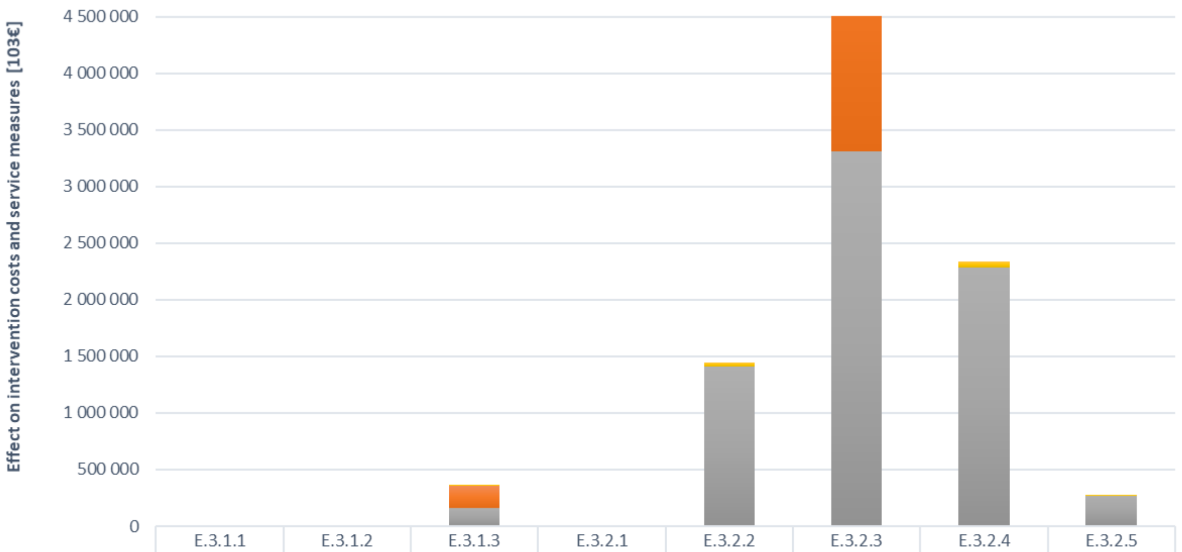
	E.1.1.1	E.1.1.2	E.1.1.3	E.1.1.4	E.1.1.6	E.1.1.7	E.1.2.1	E.1.2.2	E.1.2.3	E.1.2.4	E.1.2.5	E.1.2.6	E.1.2.7	E.1.3.1	E.1.3.2	E.1.3.3
Socio-econ.	12 899	11 609	15 056	9 564	19 236	16 025	16 595	34 696	0	3 914	0	0	12 719	30 175	30 028	70 705
Accident	697 891	628 102	814 608	517 473	1 040 750	867 041	0	0	0	0	0	0	0	1 632 583	1 624 614	3 825 433
Travel Time	0	0	670 808	426 126	857 030	713 985	739 374	1 545 836	0	174 362	0	0	566 684	1 344 389	1 337 827	3 150 144
Intervention	0	0	1 107	703	1 415	1 179	0	0	0	0	0	0	0	2 219	2 209	5 200

Figure 19. CS#6, Infrastructure: Measures of Resilience for each Indicator, using the Actual Value of all Indicators, by Intervention Costs and each Measure of Service [IP].



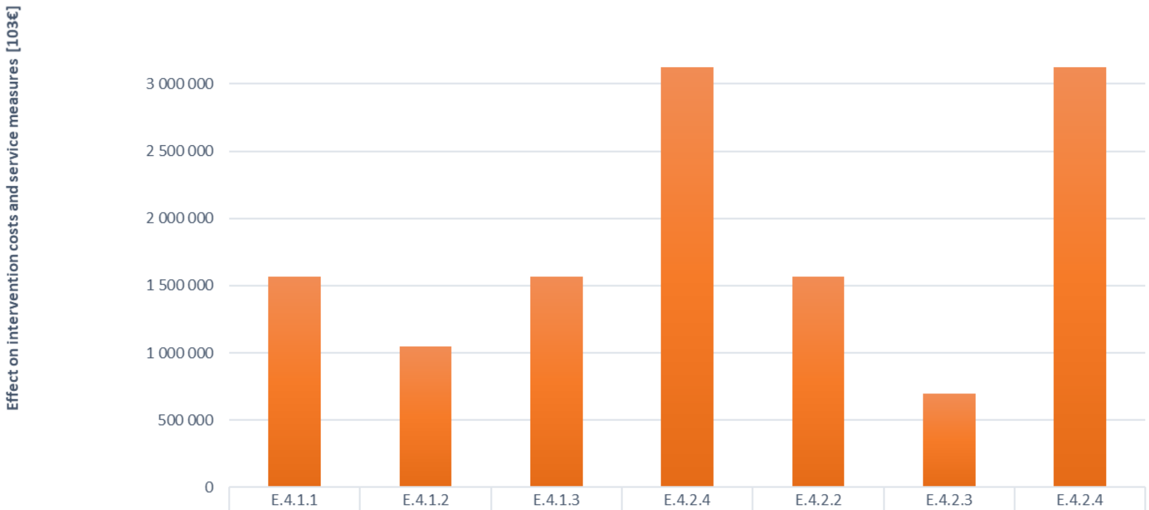
	E.2.1.1	E.2.1.2	E.2.1.3	E.2.1.4	E.2.1.5	E.2.1.6	E.2.1.7	E.2.1.8	E.2.1.9	E.2.1.10
Socio-econ.	0	0	0	7 504	0	0	0	15 323	0	0
Accident	0	2 872 559	0	406 000	0	3 890 266	0	829 011	1 277 927	3 516 083
Travel time	0	0	0	334 330	0	0	0	682 669	0	0
Intervention	5 600	0	0	552	228	5 289	0	1 127	0	0

Figure 20. CS#6, Environment: Measures of Resilience for each Indicator, using the Actual Value of all Indicators, by Intervention Costs and each Measure of Service [IP].



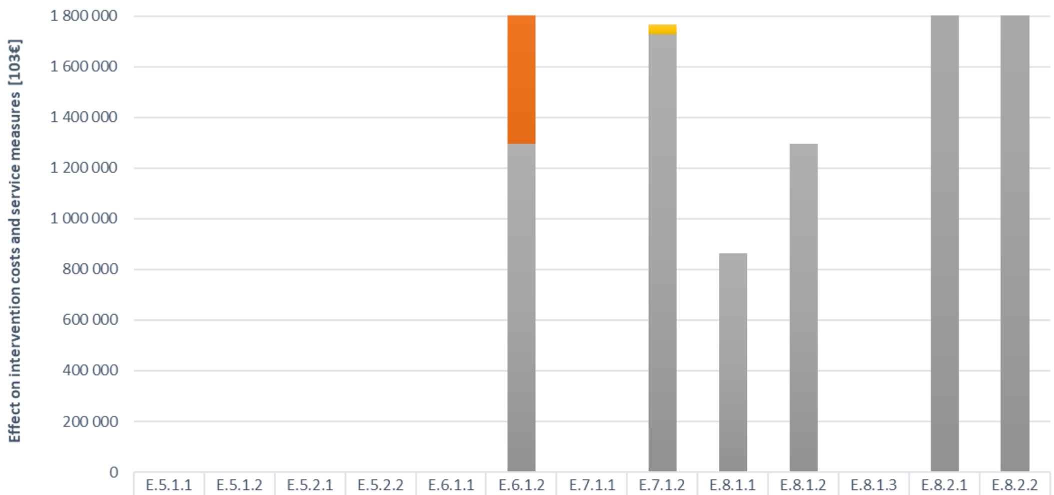
	E.3.1.1	E.3.1.2	E.3.1.3	E.3.2.1	E.3.2.2	E.3.2.3	E.3.2.4	E.3.2.5
Socio-econ.	0	0	3 624	0	31 646	74 238	51 273	6 074
Accident	0	0	196 088	0	0	4 016 589	0	0
Travel time	0	0	161 473	0	1 409 950	3 307 556	2 284 364	270 623
Intervention	0	0	267	0	0	0	3 771	447

Figure 21. CS#6, Organization: Measures of Resilience for each Indicator, using the Actual Value of all Indicators, by Intervention Costs and each Measure of Service [IP].



	E.4.1.1	E.4.1.2	E.4.1.3	E.4.2.4	E.4.2.2	E.4.2.3	E.4.2.4
Socio-econ.	0	0	0	0	0	0	0
Accident	1 561 125	1 046 837	1 561 125	3 122 249	1 561 125	697 891	3 122 249
Travel time	0	0	0	0	0	0	0
Intervention	2 122	1 423	2 122	4 245	2 122	949	4 245

Figure 22. CS#6, Structural Health Monitoring: Measures of Resilience for each Indicator, using the Actual Value of all Indicators, by Intervention Costs and each Measure of Service [IP].



	E.5.1.1	E.5.1.2	E.5.2.1	E.5.2.2	E.6.1.1	E.6.1.2	E.7.1.1	E.7.1.2	E.8.1.1	E.8.1.2	E.8.1.3	E.8.2.1	E.8.2.2
Socio-econ.	0	0	0	0	0	29 023	0	38 697	0	0	0	0	0
Accident	0	0	0	0	0	1 570 25	0	0	0	0	0	0	0
Travel time	0	0	0	0	0	1 293 06	0	1 724 08	862 043	1 293 06	0	2 586 12	2 586 12
Intervention	0	0	0	0	0	2 135	0	2 846	0	2 135	0	0	0

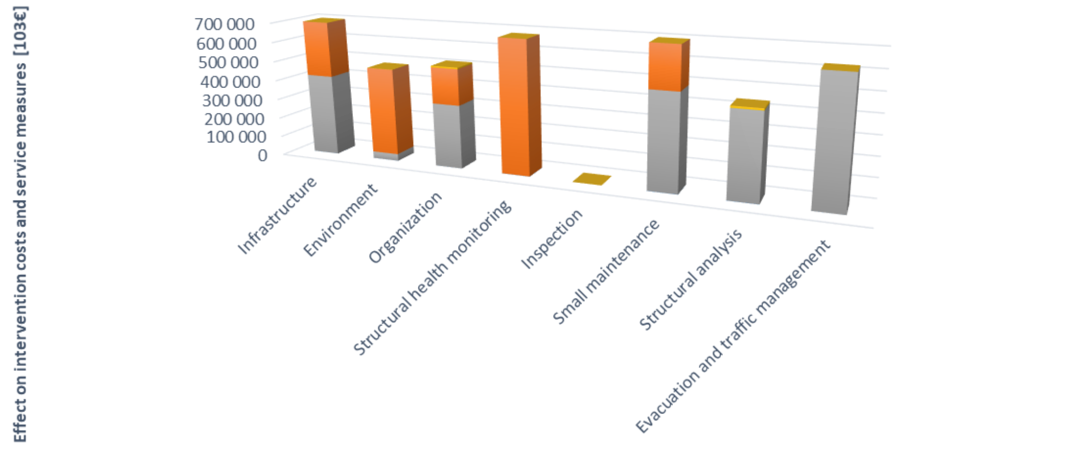
Figure 23. CS#6, Inspection, Small Maintenance, Structural Analysis and Evacuation and Traffic Management: Measures of Resilience for each Indicator, using the Actual Value of all Indicators, by Intervention Costs and each Measure of Service [IP].

Assessing the measures of resilience for intervention costs and each measure of service in this manner, provides an infrastructure manager an idea of which of these are the most problematic and how and where can an infrastructure manager focus their efforts to improve resilience.

It can be seen from the measures of resilience shown in this Section and Table 40, for example, that the safety/accident measure of service is significantly more important than intervention costs and the travel time and socio-economic measures of service.

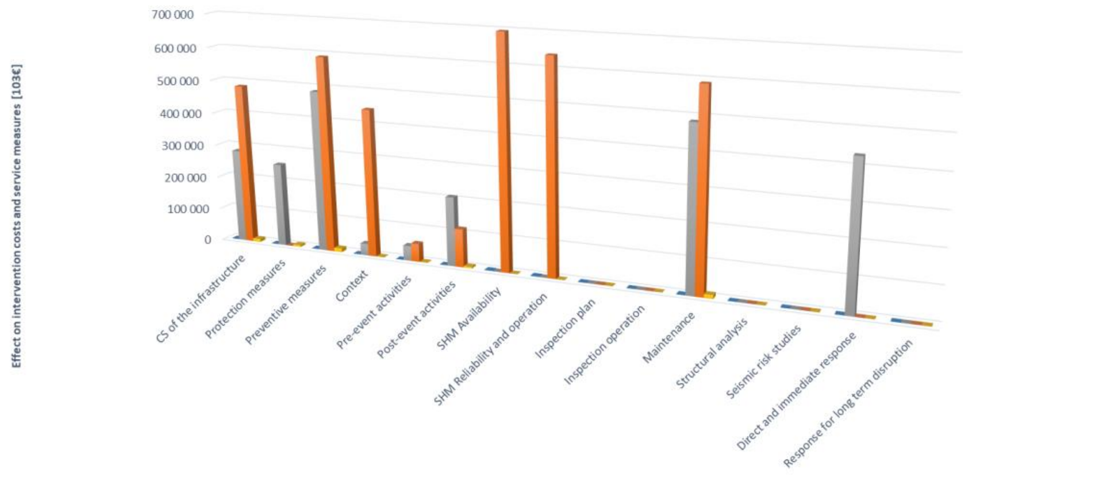
1.6 MEASURES OF RESILIENCE PER INDICATOR CATEGORY

The measures of resilience per indicator category (Level "0") are shown in Figure 24. A measure of resilience for an indicator category is the ratio between the sum of the actual and the sum of the highest possible values of all indicators in the category multiplied by the average of the values of their individual measures of resilience.



	Infrastructure	Environment	Organization	Structural health monitoring	Inspection	Small maintenance	Structural analysis	Evacuation and traffic management
Socio-econ.	10 248	794	7 300	0	0	10 884	9 674	0
Accident	421 492	444 934	184 305	678 889	0	588 846	0	0
Travel time	417 080	35 374	325 236	0	0	484 899	431 021	628 060
Intervention	508	445	196	923	0	801	712	183

Figure 24. Measures of Resilience for Level "0" Indicator Categories.



	CS of the infrastructure	Protection measures	Preventive measures	Context	Pre-event activities	Post-event activities	SHM Availability	SHM Reliability and operation	Inspection plan	Inspection operation	Maintenance	Structural analysis	Seismic risk studies	Direct and immediate response	Response for long term disruption
Intervention	467	0	802	445	74	121	945	867	0	0	801	0	0	427	0
Travel time	282 964	252 188	486 030	35 374	44 854	207 786	0	0	0	0	484 899	0	0	431 021	0
Accident	484 258	0	590 219	444 934	54 469	114 760	694 848	637 764	0	0	588 846	0	0	0	0
Socio-econ.	8 951	5 660	10 909	794	1 007	4 664	0	0	0	0	10 884	0	0	0	0

Figure 25. Measures of Resilience for the Condition State, Protection Measures, Preventive Measures, Context, Pre- and Post-Event Activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic Risk Studies, Direct and Intermediate Response and Response for Long Term Disruption Indicator Categories.

Therefore, it can be seen from Figure 25, that there is the most potential to improve resilience by improving the values of the condition state of the infrastructure, preventive measures, SHM Availability, SHM Reliability and Operation, Maintenance and Direct and Immediate Response activities indicators, and improvements of their values would have the largest impact on the safety measure of service, followed by travel time, with very little of the resilience related to intervention costs or socio-economic impact.

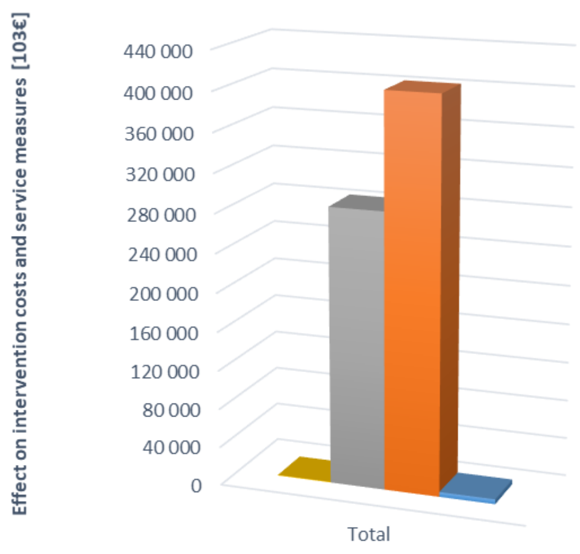
Also, Figure 28 shows that Infrastructure, Environment, Organization, Structural Health Monitoring, Small Maintenance and Evacuation and Traffic Management indicators are the largest contributor to resilience.

1.7 MEASURES OF RESILIENCE FOR THE TRANSPORT SYSTEM (BRIDGE)

The measures of resilience for the whole transport system are shown in Figure 26.

The measure of resilience for the intervention costs and all measures of service was €694’700’600, i.e. the sum of the expected intervention cost (€524’000), and expected reductions in the travel time, safety and socio-economic measures of service (€285’362’000, €403’695’000, and €5’088’000) if the reference earthquake occurs. The measures of resilience for the transport system were obtained with the same logic as for the indicator categories explained in Section 1.6.

For example, the safety measure of resilience was the sum of the actual values of indicators 1.1.1 to 8.2.2 divided by the sum of their highest possible values, multiplied by the average measures of resilience per indicator.



	Total
Intervention	524
Travel Time	285 362
Accident	403 695
Socio-Economic	5 088

Figure 26. Measures of Resilience for the Transport System.

1.8 DIFFERENCE BETWEEN MEASURES OF RESILIENCE USING WORST AND ACTUAL VALUES OF INDICATORS

The differences between the measures of resilience using the worst and actual values of indicators are shown in next figures for the whole transport system, for Level "0", "1" and "2" categories/indicators.

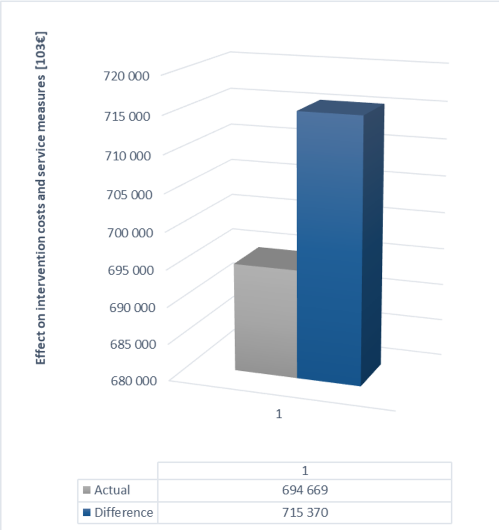


Figure 27. Difference between Measures of Resilience for the Transport System (Bridge).

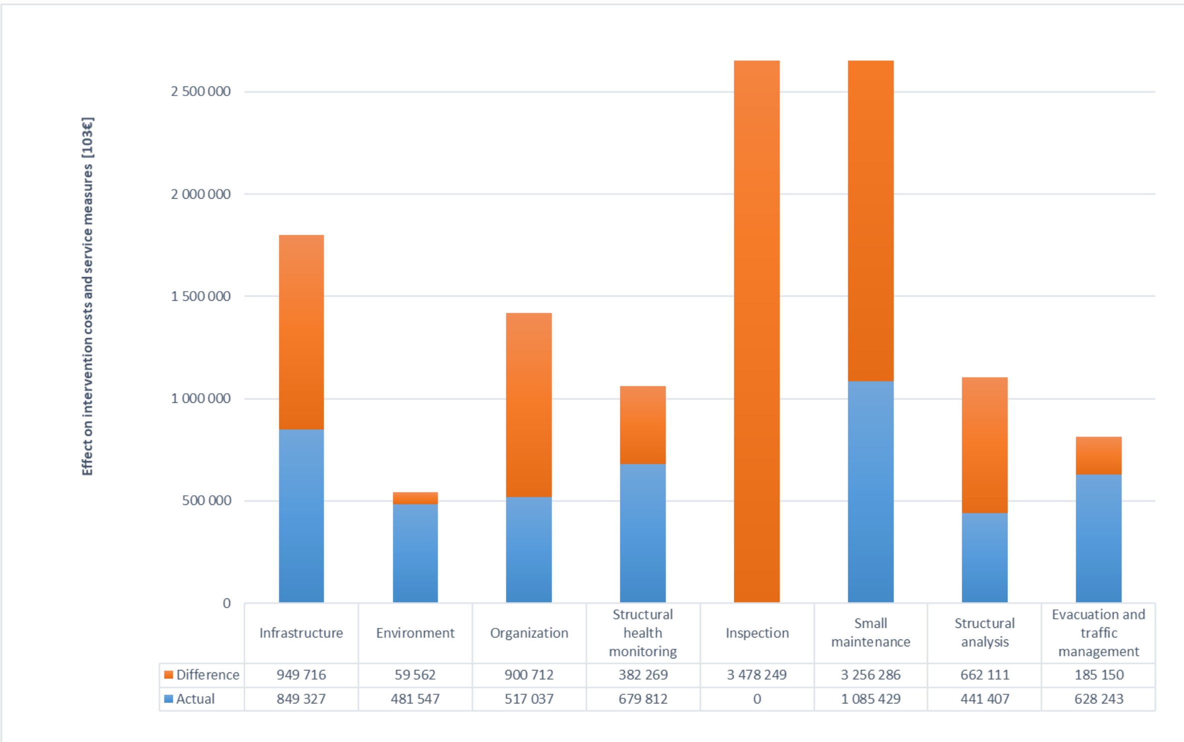
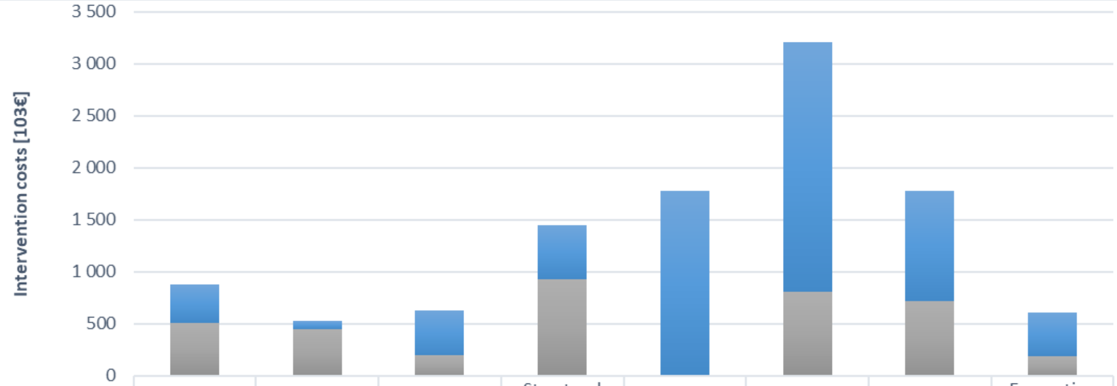
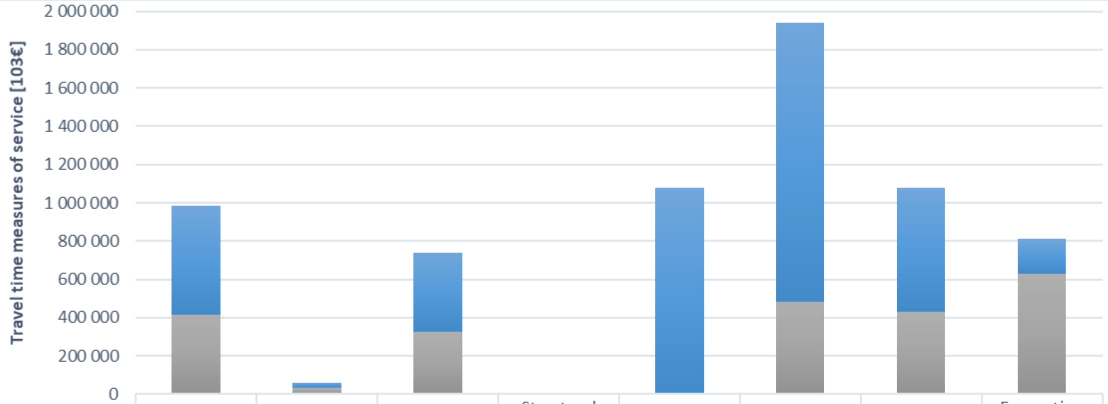


Figure 28. Difference between Measures of Resilience for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management Categories.



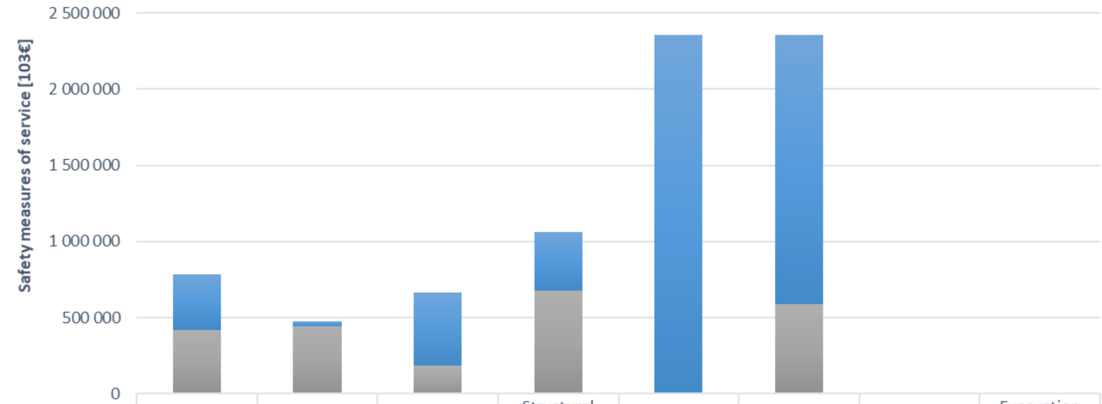
	Infrastructure	Environment	Organization	Structural health monitoring	Inspection	Small maintenance	Structural analysis	Evacuation and traffic management
Difference	366	84	427	519	1 779	2 402	1 067	427
Actual	508	445	196	923	0	801	712	183

Figure 29. Difference between Measures of Resilience for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management Categories using only Intervention Costs.



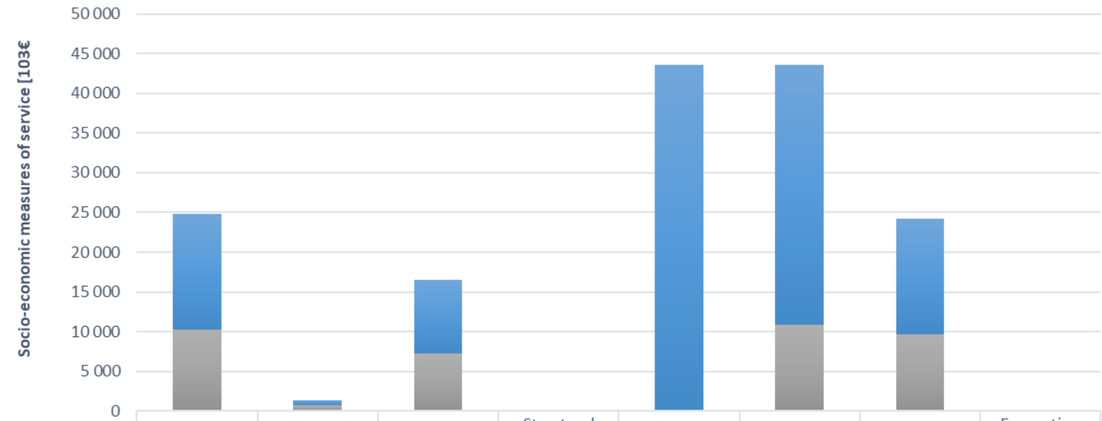
	Infrastructure	Environment	Organization	Structural health monitoring	Inspection	Small maintenance	Structural analysis	Evacuation and traffic management
Difference	569 398	26 591	412 374	0	1 077 553	1 454 697	646 532	184 723
Total	417 080	35 374	325 236	0	0	484 899	431 021	628 060

Figure 30. Difference between Measures of Resilience for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management Categories using only Travel Time Measure of Service.



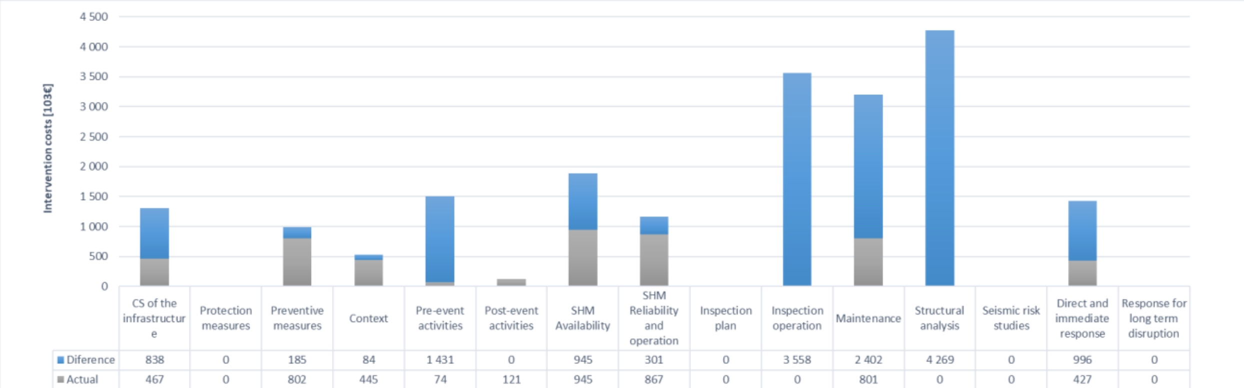
	Infrastructure	Environment	Organization	Structural health monitoring	Inspection	Small maintenance	Structural analysis	Evacuation and traffic management
Difference	365 398	32 291	478 655	381 750	2 355 382	1 766 537	0	0
Actual	421 492	444 934	184 305	678 889	0	588 846	0	0

Figure 31. Difference between Measures of Resilience for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management Categories using only Safety Measure of Service.



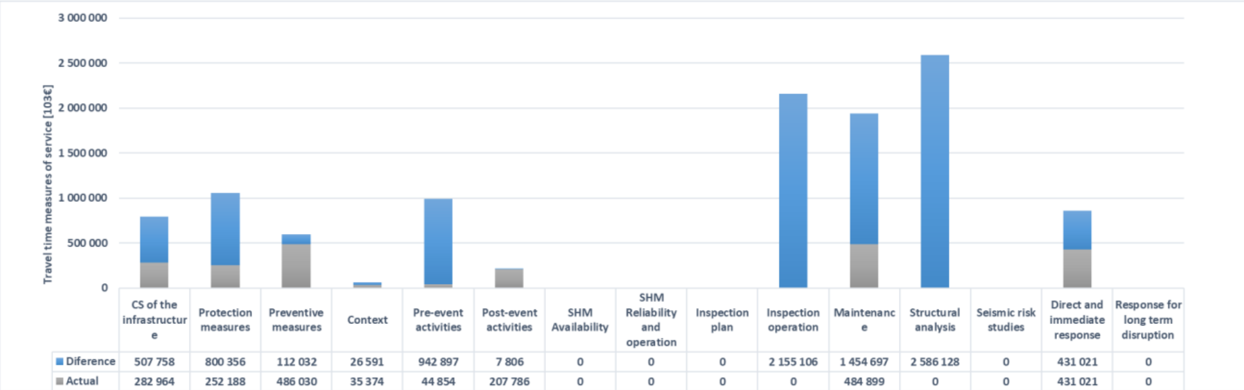
	Infrastructure	Environment	Organization	Structural health monitoring	Inspection	Small maintenance	Structural analysis	Evacuation and traffic management
Difference	14 554	597	9 256	0	43 534	32 651	14 511	0
Actual	10 248	794	7 300	0	0	10 884	9 674	0

Figure 32. Difference between Measures of Resilience for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management categories using only Socio-Economic Measure of Service.



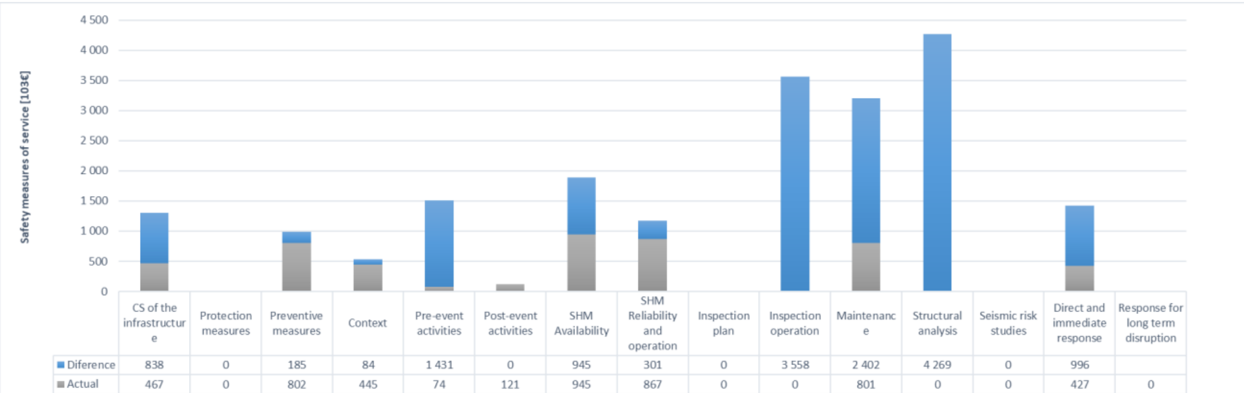
	CS of the infrastructure	Protection measures	Preventive measures	Context	Pre-event activities	Post-event activities	SHM Availability	SHM Reliability and operation	Inspection plan	Inspection operation	Maintenance	Structural analysis	Seismic risk studies	Direct and immediate response	Response for long term disruption
Diference	838	0	185	84	1 431	0	945	301	0	3 558	2 402	4 269	0	996	0
Actual	467	0	802	445	74	121	945	867	0	0	801	0	0	427	0

Figure 33. Difference between Measures of Resilience for Condition State, Protection Measures, Preventive Measures, Context, Pre- and Post-Event Activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic Risk Studies, Direct and Intermediate Response and Response for Long Term Disruption Indicator Categories using only Intervention Costs.



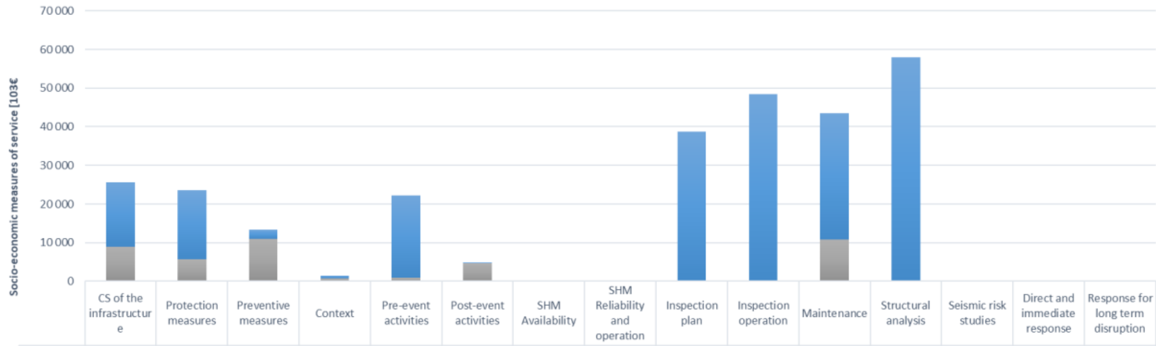
	CS of the infrastructure	Protection measures	Preventive measures	Context	Pre-event activities	Post-event activities	SHM Availability	SHM Reliability and operation	Inspection plan	Inspection operation	Maintenance	Structural analysis	Seismic risk studies	Direct and immediate response	Response for long term disruption
Diference	507 758	800 356	112 032	26 591	942 897	7 806	0	0	0	2 155 106	1 454 697	2 586 128	0	431 021	0
Actual	282 964	252 188	486 030	35 374	44 854	207 786	0	0	0	0	484 899	0	0	431 021	0

Figure 34. Difference between Measures of Resilience for Condition State, Protection Measures, Preventive Measures, Context, Pre- and Post-Event Activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic Risk Studies, Direct and Intermediate Response and Response for Long Term Disruption Indicator Categories using only Travel Time Measure of Service.



	CS of the infrastructure	Protection measures	Preventive measures	Context	Pre-event activities	Post-event activities	SHM Availability	SHM Reliability and operation	Inspection plan	Inspection operation	Maintenance	Structural analysis	Seismic risk studies	Direct and immediate response	Response for long term disruption
Diference	838	0	185	84	1 431	0	945	301	0	3 558	2 402	4 269	0	996	
Actual	467	0	802	445	74	121	945	867	0	0	801	0	0	427	0

Figure 35. Difference between Measures of Resilience for Condition State, Protection Measures, Preventive Measures, Context, Pre- and Post-Event Activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic Risk Studies, Direct and Intermediate Response and Response for Long Term Disruption Indicator Categories using only Safety Measure of Service.



	CS of the infrastructure	Protection measures	Preventive measures	Context	Pre-event activities	Post-event activities	SHM Availability	SHM Reliability and operation	Inspection plan	Inspection operation	Maintenance	Structural analysis	Seismic risk studies	Direct and immediate response	Response for long term disruption
Diference	16 595	17 964	2 515	597	21 163	175	0	0	38 697	48 372	32 651	58 046	0	0	0
Actual	8 951	5 660	10 909	794	1 007	4 664	0	0	0	0	10 884	0	0	0	0

Figure 36. Difference between Measures of Resilience for Condition State, Protection Measures, Preventive Measures, Context, Pre- and Post-Event Activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic Risk Studies, Direct and Intermediate Response and Response for Long Term Disruption Indicator Categories using only Socio-Economic Measure of Service.

The differences between the measures of resilience using the worst and actual values of indicators are shown in Figure 27 and Figure 28 for the whole transport system and Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management categories using intervention costs and all measures of service.

Figures 29 to 32 shows the resilience indicators for Infrastructure, Environment, Organization, Structural Health Monitoring, Inspection, Small Maintenance, Structural analysis and Evacuation and Traffic Management using only intervention costs and only each measure of service.

Figures 33 to 36 shows the safety measures condition state, protection measures, preventive measures, context, pre- and post-event activities, SHM Availability, SHM Reliability and Operation, Inspection Plan, Maintenance, Structural Analysis, Seismic risk studies, Direct and Intermediate Response and Response for long term disruption indicator categories.

Through these figures, an infrastructure manager obtains an idea of how much better and how much worse resilience can be. For example, although the measure of resilience of the transport system is €694’669’000 (Figure 26), which is arguably a high number, but it is half of what it could be, i.e. €1’410’039’000. Although alone, even this might not be much information, it would be very useful if being used to track resilience over time. It can also be seen quickly where little or no additional improvements in resilience can be achieved.

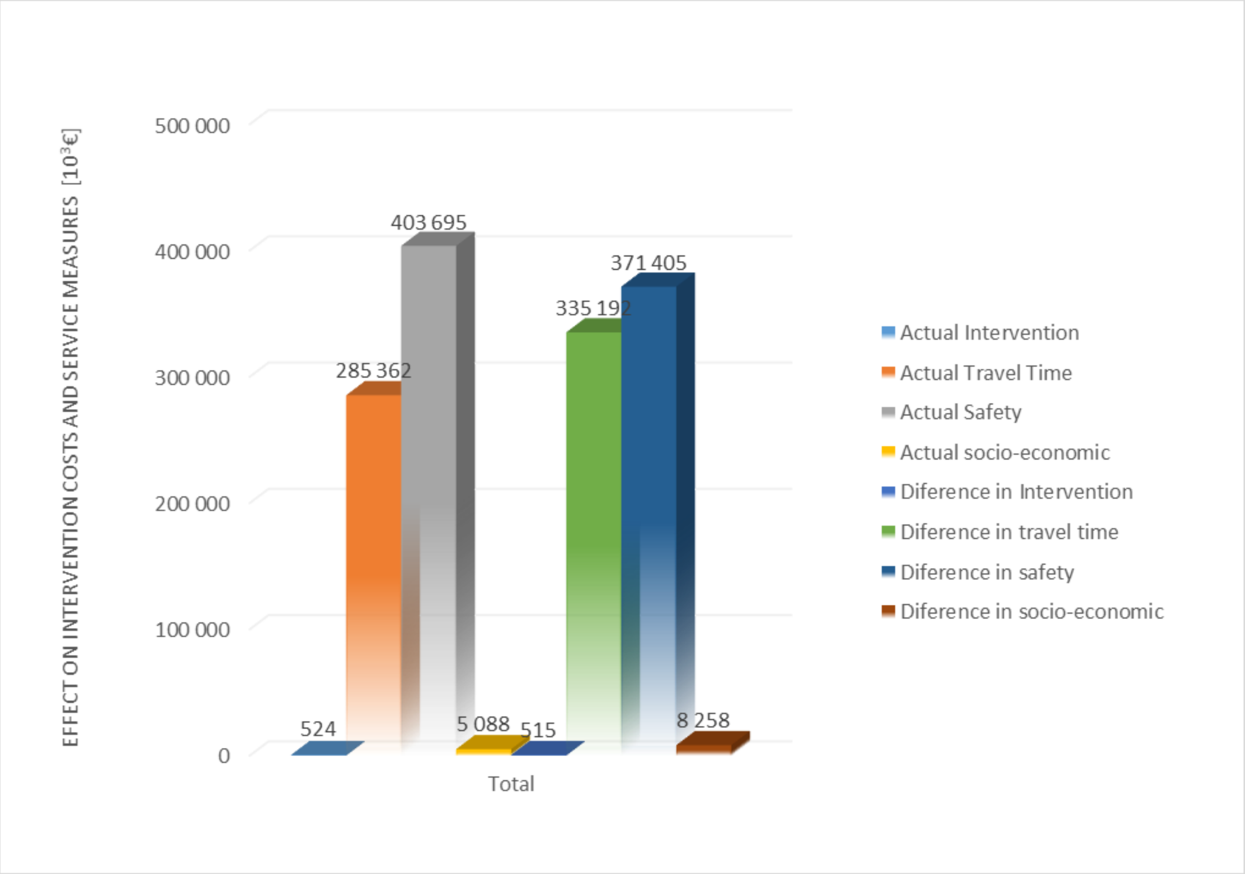


Figure 37. Difference between Measures of Resilience (possible maximum value and actual value) for the Asset (bridge).

1.9 KEY RESILIENCE TARGETS

The resilience indicators target for the example infrastructure (bridge) were set by a net-benefit analysis that was performed on Deliverable D1.2 including some other indicators that were considered very important for assessing the resilience of this bridge.

In general, the infrastructure manager should first identify both the legal requirements and his own, as well as the owners', requirements, i.e. the things that they empirically know had to be done. He then systematically estimated the approximate costs and benefits of improving the values of each of the indicators, with respect to the likely restoration costs and the likely reductions in service with respect to the reference earthquake.

Finally, he then selected the target values that were likely to give the maximum net-benefit, while satisfying all of the requirements. Each of these steps is explained in the following sections in more detail. The process to set the targets starts directly with the estimate of the net-benefit.

Table 41 shows the impact factor for increasing the value of the resilience indicators, which can provide proper information, for the infrastructure manager, of the importance of each indicator on intervention costs and reductions in the measures of service as well on resilience.

Table 41. CS#6, Impact Factor for Increasing the Value of the Resilience Indicator [ETH/IP].

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because…)	Likely effect on measures of service and intervention costs				The… the resilience
							Intervention	Travel time	Accidents	Socio-econ. activities	
E.1	Infrastructure	E.1.1	Condition state of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	The older the warning systems, the more obsolete their performances and therefore the higher it is the probability of accidents due to a lack of signaling the danger in case of an earthquake.	the same	the same	higher	higher	lower
				E.1.1.2	Age / Age of replacement of safe shut down system	The older the safe shut down system, the more obsolete their performances and therefore the higher is the probability of accidents due to a lack of stopping the traffic in case of an earthquake.	the same	the same	higher	higher	lower
				E.1.1.3	Condition state of infrastructure	The better the condition state of the infrastructure, the lower is the probability of the infrastructure to be damaged following up with an earthquake and the lower the consequences are in case it occurs.	lower	lower	lower	lower	higher
				E.1.1.4	Condition state of protective structures/systems	The more deteriorated the protection barriers, the lower is the probability that it can provide the LOS for which it was designed, and the higher the expected consequences are in case of earthquakes.	lower	lower	lower	lower	higher
				E.1.1.5	Expected condition state of infrastructure (after the event)	The expected share of the infrastructure in excellent (i.e. CS1) good (i.e. CS1 and 2), decent (CS 3 or 4) or bad (CS5) after an event, is an indication of its ability to withstand the earthquake and, therefore, of higher resiliency.	lower	lower	lower	lower	higher
				E.1.1.6	Expected condition state of protective structures/systems (after the event)	The expectation of theprotective structure to be in excellent (i.e. CS1) good (i.e. CS1 and 2), decent (CS 3 or 4) or bad (CS5) after an event, is an indication of its ability to function after an earthquake and, therefore, of higher resiliency of the infrastructure.	lower	lower	lower	lower	higher
		E.1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	The possibility of re-routing the traffic through temporary paths reduces the consequences of an infrastructure being out of service after an earthquake.	the same	lower	the same	lower	higher
				E.1.2.2	The possibility of using another means to satisfy transport demand	The possibility of re-routing people and goods using temporary means reduces the consequences of an infrastructure being out of service.	the same	lower	the same	lower	higher
				E.1.2.3	The number of possible existing alternative ways to deviate vehicles	The possibility of re-routing the traffic through existing temporary paths reduces the consequences of an infrastructure being out of service after an earthquake.	the same	lower	the same	lower	higher
				E.1.2.4	The presence of a warning system	The presence of a warning system to prevent users to pass by a road section in case of danger, reduces the consequence of an earthquake.	the same	lower	the same	lower	higher
				E.1.2.5	The presence of a safe shutdown system	The presence of a safe shut down system to prevent users to access a road section in case of danger, reduces the consequence of an earthquake.	the same	lower	the same	lower	higher
				E.1.2.6	The presence of emergency / evacuation paths	The presence of an emergency path to allow users to escape a road section in case of danger, reduces the consequence of an earthquake.	the same	lower	the same	lower	higher
				E.1.2.7	The presence of special measures to help evacuate persons	The possibility of using extraordinary measures (e.g. helicopter) to allow users to escape a road section in case of danger, reduces the consequence of an earthquake.	the same	lower	the same	lower	higher
		E.1.3	Preventive measures	E.1.3.1	Compliance with the current seismic design code	The more recent the seismic regulation's level of compliance, the lower the impact of an earthquake on the infrastructure.	lower	lower	lower	lower	higher
				E.1.3.2	Presence of systems to reduce seismic effects	The presence of systems to reduce seismic effects prevent the road section to be hit in case of earthquakes.	lower	lower	lower	lower	higher
				E.1.3.3	Adequate systems to reduce seismic effects	The adequate functioning of systems to reduce seismic effects prevent the road section to be hit in case of earthquakes.	lower	lower	lower	lower	higher
E.2	Environment	E.2.1	Context	E.2.1.1	Accessibility	The more the road is accessible, the less expensive it is to conduct the intervention on it.	lower	the same	the same	the same	higher
				E.2.1.2	Presence of persons/property below the infrastructure	The possibility to affect third parties below the infrastructure rises the consequences of an earthquake when it occurs.	the same	the same	higher	the same	lower
				E.2.1.3	Extent of past damages due to hazards	The higher the past damages connected to earthquakes, the higher is its probability of suffering strong events also in the future.	higher	the same	the same	the same	lower
				E.2.1.4	Hazard zone	The more the road is in a zone exposed to frequent and high magnitude earthquakes, the higher is its probability of being hit.	higher	higher	higher	higher	lower
				E.2.1.5	Duration of past down time due to hazards	The highest the Nº of days per year that earthquakes have interrupted the service, the higher is its probability of suffering interruptions also in future.	higher	the same	the same	the same	lower
				E.2.1.6	Land type	The harder the material of the landslides, the higher are the consequences in case of a landslide following up with an earthquake.	higher	the same	higher	the same	lower
				E.2.1.7	Budget availability	The higher the budget availability is, the higher is the probability and effectiveness of the executing the interventions to recover the disruption of an earthquake.	lower	lower	lower	lower	higher
				E.2.1.8	Traffic	The more traffic is on a road the higher is the exposition to consequences in case an earthquake occurs.	higher	higher	higher	higher	lower
				E.2.1.9	Hazards goods traffic	The presence of dangerous goods transported on the road raises the consequences in case of accident.	the same	the same	higher	the same	lower
				E.2.1.10	Flammable goods traffic	The presence of inflammable goods transported on the road raises the consequences in case of accident.	the same	the same	higher	the same	lower
E.3	Organization	E.3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	The presence of a monitoring plan raises the awareness of the IM on the state of the road and his preparedness to react when necessary. A prepared IM is trusted to be more reactive and reduces the consequences of an earthquake on traffic.	lower	lower	lower	lower	higher
				E.3.1.2	The presence of a maintenance strategy	The presence of an intervention strategy lowers the probability that an infrastructure ends up in a deteriorated state.	lower	lower	lower	lower	higher
				E.3.1.3	The extent of interventions executed prior to the event	The more it is spent on regular maintenance before the event, the lower is the probability that the infrastructure will suffer a drop in LOS following up with an earthquake.	higher	higher	higher	higher	lower
		E.3.2	Post event activities	E.3.2.1	The presence of an emergency plan	The presence of an emergency plan reduces the time between the occurrence of an earthquake and the moment an IM reacts.	the same	lower	the same	lower	higher
				E.3.2.2	Practice of the emergency plan	The regular execution of the emergency plan raises the ability of the IM to apply it when needed, reducing the time for execution and the risk of failure.	the same	lower	the same	lower	higher
				E.3.2.3	Review/update of the emergency plan	The highest the Nº years since the last review/update of the emergency plan the less the plan is trust to be effective.	the same	higher	higher	higher	lower
				E.3.2.4	Expected time for tendering	The longer the time for the for public tender the loger the infrastructure stay out of service.	higher	higher	the same	higher	lower
				E.3.2.5	Expected time for construction	The longer the time for construction the loger the infrastructure stay out of service.	higher	higher	the same	higher	lower

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because…)	Likely effect on measures of service and intervention costs				The… the resilience
							Intervention	Travel time	Accidents	Socio-econ. activities	
E.4	Structural Health Monitoring	E.4.1	SHM Availability	E.4.1.1	Continuous vibration monitoring	A monitoring system permanently installed for capturing the natural modes' frequencies and shapes allows assessing, in real-time, important changes in the stifness and boundary conditions.	higher	the same	lower	the same	higher
				E.4.1.2	Continuous stress and displacement monitoring of resistance elements	A monitoring system permanently installed for measuring stress and displacements during and after na earthquake allow for the direct comparison of values obtained from seismic design.	higher	the same	lower	the same	higher
				E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	Moving components and seismic devices should include relative displacement monitoring to assess, during operation and after na earthquake, the presence of possible discontinuities in structural supports / boundary conditions as well as possible obstacles to traffic circulation.	higher	the same	lower	the same	higher
		E.4.2	SHM Reliability and Operation	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	In case of a seismic event the monitoring system needs to function in the subsequent hours to allow for the estimation of modal features, stresses and displacements, and posterior comparison with the pre-event baseline	higher	the same	lower	the same	higher
				E.4.2.2	Permanent fail-safe communication of monitoring relevant information	In case of a seismic event, and in case conventional data and cellular networks fail, the results obtained from the monitoring system should be consulted remotely and in real-time.	higher	the same	lower	the same	higher
				E.4.2.3	SHM data analysis	The analysis of the data acquired should allow for the extraction of information regarding the structural behaviour and the health condition	higher	the same	lower	the same	higher
				E.4.2.4	Update rate on the feedback of the structural condition	The SHM system should be capable of providing feedback on the structural condition with the fastest cadency possible without compromising the sensitivity to damages nor the resolution against false alerts	higher	the same	lower	the same	higher
E.5	Inspection	E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan	An inspection and testing plan of the critical components (screw faults, bridge moorings, bearings, joints, suspension cables) must be defined and implemented to evaluate diferences between the last and current inspection, based on pre-defined damage indicators to allows for the monitoring of component structural health and earlier detection of damage.	the same	the same	lower	lower	higher
				E.5.1.2	Repair plan of damaged components	A repair plan of damage components observed during the inspection should be defined and will improve and speed up maintenance interventions. A contigency repair plan of critical components should be in place in case of a seismic event.	the same	the same	lower	lower	higher
		E.5.2	Inspection operation	E.5.2.1	Visual inspections	The implementation of regular visual inspection of components (bridge moorings, bearings, joints) allows detecting unexpected damage in an early stage.	higher	higher	lower	higher	higher
				E.5.2.2	Technical measurements	The measurement of parameters to assess and quantify the deviation of structural components from their standard functioning, between inspections and after a seismic safety coeficient.	higher	higher	lower	higher	higher
E.6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	The implementation of maintenance intervention (welding repair, retightening and screws replacing, etc) increases structural performance in case of seismic event and lowers probability of accident in case of seismic hazards.	higher	higher	lower	higher	higher
				E.6.1.2	Corrective maintenance interventions	The adequate and timely execution of corrective maintenance, prior to any hazardous event, increases structural performance in case of seismic event and lowers probability of accident in case of seismic hazards.	higher	higher	lower	higher	higher
E.7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	Structural model	A structural model calibrated to reproduce the structural response should be developed and calibrated to the structural response using on site measurement. In case of seismic occurrence it can be used to compared against structural measruements and analysis the structural condition.	higher	higher	the same	higher	higher
		E.7.2	Seismic risk studies	E.7.2.1	Seismic risk studies	Using the structural model as well as information from site geology and seismic action, seismic risk studies should be conducted to allow for precise and rapid estimations of the expected damage scenarios on the structural system	higher	higher	the same	higher	higher
E.8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	Coordination between services	While working on a complex infrastructure, with a diferente environment from the normal road/street, and where operational hazards are a strong reality, the quality and quantity of communication between the police, the concession operator, emergency services and civil protection is of paramount imporance.	the same	lower	the same	the same	higher
				E.8.1.2	Availability of resources on site	The availability of police and concession operator resources in the vacinity of the bridge and/or dedicated police officers to the bridge trafic control have a strong influence on the rapidness and the acuracy of the police dispatch/deployment.	higher	lower	the same	the same	higher
				E.8.1.3	Availability of safe-through equipment	The availability of equipment especially designed to ensure the minimum/critical operation of a long-span bridge in case of earthquake can prove very important, especially to aid in emergency services and disaster management. Examples consist of plates to cover damaged joints.	higher	the same	the same	the same	higher
		E.8.2	Response for long term disruption	E.8.2.1	Long-term contingency plans	Coherent crise managment plans, in case of long term unavailability of the bridge, should be defined and ready to be implemented.	the same	lower	the same	the same	higher
				E.8.2.2	Long-term traffic/mobility plans	Specific alternative mobility plans in case of long term unavailability of the bridge, with specific focus on the mobility of emergency services, should be designed and ready to implement	the same	lower	the same	the same	higher

Taking into consideration the outputs coming from the previous study, we can obtain the following key resilience indexes, whose values are under the maximum possible level. In result, these are the indicators we could improve using the tools developed as part of the FORESEE Project.

Table 42. CS#6, Key Resilience Indicators and Targets [ETH/IP].

ID	Level 0	ID	Level 1	ID	N possible values	Legal requirement	Possible values	Costs	Unconstrained target	Indicator	Target	Max/ actual	Intervention	Travel time	Accident	Socio-econ.	Total	B/C	Net benefit
E.1	Infrastructure	E.1.1	CS of the infrastructure	E.1.1.1	3				2	Age / Age of replacement of the warning system	2	Max			2 093 673	38 697	2 132 370		
							0	0				0	0	0	0	0	0	0,00	-
							1	333 000				1			697 891	12 899	710 790	2,13	377 790
							2	666 000				2			697 891	12 899	710 790	1,07	422 580
							3	1 000 000				3			697 891	12 899	710 790	0,71	133 370
				E.1.1.2	3				1	Age / Age of replacement of safe shut down system	1	Max			1 884 306	34 828	1 919 133		
							0	0				0	0	0	0	0	0	0,00	-
							1	333 000				1			628 102	11 609	639 711	1,92	306 711
							2	666 000				2			628 102	11 609	639 711	0,96	280 422
							3	1 000 000				3			628 102	11 609	639 711	0,64	-79 867
				E.1.1.3	5	3			0	Condition state of infrastructure (pre-event)	3	Max	2 769	1 677 021	2 036 520	37 641	3 753 950		
							0	0				0	0	0	0	0	0	0,00	-
							1	2 500 000				1	554	335 404	407 304	7 528	750 790	0,30	-1 749 210
							2	7 500 000				2	554	335 404	407 304	7 528	750 790	0,10	-8 498 420
							3	20 000 000				3	554	335 404	407 304	7 528	750 790	0,04	-27 747 630
							4	25 000 000				4	554	335 404	407 304	7 528	750 790	0,03	-51 996 840
							5	50 000 000				5	554	335 404	407 304	7 528	750 790	0,02	-101 246 050
				E.1.1.4	5	3			1	Condition state of protective structures/systems (pre-event)	3	Max	1 759	1 065 314	1 293 683	23 911	2 384 666		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000				1	352	213 063	258 737	4 782	476 933	1,91	226 933
							2	750 000				2	352	213 063	258 737	4 782	476 933	0,64	-46 133
							3	2 000 000				3	352	213 063	258 737	4 782	476 933	0,24	-1 569 200
							4	2 500 000				4	352	213 063	258 737	4 782	476 933	0,19	-3 592 267
							5	5 000 000				5	352	213 063	258 737	4 782	476 933	0,10	-8 115 334
				E.1.1.5	3	1			0	Expected condition state of infrastructure (post-event)	1	Max	4 245	2 571 090	3 122 249	57 708	5 755 293		
							0	0				0	0	0	0	0	0	0,00	-
							1	2 500 000				1	1 415	857 030	1 040 750	19 236	1 918 431	0,77	-581 569
							2	22 500 000				2	1 415	857 030	1 040 750	19 236	1 918 431	0,09	-21 163 138
							3	1 000 000 000				3	1 415	857 030	1 040 750	19 236	1 918 431	0,00	-1 019 244 707
				E.1.1.6	3	1			1	Expected condition state of protective structures/systems (post-event)	1	Max	3 536	2 141 956	2 601 122	48 076	4 794 690		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000				1	1 179	713 985	867 041	16 025	1 598 230	6,39	1 348 230
							2	2 250 000				2	1 179	713 985	867 041	16 025	1 598 230	0,71	696 460
							3	100 000 000				3	1 179	713 985	867 041	16 025	1 598 230	0,02	-97 705 310
		E.1.2	Protection measures	E.1.2.1	2				2	The possibility of building a temporary alternative route for vehicles	2	Max		1 478 749		33 191	1 511 939		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1		739 374		16 595	755 970	15,12	705 970
							2	100 000				2		739 374		16 595	755 970	7,56	1 361 939
				E.1.2.2	2				2	The possibility of using another means to satisfy transport demand	2	Max		3 091 673		69 393	3 161 066		
							0	0				0	0	0	0	0	0	0,00	-
							1	100 000				1		1 545 836		34 696	1 580 533	15,81	1 480 533
							2	200 000				2		1 545 836		34 696	1 580 533	7,90	2 861 066
				E.1.2.3	1				1	The number of possible existing alternative ways to deviate vehicles	1	Max		2 463 116		55 285	2 518 401		
							0	0				0	0	0	0	0	0	0,00	-
							1	20 000				1		2 463 116		55 285	2 518 401	125,92	2 498 401
				E.1.2.4	2				2	The presence of a warning system	2	Max		348 725		7 827	356 552		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1		174 362		3 914	178 276	3,57	128 276
							2	100 000				2		174 362		3 914	178 276	1,78	206 552
				E.1.2.5	1				1	The presence of a safe shutdown system	1	Max		1 484 631		33 323	1 517 954		
							0	0				0	0	0	0	0	0	0,00	-
							1	100 000				1		1 484 631		33 323	1 517 954	15,18	1 417 954
				E.1.2.6	2	0			2	The presence of emergency / evacuation paths	2	Max		3 196 953		71 756	3 268 709		
							0	0				0	0	0	0	0	0	0,00	-
							1	10 000				1		1 598 477		35 878	1 634 354	163,44	1 624 354
							2	500 000				2		1 598 477		35 878	1 634 354	3,27	2 758 709
				E.1.2.7	2				2	The presence of special measures to help evacuate persons	2	Max		566 684		12 719	579 403		
							0	0				0	0	0	0	0	0	0,00	-
							1	60 000				1		283 342		6 360	289 701	4,83	229 701
							2	120 000				2		283 342		6 360	289 701	2,41	399 403
		E.1.3	Preventive measures	E.1.3.1	2	0			0	Complience with the current seismic design code	0	Max	4 439	2 688 778	3 265 166	60 350	6 018 732		
							0	0				0	0	0	0	0	0	0,00	-
							1	25 200 000				1	2 219	1 344 389	1 632 583	30 175	3 009 366	0,12	-22 190 634
							2	50 300 000				2	2 219	1 344 389	1 632 583	30 175	3 009 366	0,06	-69 481 268
				E.1.3.2	1				0	Presence of systems to reduce seismic effects	0	Max	2 209	1 337 827	1 624 614	30 028	2 994 678		
							0	0				0	0	0	0	0	0	0,00	-
							1	20 000 000				1	2 209	1 337 827	1 624 614	30 028	2 994 678	0,15	-17 005 322
				E.1.3.3	1				0	Adequate systems to reduce seismic effects	0	Max	5 200	3 150 144	3 825 433	70 705	7 051 482		
							0	0				0	0	0	0	0	0	0,00	-
							1	20 000 000				1	5 200	3 150 144	3 825 433	70 705	7 051 482	0,35	-12 948 518
E2	Environment	E2.1	Context	E.2.1.1	3				0	Accessibility	0	Max	5 600				5 600		
							0	20 000				0	0	0	0	0	0	0,00	-20 000
							1	30 000				1	1 867				1 867	0,06	-48 133
							2	1 000 000 000				2	1 867				1 867	0,00	-1 000 046 267
							3	1 000 000 000				3	1 867				1 867	0,00	-2 000 044 400
				E.2.1.2	1				0	Presence of persons/property below the infrastructure	0	Max			2 872 559		2 872 559		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000 000				1			2 872 559		2 872 559	0,06	-47 127 441
				E.2.1.3	3				0	Extent of past damages due to hazards	0	Max	692				692		
							0	7 500 000				0	0	0	0	0	0	0,00	-7 500 000
							1	20 000 000				1	231				231	0,00	-27 499 769
							2	25 000 000				2	231				231	0,00	-52 499 538
							3	50 000 000				3	231				231	0,00	-102 499 308
				E.2.1.4	2				0	Hazard zone	0	Max	1 104	668 660	811 999	15 008	1 496 772		
							0	1				0	0	0	0	0	0	0,00	-1
							1	1 000 000 000				1	552	334 330	406 000	7 504	748 386	0,00	-999 251 615
							2	1 000 000 000				2	552	334 330	406 000	7 504	748 386	0,00	-1 998 503 229
				E.2.1.5	3				0	Duration of past down time due to hazards	0	Max	685				685		
							0	0				0	0	0	0	0	0	0,00	-
							1	1 000 000				1	228				228	0,00	-999 772
							2	4 000 000				2	228				228	0,00	-4 999 543
				E.2.1.6	3				1	Land type	1	Max	5 289		3 890 266		3 895 555		
							0	0				0	0	0	0	0	0	0,00	-
							1	1 000 000				1	1 763		1 296 755		1 298 518	1,30	298 518
							2	1 000 000 000				2	1 763		1 296 755		1 298 518	0,00	-998 402 964
							3	1 000 000 000				3	1 763		1 296 755		1 298 518	0,00	-1 997 104 445
				E.2.1.7	2				0	Budget availability	0	Max	710	430 152	522 363	9 655	962 880		
							0	10 000 000				0	0	0	0	0	0	0,00	-10 000 000
							1	15 000 000				1	355	215 076	261 181	4 827	481 440	0,03	-24 518 560
							2	20 000 000				2	355	215 076	261 181	4 827	481 440	0,02	-44 037 120
				E.2.1.8	3				0	Traffic	0	Max	1 127	682 669	829 011	15 323	1 528 129		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000 000				1	376	227 556	276 337	5 108	509 376	0,00	-249 490 624
							2	500 000 000				2	376	227 556	276 337	5 108	509 376	0,00	-748 981 247
							3	1 000 000 000				3	376	227 556	276 337	5 108	509 376	0,00	-1 748 471 871
				E.2.1.9	2				2	Hazards goods traffic	2	Max			1 277 927		1 277 927		
							0	0				0	0	0	0	0	0	0,00	-
							1	25 000				1			638 963		638 963	25,56	613 963
							2	50 000				2			638 963		638 963	12,78	1 202 927
				E.2.1.10	1				1	Flammable goods traffic	1	Max			3 516 083		3 516 083		
							0	0				0	0	0	0	0	0	0,00	-
							1	25 000				1			3 516 083		3 516 083	140,64	3 491 083

ID	Level 0	ID	Level 1	ID	N possible values	Legal requirement	Possible values	Costs	Unconstrained target	Indicator	Target	Max/ actual	Intervention	Travel time	Accident	Socio-econ.	Total	B/C	Net benefit
E.3	Organization	E3.1	Pre-event activities	E.3.1.1	2	0			2	The presence of a monitoring strategy	2	Max	4 608	2 791 173	3 389 511	62 648	6 247 940		
							0	0				0	0	0	0	0	0	0,00	-
							1	740 000				1	2 304	1 395 587	1 694 755	31 324	3 123 970	4,22	2 383 970
							2	3 000 000				2	2 304	1 395 587	1 694 755	31 324	3 123 970	1,04	2 507 940
				E.3.1.2	2				1	The presence of an maintenance strategy	1	Max	4 886	2 959 754	3 594 230	66 432	6 625 302		
							0	0				0	0	0	0	0	0	0,00	-
							1	500 000				1	2 443	1 479 877	1 797 115	33 216	3 312 651	6,63	2 812 651
							2	5 000 000				2	2 443	1 479 877	1 797 115	33 216	3 312 651	0,66	1 125 302
				E.3.1.3	2	0			0	The extent of interventions executed prior to the event	0	Max	533	322 947	392 176	7 249	722 904		
							0	0				0	0	0	0	0	0	0,00	-
							1	10 000 000				1	267	161 473	196 088	3 624	361 452	0,04	-9 638 548
							2	20 000 000				2	267	161 473	196 088	3 624	361 452	0,02	-29 277 096
		E3.2	Post event activities	E.3.2.1	2				0	The presence of an emergency plan	0	Max		273 203		6 132	279 335		
							0	0				0	0	0	0	0	0	0,00	-
							1	1 000 000				1		136 601		3 066	139 667	0,14	-860 333
							2	2 000 000				2		136 601		3 066	139 667	0,07	-2 720 665
				E.3.2.2	4	0			2	Practice of the emergency plan	2	Max		1 409 950		31 646	1 441 596		
							0	0				0	0	0	0	0	0	0,00	-
							1	125 000				1		352 487		7 912	360 399	2,88	235 399
							2	250 000				2		352 487		7 912	360 399	1,44	345 798
							3	500 000				3		352 487		7 912	360 399	0,72	206 197
							4	1 000 000				4		352 487		7 912	360 399	0,36	-433 404
				E.3.2.3	2				2	Review/update of the emergency plan	2	Max		3 307 556	4 016 589	74 238	7 398 383		
							0	0				0	0	0	0	0	0	0,00	-
							1	200 000				1		1 653 778	2 008 295	37 119	3 699 192	18,50	3 499 192
							2	500 000				2		1 653 778	2 008 295	37 119	3 699 192	7,40	6 698 383
				E.3.2.4	3	0			3	Expected time for tendering	3	Max	3 771	2 284 364		51 273	2 339 407		
							0	0				0	0	0	0	0	0	0,00	-
							1	10 000				1	1 257	761 455		17 091	779 802	77,98	769 802
							2	20 000				2	1 257	761 455		17 091	779 802	38,99	1 529 605
							3	30 000				3	1 257	761 455		17 091	779 802	25,99	2 279 407
				E.3.2.5	3				0	Expecetd time for construction	0	Max	447	270 623		6 074	277 144		
							0	0				0	0	0	0	0	0	0,00	-
							1	800 000				1	149	90 208		2 025	92 381	0,12	-707 619
							2	1 000 000				2	149	90 208		2 025	92 381	0,09	-1 615 237
							3	20 000 000				3	149	90 208		2 025	92 381	0,00	-21 522 856
E.4	Structural health monitoring	E.4.1	SHM Availability	E.4.1.1	2				2	Continuous vibration monitoring	2	Max	4 245		3 122 249		3 126 494		
							0	0				0	0	0	0	0	0	0,00	-
							1	100 000				1	2 122		1 561 125		1 563 247	15,63	1 463 247
							2	150 000				2	2 122		1 561 125		1 563 247	10,42	2 876 494
				E.4.1.2	2				2	Continuous stress and displacement monitoring of resistance elements	2	Max	2 846		2 093 673		2096519,464		
							0	0				0	0	0	0	0	0	0,00	-
							1	100 000				1	1 423		1 046 837		1048259,732	10,48	948 260
							2	200 000				2	1 423		1 046 837		1048259,732	5,24	1 796 519
				E.4.1.3	2				2	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	Max	4 245		3 122 249		3126493,792		
							0	0				0	0	0	0	0	0	0,00	-
							1	100 000				1	2 122		1 561 125		1563246,896	15,63	1 463 247
							2	130 000				2	2 122		1 561 125		1563246,896	12,02	2 896 494
		E.4.2	SHM Reliability and operation	E.4.2.1	2				2	Autonomous short-term electrical supply to the monitoring system installed on site	2	Max	4 245		3 122 249		3126493,792		
							0	0				0	0	0	0	0	0	0,00	-
							1	30 000				1	2 122		1 561 125		1563246,896	52,11	1 533 247
							2	45 000				2	2 122		1 561 125		1563246,896	34,74	3 051 494
				E.4.2.2	2				2	Permanent fail-safe communication of monitoring relevant information	2	Max	4 245		3 122 249		3126493,792		
							0	0				0	0	0	0	0	0	0,00	-
							1	10 000				1	2 122		1 561 125		1563246,896	156,32	1 553 247
							2	30 000				2	2 122		1 561 125		1563246,896	52,11	3 086 494
				E.4.2.3	3				3	SHM data analysis	3	Max	2 846		2 093 673		2096519,464		
							0	0				0	0	0	0	0	0	0,00	0
							1	75 000				1	949		697 891		698 840	9,32	623 840
							2	100 000				2	949		697 891		698 840	6,99	1222679,643
							3	150000				3	949		697 891		698 840	4,66	1771519,464
				E.4.2.4	3				3	Update rate on the feedback of the structural condition	3	Max	4 245		3 122 249		3126493,792		
							0	0				0	0	0	0	0	0	0,00	0
							1	25 000				1	1 415		1 040 750		1 042 165	41,69	1017164,597
							2	50 000				2	1 415		1 040 750		1 042 165	20,84	2009329,195
							3	100000				3	1 415		1 040 750		1 042 165	10,42	2951493,792
E.5	Inspection	E.5.1	Inspection plan	E.5.1.1	2				2	Component inspection and testing plan	2	Max			2 093 673	38 697	2132370,444		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1			1 046 837	19 349	1066185,222	21,32	1 016 185
							2	150 000				2			1 046 837	19 349	1066185,222	7,11	1 932 370
				E.5.1.2	2				2	Repair plan of damaged components	2	Max			2 093 673	38 697	2132370,444		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1			1 046 837	19 349	1066185,222	21,32	1 016 185
							2	150 000				2			1 046 837	19 349	1066185,222	7,11	1 932 370
		E.5.2	Inspection operation	E.5.2.1	2				2	Visual inspections	2	Max	4 269	2 586 128	3 140 510	58 046	5788952,54		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000				1	2 135	1 293 064	1 570 255	29 023	2894476,27	11,58	2 644 476
							2	2 500 000				2	2 135	1 293 064	1 570 255	29 023	2894476,27	1,16	3 038 953
				E.5.2.2	2				2	Technical measurements	2	Max	2 846	1 724 085	2 093 673	38 697	3859301,694		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1	1 423	862 043	1 046 837	19 349	1929650,847	38,59	1 879 651
							2	250 000				2	1 423	862 043	1 046 837	19 349	1929650,847	7,72	3 559 302
E.6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	2				2	Periodic routine maintenance interventions	2	Max	4 269	2 586 128	3 140 510	58 046	5788952,54		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000				1	2 135	1 293 064	1 570 255	29 023	2894476,27	11,58	2 644 476
							2	2 500 000				2	2 135	1 293 064	1 570 255	29 023	2894476,27	1,16	3 038 953
				E.6.1.2	2				2	Corrective maintenance interventions	2	Max	4 269	2 586 128	3 140 510	58 046	5788952,54		
							0	0				0	0	0	0	0	0	0,00	-
							1	250 000				1	2 135	1 293 064	1 570 255	29 023	2894476,27	11,58	2 644 476
							2	2 500 000				2	2 135	1 293 064	1 570 255	29 023	2894476,27	1,16	3 038 953
E.7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	3				3	Structural model	3	Max	4 269	2 586 128		58 046	2648442,719		
							0	0				0	0	0	0	0	0	0,00	0
							1	50 000				1	1 423	862 043		19 349	882 814	17,66	832814,2396
							2	100 000				2	1 423	862 043		19 349	882 814	8,83	1615628,479
							3	150000				3	1 423	862 043		19 349	882 814	5,89	2348442,719
		E.7.2	Seismic risk studies	E.7.2.1	3				3	Seismic risk studies	3	Max	2 846	1 724 085		38 697	1765628,479		
							0	0				0	0	0	0	0	0	0,00	0
							1	50 000				1	949	574 695		12 899	588 543	11,77	538542,8264
							2	100 000				2	949	574 695		12 899	588 543	5,89	1027085,653
							3	150000				3	949	574 695		12 899	588 543	3,92	1465628,479
E.8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	2				2	Coordination between services	2	Max		1 724 085			1724085		
							0	0				0	0	0	0	0	0	0,00	-
							1	50 000				1		862 043			862042,5	17,24	812 043
							2	100 000				2		862 043			862042,5	8,62	1 574 085
				E.8.1.2	2				1	Availability of resources on site	1	Max	4 269	2 586 128			2590396,875		
							0	0				0	0	0	0	0	0	0,00	-
							1	750 000				1	2 135	1 293 064			1295198,438	1,73	545 198
							2	1 500 000				2	2 135	1 293 064			1295198,438	0,86	340 397
				E.8.1.3	1				0	Availability of safe-through equipment	0	Max	2 846				2846,25		
							0	0				0	0	0	0	0	0	0,00	-
							1	20 000				1	2 846				2846,25	0,14	-17 154
		E.8.2	Response for long term disruption	E.8.2.1	1				1	Long-term contingency plans	1	Max		2 586 128			2586127,5		
							0	0				0	0	0	0	0	0	0,00	-
							1	200 000				1		2 586 128			2586127,5	12,93	2 386 128
				E.8.2.2	1				1	Long-term traffic/mobility plans	1	Max		2 586 128			2586127,5		
							0	0				0	0	0	0	0	0	0,00	-
							1	400 000				1		2 586 128			2586127,5	6,47	2 186 128

1.10 NET BENEFIT ANALYSIS AND RESILIENCE VALIDATION IN CS#6

Beyond the requirements for the indicator values, the targets were determined using incremental cost-benefit analysis, i.e. for each indicator estimating the approximate net-benefit from the lowest acceptable level to the level where the incremental net-benefit of a further increase is negative (which is equivalent to the benefit/cost ratio being less than 1.0).

An example of how this was done using the Review/Update of the emergency plan (E.3.2.3) is shown in Table 43 where:

- The indicator was first assumed to have its worst possible value (0) and the likely intervention costs and reductions in service (€7’398’383’000) that would follow the occurrence of the reference earthquake were estimated (listed as the maximum values for the reductions in service (€3’307’556’000 - travel time, €4’016’589’000 - safety, and €74’238’000 - socio-economic).
- The cost of improving the value of the indicator by one unit and the expected benefit in terms of avoided reductions in service, were then estimated, incrementally, assuming the indicator had the value of 1 and 2. For example, the cost of moving the value of the Review/update of the emergency plan indicator from 1 to 2 was estimated in €500’000 and the expected avoided reductions in service in €3’699’192’000, yielding a net benefit of €3’499’192’000 and a B/C of 7.40, which indicates that the target should be moved to 2 from 1.

Table 43. Setting Targets based on Net-Benefit for Review/Update of the Emergency Plan (E.3.2.3).

ID	Possible values	Possible values	Costs (10^3€)	Target	Max/ actual	Measures of Resilience [10^3€]					B/C	Net benefit (103€)
						Avoided Intervention Costs	Avoided Reductions in Service			Total		
							Travel time	Safety/Accident	Socio-econ.			
E.3.2.3	2			2	Max	0	3 307 556	4 016 589	74 238	7 398 383	N/A	N/A
		0	0		0	0	0	0	0	0	0,00	-
		1	200 000		1	0	1 653 778	2 008 295	37 119	3 699 192	18,50	3 499 192
		2	500 000		2	0	1 653 778	2 008 295	37 119	3 699 192	7,40	6 698 383

Following this logic, targets were set for 54 (fifty-four) resilience indicators, as presented in Table 44.

Table 44. CS#6, Targets proposed for the 54 (fifty-four) Resilience Indicators with Cost-Benefit Analysis.

ID	Indicator	Scale	Restrictions (Legal Requirements)	Current measure	Target Value
E.1.1.1	Age / Age of replacement of the warning system	3		2	2
E.1.1.2	Age / Age of replacement of safe shut down system	3		2	1
E.1.1.3	Condition state of infrastructure (pre-event)	5	3	3	3
E.1.1.4	Condition state of protective structures/systems (pre-event)	5	3	3	3
E.1.1.5	Expected condition state of infrastructure (post-event)	3	1	2	1
E.1.1.6	Expected condition state of protective structures/systems (post-event)	3	1	2	1
E.1.2.1	**The possibility of building a temporary alternative route for vehicles**	**2**		**1**	**2**
E.1.2.2	**The possibility of using another means to satisfy transport demand**	**2**		**1**	**2**
E.1.2.3	The number of possible existing alternative ways to deviate vehicles	1		1	1
E.1.2.4	**The presence of a warning system**	**2**		**1**	**2**
E.1.2.5	The presence of a safe shutdown system	1		1	1
E.1.2.6	The presence of emergency / evacuation paths	2		2	2
E.1.2.7	**The presence of special measures to help evacuate persons**	**2**		**0**	**2**
E.1.3.1	Complience with the current seismic design code	2		1	0
E.1.3.2	Presence of systems to reduce seismic effects	1		0	0
E.1.3.3	Adequate systems to reduce seismic effects	1		0	0
E.2.1.1	Accessibility	3		0	0
E.2.1.2	Presence of persons/property below the infrastructure	1		0	0
E.2.1.3	Extent of past damages due to hazards	3		3	0
E.2.1.4	Hazard zone	2		1	0
E.2.1.5	Duration of past down time due to hazards	3		2	0
E.2.1.6	Land type	3		0	1
E.2.1.7	Budget availability	2		2	0
E.2.1.8	Traffic	3		0	0
E.2.1.9	**Hazards goods traffic**	**2**		**0**	**2**
E.2.1.10	**Flammable goods traffic**	**1**		**0**	**1**
E.3.1.1	The presence of a monitoring strategy	2		2	2
E.3.1.2	The presence of an maintenance strategy	2		2	1
E.3.1.3	The extent of interventions executed prior to the event	2		1	0
E.3.2.1	The presence of an emergency plan	2		2	0
E.3.2.2	**Practice of the emergency plan**	**4**		**0**	**2**
E.3.2.3	**Review/update of the emergency plan**	**2**		**0**	**2**
E.3.2.4	**Expected time for tendering**	**3**		**0**	**3**
E.3.2.5	Expecetd time for construction	3		0	0
E.4.1.1	**Continuous vibration monitoring**	**2**		**1**	**2**
E.4.1.2	**Continuous stress and displacement monitoring of resistance elements**	**2**		**1**	**2**
E.4.1.3	**Continuous relative displacement monitoring of moving components and anti-seismic devices**	**2**		**1**	**2**
E.4.2.1	**Autonomous short-term electrical supply to the monitoring system installed on site**	**2**		**0**	**2**
E.4.2.2	**Permanent fail-safe communication of monitoring relevant information**	**2**		**1**	**2**
E.4.2.3	**SHM data analysis**	**3**		**2**	**3**
E.4.2.4	**Update rate on the feedback of the structural condition**	**3**		**2**	**3**
E.5.1.1	Component inspection and testing plan	2		2	2
E.5.1.2	Repair plan of damaged components	2		2	2
E.5.2.1	Visual inspections	2		2	2
E.5.2.2	Technical measurements	2		2	2
E.6.1.1	Periodic routine maintenance interventions	2		2	2
E.6.1.2	**Corrective maintenance interventions**	**2**		**1**	**2**
E.7.1.1	Structural model	3		3	3
E.7.2.1	**Seismic risk studies**	**3**		**0**	**3**
E.8.1.1	**Coordination between services**	**2**		**1**	**2**
E.8.1.2	Availability of resources on site	2		1	1
E.8.1.3	Availability of safe-through equipment	1		1	0
E.8.2.1	**Long-term contingency plans**	**1**		**0**	**1**
E.8.2.2	**Long-term traffic/mobility plans**	**1**		**0**	**1**
	Total/ Average			***1,15***	***1,41***

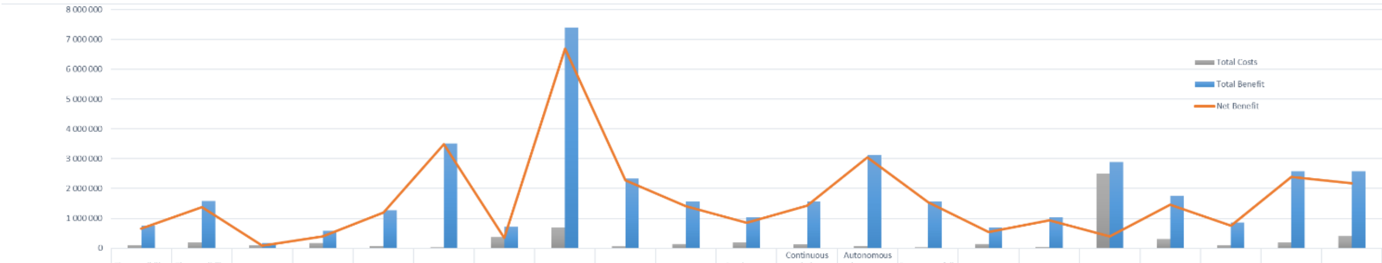
Note: The blue shaded actual values highlight the ones that are below the target and it is worth it to increase (Cost-Benefit Analysis).

Table 45. CS#6, Consequences of reaching the Target (worst to maximum value).

ID	Indicator	Scale	Restrictions (Legal Requirements)	Current measure	Target Value	Consequences of reaching the target (worst to maximum value)			
						Total costs	Total benefit	B/C	Net benefit
E.1.2.1	The possibility of building a temporary alternative route for vehicles	2		1	2	150 000	1 511 939	7,56	1 361 939
E.1.2.2	The possibility of using another means to satisfy transport demand	2		1	2	300 000	3 161 066	7,90	2 861 066
E.1.2.4	The presence of a warning system	2		1	2	150 000	356 552	1,78	206 552
E.1.2.7	The presence of special measures to help evacuate persons	2		0	2	180 000	579 403	2,41	399 403
E.2.1.9	Hazards goods traffic	2		0	2	75 000	1 277 927	12,78	1 202 927
E.2.1.10	Flammable goods traffic	1		0	1	25 000	3 516 083	140,64	3 491 083
E.3.2.2	Practice of the emergency plan	4		0	2	1 875 000	1 441 596	0,36	-433 404
E.3.2.3	Review/update of the emergency plan	2		0	2	700 000	7 398 383	7,40	6 698 383
E.3.2.4	Expected time for tendering	3		0	3	60 000	2 339 407	25,99	2 279 407
E.4.1.1	Continuous vibration monitoring	2		1	2	250 000	2 096 519	10,42	2 876 494
E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2		1	2	300 000	2 096 519	5,24	1 796 519
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2		1	2	230 000	3 126 494	12,02	2 896 494
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2		0	2	75 000	3 126 494	34,74	3 051 494
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2		1	2	40 000	3 126 494	52,11	3 086 494
E.4.2.3	SHM data analysis	3		2	3	325 000	2 096 519	4,66	1 771 519
E.4.2.4	Update rate on the feedback of the structural condition	3		2	3	175 000	3 126 494	10,42	2 951 494
E.6.1.2	Corrective maintenance interventions	2		1	2	2 750 000	5 788 953	1,16	3 038 953
E.7.2.1	Seismic risk studies	3		0	3	300 000	1 765 628	3,92	1 465 628
E.8.1.1	Coordination between services	2		1	2	150 000	1 724 085	8,62	1 574 085
E.8.2.1	Long-term contingency plans	1		0	1	200 000	2 586 128	12,93	2 386 128
E.8.2.2	Long-term traffic/mobility plans	1		0	1	400 000	2 586 128	6,47	2 186 128
	Total/ Average					*8 710 000*	*54 828 811*	*17,60*	*47 148 785*

Table 46. CS#6, Targets proposed for the 21 (twenty-one) Resilience Indicators with Cost-Benefit Analysis/Consequences of reaching the Target.

ID	Indicator	Scale	Current measure	Target	Consequences of reaching the target value		
					Total costs [10^3€]	Total benefit [10^3€]	Net benefit [10^3€]
E.1.2.1	The possibility of building a temporary alternative route for vehicles	2	1	2	100 000	755 970	655 970
E.1.2.2	The possibility of using another means to satisfy transport demand	2	1	2	200 000	1 580 533	1 380 533
E.1.2.4	The presence of a warning system	2	1	2	100 000	178 276	78 276
E.1.2.7	The presence of special measures to help evacuate persons	2	0	2	180 000	579 403	399 403
E.2.1.9	Hazards goods traffic	2	0	2	75 000	1 277 927	1 202 927
E.2.1.10	Flammable goods traffic	1	0	1	25 000	3 516 083	3 491 083
E.3.2.2	Practice of the emergency plan	4	0	2	375 000	720 798	345 798
E.3.2.3	Review/update of the emergency plan	2	0	2	700 000	7 398 383	6 698 383
E.3.2.4	Expected time for tendering	3	0	3	60 000	2 339 407	2 279 407
E.4.1.1	Continuous vibration monitoring	2	1	2	150 000	1 563 247	1 413 247
E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2	1	2	200 000	1 048 260	848 260
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	1	2	130 000	1 563 247	1 433 247
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0	2	75 000	3 126 494	3 051 494
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2	1	2	30 000	1 563 247	1 533 247
E.4.2.3	SHM data analysis	3	2	3	150 000	698 840	548 840
E.4.2.4	Update rate on the feedback of the structural condition	3	2	3	50 000	1 042 165	942 165
E.6.1.2	Corrective maintenance interventions	2	1	2	2 500 000	2 894 476	394 476
E.7.2.1	Seismic risk studies	3	0	3	300 000	1 765 628	1 465 628
E.8.1.1	Coordination between services	2	1	2	100 000	862 043	762 043
E.8.2.1	Long-term contingency plans	1	0	1	200 000	2 586 128	2 386 128
E.8.2.2	Long-term traffic/mobility plans	1	0	1	400 000	2 586 128	2 186 128
	Total				***6 100 000***	***39 646 681***	***33 496 681***



	E.1.2.1 The possibility of building a temporary alternative route for vehicles	E.1.2.2 The possibility of using another means to satisfy transport demand	E.1.2.4 The presence of a warning system	E.1.2.7 The presence of special measures to help evacuate persons	E.2.1.9 Hazards goods traffic	E.2.1.10 Flammable goods traffic	E.3.2.2 Practice of the emergency plan	E.3.2.3 Review/update of the emergency plan	E.3.2.4 Expected time for tendering	E.4.1.1 Continuous vibration monitoring	E.4.1.2 Continuous stress and displacement monitoring of resistance elements	E.4.1.3 Continuous relative displacement monitoring of moving components and anti-seismic devices	E.4.2.1 Autonomous short-term electrical supply to the monitoring system installed on site	E.4.2.2 Permanent fail-safe communication of monitoring relevant information	E.4.2.3 SHM data analysis	E.4.2.4 Update rate on the feedback of the structural condition	E.6.1.2 Corrective maintenance interventions	E.7.2.1 Seismic risk studies	E.8.1.1 Coordination between services	E.8.2.1 Long-term contingency plans	E.8.2.2 Long-term traffic/mobility plans
Total Costs	100 000	200 000	100 000	180 000	75 000	25 000	375 000	700 000	60 000	150 000	200 000	130 000	75 000	30 000	150 000	50 000	2 500 000	300 000	100 000	200 000	400 000
Total Benefit	755 970	1 580 533	178 276	579 403	1 277 927	3 516 083	720 798	7 398 383	2 339 407	1 563 247	1 048 260	1 563 247	3 126 494	1 563 247	698 840	1 042 165	2 894 476	1 765 628	862 043	2 586 128	2 586 128
Net Benefit	655 970	1 380 533	78 276	399 403	1 202 927	3 491 083	345 798	6 698 383	2 279 407	1 413 247	848 260	1 433 247	3 051 494	1 533 247	548 840	942 165	394 476	1 465 628	762 043	2 386 128	2 186 128

Figure 38. CS#6, Net Benefit Analysis [IP].

In Table 44 it can be seen that 21 (twenty-one) indicators have actual values below the target values, as presented on Table 45. Of these 21 (twenty-one) indicators (Table 45 and Table 46), it seems that the greatest net-benefit (€6'698'383'000) would be review/developing and updating the emergency plan, i.e. replacing the current generic emergency plan with one where specific tasks, resources and responsibilities are defined; the second best would be avoided the presence of inflammable goods transported on the road, which can raise the consequences in case of accident; the third would be achieved by improving the autonomous short-term electrical supply to the monitoring system installed on site following the occurrence of the reference earthquake, i.e. the monitoring system needs to function in the subsequent hours to allow for the estimation of modal features, stresses and displacements, and posterior comparison with the pre-event baseline, etc.

In the next table, the monetisation of the resilience indicators and targets in the form of the LOS as a Cost Value are presented (quantitative validation- analysing the net benefit costs).

It can be seen all 21 (twenty-one) indicators that needs to be improved.

So, it is assumed that for the identified **key resilience indicators**

ID	Indicator
E.1.2.1	The possibility of building a temporary alternative route for vehicles
E.1.2.2	The possibility of using another means to satisfy transport demand
E.1.2.4	The presence of a warning system
E.1.2.7	The presence of special measures to help evacuate persons
E.2.1.9	Hazards goods traffic
E.2.1.10	Flammable goods traffic
E.3.2.2	Practice of the emergency plan
E.3.2.3	Review/update of the emergency plan
E.3.2.4	Expected time for tendering
E.4.1.1	Continuous vibration monitoring
E.4.1.2	Continuous stress and displacement monitoring of resistance elements
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site
E.4.2.2	Permanent fail-safe communication of monitoring relevant information
E.4.2.3	SHM data analysis
E.4.2.4	Update rate on the feedback of the structural condition
E.6.1.2	Corrective maintenance interventions
E.7.2.1	Seismic risk studies
E.8.1.1	Coordination between services
E.8.2.1	Long-term contingency plans
E.8.2.2	Long-term traffic/mobility plans

The key resilience targets (increase by one, two or three stages in each case) will be achieved in CS#6 through the use of the selected **FORESEE Tools**:

- **T2.1 Risk Mapping.**
- **T3.4 Traffic Module (D3.7).**
- **T5.5 Command and Control Centre (D5.6).**
- **T7.2 Design, construction and remediation plans (D7.2/D7.5).**
- **T7.3 Operational and maintenance plans (D7.3/D7.6).**
- **T7.4 Management and contingency plans (D7.4).**

In this case a notable improvement in resilience is obtained as shown the exposed Table 46 and Figure 38, according to the application of the FORESEE Tools.

The use of the FORESEE Tools to CS#6, provide a high degree of resilience, against specific hazards, as earthquake, as demonstrated by the verification through the current asset management and the principles of resilience, since they provide robustness, resourcefulness, rapid-recovery and adaptability, before, during and after the event of the hazard.

In addition, it can be said that the use of these guidelines (Deliverables D1.1 and D1.2) helps ensure that infrastructure managers define service and resilience clearly and consistently and that they are systematically considered when evaluating the resilience of the transport system, as well obtaining an idea of how to improve resilience.

Guidelines should be of course developed/applied for the different risk scenarios to allow comparison, best use of available resources and optimal decisions.

Although, more detailed analysis will be required such as specific measures to be implemented, these framework gives a good idea that it is worthwhile to undertake the efforts (enhance resilience) in terms of:

- The possibility to create more temporary alternative route for vehicles.
- The possibility of using another means to satisfy transport demand.
- Improve the presence of a warning system (create multiple systems).
- Improve the presence of special measures to help evacuate persons.
- Create/deploy alternative routes for hazards goods traffic and flammable goods traffic.
- Promote more often the review/update and practice of the emergency plan.
- Reduce expected time for tendering.
- Promote continuous vibration monitoring to be able to identify local natural modes in the major structural elements.
- Promote continuous stress and displacement monitoring of resistance elements to be able to characterize stresses or absolute displacements in all major structural elements.
- Promote continuous relative displacement monitoring of moving components and anti-seismic devices which can give information related on relative displacements in all movable components.

- autonomous short-term electrical supply to the monitoring system installed on site to guarantee the perfect function of the SHM system (autonomous operation during days after a hazard).
- Improve permanent fail-safe communication of monitoring relevant information which improves direct access to SHM data by technical staff, using special fail-safe communication systems (satellite, other).
- Deploy automatized SHM data analysis which means automatic comparison of data with numerically generated damage scenarios considered likely to occur in case of earthquake.
- Update rate on the feedback of the structural condition in terms of feedback on-demand (automatic).
- Corrective maintenance interventions in terms of a permanent maintenance team available on site.
- Seismic risk studies which mean perform probabilistic studies for seismic hazard, vulnerability and risk assessment.
- Coordination between services which consists of formal coordination and communication between all intervenient emergency and response services through exclusive channels,
- Presence of long-term contingency plans to be followed, in case of earthquake and other type of hazard.
- Presence of Long-term traffic/mobility plans to be followed, in case of earthquake and other type of hazard.

ANNEX 2. FORESEE TOOL VALIDATION

2.1 OUTPUTS FROM THE FORESEE TOOL 2.2 "RISK MAPPING"

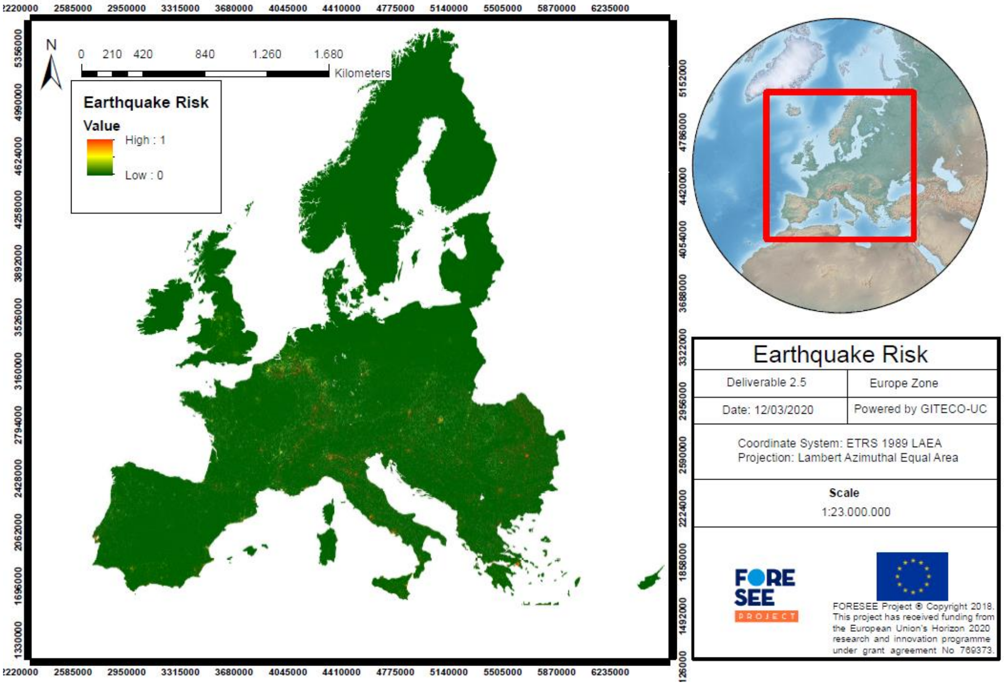


Figure 39. CS#6, Hazard Map Output from FORESEE Tool 2.2 [UC/D2.5[i]].

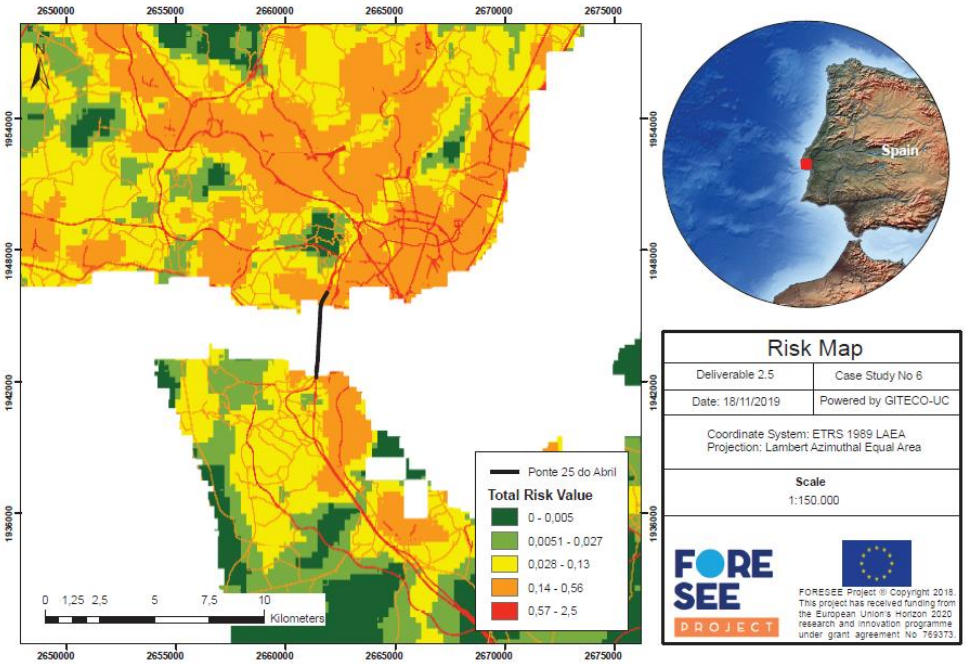


Figure 40. CS#6, Risk Map Output from FORESEE Tool 2.2 [UC/D2.5].

2.2 TOOL VERIFICATION AND OUTPUT T7.2 – DESIGN, CONSTRUCTION AND REMEDIATION PLANS (D7.5)

2.2.1 ASSESS CRITICALITY

CR1. OPERATIONAL AND ECONOMIC RELEVANCE

EVALUATION OF CRITERION CR1 (OPERATIONAL AND ECONOMIC RELEVANCE)

a) Traffic volume and composition

Complete the following information to obtain a score for factor (a):

Traffic composition:

Number of passengers travelling per day	300 000,00	p/day
% passengers travelling per work	66,70	%
% passengers travelling per leisure	33,30	%
Number of passengers travelling per work per day	200 100,00	p/day
Number of passengers travelling per work per day	99 900,00	p/day
Amount of goods travelling per day	5 000,00	p/day

Characteristics of the route

Length	2,28	km
Average speed	70,00	km/h

Costs associated:

Cost of work time	0,42	€/veh/min
Cost of leisure time	0,12	€/veh/min
Cost for goods	1,00	€/min/truck
Total costs associated	**72 066,14**	10^3 €

The total costs obtained is then compared to the following ranges shown in the table below. Category A is equivalent to a motorway-type road category, while Category D is equivalent to a minor accesss. The reference values of these ranges are obtained based on the number of vehicles usually defined for this hierarchy multiplied by the different costs defined by the users in the previous step.

Category	A	B	C	D	E
Range cost (€)	(> 7311)	(7311 - 4137)	(4137 - 1455)	(1455 - 596)	(< 596)
Score	5	4	3	2	1

Suggested Score for Factor (a)	5
Adopted Score for Factor (a)	5

CR1. OPERATIONAL AND ECONOMIC RELEVANCE

EVALUATION OF CRITERION CR1

b) Additional transport modes

Select one of the following answers to obtain a score for factor (b):

Does the route provide additional transport modes?

- No. ☐
- Yes, pedestrians and/or cyclists. ☐
- Yes, pedestrians and/or cyclists, and rail/road. ☑

Suggested Score for Factor (b) 5

Adopted Score for Factor (b) 5

c) Population of linked places

This factor is scored according to the following population reference ranges:

Population (10^3 hab)	> 100	100 - 40	40 - 10	10 - 1	< 1
Score	5	4	3	2	1

Population of linked places 1 000 000,00 hab

Suggested Score for Factor (c) 5

Adopted Score for Factor (c) 5

Factors Assessment

	Score	Weight
a) Traffic volume and composition	5,00	33,0%
b) Additional transport modes	5,00	33,0%
c) Population of linked places	5,00	34,0%

CR1 - Results

Suggested Score for CR1 5,00

Adopted Score for CR1 **5,00**

1 2 3 4 5

CR2. ACCESS TO CRITICAL INFRASTRUCTURES

This criterion assesses the criticality of the route in terms of whether it provides access to critical infrastructures such as:

- key utilities such as water, wastewater, power and telecoms.
- critical transport hubs such as ports and airports.
- routes that are considered themselves evacuation routes.

This criterion is rated based on the number of utilities to which the route provides access as well as the criticality of the utility itself. For the purpose of analysis of this criterion, five groups have been defined with corresponding scores, as shown in the table below:

Group	Description	Score
1	≥ 5 locally-significant utility assets; or ≥ 3 regionally-significant assets; or ≥ 1 nationally-significant assets.	5
2	'4 locally-significant utility assets; or 2 regionally-significant assets; or the route itself is an essential evacuation route	4
3	3 locally-significant utility assets; or 1 regionally-significant assets	3
4	'1 or 2 locally-significant utility assets	2
5	No access for critical infrastructure	1

Additional information:

Official definition of critical infrastructures varies across countries. Within the scope of this task, critical infrastructures have been defined as those assets and networks that provide essential services to the functioning of a community and that they need to be functioning to their fullest possible extent during an emergency. In this step, the following sectors are considered critical:

1.- Water and wastewater (e.g.: treatment plants, water supply systems, etc.).
2.- Energy (e.g.: power plants, gas lines, etc.).
3.- Trasnport (e.g.: evacuation routes, major hubs, etc.).
4.- Telecommunications services.

Meaning of nationally/regionally/locally significance:

- *Nationally-significant means that a disruption in service would have national significance or cause loss of utility supply to most of a region.*
- *Regionally-significant means that a disruption in service would cause loss of supply to more than 20.000 customers or loss of supply to a regionally significant site.*
- *Locally-significant means that a disruption in service would cause loss of supply to more than 2.000 customers or loss of supply to a locally significant customer.*

CR2. ACCESS TO CRITICAL INFRASTRUCTURES

EVALUATION OF CRITERION CR2

Complete the following inventory of critical infrastructures, indicating whether they are nationally / regionally / locally relevant

Critical Infrastructures inventory	Relevance	Quantity
Water and waste water utilities		
There is no critical infrastructures along the 25 th Abril Bridge	National	0
	Regional	0
	Local	0
Energy		
There is no critical infrastructures along the 25 th Abril Bridge	National	0
	Regional	0
	Local	0
Transport		
Critical connection between North and south by train	National	4
	Regional	4
	Local	5
Telecommunications services		
There is no critical infrastructures along the 25 th Abril Bridge	National	0
	Regional	0
	Local	0
Is it an evacuation route?		No

CR2 - Results

Suggested Score for CR2	5,00
Adopted Score for CR2	**5,00**

1 2 3 4 5

CR3. ACCESS TO ESSENTIAL SERVICES

This criterion assesses the criticality of the route in terms of whether it provides access to essential services that would be required for response and recovery activities during and after an extreme hazard event.

Essential services include:

- Hospital, shelters, age-care facilities, welfare centres…
- Ambulance, fire, police and facilities for emergency operations.
- Major utility control centres.
- Key retail outlets - hardware stores.
- Schools.
- Sector posts and major industry.
- Construction resources and supermarkets.

This criterion is rated according to the priority of the essential service to which the route provide access. For the purpose of analysis of this criterion, essential services have been clustered into five groups from highest to lowest priority during response and recovery phases.

Group	Description	Score
1	Hospital, shelters, and large-scale facilities	5
2	Ambulance, fire, police and emergency operations	4
3	Major utility control centres, telecom and power	3
4	Key retail outlets - hardware stores; construction resources and supermarkets	2
5	Schools, post offices, and major industry	1

EVALUATION OF CRITERION CR3

Please, indicate whether the route provides access to any of the following services:

- [x] Hospital
- [ ] Shelters
- [ ] Large age-care facilities
- [x] Ambulance operations
- [ ] Fire Station
- [ ] Police Station
- [x] Route for emergency Operations
- [ ] Utility control centres
- [ ] Telecom centres
- [ ] Retail stores
- [ ] Hardware stores
- [ ] Construction resources
- [ ] Supermarkets
- [ ] Schools
- [ ] Post office
- [ ] Major industry
- [ ] Power plants

CR3 - Results

Suggested Score for CR3	5,00
Adopted Score for CR3	**5,00**

1	2	3	4	5

CR4. ALTERNATIVE ROUTES

This criterion assesses the criticality of the route in terms of whether there is an alternative route as well as whether the alternative route is appropiate.

It is rated based on the following subcriteria:

	Score
(a) Presence of an alternative route	
Yes	0
No	5
(b) Likelihood of the alternative route being affected by the same hazard	
Low	0
Medium	1
High	2
(c) Capacity of the route to absorb additional traffic volumes	
Low	2
Medium	1
High	0
(d) Detour length	
Low	0
Medium	0,5
High	1

EVALUATION OF CRITERION CR4

Please, indicate whether the route provides access to any of the following services:

a) Presence of an alternative route	Yes
b) Likelihood of the alternative route being affected by the same hazard	High
c) Capacity of the route to absorb additional traffic volumes	Medium
d) Detour Length	Medium

CR4 - Results

Suggested Score for CR4	3,50
Adopted Score for CR4	3,50

1 2 3 4 5

CRITICALITY ASSESSMENT

	Score	Weight
CR1. OPERATIONAL AND ECONOMIC RELEVANCE	5,00	40%
CR2. ACCESS TO CRITICAL INFRASTRUCTURES	5,00	15%
CR3. ACCESS TO ESSENTIAL SERVICES	5,00	15%
CR4. ALTERNATIVE ROUTES	3,50	30%

CRITICALITY SCORE	4,55
CRITICALITY CATEGORY	I. Vital

CRITICALITY CATEGORY

I. Vital (Score: 4-5)
A route whose failure would have a nationally significant economic or social impact, or is a nationally significant lifeline, ensuring access or continuity of supply to essential services during an unforseen event.

II. Major (Score: 3-4)
A route whose failure would have a significant economic or social impact to more than one major area, o is a regionally significant lifeline, ensuring access or continuity of supply of essential services during an extreme event

III. Significant (Score: 2-3)
An important route whose failure would have a significant economic or social impact to a region, or is a signigicant lifeline, ensuring access or continuity of supply of essential services during an extreme event.

IV. Normal (Score: 1-2)
A route whose failure would have a serious local economic or social impact, or is a locally important lifeline, ensuring access or continuity of supply of essential services during an extreme event

The overall score leads to a value of 4,55. According to this final score, the bridge is classified as Vital (on a scale: Vital, Major, Significant, Normal): "its failure would have a nationally significant economic or social impact to more than one major area, or is a nationally significant lifeline, ensuring access or continuity of supply of essential services during an extreme event".

Within this approach, the most sensitive "critical parameters" are CR1 - Operational and Economic Relevance, CR2 - Access to Critical Infrastructures and C3 - Access to Essential Services, while the less relevant is CR4-Alternative routes, as it is shown on previous figure.

PERFORMANCE-BASED DESIGN

As far as it concerns the performance levels, they have been defined in terms of Damage States and Service differently for the bridge/section in function of the diverse time horizons.

Performance-based design (PBD) represents an evolution in design thinking that allows owners, managers, and designers to evaluate the explicit risks at the site, consider the purpose and usage of the infrastructure, and set the design for appropriate performance.

Furthermore, this approach gives the opportunity to define different levels of hazards to be designed against, with the corresponding performance to be achieved.

The approach to performance-based design proposed in this task has been developed from a resilience perspective focusing on analyzing the variation in performance during an extreme event.

Since resilience is a combination of service quality and recovery time during and after a hazard event, the PBD approach proposed is based on setting objectives for these two key aspects:

- Performance (system-level): represents the level of service that the infrastructure can provide after a given extreme event.
- Maximum acceptable restoration time: represents the maximum time allowed for the transport system to be operating at the desired level.

These two factors are detailed below.

PERFORMANCE LEVELS

Five performance levels have been defined in terms of the Damage State and the Service that the transport system is able to provide after a hazard event.

Performance Level		Description of Performance	
		Service	Damage
A	80 - 100 %	Full access to normal traffic is available immediately (or almost immediately) following the hazard event.	Only slight damage that requires routine maintenance.
B	60 - 80 %	Available for slow access, only partial lane blockages, erosion, or deformations.	Minor damages requiring clean-up of small volumes of debris and culverts.
C	40 - 60 %	Single lane access.	Moderate damage requiring removal of a moderate volume of debris, minor repairs to walls, culverts, and other structures.
D	20 - 40 %	Difficult single-lane access, only available for emergency vehicles.	Severe damage requiring removal of large volumes of debris, stabilization and/or major repairs to walls, culverts and other significant structures.
E	0 - 20 %	Closed and unavailable for any use.	Total collapse or extensive damage.

RECOVERY PHASES

When setting performance objectives, it is necessary to define not only the desired level of performance but also the time horizon within which this level of performance is to be achieved. In this regard, three recovery phases are defined:

- **Short-term** - This phase is expected to occur over a period of hours to days.
- **Intermediate** - This phase may extend for weeks to months.
- **Long-term** - This phase may continue for months to years after the event.

HAZARDS LEVELS

HAZARD LEVELS

Performance is evaluated at three levels - routine, design, and extreme - for each hazard. This approach will help designers and infrastructure managers understand and set objectives for performance accross a reasonable range of hazard levels.

Routine Level:	This hazard level is below the design level and occurs more frequently. It has a probability of occurring on the order of 50% over a 50-year period.
Design Level:	This is the hazard level used in codes and standards. Depends on the nature of the hazard and type of infrastructure but tends to have a probability of occuring on the order of 10% over a 50-year period for ordinary infrastructure.
Extreme Level:	This level exceeds the design level. It has a small probability of occurrence, on the order of 2% to 3% over a 50-year period. It may include anticipated long-term changes in hazards due to the effects of climate change.

Table below shows the return periods that were used for CS#6 to define the three hazard levels:

HAZARD	Routine Level	Design Level	Extreme Level
Earthquake	95-year event *41% in 50 years*	475-year event *10% in 50 years*	2,500-year event *2% in 50 years*

EARTHQUAKE	Routine	Design	Extreme
Return Period of the event (years)	50	475	2500
Probability of being exceeded in 50 years (%)	63,58	10,00	1,98

For each hazard leve/cenariol (routine, design and extreme), it was made an exercise, mainly focus on our emergency plan and somehow with our experience in other disruption event, p.e, wind action.

So, resilence curves for *25 de Abril* Bridge were perfomed taking into account the following aspects, concerning on level of performance and the period to recover:

- Routine: Has to be something that works very quickly, we are talking about inspection, small repairs to joints, etc. In this case, the structure will always have a freeway (one lane) to emergency vehicles and in 2-3 days it will return to normality (although it may need repairs).
- Design corresponds to replacement of joints or bearings, a slipping saddle, etc. In this case, in days we will have a 1 free lane at least for cars and emergency vehicles and in 4-8 weeks we must have some reinforcement works, temporary support structures, among others) that allows a conditioned one or two lanes to be used, with reduced speed, etc.
- in an extreme scenario the bridge is seriously damaged and in this context, of great uncertainty, the first days are for inspection, the following weeks are to ensure stability and access for emergency vehicles, and then, for a period of 24 months to lead major repairs on the bridge.

2.2.2 ESTABLISH OVERARCHING RESILIENCE-PERFORMANCE OBJECTIVES (RESILIENCE CURVE)

PERFORMANCE-BASED DESIGN - RESILIENCE CURVE

HAZARD

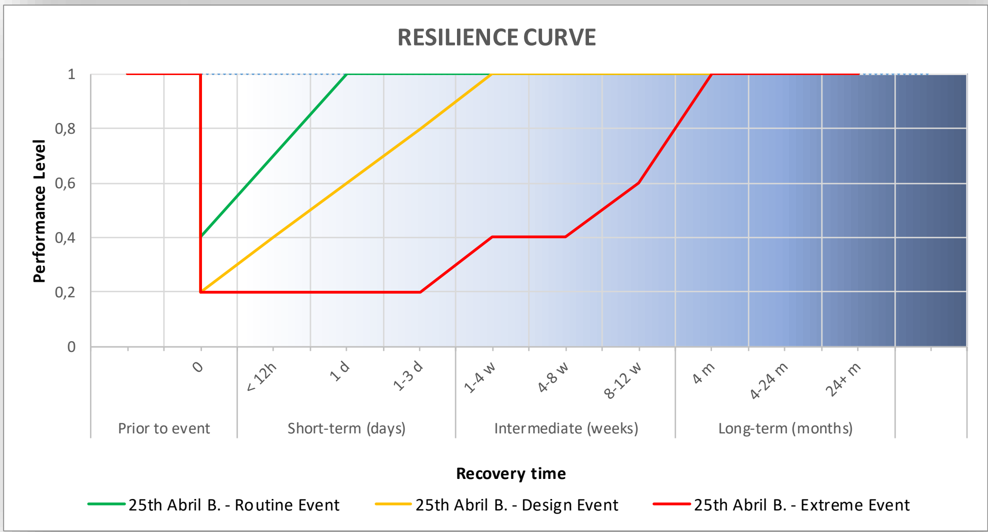
Hazard Type: **EARTHQUAKE**

		Return Period (year)	*Probability of being exceed in 50 years (%)*
Hazard Level	**Routine**	50	63,58
	Design	475	10,00
	Extreme	2500	1,98

PERFORMANCE OBJECTIVES

	TRANSPORT INFRASTRUCTURE		DESIRED PERFORMANCE LEVELS								
			Short-term			Intermediate			Long-term		
			Days			Weeks			Months		
	Description	Category	0-12h	1 d	1-3 d	1-4	4-8	8-12	4	4-24	24+
1	25th Abril B. - Routine Event	IV	40%	70%	100%						
2	25th Abril B. - Design Event	IV	20%	40%	60%	80%	100%				
3	25th Abril B. - Extreme Event	IV	20%	20%	20%	20%	40%	40%	60%	100%	

RESILIENCE CURVE



Of course, the proposed approach is particularly relevant during planning and preliminary design since decisions at these stages may have a major impact on the performance of the infrastructure during extreme events.

However, it also gives to an infrastructure manager some indications regarding the resilience performance, expressed in terms of performance levels and recovery times associated, relevant aspects during Operation & Maintenance phase (Extract from Deliverable D7.5).

2.2.3 ASSESS RESILIENCE TROUGH RESILIENCE INDICATORS

This step evaluates the resilience of the system using two types of indicators. For this purpose, two outputs from FORESEE Project are used:

1. Guidelines in Deliverables D1.1 and D1.2 (Adey, et al., 2019): firstly, following these guidelines the resilience of the system is measured through specific indicators and also target values are set for these indicators, as already shown on Annex 1.
2. Guideline in Deliverable D7.1 (Toribio-Díaz, et al., 2021): then, this guideline defines a procedure to obtain **global performance indicators of resilience** based on the result obtained using specific indicators (WP1).

These two steps combined will provide useful insight on the resilience of the system as it is shown in the following figures corresponding to the resilience assessment of Case Study #6. The results from measuring the resilience using specific indicators (Work Package WP1) were used to obtain the Resilience-principles Performance Indicators (Work Package WP7).

As it was explained in Deliverable D7.1 (Toribio-Díaz, et al., 2021), each indicator from Deliverable D1.1 is analysed whether it is related to:

- The ability of the system to absorb shocks and continue operating (i.e., robustness).
- The ability to skilfully manage a disruption as it unfolds (i.e., resourcefulness).
- The ability to get back to normal as quickly as possible after a disruption (i.e., rapid recovery). Or
- To the to the ability to absorb new lessons (i.e., adaptability).

The practical validation presented as followed was made by Case-Study Leader in collaboration with CEMOSA (responsible for Deliverable D7.5).

Table 47. CS#6, Relationship between Resilience Indicators and Resilience Concepts (Deliverables D7.1 and D7.5)

RESILIENCE INDICATORS (CS#6)				RESILIENCE CONCEPTS			
PART (LEVEL 0)	LEVEL I	ID	DESCRIPTION	ROBUST.	RESOURC.	RAPID REC.	ADAPTAB.
INFRASTRUCTURE	Condition State	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents due to a lack of signalling in case of a landslide / earthquake / wind…	3		2	
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of acciden	3		2	
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	3		2	
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	3		2	
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3		3	
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	3		3	
	Protection measures	1.2.1	Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.	3	1	2	
		1.2.2	Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.	3	1	2	
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	3	1	2	
		1.2.4	Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event	3	2	2	
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	3	2	2	
		1.2.6	Presence of emergency / evacuation paths allows users to escape in case of danger, which reduces the consequence of an extreme event	1	3	1	
		1.2.7	Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event	1	3	1	
	Preventive measures	1.3.1	Compliance with the current design code (seismic/slope stability/flooding…) decreases the extent of the extreme event.	3		1	
		1.3.2	Presence of systems to reduce seismic effects	3		1	
		1.3.3	Adequate systems to reduce seismic effects	3		1	
ENVIRONMENT	Context	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	1		3	
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an extreme event occurs	1	1		
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	2			3
		2.1.4	Hazard zone affects the likelihood of future events	2			3
		2.1.5	Duration of past down time due to hazards	2		1	3
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	1		2	2
		2.1.7	Budget availability affects the likelihood that speed of restoration		2	3	
		2.1.8	The amount of traffic affects the consequences of a landslide		2	2	
		2.1.9	The amount of hazardous goods traffic affects the consequences of an accident		2	2	
		2.1.10	The amount of flammable goods traffic affects the consequences of an accident		2	2	
ORGANIZATION	Pre-event measures	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road and is likely to increase their preparedness to react when necessary		2	2	3
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	3		1	3
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	3		1	
	Post-event measures	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a hazard and the moment a manager reacts.		3	2	2
		3.2.2	Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.		3	2	2
		3.2.3	Review/update of the emergency plan affects the likelihood that it will be fit for purpose		3	2	3
		3.2.4	Expected time for tendering affects the time required to restore service		1	3	
		3.2.5	Expecetd time for construction affects the time required to restore service		1	3	
STRUCTURAL HEALTH MONITORING	Availability	4.1.1	Continuous vibration monitoring	3			1
		4.1.2	Continuous stress and displacement monitoring of resistance elements	3			1
		4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	3			1
	Reliability and operation	4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	3			
		4.2.2	Permanent fail-safe communication of monitoring relevant information	3			
		4.2.3	SHM data analysis	3			
		4.2.4	Update rate on the feedback of the structural condition	3			2
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	3			2
		5.1.2	Repair plan of damaged components	3			
	Inspection Operation	5.2.1	Visual inspections	3			2
		5.2.2	Technical measurements	3			2
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	3			1
		6.1.2	Corrective maintenance interventions	3			1
STRUCTURAL ANALYSIS	Structural analysis	7.1.1	Structural model	3			1
	Seismic risk studies	7.2.1	Seismic risk studies	3			2
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	8.1.1	Coordination between services		3	2	
		8.1.2	Availability of resources on site		3	2	
		8.1.3	Availability of safe-through equipment		3	2	
	Response for long term	8.2.1	Long-term contingency plans		3	2	1
		8.2.2	Long-term traffic/mobility plans		3	2	1

2.2.3.1 MEASURE OF RESILIENCE OF THE TRANSPORT SYSTEM/BRIDGE (ACTUAL VALUE – CURRENT VALUE)

Table 48. CS#6, Relationship between Resilience Indicators - Resilience Concepts and Impact on Intervention Costs and Measures of Service.

PART	LEVEL I	ID	LEVEL II	Scale	Measure	IMPACT				WEIGHT (%)	ROBUST.	RESOURC.	RAPID RECOV.	ADAPT.
						Intervention	Travel time	Safety	Socio-econ.					
INFRASTRUCTURE	Condition state	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents due to a lack of signalling in case of a landslide / earthquake / wind…	3	2			X	X	50%	3	0	2	0
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of accidents	3	2			X	X	45%	3	0	2	0
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	5	3	X	X	X	X	49%	3	0	2	0
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	5	3	X	X	X	X	31%	3	0	2	0
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3	2	X	X	X	X	75%	3	0	3	0
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	3	2	X	X	X	X	62%	3	0	3	0
	Protection measures	1.2.1	Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.	2	1		X		X	43%	3	1	2	0
		1.2.2	Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.	2	1		X		X	90%	3	1	2	0
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	1	1		X		X	71%	3	1	2	0
		1.2.4	Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event	2	1		X		X	10%	3	2	2	0
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	1	1		X		X	43%	3	2	2	0
		1.2.6	Presence of emergency / evacuation paths allows users to escape in case of danger, which reduces the consequence of an extreme event	2	2		X		X	93%	1	3	1	0
		1.2.7	Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event	2	0		X		X	16%	1	3	1	0
	Preventive Measures	1.3.1	Compliance with the current design code (seismic/slope stability/flooding…) decreases the extent of the extreme event.	2	1	X	X	X	X	78%	3	0	1	0
		1.3.2	Presence of systems to reduce seismic effects	1	0	X	X	X	X	39%	3	0	1	0
		1.3.3	Adequate systems to reduce seismic effects	1	0	X	X	X	X	91%	3	0	1	0
ENVIRONMENT	Physical	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	3	0	X				98%	1	0	3	0
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an extreme event occurs	1	0			X		69%	1	1	0	0
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	3	3	X				12%	2	0	0	3
		2.1.4	Hazard zone affects the likelihood of future events	2	1	X	X	X	X	19%	2	0	0	3
		2.1.5	Duration of past down time due to hazards	3	2	X				12%	2	0	1	3
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	3	0	X		X		93%	1	0	2	2
		2.1.7	Budget availability affects the likelihood that speed of restoration	2	2	X	X	X	X	12%	0	2	3	0
		2.1.8	The amount of traffic affects the consequences of a landslide	3	0	X	X	X	X	20%	0	2	2	0
		2.1.9	The amount of hazardous goods traffic affects the consequences of an accident	2	0			X		31%	0	2	2	0
		2.1.10	The amount of flammable goods traffic affects the consequences of an accident	1	0			X		84%	0	2	2	0
ORGANISATION	Pre-event activities	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road and is likely to increase their preparedness to react when necessary	2	2	X	X	X	X	81%	0	2	2	3
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	2	2	X	X	X	X	86%	3	0	1	3
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	2	1	X	X	X	X	9%	3	0	1	0
	Post-event activities	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a hazard and the moment a manager reacts.	2	2		X		X	8%	0	3	2	2
		3.2.2	Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.	4	0		X		X	41%	0	3	2	2
		3.2.3	Review/update of the emergency plan affects the likelihood that it will be fit for purpose	2	0		X	X	X	96%	0	3	2	3
		3.2.4	Expected time for tendering affects the time required to restore service	3	0	X	X		X	66%	0	1	3	0
		3.2.5	Expecetd time for construction affects the time required to restore service	3	0	X	X		X	8%	0	1	3	0
STRUCTURAL HEALTH MONITORI	Availability	4.1.1	Continuous vibration monitoring	2	1	X		X		75%	3	0	0	1
		4.1.2	Continuous stress and displacement monitoring of resistance elements	2	1	X		X		50%	3	0	0	1
		4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	1	X		X		75%	3	0	0	1
	Reliability and operation	4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0	X		X		75%	3	0	0	0
		4.2.2	Permanent fail-safe communication of monitoring relevant information	2	1	X		X		75%	3	0	0	0
		4.2.3	SHM data analysis	3	2	X		X		50%	3	0	0	0
		4.2.4	Update rate on the feedback of the structural condition	3	2	X		X		75%	3	0	0	2
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	2	2			X	X	50%	3	0	0	2
		5.1.2	Repair plan of damaged components	2	2			X	X	50%	3	0	2	0
	Inspection Operation	5.2.1	Visual inspections	2	2	X	X	X	X	75%	3	0	0	2
		5.2.2	Technical measurements	2	2	X	X	X	X	50%	3	0	0	2
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	2	2	X	X	X	X	75%	3	0	0	1
		6.1.2	Corrective maintenance interventions	2	1	X	X	X	X	75%	3	0	0	1
STRUCTURAL ANALYSIS	Structural analysis	7.1.1	Structural model	3	3	X	X		X	75%	3	0	0	1
	Seismic risk studies	7.2.1	Seismic risk studies	3	0	X	X		X	50%	3	0	0	2
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	8.1.1	Coordination between services	2	1		X			50%	0	3	2	0
		8.1.2	Availability of resources on site	2	1	X	X			75%	0	3	2	0
		8.1.3	Availability of safe-through equipment	1	1	X				50%	0	3	2	0
	Response for long term disrup	8.2.1	Long-term contingency plans	1	0		X			75%	0	3	2	1
		8.2.2	Long-term traffic/mobility plans	1	0		X			75%	0	3	2	1
				122	62						104	50	72	42

Table 49. CS#6, Expected Intervention Costs and Reduction of Services if each Indicator had its worst possible Value (zero).

1) Expected intervention costs and reduction of services if each indicator had its worst possible value (zero)

PART	LEVEL I	ID	LEVEL II	Intervention Costs (€)	Measure of Service (€) Travel time	Safety	Socio-econ.	TOTAL (€)
INFRASTRUCTURE	Condition state	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents	-	-	2 093 673	38 697	**2 132 370**
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of accidents	-	-	1 884 306	34 827	**1 919 133**
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	2 768,796	1 677 021	2 036 520	37 641	**3 753 950**
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	1 758,855	1 065 314	1 293 683	23 911	**2 384 666**
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3 536,413	2 141 956	2 601 122	48 076	**4 794 690**
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	-	1 478 749	-	33 190	**1 511 939**
	Protection measures	1.2.1	Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.	-	1 478 749	-	33 190	**1 511 939**
		1.2.2	Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.	-	3 091 673	-	69 392	**3 161 065**
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	-	2 463 116	-	55 285	**2 518 400**
		1.2.4	Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event	-	348 725	-	7 827	**356 552**
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	-	1 484 631	-	33 322	**1 517 954**
		1.2.6	Presence of emergency / evacuation paths allows users to escape in case of danger, which reduces the consequence of an extreme event	-	3 196 953	-	71 755	**3 268 709**
		1.2.7	Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event	-	566 684	-	12 719	**579 403**
	Preventive Measures	1.3.1	Compliance with the current design code (seismic/slope stability/flooding…) decreases the extent of the extreme event.	4 439,228	2 688 778	3 265 165	60 349	**6 018 732**
		1.3.2	Presence of systems to reduce seismic effects	2 208,781	1 337 827	1 624 614	30 027	**2 994 678**
		1.3.3	Adequate systems to reduce seismic effects	5 200,952	3 150 144	3 825 432	70 705	**7 051 482**
ENVIRONMENT	Physical and Non-physical (E2.1.7)	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	5 600,213	-	-	-	**5 600,213**
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an	-	-	2 872 559	-	**2 872 559**
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	692,347	-	-	-	**692,347**
		2.1.4	Hazard zone affects the likelihood of future events	1 103,972	668 660	811 999	15 008	**1 496 772**
		2.1.5	Duration of past down time due to hazards	685,188	-	-	-	**685,188**
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	5 289,098	-	3 890 266	-	**3 895 555**
		2.1.7	Budget availability affects the likelihood that speed of restoration	710,190	430 152	522 363	9 655	**962 879**
		2.1.8	The amount of traffic affects the consequences of a landslide	1 127,100	682 669	829 011	15 322	**1 528 129**
		2.1.9	The amount of hazardous goods traffic affects the consequences of an accident	-	-	1 277 927	-	**1 277 927**
		2.1.10	The amount of flammable goods traffic affects the consequences of an accident	-	-	3 516 083	-	**3 516 082,858**
ORGANISATION	Pre-event activities	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road	4 608,285	2 791 173	3 389 511	62 648	**6 247 940**
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	4 886,615	2 959 754	3 594 229	66 432	**6 625 302**
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	533,192	322 947	392 176	7 249	**722 904**
	Post-event activities	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a	-	273 203	-	6 132	**279 335**
		3.2.2	Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.	-	1 409 950	-	31 646	**1 441 596**
		3.2.3	Review/update of the emergency plan affects the likelihood that it will be fit for	-	3 307 556	4 016 589	74 238	**7 398 382**
		3.2.4	Expected time for tendering affects the time required to restore service	3 771,531	2 284 364	-	51 272	**2 339 408**
		3.2.6	#N/D	446,805	270 623	-	6 074	**277 144**
STRUCTURAL HEALTH MONITORING	Availability	4.1.1	Continuous vibration monitoring	4 244,923	-	3 122 249	-	**3 126 494**
		4.1.2	Continuous stress and displacement monitoring of resistance elements	2 846,500	-	2 093 673	-	**2 096 520**
		4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	4 244,923	-	3 122 249	-	**3 126 494**
	Reliability and operation	4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	4 244,923	-	3 122 249	-	**3 126 494**
		4.2.2	Permanent fail-safe communication of monitoring relevant information	4 244,923	-	3 122 249	-	**3 126 494**
		4.2.3	SHM data analysis	2 846,500	-	2 093 673	-	**2 096 520**
		4.2.4	Update rate on the feedback of the structural condition	4 244,923	-	3 122 249	-	**3 126 494**
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	-	-	2 093 673	38 697	**2 132 370**
		5.1.2	Repair plan of damaged components	-	-	2 093 673	38 697	**2 132 370**
	Inspection Operation	5.2.1	Visual inspections	4 269,750	2 586 128	3 140 510	58 046	**5 788 952**
		5.2.2	Technical measurements	2 846,500	1 724 085	2 093 673	38 697	**3 859 302**
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	4 269,750	2 586 128	3 140 510	58 046	**5 788 952**
		6.1.2	Corrective maintenance interventions	4 269,750	2 586 128	3 140 510	58 046	**5 788 952**
STRUCTURAL ANALYSIS	Structural analysis	7.1.1	Structural model	4 269,750	2 586 128	-	58 046	**2 648 443**
	Seismic risk studies	7.2.1	Seismic risk studies	2 846,500	1 724 085	-	38 697	**1 765 629**
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	8.1.1	Coordination between services	-	1 724 085	-	-	**1 724 085**
		8.1.2	Availability of resources on site	4 269,750	2 586 128	-	-	**2 590 397**
		8.1.3	Availability of safe-through equipment	2 846,500	-	-	-	**2 846,500**
	Response for long term disrup	8.2.1	Long-term contingency plans	-	2 586 128	-	-	**2 586 128**
		8.2.2	Long-term traffic/mobility plans	-	2 586 128	-	-	**2 586 128**
				106 173,428	**64 846 515**	**79 238 364**	**1 393 562**	**145 584 614**

Table 50. CS#6, Expected Intervention Costs and Reduction of Service Level has the Indicator, taking into account the measure of the Indicator and its Weight.

2) Calculation of intervention costs and reduction of service level has the indicator, taking into account the measure of the indicator and its weight

PART	LEVEL I	ID	LEVEL II	Scale	Measure	COST (€)				TOTAL	Fulfillment (%)	ROBUST.	RESOURC.	RAPID RECOV.	ADAPT.
						Intervention	Travel time	Safety	Socio-econ.						
INFRASTRUCTURE	Condition state	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents due to a lack of signalling in case of a landslide / earthquake / wind…	3	2	- €	- €	697 891 €	12 899 €	**710 790**	**67%**	2,00	0,00	1,33	0,00
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of accidents	3	2	- €	- €	628 102 €	11 609 €	**639 711**	**67%**	2,00	0,00	1,33	0,00
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	5	3	1 108 €	670 808 €	814 608 €	15 056 €	**1 501 580**	**60%**	1,80	0,00	1,20	0,00
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	5	3	704 €	426 126 €	517 473 €	9 564 €	**953 866**	**60%**	1,80	0,00	1,20	0,00
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3	2	1 179 €	713 985 €	867 041 €	16 025 €	**1 598 230**	**67%**	2,00	0,00	2,00	0,00
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	3	2	- €	492 916 €	- €	11 063 €	**503 980**	**67%**	2,00	0,67	1,33	0,00
	Protection measures	1.2.1	Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.	2	1	- €	739 374 €	- €	16 595 €	**755 970**	**50%**	1,50	0,50	1,00	0,00
		1.2.2	Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.	2	1	- €	1 545 836 €	- €	34 696 €	**1 580 533**	**50%**	1,50	0,50	1,00	0,00
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	1	1	- €	- €	- €	- €	-	**100%**	3,00	1,00	2,00	0,00
		1.2.4	Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event	2	1	- €	174 362 €	- €	3 914 €	**178 276**	**50%**	1,50	1,00	1,00	0,00
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	1	1	- €	- €	- €	- €	-	**100%**	3,00	2,00	2,00	0,00
		1.2.6	Presence of emergency / evacuation paths allows users to	2	2	- €	- €	- €	- €	-	**100%**	1,00	3,00	1,00	0,00
		1.2.7	Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event	2	0	- €	566 684 €	- €	12 719 €	**579 403**	**0%**	0,00	0,00	0,00	0,00
	Preventive Measures	1.3.1	Compliance with the current design code (seismic/slope	2	1	2 220 €	1 344 389 €	1 632 583 €	30 175 €	**3 009 366**	**50%**	1,50	0,00	0,50	0,00
		1.3.2	Presence of systems to reduce seismic effects	1	0	2 209 €	1 337 827 €	1 624 614 €	30 027 €	**2 994 678**	**0%**	0,00	0,00	0,00	0,00
		1.3.3	Adequate systems to reduce seismic effects	1	0	5 201 €	3 150 144 €	3 825 432 €	70 705 €	**7 051 482**	**0%**	0,00	0,00	0,00	0,00
ENVIRONMENT	Physical and Non-physical (E2.1.7)	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	3	0	- €	- €	- €	- €	-	**100%**	1,00	0,00	3,00	0,00
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an extreme event occurs	1	0	- €	- €	- €	- €	-	**100%**	1,00	1,00	0,00	0,00
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	3	3	- €	- €	- €	- €	-	**100%**	2,00	0,00	0,00	3,00
		2.1.4	Hazard zone affects the likelihood of future events	2	1	552 €	- €	- €	- €	**552**	**100%**	2,00	0,00	0,00	3,00
		2.1.5	Duration of past down time due to hazards	3	2	228 €	- €	- €	- €	**228**	**67%**	1,33	0,00	0,67	2,00
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	3	0	5 289 €	- €	3 890 266 €	- €	**3 895 555**	**0%**	0,00	0,00	0,00	0,00
		2.1.7	Budget availability affects the likelihood that speed of	2	2	- €	- €	- €	- €	-	**100%**	0,00	2,00	3,00	0,00
		2.1.8	The amount of traffic affects the consequences of a landslide	3	0	- €	- €	829 011 €	- €	**829 011**	**46%**	0,00	0,91	0,91	0,00
		2.1.9	The amount of hazardous goods traffic affects the consequences of an accident	2	0	- €	- €	1 277 927 €	- €	**1 277 927**	**0%**	0,00	0,00	0,00	0,00
		2.1.10	The amount of flammable goods traffic affects the consequences of an accident	1	0	- €	- €	3 516 083 €	- €	**3 516 083**	**0%**	0,00	0,00	0,00	0,00
ORGANISATION	Pre-event activities	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road and is likely to increase their preparedness to react when necessary	2	2	- €	- €	- €	- €	-	**100%**	0,00	2,00	2,00	3,00
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	1,00	3,00
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	2	1	267 €	161 473 €	196 088 €	3 624 €	**361 452**	**50%**	1,50	0,00	0,50	0,00
	Post-event activities	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a hazard and the moment a manager reacts.	2	2	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	2,00
		3.2.2	Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.	4	0	- €	1 409 950 €	- €	31 646 €	**1 441 596**	**0%**	0,00	0,00	0,00	0,00
		3.2.3	Review/update of the emergency plan affects the likelihood that it will be fit for purpose	2	0	- €	3 307 556 €	4 016 589 €	74 238 €	**7 398 382**	**0%**	0,00	0,00	0,00	0,00
		3.2.4	Expected time for tendering affects the time required to restore service	3	0	3 772 €	2 284 364 €	- €	51 272 €	**2 339 408**	**0%**	0,00	0,00	0,00	0,00
		3.2.5	Expected time for construction affects the time required to	3	0	447 €	270 623 €	- €	6 074 €	**277 144**	**0%**	0,00	0,00	0,00	0,00
STRUCTURAL HEALTH MONITORING	Availability	4.1.1	Continuous vibration monitoring	2	1	2 122 €	- €	1 561 124 €	- €	**1 563 247**	**50%**	1,50	0,00	0,00	0,50
		4.1.2	Continuous stress and displacement monitoring of resistance elements	2	1	1 423 €	- €	1 046 837 €	- €	**1 048 260**	**50%**	1,50	0,00	0,00	0,50
		4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	1	2 122 €	- €	1 561 124 €	- €	**1 563 247**	**50%**	1,50	0,00	0,00	0,50
	Reliability and operation	4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0	4 245 €	- €	3 122 249 €	- €	**3 126 494**	**0%**	0,00	0,00	0,00	0,00
		4.2.2	Permanent fail-safe communication of monitoring relevant information	2	1	2 122 €	- €	1 561 124 €	- €	**1 563 247**	**50%**	1,50	0,00	0,00	0,00
		4.2.3	SHM data analysis	3	2	949 €	- €	697 891 €	- €	**698 840**	**67%**	2,00	0,00	0,00	0,00
		4.2.4	Update rate on the feedback of the structural condition	3	2	1 415 €	- €	1 040 750 €	- €	**1 042 165**	**67%**	2,00	0,00	0,00	1,33
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
		5.1.2	Repair plan of damaged components	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	2,00	0,00
	Inspection Operation	5.2.1	Visual inspections	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
		5.2.2	Technical measurements	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
		6.1.2	Corrective maintenance interventions	2	1	2 135 €	1 293 064 €	1 570 255 €	29 023 €	**2 894 476**	**50%**	1,50	0,00	0,00	0,50
STRUCTURAL ANALYSIS	Structural analysis	7.1.1	Structural model	3	3	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
	Seismic risk studies	7.2.1	Seismic risk studies	3	0	2 847 €	1 724 085 €	- €	38 697 €	**1 765 629**	**0%**	0,00	0,00	0,00	0,00
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	8.1.1	Coordination between services	2	1	- €	862 043 €	- €	- €	**862 043**	**50%**	0,00	1,50	1,00	0,00
		8.1.2	Availability of resources on site	2	1	2 135 €	1 293 064 €	- €	- €	**1 295 199**	**50%**	0,00	1,50	1,00	0,00
		8.1.3	Availability of safe-through equipment	1	1	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	0,00
	Response for long term disrup	8.2.1	Long-term contingency plans	1	0	- €	2 586 128 €	- €	- €	**2 586 128**	**0%**	0,00	0,00	0,00	0,00
		8.2.2	Long-term traffic/mobility plans	1	0	- €	2 586 128 €	- €	- €	**2 586 128**	**0%**	0,00	0,00	0,00	0,00

3) Measure of resilience of the transport system

	MAX VALUE	ACTUAL VALUE	COST (10^3 €)				TOTAL (10^6 €)
			Intervention	Travel time	Safety	Socio-econ.	
MEASURE OF RESILIENCE OF THE SYSTEM	122	62	421	272 365	343 457	4 796	**621,04**

ANALYSIS OF RESILIENCE-PRINCIPLE PERFORMANCE INDICATORS

GLOBAL RESILIENCE

	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	104	65,93	63,4%
Resourcefulness Performance Index (RePI)	50	23,58	47,2%
Rapid Recovery Performance Index (RrPI)	72	35,98	50,0%
Adaptability Performance Index (AdPI)	42	27,33	65,1%

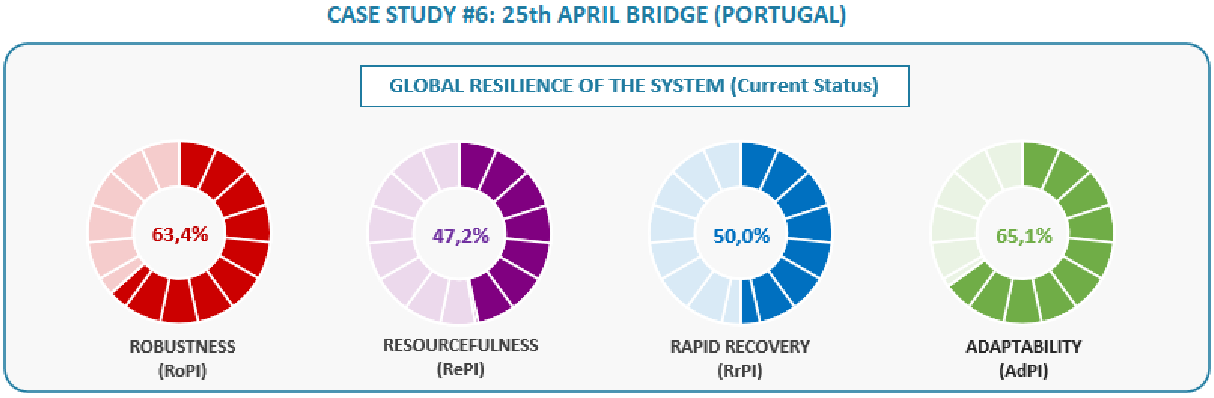


Figure 41. Resilience-principles Performance Indicators: CS#6 (current level)

CONDITION STATE

	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	18	11,60	64,4%
Rapid Recovery Performance Index (RrPI)	14	8,40	60,0%

PROTECTION MEASURES

	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	17	11,50	67,6%
Resourcefulness Performance Index (RePI)	13	8,00	61,5%
Rapid Recovery Performance Index (RrPI)	12	8,00	66,7%

PREVENTIVE MEASURES

	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	9	1,50	16,7%
Rapid Recovery Performance Index (RrPI)	3	0,50	16,7%

PHYSICAL/NON-PHYSICAL	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	9	7,33	81,5%
Resourcefulness Performance Index (RePI)	9	3,91	43,5%
Rapid Recovery Performance Index (RrPI)	15	7,58	50,5%
Adaptability Performance Index (AdPI)	11	8,00	72,7%

PRE-EVENT MEASURES	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	4,50	75,0%
Resourcefulness Performance Index (RePI)	2	2,00	100,0%
Rapid Recovery Performance Index (RrPI)	4	3,50	87,5%
Adaptability Performance Index (AdPI)	6	6,00	100,0%

POST-EVENT MEASURES	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Resourcefulness Performance Index (RePI)	11	3,00	27,3%
Rapid Recovery Performance Index (RrPI)	12	2,00	16,7%
Adaptability Performance Index (AdPI)	7	2,00	28,6%

STRUCTURAL HEALTH MONITORING	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	21	10,00	47,6%
Adaptability Performance Index (AdPI)	5	2,83	56,7%

INSPECTION	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	12	12,00	100,0%
Adaptability Performance Index (AdPI)	6	6,00	100,0%

SMALL MAINTENANCE	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	4,50	75,0%
Adaptability Performance Index (AdPI)	2	1,50	75,0%

STRUCTURAL ANALYSIS	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	3,00	50,0%
Adaptability Performance Index (AdPI)	3	1,00	33,3%

EVACUATION AND TRAFFIC MANAGEMENT	MAX VALUE	ACTUAL VALUE	% FULFILLMENT
Resourcefulness Performance Index (RePI)	15	6,00	40,0%
Rapid Recovery Performance Index (RrPI)	10	4,00	40,0%
Adaptability Performance Index (AdPI)	2	0,00	0,0%

2.2.3.2 MEASURE OF RESILIENCE OF THE TRANSPORT SYSTEM/BRIDGE (TARGET VALUE/LEVEL)

Table 51. CS#6, Relationship between Resilience Indicators- Resilience Concepts and Impact on Intervention Costs and Measures of Service – Indicator Target Values (grey shadow).

PART	LEVEL I	ID	LEVEL II	Scale	Measure	IMPACT				WEIGHT (%)	ROBUST.	RESOURC.	RAPID RECOV.	ADAPT.
						Intervention	Travel time	Safety	Socio-econ.					
INFRASTRUCTURE	Condition state	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents due to a lack of signalling in case of a landslide / earthquake / wind…	3	2			X	X	50%	3	0	2	0
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of accidents	3	2			X	X	45%	3	0	2	0
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	5	3	X	X	X	X	49%	3	0	2	0
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	5	3	X	X	X	X	31%	3	0	2	0
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3	2	X	X	X	X	75%	3	0	3	0
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	3	2	X	X	X	X	62%	3	0	3	0
	Protection measures	**1.2.1**	**Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.**	2	**2**		X		X	43%	3	1	2	0
		1.2.2	**Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.**	2	**2**		X		X	90%	3	1	2	0
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	1	1		X		X	71%	3	1	2	0
		1.2.4	**Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event**	2	**2**		X		X	10%	3	2	2	0
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	1	1		X		X	43%	3	2	2	0
		1.2.6	Presence of emergency / evacuation paths allows users to escape in case of danger, which reduces the consequence of an extreme event	2	2		X		X	93%	1	3	1	0
		1.2.7	**Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event**	2	**2**		X		X	16%	1	3	1	0
	Preventive Measures	1.3.1	Compliance with the current design code (seismic/slope stability/flooding…) decreases the extent of the extreme event.	2	1	X	X	X	X	78%	3	0	1	0
		1.3.2	Presence of systems to reduce seismic effects	1	0	X	X	X	X	39%	3	0	1	0
		1.3.3	Adequate systems to reduce seismic effects	1	0	X	X	X	X	91%	3	0	1	0
ENVIRONMENT	Physical and Non-Physical (E2.1.7)	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	3	0	X				98%	1	0	3	0
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an extreme event occurs	1	0			X		69%	1	1	0	0
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	3	3	X				12%	2	0	0	3
		2.1.4	Hazard zone affects the likelihood of future events	2	1	X	X	X	X	19%	2	0	0	3
		2.1.5	Duration of past down time due to hazards	3	2	X				12%	2	0	1	3
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	3	0	X		X		93%	1	0	2	2
		2.1.7	Budget availability affects the likelihood that speed of restoration	2	2	X	X	X	X	12%	0	2	3	0
		2.1.8	The amount of traffic affects the consequences of a landslide	3	0	X	X	X	X	20%	0	2	2	0
		2.1.9	**The amount of hazardous goods traffic affects the consequences of an accident**	2	**2**			X		31%	0	2	2	0
		2.1.10	**The amount of flammable goods traffic affects the consequences of an accident**	1	**1**			X		84%	0	2	2	0
ORGANISATION	Pre-event activities	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road and is likely to increase their preparedness to react when necessary	2	2	X	X	X	X	81%	0	2	2	3
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	2	2	X	X	X	X	86%	3	0	1	3
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	2	1	X	X	X	X	9%	3	0	1	0
	Post-event activities	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a hazard and the moment a manager reacts.	2	2		X		X	8%	0	3	2	2
		3.2.2	**Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.**	4	**2**		X		X	41%	0	3	2	2
		3.2.3	**Review/update of the emergency plan affects the likelihood that it will be fit for purpose**	2	**2**		X	X	X	96%	0	3	2	3
		3.2.4	Expected time for tendering affects the time required to restore service	3	0	X	X		X	66%	0	1	3	0
		3.2.5	Expecetd time for construction affects the time required to restore service	3	0	X	X		X	8%	0	1	3	0
STRUCTURAL HEALTH MONITORIN	Availability	**4.1.1**	**Continuous vibration monitoring**	2	**2**	X		X		75%	3	0	0	1
		4.1.2	**Continuous stress and displacement monitoring of resistance elements**	2	**2**	X		X		50%	3	0	0	1
		4.1.3	**Continuous relative displacement monitoring of moving components and anti-seismic devices**	2	**2**	X		X		75%	3	0	0	1
	Reliability and operation	**4.2.1**	**Autonomous short-term electrical supply to the monitoring system installed on site**	2	**2**	X		X		75%	3	0	0	0
		4.2.2	**Permanent fail-safe communication of monitoring relevant information**	2	**2**	X		X		75%	3	0	0	0
		4.2.3	**SHM data analysis**	3	**3**	X		X		50%	3	0	0	0
		4.2.4	**Update rate on the feedback of the structural condition**	3	2	X		X		75%	3	0	0	2
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	2	2			X	X	50%	3	0	0	2
		5.1.2	Repair plan of damaged components	2	2			X	X	50%	3	0	2	0
	Inspection Operation	5.2.1	Visual inspections	2	2	X	X	X	X	75%	3	0	0	2
		5.2.2	Technical measurements	2	2	X	X	X	X	50%	3	0	0	2
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	2	2	X	X	X	X	75%	3	0	0	1
		6.1.2	**Corrective maintenance interventions**	2	2	X	X	X	X	75%	3	0	0	1
STRUCTURAL AN	Structural analysis	7.1.1	Structural model	3	3	X	X		X	75%	3	0	0	1
	Seismic risk studies	**7.2.1**	**Seismic risk studies**	3	3	X	X		X	50%	3	0	0	2
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	**8.1.1**	**Coordination between services**	2	2		X			50%	0	3	2	0
		8.1.2	Availability of resources on site	2	1	X	X			75%	0	3	2	0
		8.1.3	Availability of safe-through equipment	1	1	X				50%	0	3	2	0
	Response for long term disrup	**8.2.1**	**Long-term contingency plans**	1	1		X			75%	0	3	2	1
		8.2.2	**Long-term traffic/mobility plans**	1	1		X			75%	0	3	2	1
				122	88						**104**	**50**	**72**	**42**

Table 52. CS#6, Expected Intervention Costs and Reduction of Service Level has the Indicator, considering the measure of each Indicator (Target Values) and its Weight.

2) Calculation of intervention costs and reduction of service level has the indicator, taking into account the measure of the indicator and its weight

PART	LEVEL I	ID	LEVEL II	Scale	Measure	COST (€)				TOTAL	Fulfillment (%)	ROBUST.	RESOURC.	RAPID RECOV.	ADAPT.
						Intervention	Travel time	Safety	Socio-econ.						
INFRASTRUCTURE	Condition state	1.1.1	Age / Age of replacement of the warning system affects the probability of accidents due to a lack of signalling in case of a landslide / earthquake / wind…	3	2	- €	- €	697 891 €	12 899 €	**710 790**	**67%**	2,00	0,00	1,33	0,00
		1.1.2	Age / Age of replacement of safe shut down system affects the probability of accidents	3	2	- €	- €	628 102 €	11 609 €	**639 711**	**67%**	2,00	0,00	1,33	0,00
		1.1.3	Condition state of infrastructure (pre-event) affects the probability of the infrastructure being damaged	5	3	1 108 €	670 808 €	814 608 €	15 056 €	**1 501 580**	**60%**	1,80	0,00	1,20	0,00
		1.1.4	Condition state of protective structures/systems (pre-event) affects the probability that they can provide the level of service for which it was designed during and following the event and the harder to repair it if damaged	5	3	704 €	426 126 €	517 473 €	9 564 €	**953 866**	**60%**	1,80	0,00	1,20	0,00
		1.1.5	Expected condition state of infrastructure providing service after a disruption affects its ease of repair.	3	2	1 179 €	713 985 €	867 041 €	16 025 €	**1 598 230**	**67%**	2,00	0,00	2,00	0,00
		1.1.6	Expected condition state of protective structures/systems after an event affects the likelihood that they will not function as intended after an event	3	2	- €	492 916 €	- €	11 063 €	**503 980**	**67%**	2,00	0,67	1,33	0,00
	Protection measures	1.2.1	Possibility of building a temporary alternative route for vehicles, reduces the consequences on infrastructure users.	2	2	- €	- €	- €	- €	-	**100%**	3,00	1,00	2,00	0,00
		1.2.2	Possibility of using another means to satisfy transport demand - reduces the consequences of an infrastructure being out of service.	2	2	- €	- €	- €	- €	-	**100%**	3,00	1,00	2,00	0,00
		1.2.3	Number of possible existing alternative ways to deviate vehicles reduces the consequences of an infrastructure being out of service.	1	1	- €	- €	- €	- €	-	**100%**	3,00	1,00	2,00	0,00
		1.2.4	Presence of a warning system allows users to bypass a road section in case of danger, which reduces the consequences of the extreme event	2	2	- €	- €	- €	- €	-	**100%**	3,00	2,00	2,00	0,00
		1.2.5	Presence of a safe shutdown system to prevent users from using a damaged road section reduces the consequences of an extreme event	1	1	- €	- €	- €	- €	-	**100%**	3,00	2,00	2,00	0,00
		1.2.6	Presence of emergency / evacuation paths allows users to	2	2	- €	- €	- €	- €	-	**100%**	1,00	3,00	1,00	0,00
		1.2.7	Presence of special measures to help evacuate persons (e.g. helicopter) allows users to escape in case of danger, reduces the consequence of an extreme event	2	2	- €	- €	- €	- €	-	**100%**	1,00	3,00	1,00	0,00
	Preventive Measures	1.3.1	Compliance with the current design code (seismic/slope	2	1	2 220 €	1 344 389 €	1 632 583 €	30 175 €	**3 009 366**	**50%**	1,50	0,00	0,50	0,00
		1.3.2	Presence of systems to reduce seismic effects	1	0	2 209 €	1 337 827 €	1 624 614 €	30 027 €	**2 994 678**	**0%**	0,00	0,00	0,00	0,00
		1.3.3	Adequate systems to reduce seismic effects	1	0	5 201 €	3 150 144 €	3 825 432 €	70 705 €	**7 051 482**	**0%**	0,00	0,00	0,00	0,00
ENVIRONMENT	Physical and Non-physical (E2.1.7)	2.1.1	Accessibility of the infrastructure affects the ability and time required to restore it	3	0	- €	- €	- €	- €	-	**100%**	1,00	0,00	3,00	0,00
		2.1.2	Presence of persons/property below the infrastructure affects the consequences if an extreme event occurs	1	0	- €	- €	- €	- €	-	**100%**	1,00	1,00	0,00	0,00
		2.1.3	Extent of past damages due to hazards indicates the likelihood of future damages	3	3	- €	- €	- €	- €	-	**100%**	2,00	0,00	0,00	3,00
		2.1.4	Hazard zone affects the likelihood of future events	2	1	552 €	- €	- €	- €	**552**	**100%**	2,00	0,00	0,00	3,00
		2.1.5	Duration of past down time due to hazards	3	2	228 €	- €	- €	- €	**228**	**67%**	1,33	0,00	0,67	2,00
		2.1.6	Land type affect the likelihood of future landslides/floodings and the probability of restoration interventions / service interruptions	3	0	5 289 €	- €	3 890 266 €	- €	**3 895 555**	**0%**	0,00	0,00	0,00	0,00
		2.1.7	Budget availability affects the likelihood that speed of	2	2	- €	- €	- €	- €	-	**100%**	0,00	2,00	3,00	0,00
		2.1.8	The amount of traffic affects the consequences of a landslide	3	0	- €	- €	829 011 €	- €	**829 011**	**46%**	0,00	0,91	0,91	0,00
		2.1.9	The amount of hazardous goods traffic affects the consequences of an accident	2	2	- €	- €	- €	- €	-	**100%**	0,00	2,00	2,00	0,00
		2.1.10	The amount of flammable goods traffic affects the consequences of an accident	1	1	- €	- €	- €	- €	-	**100%**	0,00	2,00	2,00	0,00
ORGANISATION	Pre-event activities	3.1.1	The presence of a monitoring strategy raises the awareness of the state of the road and is likely to increase their preparedness to react when necessary	2	2	- €	- €	- €	- €	-	**100%**	0,00	2,00	2,00	3,00
		3.1.2	The presence of an maintenance strategy increases the likelihood that the infrastructure will be in a condition to resist a hazard	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	1,00	3,00
		3.1.3	The extent of interventions executed prior to the event affects the likelihood that the infrastructure will be in a condition to resist a hazard	2	1	267 €	161 473 €	196 088 €	3 624 €	**361 452**	**50%**	1,50	0,00	0,50	0,00
	Post-event activities	3.2.1	The presence of an emergency plan reduces the time between the occurrence of a hazard and the moment a manager reacts.	2	2	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	2,00
		3.2.2	Practice of the emergency plan affects the ability of the manager to use it when needed, reducing the time for execution.	4	2	- €	704 975 €	- €	15 823 €	**720 798**	**50%**	0,00	1,50	1,00	1,00
		3.2.3	Review/update of the emergency plan affects the likelihood that it will be fit for purpose	2	2	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	3,00
		3.2.4	Expected time for tendering affects the time required to restore service	3	0	3 772 €	2 284 364 €	- €	51 272 €	**2 339 408**	**0%**	0,00	0,00	0,00	0,00
		3.2.5	Expecetd time for construction affects the time required to restore service	3	0	447 €	270 623 €	- €	6 074 €	**277 144**	**0%**	0,00	0,00	0,00	0,00
STRUCTURAL HEALTH MONITORING	Availability	4.1.1	Continuous vibration monitoring	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
		4.1.2	Continuous stress and displacement monitoring of resistance elements	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
		4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
	Reliability and operation	4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	0,00
		4.2.2	Permanent fail-safe communication of monitoring relevant information	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	0,00
		4.2.3	SHM data analysis	3	3	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	0,00
		4.2.4	Update rate on the feedback of the structural condition	3	2	1 415 €	- €	1 040 750 €	- €	**1 042 165**	**67%**	2,00	0,00	0,00	1,33
INSPECTION	Inspection plan	5.1.1	Component inspection and testing plan	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
		5.1.2	Repair plan of damaged components	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	2,00	0,00
	Inspection Operation	5.2.1	Visual inspections	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
		5.2.2	Technical measurements	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
SMALL MAINTENANCE	Maintenance	6.1.1	Periodic routine maintenance interventions	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
		6.1.2	Corrective maintenance interventions	2	2	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
STRUCTURAL ANALYSIS	Structural analysis	7.1.1	Structural model	3	3	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	1,00
	Seismic risk studies	7.2.1	Seismic risk studies	3	3	- €	- €	- €	- €	-	**100%**	3,00	0,00	0,00	2,00
EVACUATION AND TRAFFIC MANAGEMENT	Direct and immediate response	8.1.1	Coordination between services	2	2	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	0,00
		8.1.2	Availability of resources on site	2	1	2 135 €	1 293 064 €	- €	- €	**1 295 199**	**50%**	0,00	1,50	1,00	0,00
		8.1.3	Availability of safe-through equipment	1	1	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	0,00
	Response for long term disrup	8.2.1	Long-term contingency plans	1	1	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	1,00
		8.2.2	Long-term traffic/mobility plans	1	1	- €	- €	- €	- €	-	**100%**	0,00	3,00	2,00	1,00
				122	88	26 723	12 850 694	16 563 857	283 919	29 725 194		**85,93**	**44,58**	**51,98**	**37,33**

5) Measure of resilience of the transport system - Target Value

	MAX VALUE	TARGET VALUE	COST (10^3 €)				TOTAL (10^6 €)
			Intervention	Travel time	Safety	Socio-econ.	
MEASURE OF RESILIENCE OF THE SYSTEM	122	88	357	171 655	221 254	3 792	**397,06**

ANALYSIS OF RESILIENCE-PRINCIPLE PERFORMANCE INDICATORS

GLOBAL RESILIENCE

	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	104	85,9326	82,6%
Resourcefulness Performance Index (RePI)	50	44,58167	89,2%
Rapid Recovery Performance Index (RrPI)	72	51,98	72,2%
Adaptability Performance Index (AdPI)	42	37,33	88,9%

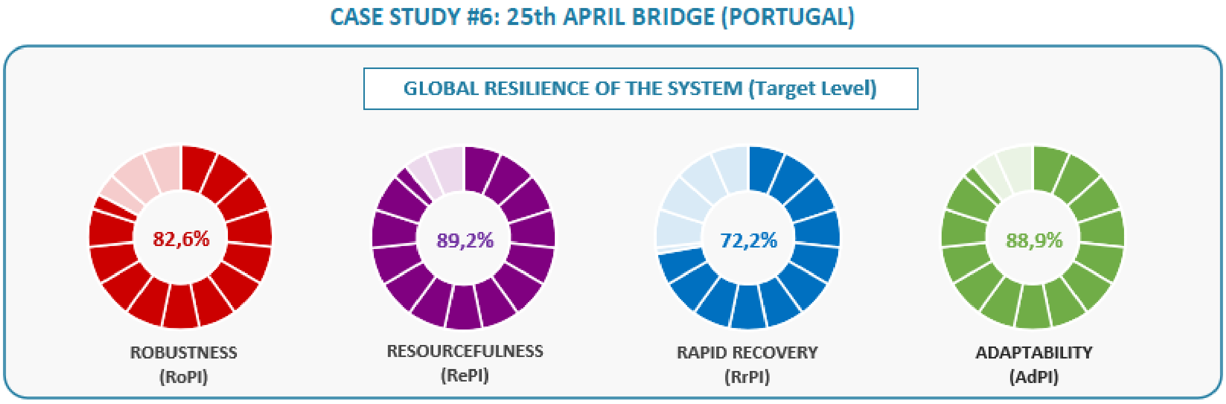


Figure 42. Resilience-principles Performance Indicators: CS#6 (target level)

CONDITION STATE	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	18	11,60	64,4%
Rapid Recovery Performance Index (RrPI)	14	8,40	60,0%

PROTECTION MEASURES	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	17	17,00	100,0%
Resourcefulness Performance Index (RePI)	13	13,00	100,0%
Rapid Recovery Performance Index (RrPI)	12	12,00	100,0%

PREVENTIVE MEASURES	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	9	1,50	16,7%
Rapid Recovery Performance Index (RrPI)	3	0,50	16,7%

PHYSICAL/NON-PHYSICAL	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	9	7,33	81,5%
Resourcefulness Performance Index (RePI)	9	7,91	87,9%
Rapid Recovery Performance Index (RrPI)	15	11,58	77,2%
Adaptability Performance Index (AdPI)	11	8,00	72,7%

PRE-EVENT MEASURES	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	4,50	75,0%
Resourcefulness Performance Index (RePI)	2	2,00	100,0%
Rapid Recovery Performance Index (RrPI)	4	3,50	87,5%
Adaptability Performance Index (AdPI)	6	6,00	100,0%

POST-EVENT MEASURES	MAX VALUE	TARGET VALUE	% FULFILLMENT
Resourcefulness Performance Index (RePI)	11	7,50	68,2%
Rapid Recovery Performance Index (RrPI)	12	5,00	41,7%
Adaptability Performance Index (AdPI)	7	6,00	85,7%

STRUCTURAL HEALTH MONITORING	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	21	20,00	95,2%
Adaptability Performance Index (AdPI)	5	4,33	86,7%

INSPECTION	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	12	12,00	100,0%
Adaptability Performance Index (AdPI)	6	6,00	100,0%

SMALL MAINTENANCE	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	6,00	100,0%
Adaptability Performance Index (AdPI)	2	2,00	100,0%

STRUCTURAL ANALYSIS	MAX VALUE	TARGET VALUE	% FULFILLMENT
Robustness Performance Index (RoPI)	6	6,00	100,0%
Adaptability Performance Index (AdPI)	3	3,00	100,0%

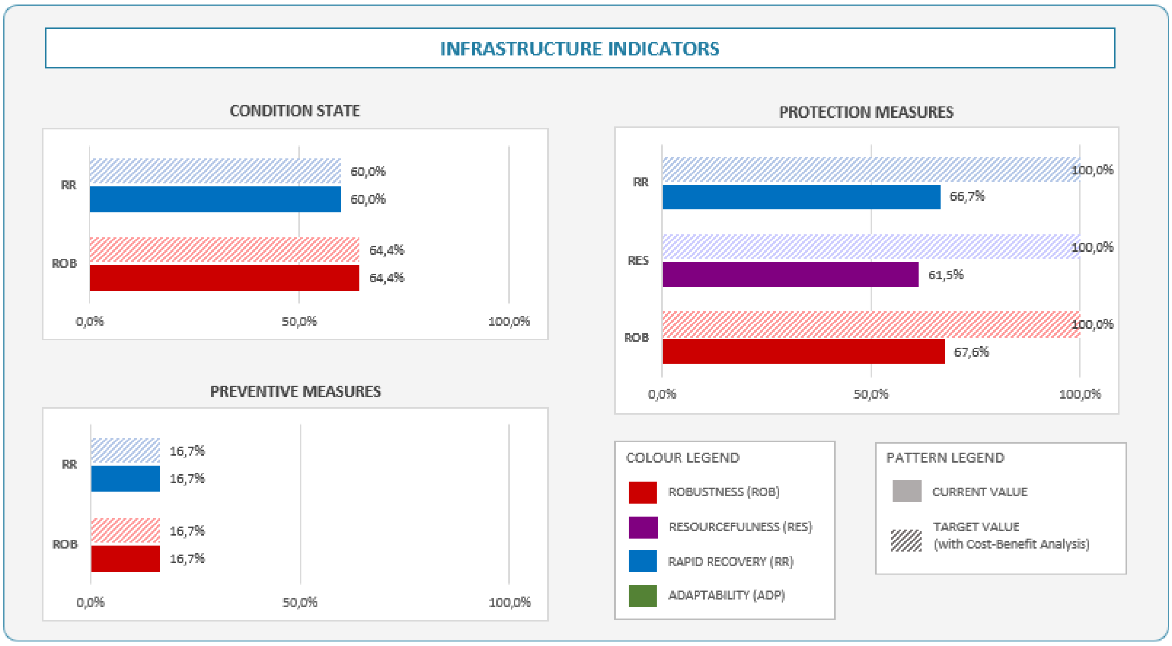
EVACUATION AND TRAFFIC MANAGEMENT	MAX VALUE	TARGET VALUE	% FULFILLMENT
Resourcefulness Performance Index (RePI)	15	13,50	90,0%
Rapid Recovery Performance Index (RrPI)	10	9,00	90,0%
Adaptability Performance Index (AdPI)	2	2,00	100,0%

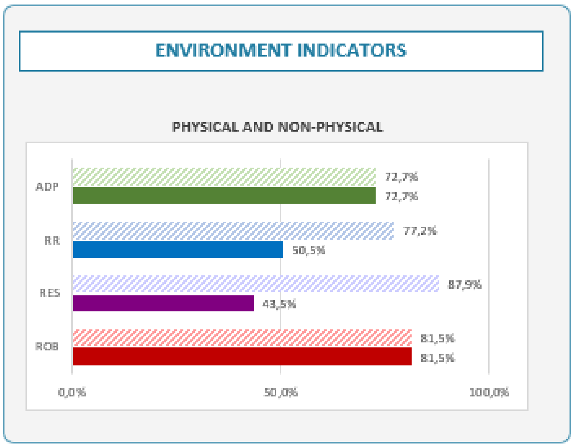
Figure 41 shows the current value of the Resilience-principles Performance Indicators, as Figure 42 shows the target values, which both have been obtained following the steps described in Deliverable D7.1 and Deliverable D7.5.

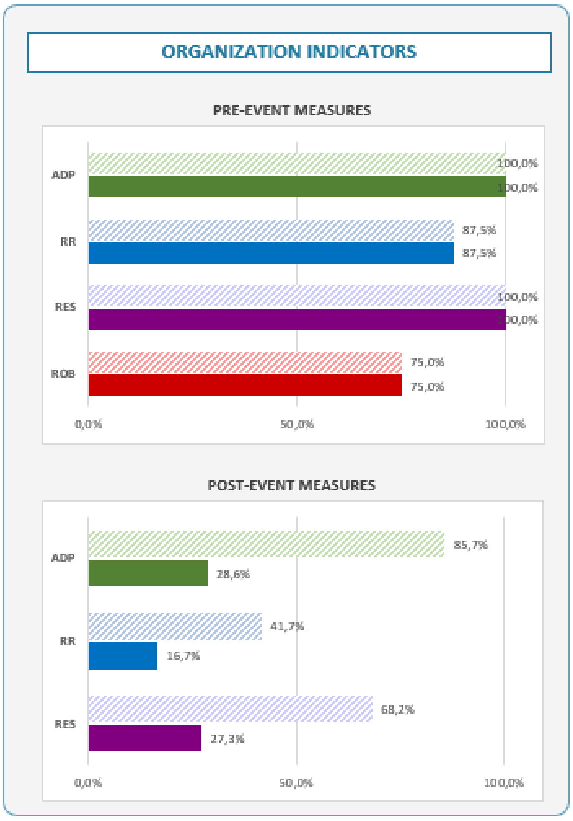
The information provided makes it possible to identify at a glance the strongest part of the system's resilience, as well as the areas where there is most room for improvement.

It can be seen those indicators that have more impact on robustness and Rapid Recovery, which means those susceptible of be improved. Moreover, it helps to identify the appropriate measures (tools) that are more related with the increase of that resilience principles.

The following figures present the global results, which can be seen the current and target value in terms of resilience principles and Level "1" Indicators.







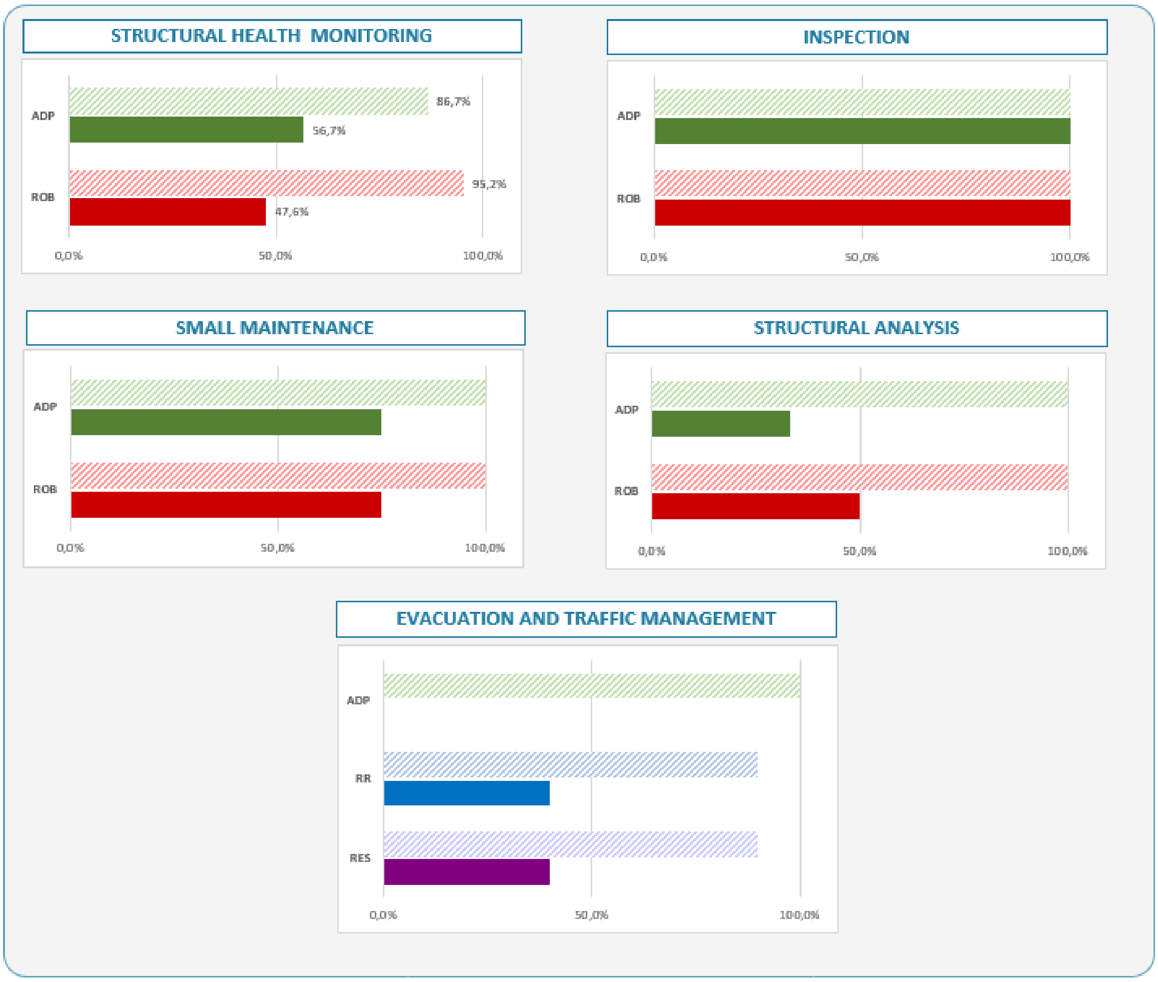


Figure 43. Resilience-principles Performance Indicators: CS#6 (current and target level).

It can be seen the impact of improvement of some indicators (KRI/KRT listed above on Table 6 – Section 3.3.) in the resilience of the infrastructure, in terms of resilience principles.

For example, the major impact would be on Evacuation and Traffic Management (in terms of Adaptability, Robustness and Resourcefulness), Structural Analysis and Structural Health Monitoring (in terms of Adaptability and Robustness), Post-Event Measures (in terms of Adaptability, Rapid Recovery and Resourcefulness) and well Protection Measures (in terms of Robustness, Resourcefulness and Rapid Recovery).

2.2.4 IDENTIFY APPROPRIATE MEASURES

This step identifies from the catalogue the measures/tools most closely aligned to the needs gathered in previous steps.

To that end, the summary table of the catalogue of measures (Table 53) is used, mostly in terms of Life Cycle phase and Resilience Stage.

Table 53. FORESEE-Tools Catalogue (from Deliverable D7.5).

Foresee Task ID	MEASURE / TOOL	MAIN CHARACTERISTICS				LIFE CYCLE				RESILIENCE STAGE					RESILIENCE PRINCIPLE			
		HAZARD	CATEGORY	LOCATION	ASSET	PLANNING	DESIGN	CONSTRUCTION	OP&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, Eartquake	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		✓		✓				✓	✓	🔴	🟡	🟢	🔴
T4.3.2	Algorithm to determine the optimal risk-reducing intervention programs	Any	Maintenance & Management	General	Infrastructure		✓		✓	✓	✓				🟢	🟡	🔴	🔴
T4.4	Hybrid Data Assessment for Diagnosis & Prognosis	Any	Research & Learning	General	Infrastructure		✓				✓		✓	✓	🟢	🟢	🟢	🔴
T4.5	SHM Algorithms	Any	Monitoring	General	Bridges				✓		✓		✓	✓	🟡	🟡	🟡	🟡
T5.5	Command and Control Center	Flooding, fog, wind	Monitoring	General	Infrastructure				✓			✓	✓		🔴	🟢	🟢	🔴

Score system from 0 to 3 accordingly D7.1 and D7.5 - to estimate the Resilience principles Performance Indicators

🔴	0
🟡	1
🟢	2
🟢	3

- 0: the measure has no relation with the resilience principle considered.
- 1: the measure slightly contributes to improve the resilience principle considered.
- 2: the measure contributes to improve the resilience principle consi
- 3: the measure highly contributes to improve the resilience principle considered.

Table 54 shows an example of the range of FORESEE Tools that are applicable to the hazard earthquake and could be used to this case study.

Table 54. Tools related to Earthquake from FORESEE-Tools Catalogue – Main characteristics (from Deliverable D7.5).

Foresee Task ID	MEASURE / TOOL	MAIN CHARACTERISTICS				LIFE CYCLE				RESILIENCE STAGE					RESILIENCE PRINCIPLE			
		HAZARD	CATEGORY	LOCATION	ASSET	PLANNING	DESIGN	CONSTRUCTION	OP&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, Eartquake	Research & Learning	On the infrastructure and surroundings	Infrastructure	✓				✓					🔴	🔴	🔴	🟢
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				✓	✓	✓	✓	✓	✓	🟡	🟢	🟢	🟢
T4.2	Shakemaps methodology	Earthquake	Research & Learning	Outside the infrastructure	Infrastructure	✓	✓			✓	✓				🟡	🟡	🔴	🟢
T4.3.1	Algorithm to determine optimal restoration programs	Any	Maintenance & Management	General	Infrastructure		✓		✓				✓	✓	🔴	🟡	🟢	🔴
T4.3.2	Algorithm to determine the optimal risk-reducing intervention programs	Any	Maintenance & Management	General	Infrastructure		✓		✓	✓	✓				🟢	🟡	🔴	🔴
T4.4	Hybrid Data Assessment for Diagnosis & Prognosis	Any	Research & Learning	General	Infrastructure		✓				✓		✓	✓	🟢	🟢	🟢	🔴
T4.5	SHM Algorithms	Any	Monitoring	General	Bridges				✓		✓		✓	✓	🟡	🟡	🟡	🟡

Score system from 0 to 3 accordingly D7.1 and D7.5 - to estimate the Resilience principles Performance Indicators

🔴	0
🟡	1
🟢	2
🟢	3

- 0: the measure has no relation with the resilience principle considered.
- 1: the measure slightly contributes to improve the resilience principle considered.
- 2: the measure contributes to improve the resilience principle consi
- 3: the measure highly contributes to improve the resilience principle considered.

2.2.5 ESTABLISH A POLICY IMPLEMENTATION MATRIX (CS#6)

Once identified a range of measures, next step is to organize the collected information developing a policy implementation matrix.

The objective of building this matrix is to rearrange the measures selected in previous step in order to group them together according to the category of measures and the resilience stages. This information provides an insight of the different actions that could be implemented in the different stages of an event.

Table 55 presents the policy matrix elaborated after selecting from the catalogue the different measures developed in FORESEE Project focused on increasing the resilience to earthquake.

In the practical application of Task T7.3 - next section (2.3.1.5) it can be seen the different tools/measures that can be applied to those selected resilience indicators that needed to be improved, to guarantee/achieve the results for Global Resilience of the bridge in terms of Resilience Principles Performance Indicators, as shown on Figure 43.

Each tool should be applied accordingly of life cycle phase and resilience stage, as shown on Table 54 and Table 55.

Table 55. CS#6, Policy Implementation Matrix.

	PRO ACTION	PREVENTION	PREPARATION	RESPONSE	RECOVERY
ROBUST DESIGN DOMAIN					
DESIGN STRATEGY DOMAIN	T3.4.2 Fragility and Vulnerability Functions and Decision Support Module				
MONITORING DOMAIN	T2.5 SHM BIM Based Alerting SAS Plataform	T5.5 Updated Structural Health Monitoring (SHM) Algorithms	T5.5 Command and Control Center	T5.5 Updated Structural Health Monitoring (SHM) Algorithms	
RESEARCH & LEARNING DOMAIN	T2.1 GIS Risk analysis platform/Risk T3.4.1 Traffic Module	T3.4.1 Hybrid Data Assessment for Diagnosis &		T3.4.1 Hybrid Data Assessment for Diagnosis & Prognosis	
MAINTENANCE & MANAGEMENT	T4.3 Development of algorithms for the selection and definition of efficient and			T4.3 Development of algorithms for the selection and definition of efficient and	

2.3 TOOL VERIFICATION AND OUTPUT T7.3 – OPERATIONAL AND MAINTENANCE PLANS

2.3.1 *25 DE ABRIL* BRIDGE – USE CASE 02 ACCORDINGLY D7.1

2.3.1.1 INFRASTRUCTURE DEFINITION

This section contains an example of how to apply the developed tool for application of Operational & Maintenance plans for a transport system in case study 6 (CS#6): The *25 de Abril* Bridge.

All considerations regarding infrastructure definition are presented on Section 2.

2.3.1.2 RISK ASSESSMENT

Risks and hazards associated have been defined in Section 5.2 of Deliverable D7.6.

These risks are going to be assessed. Risk's ID's are listed as follows:

FLOODING	Flash flood.	1
	River flood.	2
	Groundwater flood.	3
	Coastal flood.	4
	Structural failure flood.	5
EARTHQUAKES	**Tectonic Earthquakes.**	**6**
	Volcanic Earthquakes.	7
	Explosion Earthquakes.	**8**
	Collapse Earthquakes.	**9**
LANDSLIDE	Landslides.	10
	Rockfalls.	11
	Flows.	12
	Lateral Spreads.	13
SNOW/ICE	Snowstorm.	14
	Snow cover.	15
	Snowslide/avalanche.	16
	Black ice/clear ice.	17
WIND	Gale.	18
	Storm.	19
	Hurricane.	20
FIRE/EXPLOSION	Wildfire.	21
	Electrical fire.	22
	Flammable/explosive material discharges fire.	23
	Vehicle fire.	24
	Terrorist attack.	25
CYBERATTACK	Internet connected vehicles attack.	26
	Traffic Control System / Centre Attack.	27

Figure 44. Risk's ID's.

Next, once the main risks are identified, it is shown the potential impacts so it allows to build the risk index matrix, following the scoring procedure explained in Section 5.4 - Risk Consequences on Deliverable D7.6, where these impacts are catalogued according to the potential damage can achieve onto the asset.

Risk index is calculated as the probability of happening one of the identified risks, collated with the impact associated.

Total risks map obtained is the following, that supports the assignation of the values for each hazard impact:

By adding the score obtained in probability and factor X (X considers the impact of the event), it is obtained the risk assessment for this use case, providing the stakeholders of the transport system a method to quickly identify the potential and more impact-sensitivity risks are present in the infrastructure.

	IMPACT								PROBABILITY		Sum X + Prob
Id	A	B	C	D	E	F	Sum	X	Value	Y	
1	2	1	2	1	1	1	8	53	2	100	153
2	2	1	2	1	1	1	8	53	2	100	153
3	2	1	1	1	2	1	8	53	2	100	153
4	2	1	1	1	2	1	8	53	2	100	153
5	2	1	1	1	2	1	8	53	1	50	103
6	3	2	2	3	3	2	15	100	2	100	200
7	3	2	2	3	3	2	15	100	1	50	150
8	3	2	2	3	3	2	15	100	1	50	150
9	3	2	2	3	3	2	15	100	2	100	200
10	2	1	2	3	2	2	12	80	2	100	180
11	2	1	2	3	2	2	12	80	2	100	180
12	2	1	2	3	2	2	12	80	2	100	180
13	2	1	1	2	2	2	10	67	2	100	167
14	2	1	1	2	3	2	11	73	2	100	173
15	2	1	1	2	3	2	11	73	2	100	173
16	2	1	1	1	2	2	9	60	1	50	110
17	1	1	1	1	2	2	8	53	2	100	153
18	1	1	2	2	2	2	10	67	2	100	167
19	1	1	2	2	2	2	10	67	2	100	167
20	1	1	2	2	2	2	10	67	2	100	167
21	2	1	1	1	2	2	9	60	2	100	160
22	2	1	1	1	2	2	9	60	2	100	160
23	2	1	1	1	2	2	9	60	2	100	160
24	2	1	1	1	2	2	9	60	2	100	160
25	3	1	2	2	2	2	12	80	1	50	130
26	2	1	1	1	2	2	9	60	1	50	110
27	3	1	1	1	2	1	9	60	2	100	160

Figure 45. CS#6, Risk Index Calculation, Figure obtained for Risk.

It is obtained that the risks associated with earthquake a high score with high probability of happening, and also wind hazard risks are detected with a high score obtained. This is the reason why the Operation & Maintenance plans are going to be applied in order to improve the resilience of the system against earthquakes.

2.3.1.3 MAINTENANCE PROTOCOL (EARTHQUAKE HAZARD / BRIDGE ASSET)

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
FOUNDATION	FO.02	Settlement.	Damaged structure of tunnels, bridges, culverts, retaining walls...	Partial collapse of the structure during or after an extreme event. Reduction of service capacity.	Command and Control Centre can detect an important anomaly if a structure is damaged, in combination with SHM Algorithms.	Hybrid Data Assessment For Diagnosis & Prognosis provides the damage state of the structure once a earthquake event is happened. The results will provide the degree of damage, and in combination with Decision Support Module stablishes a proper monitoring frequency after the earthquake.	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after an earthquake, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring frequency after a earthquake. SHM Algorithms can early detect a structural damage by changes on the structural response.
FOUNDATION	FO.03	Lack of stability.	Failure induced by ground shaking.	Differential movements of structures, presence of structural cracking or any other visible pathologies.	SHM algorithms deployed on the structure can detect a loss on	For critical infrastructures for transport system, a continuous monitoring is	Repair and reinforcement of foundation structures against the damages. Shake	Algorithms for the selection and definition of efficient and optimal actions / Intervention &	SHM Algorithms to evaluate the structural damages. Command and Control to detect anomalies caused by foundation

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
					rigidity of the structure related to the damage. Command and Control can detect this anomaly in conjunction.	recommended.	maps methodology can support the foundation design and risk associated.	Mitigation can provide the actions to be performed in order to assess and intervene on this risk.	damages. Algorithms for selection of optimal actions can provide the actions to be performed or the inspection frequencies. Shake maps methodology to identify the most exposed areas to earthquakes.
PIERS AND ABUTMENTS	PA.02	Excessive displacement.	Excessive displacement of piers and abutments can lead to cracking or structural damage.	Cracking on piers or abutments appears, or damaged elements.	Command and Control Centre can detect an important anomaly if a structure is damaged, in combination with SHM Algorithms.	Hybrid Data Assessment For Diagnosis & Prognosis provides the damage state of the structure once a snow event is happened. The results will provide the degree of damage, and in combination with Decision	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after an earthquake, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
						Support Module stablishes a proper monitoring frequency after the hazard.			frequency after a snow. SHM Algorithms can early detect a structural damage by changes on the structural response.
PIERS AND ABUTMENTS	PA.03	Settlement.	Settlement (as well as differential settlement).	Differential movements or even partial collapse of the piers or abutments during or after an extreme event. Reduction of service capacity.	Command and Control Centre can detect an important anomaly if a structure is damaged, in combination with SHM Algorithms.	Hybrid Data Assessment for Diagnosis & Prognosis provides the damage state of the structure once a snow event is happened. The results will provide the degree of damage, and in combination with Decision Support Module stablishes a proper monitoring frequency after the hazard.	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after an earthquake, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring frequency after a snow. SHM Algorithms can early detect a structural damage by changes on the structural response.

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
DECK AND STRUCTURAL ELEMENTS	DE.02	Unfastening of expansion joints.	Bolts of expansion joints can be unfastened, losing capability of stay fixed the joint with the structure.	Visual deformation of the expansion joint, users may experience higher impact when passing over.	Monitoring devices on the expansion joint, Command and control center can detect an anomaly on the behaviour.	For critical infrastructures for transport system, a continuous monitoring is recommended.	Replacement of the fastening of the expansion joint, or even the full joint. Algorithms to define optimal interventions to define a proper maintenance strategy.	According to the maintenance plan of the bridge.	Command and Control Centre to detect anomalies. Algorithms to define optimal interventions to define the maintenance strategy.
SIGNALLING	SI.01	Equipment failures.	Points and signalling equipment failures: this type of equipment relies on wiring and power supplies that are vulnerable to failure during flooding, landslides...	Stop working of the signal display during or after an extreme event.	Regular control of the correct status of the wires and equipment of the communication system elements. Isolate as much as possible these from the exposure to the hazards.	According to Decision Support Module outputs.	Replacement of damaged elements identified in the regular inspections.	According to Decision Support Module outputs.	Decision Support Module: To establish a contingency plan if this happens and stablish a regular maintenance plan to check everything is properly maintained.
SIGNALLING	SI.02	Damage to signs, lighting and supports.	Sign's deterioration. Damage guideposts, line marking and regulatory and warning signs.	Visible damages and erosion of paintings, signalling status.	Regular control of the correct status of the elements.	According to Decision Support Module outputs.	Repainting lines on pavement, replacing signs that are damaged.	According to Decision Support Module outputs.	Decision Support Module: To establish a contingency plan if this happens and stablish a regular maintenance plan to check everything is properly maintained.

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
SIGNALLING	SI.03	Collapse.	Sign and signals break and fall.	Visible collapse of the signals.	Regular control of the correct status of the elements.	According to Governance Module outputs.	Replacement of damaged elements as soon as are identified.	According to Governance Module outputs.	Governance Module provides a fast-decision-making support, as this risk must be assessed as soon as it happens.
DRAINAGE SYSTEM	DR.03	Structural damages and erosion.	By water, displaced debris or soil...	Differential movements of drainage structures, presence of structural cracking or any other visible pathologies.	SHM algorithms deployed on the structure can detect a loss on rigidity of the structure related to the damage. Command and Control can detect this anomaly in conjunction.	For critical infrastructures for transport system, a continuous monitoring is recommended.	Repair and reinforcement of structures against the damages. Erosion of structures might need protective measures to be installed, as the eroded material need to be replaced.	Algorithms for the selection and definition of efficient and optimal actions / Intervention & Mitigation can provide the actions to be performed in order to assess and intervene on this risk.	SHM Algorithms to evaluate the structural damages. Command and Control to detect anomalies caused by structural damage or erosion. Algorithms for selection of optimal actions can provide the actions to be performed or the inspection frequencies.

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
DRAINAGE SYSTEM	DR.04	Collapse.	Total collapse of the drainage elements as structural capacity is overloaded by the pressures and forces of the water flow.	Visible collapse of the drainage system, drainage capacity is null.	Command and Control Centre can detect an important anomaly if one of the drainage elements collapse. Collapse can be prevented by a correct design employing Guidelines for a sustainable drainage.	Preventive actions can be performed by regular inspections of the critical elements of the drainage system.	Removing of material deposited in the drainage ducts and culverts reduce water pressures that can exceed the permissible of the element.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Guidelines for a sustainable drainage can support employing optimised drainage elements that can reduce the water pressures. Governance Module to provide a fast-decision-making support as this risk must be assessed as soon as it happens.
STRUCTURAL ELEMENTS	ST.01	Loss of loading capacity.	Damaged structure of tunnels, bridges, culverts, retaining walls...	Partial collapse of the structure during or after an extreme event. Reduction of service capacity.	Command and Control Centre can detect an important anomaly if a structure is damaged, in combination with SHM Algorithms.	Hybrid Data Assessment For Diagnosis & Prognosis provides the damage state of the structure once a fire event is happened. The results will provide the degree of damage, and in combination with Decision Support Module stablishes a proper monitoring frequency after the fire.	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after a fire, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring frequency after a fire. SHM Algorithms can early detect a structural damage by changes on the

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
									structural response.
STRUCTURAL ELEMENTS	ST.02	Cracking.	Structural cracking appears, being these superficial or structural due to differential movements.	Visible detection of cracking, mainly on the peak stresses' direction.	Fissure meter devices to monitor the evolution of cracking.	Depending on the growing rate of cracking and the criticality of the structural element.	Two main types of cracking are identified: The superficial ones, due to retraction/contraction of the external layers of the material, can be repaired by adding coating material. Structural cracks are a signal of differential movements, meaning an action is required if these are not stable.	Algorithms for the selection and definition of efficient and optimal actions / Intervention & Mitigation can provide the actions to be performed in order to assess and intervene on this risk. If structural cracking is identified, a repairing action must be performed urgently prior to bigger damages. SHM algorithms in combination with Command-and-Control Centre can provide a	SHM Algorithms to evaluate the structural damages. Command and Control to detect anomalies caused by structural damage by cracking. Algorithms for selection of optimal actions can provide the actions to be performed or the inspection frequencies.

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
								continuous monitoring that reflects the evolution and affection rate of the cracking.	
STRUCTURAL ELEMENTS	ST.03	Collapse.	Collapse off different structural elements: bridges, retaining walls, tunnel structures, hub buildings, parking slots.... Bridges are the most vulnerable components of the transportation system affected by earthquakes. In addition to ground surface and geotechnical failures, bridges are vulnerable to complete structural collapse.	Collapse of the structure during or after an extreme event. Total lack of service capacity.	Command and Control Centre can detect an important anomaly if a structure collapse.	Hybrid Data Assessment For Diagnosis & Prognosis provides the damage state of the structure once a landslide event is happened. The results will provide the degree of damage, and in combination with Decision Support Module stablishes a proper monitoring frequency after the landslide.	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after an earthquake, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring frequency after earthquake.
EMBANKMENT / CUTTING (SLOPES)	EC.02	Lack of stability.	An increase in pore pressure reduces strength of coarse	SHM BIM based alerting SAS platform controls ground surface points movements	Fixed ground surface points movements	A measure is raised each time the satellite is	Shake maps methodology generating	After an earthquake the embankments and	SHM BIM based alerting SAS platform to control ground surface movement.

				MAINTENANCE PLANNING					
ELEMENT	**ID**	**DAMAGE**	**DESCRIPTION**	**How is it measured/detected?**	**How is it monitored?**	**How often? (T period)**	**How is it maintained?**	**How often? (T period)**	**FORESEE new tools/solutions/options**
			granular material that might lead to failures.	after a earthquake.	detected by satellite control.	passing over the area.	prioritised ranked site/asset risk map to detect the most critical slopes that need to be protected. New slope stabilisation systems can improve the response of the slope against earthquake or reduce the impact on the service of the transport system if a slope failure is triggered during or after the shaking.	slopes need to be evaluated.	Shake maps methodology to detect the critical areas. New slope stabilization systems to improve the response of the slope after an earthquake.
PIERS AND ABUTMENTS	PA.03	Settlement.	Settlement (as well as differential settlement).	Differential movements or even partial collapse of the piers or abutments during or after an extreme event. Reduction of service capacity.	Command and Control Centre can detect an important anomaly if a structure is damaged, in combination with SHM Algorithms.	Hybrid Data Assessment For Diagnosis & Prognosis provides the damage state of the structure once a snow event is happened. The results will provide the degree of damage, and in combination with Decision Support Module stablishes a proper	Proper design of the structure and stablish a maintenance strategy to keep the resilience of the system as high as possible.	According to Governance Module outputs.	Command and Control can detect the collapse as an anomaly is raised. Hybrid Data Assessment to stablish the state of the structure after an earthquake, depending on the magnitude of it. Governance Module to provide a fast-decision-making support if collapse is reached. Decision Support Module to establish the optimal monitoring frequency after

ELEMENT	ID	DAMAGE	DESCRIPTION	MAINTENANCE PLANNING How is it measured/detected?	How is it monitored?	How often? (T period)	How is it maintained?	How often? (T period)	FORESEE new tools/solutions/options
						monitoring frequency after the hazard.			a snow. SHM Algorithms can early detect a structural damage by changes on the structural response.
DECK AND STRUCTURAL ELEMENTS	DE.02	Unfastening of expansion joints.	Bolts of expansion joints can be unfastened, losing capability of stay fixed the joint with the structure.	Visual deformation of the expansion joint, users may experience higher impact when passing over.	Monitoring devices on the expansion joint, Command and control center can detect an anomaly on the behaviour.	For critical infrastructures for transport system, a continuous monitoring is recommended.	Replacement of the fastening of the expansion joint, or even the full joint. Algorithms to define optimal interventions to define a proper maintenance strategy.	According to the maintenance plan of the bridge.	Command and Control Centre to detect anomalies. Algorithms to define optimal interventions to define the maintenance strategy.

2.3.1.4 OPERATIONAL PROTOCOL (EARTHQUAKE HAZARD / BRIDGE ASSET)

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
OP.01	REDUCED TRAFFIC CAPACITY	Occasional / brief lane closure, but roads remain open. This impact includes lane obstruction due to snow, debris, fallen trees, rock falls, etc.)	By measuring the traffic flow of the road.	Counter vehicles devices / satellite monitoring / CCTV	Continuously.	Traffic agents need to provide alternative routes to the traffic.	Prior to expected traffic demand peak	Governance module: To identify critical transport system sections, and define critical dates of peak demand Traffic module: Evaluation of affection of different scenarios
OP.02	TEMPORARY CLOSURE	Minor damages that result in temporary closure of road or in closing railway lines, from hours to weeks up to 60 days. Vehicles would be forced to reroute to other roads during rehabilitation works.	Interruption of the traffic in a section leads to diverged traffic flow to other areas.	SHM BIM based alerting SAS platform can raise an alarm as soon a congestion is detected in the traffic flow.	Continuously.	Preventive actions can be provided in order to avoid unexpected events that cause a temporary closure. A continuous monitoring of the network is recommended to detect as soon as possible the irruption.	Needed actuation as soon as it happens.	Governance module: To identify critical transport system sections and define critical dates of peak demand Traffic module: Evaluation of affection of different scenarios SHM BIM based alerting SAS platform: Detection of a disruption from satellite information or other source. Hybrid Data Assessment: Prediction of the performance of a temporary closure of a part of a transport network.
OP.03	COLLAPSE / LONGTIME CLOSURE	Total loss or ruin of asset. It implies immediate road/line closure and requires major repair or rebuild over an extended period of time.	Interruption of the traffic in a section leads to diverged traffic flow to other areas. Anomalies can be detected by Command-and-Control Centre, using the predictive	SHM BIM based alerting SAS platform can raise an alarm as soon a collapse is detected in the network. Command and Control Centre can detect an anomaly, in conjunction with SHM Algorithms.	Continuously.	Alerts can be raised from predictive tools (Command and Control Centre, SHM Algorithms) in order to perform an action prior to the collapse, or to be detected once these are triggered (SHM BIM based alerting SAS platform).	Needed actuation as soon as it is detected, any kind of anomaly or once it has been triggered.	Governance module: To identify critical transport system sections where to focus the continuous monitoring. Traffic module: Evaluation of affection of different scenarios, assessment of alternative routes. SHM BIM based alerting SAS platform: Detection of a disruption from satellite information or other source.

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
			algorithms to avoid the collapse in conjunction with the SHM Algorithms.					Hybrid Data Assessment: Prediction of the performance of a diverged part of a transport network. Command and Control Centre: To predict and detect any anomaly to prevent the collapse. SHM Algorithms: Perform a continuous monitoring of any signal of potential collapse.
OP.05	TRAVEL DELAYS	Delays due to congestion caused by speed reductions, lane closure, driver capabilities, slippery surfaces, etc.	By measuring the time employed of individual users to complete a route predefined.	Using traffic module simulations, the travel delays can be simulated under different environments.	Once it is required	Traffic agents need to provide alternative routes to the traffic to the restricted vehicles. Sustainable drainage systems deployed on a section can prevent the traffic restrictions during a flooding event. Traffic module can simulate the affection of this restriction to the transport network.	During the event, management of the traffic to diverged routes. Prior an event, simulation and preparedness of the network is this event is triggered.	Traffic module: Evaluation of affection of different scenarios
OP.06	INFRASTRUCTURE LIFESPAN DECREASE	Lifespan decrease due to infrastructure's damages	Routine inspections detect pathologies at the infrastructure. Users may experience in commodities.	SHM Algorithms can detect damages or deteriorations at the infrastructures.	Continuous monitoring is advised in critical infrastructures.	Command and Control Centre detects the anomaly from the data collected employing SHM algorithms	Continuous monitoring is advised in critical infrastructures.	SHM Algorithms can detect structural behaviour changes related to damages Command and Control Centre detect the anomaly arisen from the data collected and raise an alert.
SF.02	ACCIDENTES (Objects)	Collisions caused by trees on the roads, rock falls, etc.	CCTV, traffic agents report, affections to the	Permanent surveying of the roads. Command and	Continuously.	An accident will lead to a reduction on the service of the road. Traffic	Prior to an accident, have a catalogue of	Traffic module: Evaluation of affection of different scenarios. Command and control Centre can

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
			traffic flow.	Control Centre can detect an anomaly in the traffic flow in order to raise an alert.		agents must divert the traffic. Traffic module tool can simulate different accident scenarios, in order to predesign the alternative routes for different accident points on the road. Other strategy is clearing the margins of the roads from trees or any other elements, and new slope protection systems can prevent of a rock fall happening.	alternative routes using Traffic module.	detect any anomaly on the traffic flow to raise an alert. New slope protection systems to prevent a rockfall on the road.
SF.05	PASSAGE OBSTRUCTION	Presence of obstacles that hinder the passage (water, snow, debris, fallen trees, rock falls, etc…)	Traffic flow affection detected.	Command and control Centre can detect an anomaly on the traffic flow.	Continuously.	SHM BIM based platform can raise alarms in case of excessive land movement that can arise to a passage obstruction. Slope protection systems can protect the slopes of rock/land obstacle the passage. Traffic module can define alternative routes.	Continuously, special attention during a flooding or prior of it is expected.	Command and Control Centre to detect any anomaly. SHM BIM based platform to detect an exceeding land movement. Slope protection systems to improve the slope stability. Traffic module to provide with alternative routes.
SF.07	VEHICLE INMOBILIZATION	Immobilisation of vehicles by being trapped by debris, water…	During/after a flooding, report from involved agents.	Triggering of a flooding.	During/after a flooding.	Traffic module to stablish alternative routes in case of immobilised vehicle blocks a passage.	During the event, management of the traffic to diverged routes. Prior an event, simulation and	SHM Algorithms can detect structural behaviour changes related to damages. Command and Control Centre detect the anomaly arisen from the data collected and raise an alert. Hybrid Data Assessment can predict the operative of the infrastructure if

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
							preparedness of the network is this event is triggered.	damaged or collapsed.
SS.01	DIRECT LOSS OF LIVES	Loss of life as a consequence of infrastructure collapse or failure	Infrastructure collapsed	SHM Algorithms can detect damages or deteriorations at the infrastructures. Command and control Centre can detect the anomalies in the data given by the algorithms.	For critical infrastructures, a continuous monitoring is advised.	Hybrid Data Assessment For Diagnosis & Prognosis can predict the operative of the infrastructure if damaged or collapsed. Preventive detection of pathologies is mandatory.	For critical infrastructures, a continuous monitoring is advised.	Decision Support Module to stablish a minimum level of service to reduce this impact.
SS.02	INDIRECT LOFF OF LIVES	Indirect loss of life due to an inability to respond and/or to provide medical aid (impeded access to hospital, evacuation areas)	Traffic flow affection detected, reducing efficiency of sanitary personal to the area.	Decision Support Module can provide an efficient support to manage the situation.	Prior to the accident.	Decision Support Module can provide an efficient support to manage the situation.	Prior to the accident.	Decision Support Module to stablish a minimum level of service to reduce this impact. Porous asphalt can provide a better resilience during an extreme event.
SS.03	DIFFICULTY FOR RESPONSE OPERATIONS	Difficulty for response operations due to the state of the road	Traffic flow affection detected, reducing efficiency of sanitary personal to the area.	Decision Support Module can provide an efficient support to manage the situation.	Prior to the accident.	Decision Support Module can provide an efficient support to manage the situation. Porous asphalt can provide a better resilience during an extreme event.	Prior to the accident.	Traffic module to provide with alternative routes.
SO.02	LOSS OF REPUTATION	Loss of confidence of the public in the ability of the roadway/railway operator to deal with flooding/hazard.	Surveys to users, reduction of active users.	Surveys to users.	Periodically survey users, or after an important event hazard.	Governance module can stablish the minimum level of service required to satisfy users.	Periodically survey users, or after an important event hazard.	Governance module to provide with financial tools. Algorithms for the selection of optimal actions to reduce the costs.
EC.01	MAINTENANCE COSTS	Increase in maintenance - replacement - rehabilitation	Increase of the economical	Governance module support the	During operation of	Algorithms for the selection and definition	When a raising in the costs is	Governance module analyse the area isolated and the impact on the level

ID	IMPACT	DESCRIPTION	OPERATION PLANNING					
			How is it measured?	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
		cost	maintenance costs of the infrastructure.	managers with financial tools.	the infrastructure.	of efficient and optimal actions / Intervention & Mitigation can optimise the actions to be performed, reducing the costs associated. Additional solutions can be introduced, analysing the return of the investment period.	detected.	of service. GIS Risk analysis platform gives the most possible areas to be isolated. Traffic module to provide alternative routes.
SE.01	ISOLATION OF AREAS	Isolation of areas due to closure of roads and railway lines.	Traffic agents reports	Governance module can track this event if happens.	When hazard is triggered.	GIS Risk Analysis platform support with the identification of the most sensitive areas that can be isolated. Provide alternative routes to access to these areas with Traffic module.	Prior to the isolation of the area.	Governance module: To identify critical transport system sections, and define critical dates of peak demand Traffic module: Evaluation of affection of different scenarios
SE.02	REDUCED ACCESS TO DESTINATIONS	Reduced access to destinations served by the road/rail line: preventing or delaying people from reaching work / education / medical facilities / terminals	By measuring the traffic flow of the transport system.	Counter vehicles devices / satellite monitoring / CCTV	Once it is triggered.	Traffic agents need to provide alternative routes to the traffic to the restricted vehicles. Sustainable drainage systems deployed on a section can prevent the traffic restrictions during a flooding event. Traffic module can simulate the effect of this restriction to the transport network.	During the event, management of the traffic to diverged routes. Prior an event, simulation and preparedness of the network is this event is triggered.	Governance module to identify critical transport system and areas.
SE.03	DISRUPTION OF ECONOMIC ACTIVITY	Reduced commerce in affected areas.	Economic reports on the studied areas, traffic	Economical commercial performance of the area. Traffic counter	Once a financial disruption is detected.	Governance module can stablish the minimum level of service required to satisfy users.	Prior to the reduction of economic activity.	Command and Control Centre to detect any anomaly. Sustainable drainage systems to reduce the pollution created.

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
			restrictions.	devices.				
EN.02	HAZARDOUS PRODUCTS RELEASE	Release of hazardous products as a consequence of accidents / derailments	Visual releases on the place of the accident.	Pollution measures after cleaning the area.	Depending on the size of the polluted area.	Cleaning the area after the accident. Compensative measures and biological solutions. Sustainable drainage solutions can help filtering the pollutants.	After an accident.	Command and Control Centre to detect any anomaly. Sustainable drainage systems to reduce the pollution created.
OP.01	REDUCED TRAFFIC CAPACITY	Occasional / brief lane closure, but roads remain open. This impact includes lane obstruction due to snow, debris, fallen trees, rock falls, etc.)	By measuring the traffic flow of the road.	Counter vehicles devices / satellite monitoring / CCTV	Continuously.	Traffic agents need to provide alternative routes to the traffic.	Prior to expected traffic demand peak	Governance module: To identify critical transport system sections, and define critical dates of peak demand Traffic module: Evaluation of affection of different scenarios
OP.02	TEMPORARY CLOSURE	Minor damages that result in temporary closure of road or in closing railway lines, from hours to weeks up to 60 days. Vehicles would be forced to reroute to other roads during rehabilitation works.	Interruption of the traffic in a section leads to diverged traffic flow to other areas.	SHM BIM based alerting SAS platform can raise an alarm as soon a congestion is detected in the traffic flow.	Continuously.	Preventive actions can be provided in order to avoid unexpected events that cause a temporary closure. A continuous monitoring of the network is recommended to detect as soon as possible the irruption.	Needed actuation as soon as it happens.	Governance module: To identify critical transport system sections and define critical dates of peak demand Traffic module: Evaluation of affection of different scenarios SHM BIM based alerting SAS platform: Detection of a disruption from satellite information or other source. Hybrid Data Assessment: Prediction of the performance of a temporary closure of a part of a transport network.
OP.03	COLLAPSE / LONGTIME CLOSURE	Total loss or ruin of asset. It implies immediate road/line closure and requires major repair or rebuild over an extended period of time.	Interruption of the traffic in a section leads to diverged traffic flow to other areas. Anomalies	SHM BIM based alerting SAS platform can raise an alarm as soon a collapse is detected in the network. Command	Continuously.	Alerts can be raised from predictive tools (Command and Control Centre, SHM Algorithms) in order to perform an action prior to the	Needed actuation as soon as it is detected, any kind of anomaly or once it has	Governance module: To identify critical transport system sections where to focus the continuous monitoring. Traffic module: Evaluation of affection of different scenarios,

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
			can be detected by Command-and-Control Centre, using the predictive algorithms to avoid the collapse in conjunction with the SHM Algorithms.	and Control Centre can detect an anomaly, in conjunction with SHM Algorithms.		collapse, or to be detected once these are triggered (SHM BIM based alerting SAS platform).	been triggered.	assessment of alternative routes. SHM BIM based alerting SAS platform: Detection of a disruption from satellite information or other source. Hybrid Data Assessment: Prediction of the performance of a diverged part of a transport network. Command and Control Centre: To predict and detect any anomaly to prevent the collapse. SHM Algorithms: Perform a continuous monitoring of any signal of potential collapse.
OP.05	TRAVEL DELAYS	Delays due to congestion caused by speed reductions, lane closure, driver capabilities, slippery surfaces, etc.	By measuring the time employed of individual users to complete a route predefined.	Using traffic module simulations, the travel delays can be simulated under different environments.	Once it is required	Traffic agents need to provide alternative routes to the traffic to the restricted vehicles. Sustainable drainage systems deployed on a section can prevent the traffic restrictions during a flooding event. Traffic module can simulate the effect of this restriction to the transport network.	During the event, management of the traffic to diverged routes. Prior an event, simulation and preparedness of the network is this event is triggered.	Traffic module: Evaluation of affection of different scenarios
OP.06	INFRASTRUCTURE LIFESPAN DECREASE	Lifespan decrease due to infrastructure's damages	Routine inspections detect pathologies at the infrastructure. Users may experience in	SHM Algorithms can detect damages or deteriorations at the infrastructures.	Continuous monitoring is advised in critical infrastructures.	Command and Control Centre detects the anomaly from the data collected employing SHM algorithms	Continuous monitoring is advised in critical infrastructures.	SHM Algorithms can detect structural behaviour changes related to damages Command and Control Centre detect the anomaly arisen from the data collected and raise an alert.

			OPERATION PLANNING					
ID	**IMPACT**	**DESCRIPTION**	**How is it measured?**	**How is it monitored?**	**How often?**	**How is it managed?**	**How often?**	**FORESEE new tools/solutions/options**
			commodities.					
SF.02	ACCIDENTES (Objects)	Collisions caused by trees on the roads, rock falls, etc.	CCTV, traffic agents report, effect to the traffic flow.	Permanent surveying of the roads. Command and Control Centre can detect an anomaly in the traffic flow in order to raise an alert.	Continuously.	An accident will lead to a reduction on the service of the road. Traffic agents have to divert the traffic. Traffic module tool can simulate different accident scenarios, in order to predesign the alternative routes for different accident points on the road. Other strategy is clearing the margins of the roads from trees or any other elements, and new slope protection systems can prevent of a rock fall happening.	Prior to an accident, have a catalogue of alternative routes using Traffic module.	Traffic module: Evaluation of affection of different scenarios. Command and Control Centre can detect any anomaly on the traffic flow to raise an alert. New slope protection systems to prevent a rockfall on the road.

2.3.1.5 RESILIENCE & NET BENEFIT ANALYSIS

The application of the operational and maintenance plans of the infrastructure will have an impact on the resilience indicators of the asset, being these indicators in same manner flexible per case. In this work, these indicators are referred to the work done CS#6 as per follow the same methodology. In this section, it is going to be analysed the final resilience of the infrastructure in the supposition that the following FORESEE Tools are implemented, compared with an initial state where no FORESEE Tools are applied:

Table 56. FORESEE Tools that apply to the Op. & Maint. Plans (extract from Deliverable D7.6).

TOOL NAME	Deliverable Id.	Tool Id.	Tool description
Governance Module	**D1.3**	**T1.3**	The tool provides rapid decision-making response regarding the decision of the level of service and resilience versus disruptive events.
SHM BIM based alerting SAS platform	**D2.9**	**T2.5**	The tool is an API that generates RAG alerts over a BIM and allows 3D visualization. The alerts are raised in correspondence with the datasets of motion observed near on the BIM using landslide failure prediction model, in-situ sensors data and InSAR data.
Traffic Module	**D3.7**	**T3.4.1**	The tool allows several scenario-based traffic simulations before and after the event occurrence, in order to evaluate the effects of disruptive events.
Decision Support Module DSM	**D3.8**	**T3.4.2**	The tool provides an efficient instrument allowing to infrastructure managers and owners to manage assets and financial resources to guarantee the optimal level of service.
Algorithms for the selection and definition of efficient and optimal actions / Intervention & Mitigation	**D4.7**	**T4.3**	The tool provides risk reducing intervention/restoration programs to determine the optimal intervention/restoration program that generates risk and costs reduction in case of future interventions.
Hybrid Data Assessment For Diagnosis & Prognosis	**D4.3**	**T4.4**	The tool provides a predictive algorithm able to diagnose damage or predict the performance of the considered system, in case of new operational or hazard event information.

Command and Control Centre	**D5.6**	**T5.5**	An anomaly detection strategy on tabular sensor or multimedia data of critical transport infrastructure assets can be done with machine learning techniques. The alarms raised using anomaly detection are meaningful and enhance the situational understanding of the infrastructure operators, leading to a faster detection time when problems occur, compared to a manual observation of the sensor data.
Shake maps scenarios	**D4.5**	**T4.2**	The tool provides an assessment of seismic hazards based on the development of shake maps.
Guidelines for the adoption of sustainable drainage systems	**D3.1 - D3.2**	**T3.3**	The tool is a web application which consist of a set of strategies to adapt current drainage designs to the sustainable drainage paradigm and to the new needs of linear infrastructures due to the effects of climate change and other man-made effects.
SHM Algorithms	**D4.9**	**T4.5**	Machine learning algorithms are employed to perform an automated Structural Health Monitoring of the infrastructure based on tabular sensor or multimedia data.
New slope stabilization flexible systems	**D3.6**	**T3.2**	New flexible systems to reduce the loss of service if a landslide occurs are designed using new developed materials for the different elements of the system, tested and evaluated.
New porous asphalts	**D3.5**	**T3.1**	Improved porous asphalt mixtures with higher air voids content and with a suitable and similar structural capacity than conventional PA mixtures.
Flooding Methodology	**D4.10**	**T4.1**	A new flood prediction methodology is presented. The methodology makes use of stochastic generation to synthetically increase the length of observed time series to better explore the space of possible events. It also accounts for the multivariate nature of flooding, improving the statistical characterization of extreme values.
GIS risk analysis platform generating prioritised ranked site/asset risk map	**D2.4**	**T2.1**	The tool provides a risk occurrence assessment for the most significant natural disasters (floods, landslides, and earthquakes).

The application of these tools will provide the best option possible to each indicator, so following with the methodology exposed Deliverable D7.6 and linked with the same assumptions made in the Deliverable D7.5, these changes are reflected in the next table where the scale and the measure chosen change, impacting in the final result of resilience, and which FORESEE Tools are related to introduce this improved measure level:

Table 57. Relation of the FORESEE Tools with the Indicators (that could be improved).

INFRASTRUCTURE INDICATORS

ID	Indicator	Number of possible values	Number of possible values Possible values and meaning		RELATED FORESEE TOOLS
E1.2.1	The possibility of building a temporary alternative route for vehicles	2	0/2	No alternative path	T3.4.1
			1/2	1 alternative path	
			2/2	Multiple alternative paths	
E1.2.2	The possibility of using another means to satisfy transport demand	2	0/2	No alternative means	T3.4.1
			1/2	1 alternative mean	
			2/2	Multiple alternative means	
E1.2.4	The presence of a warning system	2	0/2	No warning systems	T3.4.1 - T5.5 - T7.2 - T7.3 - T7.4
			1/2	1 warning system	
			2/2	Multiple warning systems	
E1.2.7	The presence of special measures to help evacuate persons (i.e. helicopters)	2	0/2	No extraordinary measures	T3.4.1 - T7.2 - T7.3 - T7.4
			1/2	1 extraordinary measure	
			2/2	Multiple extraordinary measures	

ENVIRONMENT INDICATORS

ID	Indicator	Number of possible values	Number of possible values Possible values and meaning		RELATED FORESEE TOOLS
E.2.1.9	Hazards goods traffic*	2	0/2	Frequent dangerous goods	T3.4.1 - T5.5
			1/2	Rare dangerous goods	
			2/2	No dangerous goods	
E.2.1.10	Flammable goods traffic*	1	0/1	Yes	T3.4.1 - T5.5
			1/1	No	

ORGANISATION INDICATORS

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning		RELATED FORESEE TOOLS
E.3.2.2	Practice of the emergency plan	4	0/4	No exercise	T4.2 - T4.3 - T7.3 - T7.4
			1/4	1 exercise every > than 2 years	
			2/4	1 exercise every 2 years	
			3/4	1 exercise every year	
			4/4	1 exercise every 6 months	
E.3.2.3	Review/update of the emergency plan	2	0/2	>5 years ago	T4.2 - T4.3 - T7.3 - T7.4
			1/2	<5 years ago	
			2/2	<2 years ago	
E.3.2.4	Expected time for tendering	3	0/3	> 1 year	T7.2 - T7.3
			1/3	> 8 months and < 1 year	
			2/3	> 4 months and < 8 months	
			3/3	< 4 month	

STRUCTURAL HEALTH MONITORING INDICATORS

ID	Indicator*	Number of possible values		Number of possible values Possible values and meaning	RELATED FORESEE TOOLS
E.4.1.1	Continuous vibration monitoring	2	0/2	Non existent	T1.3 - T2.1 - T3.4.1 - T4.5
			1/2	Ability to identify global natural modes	
			2/2	Ability to identify local natural modes in the major structural elements	
E.4.1.2	Continuous stress and absolute displacement monitoring	2	0/2	Non existent	T1.3 - T2.1 - T3.4.1 - T4.5
			1/2	Ability to characterize stresses or absolute displacements in one or more major structural elements	
			2/2	Ability to characterize stresses or absolute displacements in all major structural elements	
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	0/2	Non existent	T1.3 - T2.1 - T3.4.1 - T4.5
			1/2	Ability to characterize relative displacements in one or more movable components	
			2/2	Ability to characterize relative displacements in all movable components	
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	0/2	No uninterruptable power supply (UPS) system	T1.3 - T2.1 - T3.4.1 - T4.5
			1/2	Uninterruptable power supply (UPS) system with capacity for autonomous operation during hours	
			2/2	Uninterruptable power supply (UPS) system with capacity for autonomous operation during days	
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2	0/2	No direct access to SHM data by technical staff	T1.3 - T2.1 - T3.4.1 - T4.5
			1/2	Direct access to SHM data by technical staff, using conventional communications	
			2/2	Direct access to SHM data by technical staff, using special fail-safe communication systems (satellite, other)	
E.4.2.3	SHM data analysis	3	0/3	No real-time automatic analysis	T1.3 - T2.1 - T3.4.1 - T4.4 - T4.5
			1/3	Automatic comparison of data to corresponding limits defined using limit states	
			2/3	Automatic comparison of data to limits defined statistically from baseline of monitoring data	
			3/3	Automatic comparison of data with numerically generated damage scenarios considered likely to occur in case of earthquake	
E.4.2.4	Update rate on the feedback of the structural condition	3	0/3	No automatic feedback	T1.3 - T2.1 - T3.4.1 - T4.4 - T4.5
			1/3	Daily feedback	
			2/3	Hourly feedback	
			3/3	Feedback on-demand	

SMALL MAINTENANCE INDICATORS

ID	Indicator*	Number of possible values		Number of possible values Possible values and meaning	RELATED FORESEE TOOLS
E.6.1.2	Corrective maintenance interventions	2	0/2	No corrective maintenance contracted	T1.3 - T3.4.1 - T4.3 - T4.4 - T7.2 - T7.3
			1/2	Corrective maintenance contracted and available on demand	
			2/2	Corrective permanent maintenance team available on site	

STRUCTURAL ANALYSIS INDICATORS

ID	Indicator*	Number of possible values		Number of possible values Possible values and meaning	RELATED FORESEE TOOLS
E.7.2	Seismic risk studies	3	0/3	No studies conducted	T2.1 - T4.2 - T4.3 - T4.4 - T7.1 - T7.2
			1/3	Seismic vulnerability studies for earthquake events	
			2/3	Seismic risk studies for earthquake events	
			3/3	Probablistic studies for seismic hazard, vulnerability and risk	

EVACUATION AND TRAFFIC MANAGEMENT INDICATORS

ID	Indicator*	Number of possible values	Number of possible values Possible values and meaning		RELATED FORESEE TOOLS
E.8.1.1	Coordination between services	2	0/2	Informal coordination between elements of one or more intervenient	T3.4.1 - T5.5 - T7.3 - T7.4
			1/2	Formal coordination and communication between a subset of intervenient	
			2/2	Formal coordination and communication between a all intervenient emergency and response services thgough dedicated channels	
E.8.2.1	Long-term contingency plans	1	0/1	No long-term contingency plans	T3.4.1 - T5.5 - T7.3 - T7.4
			1/1	Existence of long-term contingency plans	
E.8.2.2	Long-term traffic/mobility plans	1	0/1	No long-term traffic/mobility plans	T3.4.1 - T5.5 - T7.3 - T7.4
			1/1	Existence of long-term traffic/mobility plans	

Next step, introduces the following table where the user of the tool can specify the current measure level for each indicator (in the supposition that there is no FORESEE Tools applying), related to the service impacts defined in the methodology of Work Package WP1.

For each indicator and related to the previous table, the desired level is the introduction of the related FORESEE Tool and introducing the specific cost as well because of the tool's application.

Table 58. CS#6, Current Measure – Desired Level and Cost Table extracted from Tool.

ID	Indicator	Impact							
		Intervention	Travel time	Accident	Socio-econ.	Scale	Current Measure	Desired level	Cost of desired level
E.1.1.1	Age / Age of replacement of the warning system			X	X	3	2	2	0,00
E.1.1.2	Age / Age of replacement of safe shut down system			X	X	3	2	2	0,00
E.1.1.3	Condition state of infrastructure (pre-event)	X	X	X	X	5	3	3	0,00
E.1.1.4	Condition state of protective structures/systems (pre-event)	X	X	X	X	5	3	3	0,00
E.1.1.5	Expected condition state of infrastructure (post-event)	X	X	X	X	3	2	2	0,00
E.1.1.6	Expected condition state of protective structures/systems (post-event)	X	X	X	X	3	2	2	0,00
E.1.2.1	The possibility of building a temporary alternative route for vehicles		X		X	2	1	2	100 000,00
E.1.2.2	The possibility of using another means to satisfy transport demand		X		X	2	1	2	200 000,00
E.1.2.3	The number of possible existing alternative ways to deviate vehicles		X		X	1	1	1	0,00
E.1.2.4	The presence of a warning system		X		X	2	1	2	100 000,00
E.1.2.5	The presence of a safe shutdown system		X		X	1	1	1	0,00
E.1.2.6	The presence of emergency / evacuation paths		X		X	2	2	2	0,00
E.1.2.7	The presence of special measures to help evacuate persons		X		X	2	0	2	180 000,00
E.1.3.1	Complience with the current seismic design code	X	X	X	X	2	1	1	0,00
E.1.3.2	Presence of systems to reduce seismic effects	X	X	X	X	1	0	0	0,00
E.1.3.3	Adequate systems to reduce seismic effects	X	X	X	X	1	0	0	0,00
E.2.1.1	Accessibility	X				3	0	0	0,00
E.2.1.2	Presence of persons/property below the infrastructure			X		1	0	0	0,00
E.2.1.3	Extent of past damages due to hazards	X				3	3	3	0,00
E.2.1.4	Hazard zone	X	X	X	X	2	1	1	0,00
E.2.1.5	Duration of past down time due to hazards	X				3	2	2	0,00
E.2.1.6	Land type	X		X		3	0	0	0,00
E.2.1.7	Budget availability	X	X	X	X	2	2	2	0,00
E.2.1.8	Traffic	X	X	X	X	3	0	0	0,00
E.2.1.9	Hazards goods traffic			X		2	0	2	75 000,00
E.2.1.10	Flammable goods traffic			X		1	0	1	25 000,00
E.3.1.1	The presence of a monitoring strategy	X	X	X	X	2	2	2	0,00
E.3.1.2	The presence of an maintenance strategy	X	X	X	X	2	2	2	0,00
E.3.1.3	The extent of interventions executed prior to the event	X	X	X	X	2	1	1	0,00
E.3.2.1	The presence of an emergency plan		X		X	2	2	2	0,00
E.3.2.2	Practice of the emergency plan		X		X	4	0	2	375 000,00
E.3.2.3	Review/update of the emergency plan		X	X	X	2	0	2	700 000,00
E.3.2.4	Expected time for tendering	X	X		X	3	0	3	60 000,00
E.3.2.5	Expected time for construction	X	X		X	3	0	0	0,00
E.4.1.1	Continuous vibration monitoring	X		X		2	1	2	150 000,00
E.4.1.2	Continuous stress and displacement monitoring of resistance elements	X		X		2	1	2	200 000,00
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	X		X		2	1	2	130 000,00
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	X		X		2	0	2	75 000,00
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	X		X		2	1	2	30 000,00
E.4.2.3	SHM data analysis	X		X		3	2	3	150 000,00
E.4.2.4	Update rate on the feedback of the structural condition	X		X		3	2	3	50 000,00
E.5.1.1	Component inspection and testing plan			X	X	2	2	2	0,00
E.5.1.2	Repair plan of damaged components			X	X	2	2	2	0,00
E.5.2.1	Visual inspections	X	X	X	X	2	2	2	0,00
E.5.2.2	Technical measurements	X	X	X	X	2	2	2	0,00
E.6.1.1	Periodic routine maintenance interventions	X	X	X	X	2	2	2	0,00
E.6.1.2	Corrective maintenance interventions	X	X	X	X	2	1	2	2 500 000,00
E.7.1.1	Structural model	X	X		X	3	3	3	0,00
E.7.2.1	Seismic risk studies	X	X		X	3	0	3	300 000,00
E.8.1.1	Coordination between services		X			2	1	2	100 000,00
E.8.1.2	Availability of resources on site	X	X			2	1	1	0,00
E.8.1.3	Availability of safe-through equipment	X				1	1	1	0,00
E.8.2.1	Long-term contingency plans		X			1	0	1	200 000,00
E.8.2.2	Long-term traffic/mobility plans		X			1	0	1	400 000,00

The next step in the tool is to stablish, following the methodology of FORESEE, the regular costs of operation and maintenance of the infrastructure, and the related cost of happening the chosen hazard at the initial step.

These values have been obtained on Deliverable D1.1 for CS#6 in particular:

Table 59. Earthquake and Bridge Service Costs extracted from Tool.

HAZARD CHOSEN: (MAIN TAB)

EARTHQUAKES

Regular costs with actual Op. & Maint. Plan

Inputs	Symbol	Value
Annual cost of regular maintenance [€/m]	Cm	500
Length of the infrastructure [m]*	Li	2277
N. of people traveling per day	P	589286
N. of people traveling per work in a day	Pw	471429
N. of people traveling per leisure in a day	Pl	117857
Goods travelling per day [trains]	G	150
Cost of work time [€/min]	Cwt	0,4
Cost of leasure time [€/min]	Clt	0,1
Socio economic costs per person [€/p.p.]	SECp	0,0
Socio economic costs for goods [€/train]	SECg	0
Impact of injuries per person [10^3€/p.p.]	Ip	398
Impact of death per person [10^3€/p.p.]	Dp	2618
Speed limit (average between weather condition) [km/h]*	Sl	70
Delay per unit (person or train) per day with no hazard event [min/p.u.]	Dpud_0	45
Property damage probability with no hazard event [%]	Ppd_0	0,15
Injury probability with no hazard event [%]	Pi_0	0,0001
Death probability with no hazard event [%]	Pd_0	0,00001
Property damage per person in case of accident [10^3€/p.p.]	PDp_0	5

The tool compute, according to the hazard chosen, the final reduction in the service after hazards related to interventions, travel time, safety and socio-economic activities, as defined in the developed methodology of the project.

Table 60. Reduction in the Service after Hazards extracted from Tool.

REDUCTION IN THE SERVICE AFTER HAZARDS

Impact level 1	Symbol	Description	Impact level 2	Symbol	Costs		
					Estimate	Computation	Estimate
Interventions	Ii_I	The impact of executing interventions			5 693	(Ci_I*Li)	**5 693**
Travel time	Itt_I	The impact of the additional travel time on passengers	Work	Itt.w_I	3 215 237	(Pw*Dppd_I*Cwt*D_I)	**3 448 170**
			Leisure	Itt.l_I	232 933	(Pw*Dppd_I*Clt*D_I)	
Safety	Is_I	The impact on the users and affected public due to the user being involved in an accident	Property damage	Is.pd_I	1 473 214	((Ppd_I/100)*PDp_I*P)	**4 187 346**
			Injury	Is.i_I	1 171 500	((Ppd_I/100)*Ip_I*P)	
			Death	Is.d_I	1 542 632	((Ppd_I/100)*Dpp_I*P)	
Socio-economic activities	Ise_I	The contribution of the road operation to socio-economic development, i.e. the socio and economical costs of people and goods not being able to travel	Persons	Ise.p_I	76 371	(P*Dppd_I*D_I*SECp)	**77 394**
			Goods	Ise.g_I	1 023	(P*Dppd_I*D_I*SECg)	
Total					7 718 603	(Ii_I+Itt_I+Is_I+Ise_I)	**7 718 603**

A final required input is the % of impact of each indicator for that infrastructure, as this data has been defined by *Infraestruturas de Portugal*, following those whose have been established on Deliverable D1.1.

This adjusts the final indicator reduction in service costs, and the tool also calculate the % of fulfilment at initial state per each indicator.

This first table (Table 61) is given for a non-introduced FORESEE Tools situation, and this support the infrastructure manager (*Infraestruturas de Portugal*), to identify the poorest indicators, as well the most covered ones.

Table 61. % of Fulfilment and Reduction on Service per Indicator, extracted from Tool.

ID	Level 0	ID	Level 1	ID	Indicator	Impact				Scale	Measure	Impact on the service per indicator						% of fullfilment at initial state
						Intervention	Travel time	Accident	Socio-econ.			Impact	Intervention	Travel time	Accident	Socio-econ.	TOTAL	
E1	Infrastructure	E1.1	CS of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system			X	X	3	2	50%	2 846	1 724 085	2 093 673	38 697	2 132 370	67%
				E.1.1.2	Age / Age of replacement of safe shut down system			X	X	3	2	45%	2 562	1 551 677	1 884 306	34 828	1 919 133	67%
				E.1.1.3	Condition state of infrastructure (pre-event)	X	X	X	X	5	3	49%	2 769	1 677 021	2 036 520	37 641	3 753 950	60%
				E.1.1.4	Condition state of protective structures/systems (pre-event)	X	X	X	X	5	3	31%	1 759	1 065 314	1 293 683	23 911	2 384 666	60%
				E.1.1.5	Expected condition state of infrastructure (post-event)	X	X	X	X	3	2	75%	4 245	2 571 090	3 122 249	57 708	5 755 293	67%
				E.1.1.6	Expected condition state of protective structures/systems (post-event)	X	X	X	X	3	2	62%	3 536	2 141 956	2 601 122	48 076	4 794 690	67%
		E1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles		X		X	2	1	43%	2 441	1 478 749	1 795 745	33 191	1 511 939	50%
				E.1.2.2	The possibility of using another means to satisfy transport demand		X		X	2	1	90%	5 104	3 091 673	3 754 428	69 393	3 161 066	50%
				E.1.2.3	The number of possible existing alternative ways to deviate vehicles		X		X	1	1	71%	4 066	2 463 116	2 991 128	55 285	2 518 401	100%
				E.1.2.4	The presence of a warning system		X		X	2	1	10%	576	348 725	423 480	7 827	356 552	50%
				E.1.2.5	The presence of a safe shutdown system		X		X	1	1	43%	2 451	1 484 631	1 802 888	33 323	1 517 954	100%
				E.1.2.6	The presence of emergency / evacuation paths		X		X	2	2	93%	5 278	3 196 953	3 882 277	71 756	3 268 709	100%
				E.1.2.7	The presence of special measures to help evacuate persons		X		X	2	0	16%	936	566 684	688 162	12 719	579 403	0%
		E1.3	Preventive measures	E.1.3.1	Complience with the current seismic design code	X	X	X	X	2	1	78%	4 439	2 688 778	3 265 166	60 350	6 018 732	50%
				E.1.3.2	Presence of systems to reduce seismic effects	X	X	X	X	1	0	39%	2 209	1 337 827	1 624 614	30 028	2 994 678	0%
				E.1.3.3	Adequate systems to reduce seismic effects	X	X	X	X	1	0	91%	5 200	3 150 144	3 825 433	70 705	7 051 482	0%
E2	Environment	E2.1	Context	E.2.1.1	Accessibility	X				3	0	98%	5 600	3 391 970	4 119 099	76 133	5 600	0%
				E.2.1.2	Presence of persons/property below the infrastructure			X		1	0	69%	3 905	2 365 477	2 872 559	53 093	2 872 559	0%
				E.2.1.3	Extent of past damages due to hazards	X				3	3	12%	692	419 345	509 239	9 412	692	100%
				E.2.1.4	Hazard zone	X	X	X	X	2	1	19%	1 104	668 660	811 999	15 008	1 496 772	50%
				E.2.1.5	Duration of past down time due to hazards	X				3	2	12%	685	415 008	503 973	9 315	685	67%
				E.2.1.6	Land type	X		X		3	0	93%	5 289	3 203 532	3 890 266	71 904	3 895 555	0%
				E.2.1.7	Budget availability	X	X	X	X	2	2	12%	710	430 152	522 363	9 655	962 880	100%
				E.2.1.8	Traffic	X	X	X	X	3	0	20%	1 127	682 669	829 011	15 323	1 528 129	0%
				E.2.1.9	Hazards goods traffic			X		2	0	31%	1 737	1 052 339	1 277 927	23 620	1 277 927	0%
				E.2.1.10	Flammable goods traffic			X		1	0	84%	4 780	2 895 402	3 516 083	64 988	3 516 083	0%
E3	Organization	E3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	X	X	X	X	2	2	81%	4 608	2 791 173	3 389 511	62 648	6 247 940	100%
				E.3.1.2	The presence of an maintenance strategy	X	X	X	X	2	2	86%	4 886	2 959 754	3 594 230	66 432	6 625 302	100%
				E.3.1.3	The extent of interventions executed prior to the event	X	X	X	X	2	1	9%	533	322 947	392 176	7 249	722 904	50%
		E3.2	Post event activities	E.3.2.1	The presence of an emergency plan		X		X	2	2	8%	451	273 203	331 768	6 132	279 335	100%
				E.3.2.2	Practice of the emergency plan		X		X	4	0	41%	2 328	1 409 950	1 712 198	31 646	1 441 596	0%
				E.3.2.3	Review/update of the emergency plan		X	X	X	2	0	96%	5 460	3 307 556	4 016 589	74 238	7 398 383	0%
				E.3.2.4	Expected time for tendering	X	X		X	3	0	66%	3 771	2 284 364	2 774 057	51 273	2 339 407	0%
				E.3.2.5	Expecetd time for construction	X	X		X	3	0	8%	447	270 623	328 636	6 074	277 144	0%
E.4	Structural health monitoring	E.4.1	SHM Availability	E.4.1.1	Continuous vibration monitoring	X		X		2	1	75%	4 245	2 571 090	3 122 249	57 708	3 126 494	50%
				E.4.1.2	Continuous stress and displacement monitoring of resistance elements	X		X		2	1	50%	2 846	1 724 085	2 093 673	38 697	2 096 519	50%
				E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	X		X		2	1	75%	4 245	2 571 090	3 122 249	57 708	3 126 494	50%
		E.4.2	SHM Reliability and operation	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	X		X		2	0	75%	4 245	2 571 090	3 122 249	57 708	3 126 494	0%
				E.4.2.2	Permanent fail-safe communication of monitoring relevant information	X		X		2	1	75%	4 245	2 571 090	3 122 249	57 708	3 126 494	50%
				E.4.2.3	SHM data analysis	X		X		3	2	50%	2 846	1 724 085	2 093 673	38 697	2 096 519	67%
				E.4.2.4	Update rate on the feedback of the structural condition	X		X		3	2	75%	4 245	2 571 090	3 122 249	57 708	3 126 494	67%
E.5	Inspection	E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan			X	X	2	2	50%	2 846	1 724 085	2 093 673	38 697	2 132 370	100%
				E.5.1.2	Repair plan of damaged components			X	X	2	2	50%	2 846	1 724 085	2 093 673	38 697	2 132 370	100%
		E.5.2	Inspection operation	E.5.2.1	Visual inspections	X	X	X	X	2	2	75%	4 269	2 586 128	3 140 510	58 046	5 788 953	100%
				E.5.2.2	Technical measurements	X	X	X	X	2	2	50%	2 846	1 724 085	2 093 673	38 697	3 859 302	100%
E.6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	X	X	X	X	2	2	75%	4 269	2 586 128	3 140 510	58 046	5 788 953	100%
				E.6.1.2	Corrective maintenance interventions	X	X	X	X	2	1	75%	4 269	2 586 128	3 140 510	58 046	5 788 953	50%
E.7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	Structural model	X	X		X	3	3	75%	4 269	2 586 128	3 140 510	58 046	2 648 443	100%
		E.7.2	Seismic risk studies	E.7.2.1	Seismic risk studies	X	X		X	3	0	50%	2 846	1 724 085	2 093 673	38 697	1 765 628	0%
E.8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	Coordination between services		X			2	1	50%	2 846	1 724 085	2 093 673	38 697	1 724 085	50%
				E.8.1.2	Availability of resources on site	X	X			2	1	75%	4 269	2 586 128	3 140 510	58 046	2 590 397	50%
				E.8.1.3	Availability of safe-through equipment	X				1	1	50%	2 846	1 724 085	2 093 673	38 697	2 846	100%
		E.8.2	Response for long term disruption	E.8.2.1	Long-term contingency plans		X			1	0	75%	4 269	2 586 128	3 140 510	58 046	2 586 128	0%
				E.8.2.2	Long-term traffic/mobility plans		X			1	0	75%	4 269	2 586 128	3 140 510	58 046	2 586 128	0%
										122	62		172 407	104 433 570	126 820 759	2 344 020	149 827 974	

Following this table and as the last step, is the application of the FORESEE Tools for detected indicators where it is required (for reduction in service costs, % of fulfilment weak…) the introduction of the FORESEE Tools, and also computing the initial cost that was given in previous tables. This will proceed as a net benefit analysis as will compute, per one side, an increase of the cost per indicator due to the investment required, but per other side the reduction of the cost per hazard. % of fulfilment is finally reassessed, per compare with the initial state.

Table 62. Final Costs and % of Fulfilment after application of FORESEE Tools, extracted from Tool.

ID	Level 0	ID	Level 1	ID	Indicator	Scale	Measure	Cost of selected measure	Costs [€]					% of fullfilment
									Intervention	Travel time	Accident	Socio-econ.	Total	
E1	Infrastructure	E1.1	CS of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	3	2	0	0	0	697 891	12 899	710 790	67%
				E.1.1.2	Age / Age of replacement of safe shut down system	3	2	0	0	0	628 102	11 609	639 711	67%
				E.1.1.3	Condition state of infrastructure (pre-event)	5	3	0	1 107	670 808	814 608	15 056	1 501 580	60%
				E.1.1.4	Condition state of protective structures/systems (pre-event)	5	3	0	703	426 126	517 473	9 564	953 867	60%
				E.1.1.5	Expected condition state of infrastructure (post-event)	3	2	0	1 415	857 030	1 040 750	19 236	1 918 431	67%
				E.1.1.6	Expected condition state of protective structures/systems (post-event)	3	2	0	1 179	713 985	867 041	16 025	1 598 230	67%
		E1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	2	2	100000	0	0	0	0	100 000	100%
				E.1.2.2	The possibility of using another means to satisfy transport demand	2	2	200000	0	0	0	0	200 000	100%
				E.1.2.3	The number of possible existing alternative ways to deviate vehicles	1	1	0	0	0	0	0	0	100%
				E.1.2.4	The presence of a warning system	2	2	100000	0	0	0	0	100 000	100%
				E.1.2.5	The presence of a safe shutdown system	1	1	0	0	0	0	0	0	100%
				E.1.2.6	The presence of emergency / evacuation paths	2	2	0	0	0	0	0	0	100%
				E.1.2.7	The presence of special measures to help evacuate persons	2	2	180000	0	0	0	0	180 000	100%
		E1.3	Preventive measures	E.1.3.1	Complience with the current seismic design code	2	1	0	2 219	1 344 389	1 632 583	30 175	3 009 366	50%
				E.1.3.2	Presence of systems to reduce seismic effects	1	0	0	2 209	1 337 827	1 624 614	30 028	2 994 678	0%
				E.1.3.3	Adequate systems to reduce seismic effects	1	0	0	5 200	3 150 144	3 825 433	70 705	7 051 482	0%
E2	Environment	E2.1	Context	E.2.1.1	Accessibility	3	0	0	5 600	0	0	0	5 600	0%
				E.2.1.2	Presence of persons/property below the infrastructure	1	0	0	0	0	2 872 559	0	2 872 559	0%
				E.2.1.3	Extent of past damages due to hazards	3	3	0	0	0	0	0	0	100%
				E.2.1.4	Hazard zone	2	1	0	552	334 330	406 000	7 504	748 386	50%
				E.2.1.5	Duration of past down time due to hazards	3	2	0	228	0	0	0	228	67%
				E.2.1.6	Land type	3	0	0	5 289	0	3 890 266	0	3 895 555	0%
				E.2.1.7	Budget availability	2	2	0	0	0	0	0	0	100%
				E.2.1.8	Traffic	3	0	0	1 127	682 669	829 011	15 323	1 528 129	0%
				E.2.1.9	Hazards goods traffic	2	2	75000	0	0	0	0	75 000	100%
				E.2.1.10	Flammable goods traffic	1	1	25000	0	0	0	0	25 000	100%
E3	Organization	E3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	2	2	0	0	0	0	0	0	100%
				E.3.1.2	The presence of an maintenance strategy	2	2	0	0	0	0	0	0	100%
				E.3.1.3	The extent of interventions executed prior to the event	2	1	0	267	161 473	196 088	3 624	361 452	50%
		E3.2	Post event activities	E.3.2.1	The presence of an emergency plan	2	2	0	0	0	0	0	0	100%
				E.3.2.2	Practice of the emergency plan	4	2	375000	0	704 975	0	15 823	1 095 798	50%
				E.3.2.3	Review/update of the emergency plan	2	2	700000	0	0	0	0	700 000	100%
				E.3.2.4	Expected time for tendering	3	3	60000	0	0	0	0	60 000	100%
				E.3.2.5	Expecetd time for construction	3	0	0	447	270 623	0	6 074	277 144	0%
E.4	Structural health monitoring	E.4.1	SHM Availability	E.4.1.1	Continuous vibration monitoring	2	2	150000	0	0	0	0	150 000	100%
				E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2	2	200000	0	0	0	0	200 000	100%
				E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	2	2	130000	0	0	0	0	130 000	100%
		E.4.2	SHM Reliability and operation	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	2	2	75000	0	0	0	0	75 000	100%
				E.4.2.2	Permanent fail-safe communication of monitoring relevant information	2	2	30000	0	0	0	0	30 000	100%
				E.4.2.3	SHM data analysis	3	3	150000	0	0	0	0	150 000	100%
				E.4.2.4	Update rate on the feedback of the structural condition	3	3	50000	0	0	0	0	50 000	100%
E.5	Inspection	E.5.1	Inspection plan	E.5.1.1	Component inspection and testing plan	2	2	0	0	0	0	0	0	100%
				E.5.1.2	Repair plan of damaged components	2	2	0	0	0	0	0	0	100%
		E.5.2	Inspection operation	E.5.2.1	Visual inspections	2	2	0	0	0	0	0	0	100%
				E.5.2.2	Technical measurements	2	2	0	0	0	0	0	0	100%
E.6	Small maintenance	E.6.1.	Maintenance	E.6.1.1	Periodic routine maintenance interventions	2	2	0	0	0	0	0	0	100%
				E.6.1.2	Corrective maintenance interventions	2	2	2 500 000,00	0	0	0	0	2 500 000	100%
E.7	Structural analysis	E.7.1	Structural analysis	E.7.1.1	Structural model	3	3	0	0	0	0	0	0	100%
		E.7.2	Seismic risk studies	E.7.2.1	Seismic risk studies	3	3	300000	0	0	0	0	300 000	100%
E.8	Evacuation and traffic management	E.8.1	Direct and immediate response	E.8.1.1	Coordination between services	2	2	100000	0	0	0	0	100 000	100%
				E.8.1.2	Availability of resources on site	2	1	0	2 135	1 293 064	0	0	1 295 198	50%
				E.8.1.3	Availability of safe-through equipment	1	1	0	0	0	0	0	0	100%
		E.8.2	Response for long term disruption	E.8.2.1	Long-term contingency plans	1	1	200 000,00	0	0	0	0	200 000	100%
				E.8.2.2	Long-term traffic/mobility plans	1	1	400000	0	0	0	0	400 000	100%
						122	92	6 100 000	29 677	11 947 443	19 842 418	263 647	38 183 185	

The tool also provides the user with tables and graphs to have a global overview of the initial situation of the infrastructure, and after application of the FORESEE Tools, related to costs, % of fulfilment, per indicators and per type of impact, as shown on following figures related of the application on CS#6 to each indicator level.

Table 63. Summary of Costs and Fulfilment (before and after), extracted from Tool.

INTIAL OP. & MAINTENANCE PLAN

ID	Level	Intervention	Travel time	Accident	Socio-econ.	% OF FULLFILLMENT
	Total	172 407	104 433 570	126 820 759	2 344 020	
E1	Infrastructure	50 415	30 538 421	37 084 873	685 437	58%
E2	Environment	25 629	15 524 555	18 852 519	348 450	35%
E3	Organization	22 484	13 619 569	16 539 166	305 692	35%
E4	Structural Health Monitoring	26 915	16 303 622	19 798 593	365 936	50%
E5	Inspection	12 808	7 758 383	9 421 529	174 138	100%
E6	Small Maintenance	8 539	5 172 255	6 281 020	116 092	75%
E7	Structural Analysis	7 116	4 310 213	5 234 183	96 743	50%
E8	Evacuation and Traffic Management	18 501	11 206 553	13 608 876	251 532	43%
E1.1	CS of the infrastructure	17 716	15 816 987	19 207 639	355 014	64%
E1.2	Protection measures	20 851	12 630 530	15 338 108	283 493	58%
E1.3	Preventive measures	11 848	7 176 749	8 715 213	161 083	25%
E2.1	Context	25 629	15 524 555	18 852 519	348 450	35%
E3.1	Pre-event activities	10 027	6 073 874	7 375 917	136 329	83%
E3.2	Post event activities	12 457	7 545 695	9 163 249	169 364	14%
E.4.1	SHM Availability	11 335	6 866 266	8 338 172	154 114	50%
E.4.2	SHM Reliability and operation	15 580	9 437 356	11 460 421	211 822	50%
E.5.1	Inspection plan	5 693	3 448 170	4 187 346	77 394	100%
E.5.2	Inspection operation	7 116	4 310 213	5 234 183	96 743	100%
E.6.1.	Maintenance	8 539	5 172 255	6 281 020	116 092	75%
E.7.1	Structural analysis	4 269	2 586 128	3 140 510	58 046	100%
E.7.2	Seismic risk studies	2 846	1 724 085	2 093 673	38 697	0%
E.8.1	Direct and immediate response	9 962	6 034 298	7 327 856	135 440	60%
E.8.2	Response for long term disruption	8 539	5 172 255	6 281 020	116 092	0%
E.1.2.1	The possibility of building a temporary alternative route for vehicles	2 441	1 478 749	1 795 745	33 191	50%
E.1.2.2	The possibility of using another means to satisfy transport demand	5 104	3 091 673	3 754 428	69 393	50%
E.1.2.4	The presence of a warning system	576	348 725	423 480	7 827	50%
E.1.2.7	The presence of special measures to help evacuate persons	936	566 684	688 162	12 719	0%
E.2.1.9	Hazards goods traffic	1 737	1 052 339	1 277 927	23 620	0%
E.2.1.10	Flammable goods traffic	4 780	2 895 402	3 516 083	64 988	0%
E.3.2.2	Practice of the emergency plan	2 328	1 409 950	1 712 198	31 646	0%
E.3.2.3	Review/update of the emergency plan	5 460	3 307 556	4 016 589	74 238	0%
E.3.2.4	Expected time for tendering	3 771	2 284 364	2 774 057	51 273	0%
E.4.1.1	Continuous vibration monitoring	4 245	2 571 090	3 122 249	57 708	50%
E.4.1.2	Continuous stress and displacement monitoring of resistance elements	2 846	1 724 085	2 093 673	38 697	50%
E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	4 245	2 571 090	3 122 249	57 708	50%
E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	4 245	2 571 090	3 122 249	57 708	0%
E.4.2.2	Permanent fail-safe communication of monitoring relevant information	4 245	2 571 090	3 122 249	57 708	50%
E.4.2.3	SHM data analysis	2 846	1 724 085	2 093 673	38 697	67%
E.4.2.4	Update rate on the feedback of the structural condition	4 245	2 571 090	3 122 249	57 708	67%
E.6.1.2	Corrective maintenance interventions	4 269	2 586 128	3 140 510	58 046	50%
E.7.2.1	Seismic risk studies	2 846	1 724 085	2 093 673	38 697	0%
E.8.1.1	Coordination between services	2 846	1 724 085	2 093 673	38 697	50%
E.8.2.1	Long-term contingency plans	4 269	2 586 128	3 140 510	58 046	0%
E.8.2.2	Long-term traffic/mobility plans	4 269	2 586 128	3 140 510	58 046	0%

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	ID	Level	Intervention	Travel time	Accident	Socio-econ.	% OF FULLFILLMENT
		Total	29 677	11 947 443	19 842 418	263 647	
	E1	Infrastructure	14 033	8 500 309	11 648 494	215 298	71%
	E2	Environment	12 796	1 016 999	7 997 836	22 827	48%
	E3	Organization	713	1 137 072	196 088	25 522	70%
	E4	Structural Health Monitoring	0	0	0	0	100%
	E5	Inspection	0	0	0	0	100%
	E6	Small Maintenance	0	0	0	0	100%
	E7	Structural Analysis	0	0	0	0	100%
	E8	Evacuation and Traffic Management	2 135	1 293 064	0	0	86%
	E1.1	CS of the infrastructure	4 404	2 667 949	4 565 865	84 391	64%
	E1.2	Protection measures	0	0	0	0	100%
	E1.3	Preventive measures	9 629	5 832 360	7 082 630	130 908	25%
	E2.1	Context	12 796	1 016 999	7 997 836	22 827	48%
	E3.1	Pre-event activities	267	161 473	196 088	3 624	83%
	E3.2	Post event activities	447	975 598	0	21 897	79%
	E.4.1	SHM Availability	0	0	0	0	100%
	E.4.2	SHM Reliability and operation	0	0	0	0	100%
	E.5.1	Inspection plan	0	0	0	0	100%
	E.5.2	Inspection operation	0	0	0	0	100%
	E.6.1.	Maintenance	0	0	0	0	100%
	E.7.1	Structural analysis	0	0	0	0	100%
	E.7.2	Seismic risk studies	0	0	0	0	100%
	E.8.1	Direct and immediate response	2 135	1 293 064	0	0	80%
	E.8.2	Response for long term disruption	0	0	0	0	100%
INDICATORS TO BE IMPROVED BY FORESEE TOOLS	E.1.2.1	The possibility of building a temporary alternative route for vehicles	0	0	0	0	100%
	E.1.2.2	The possibility of using another means to satisfy transport demand	0	0	0	0	100%
	E.1.2.4	The presence of a warning system	0	0	0	0	100%
	E.1.2.7	The presence of special measures to help evacuate persons	0	0	0	0	100%
	E.2.1.9	Hazards goods traffic	0	0	0	0	100%
	E.2.1.10	Flammable goods traffic	0	0	0	0	100%
	E.3.2.2	Practice of the emergency plan	0	704 975	0	15 823	50%
	E.3.2.3	Review/update of the emergency plan	0	0	0	0	100%
	E.3.2.4	Expected time for tendering	0	0	0	0	100%
	E.4.1.1	Continuous vibration monitoring	0	0	0	0	100%
	E.4.1.2	Continuous stress and displacement monitoring of resistance elements	0	0	0	0	100%
	E.4.1.3	Continuous relative displacement monitoring of moving components and anti-seismic devices	0	0	0	0	100%
	E.4.2.1	Autonomous short-term electrical supply to the monitoring system installed on site	0	0	0	0	100%
	E.4.2.2	Permanent fail-safe communication of monitoring relevant information	0	0	0	0	100%
	E.4.2.3	SHM data analysis	0	0	0	0	100%
	E.4.2.4	Update rate on the feedback of the structural condition	0	0	0	0	100%
	E.6.1.2	Corrective maintenance interventions	0	0	0	0	100%
	E.7.2.1	Seismic risk studies	0	0	0	0	100%
	E.8.1.1	Coordination between services	0	0	0	0	100%
	E.8.2.1	Long-term contingency plans	0	0	0	0	100%
	E.8.2.2	Long-term traffic/mobility plans	0	0	0	0	100%

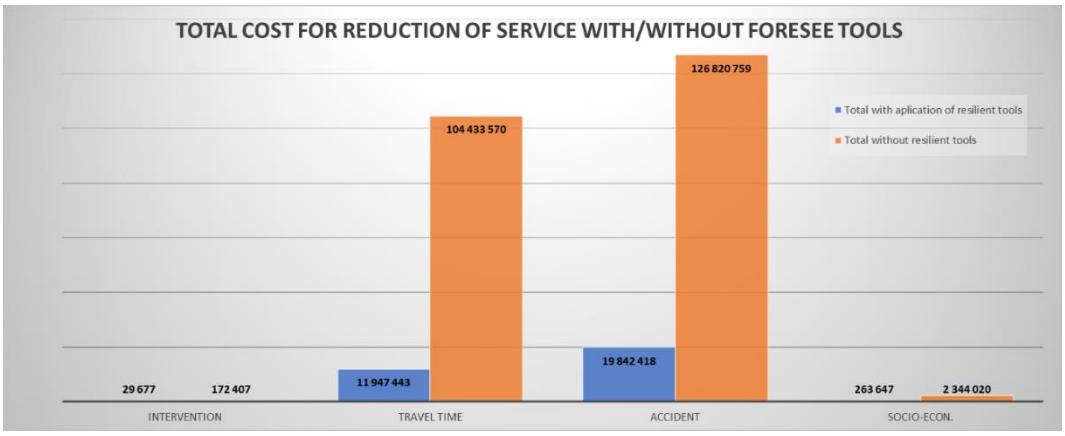

Figure 46. CS#6, Costs related to Indicator Graph, extracted from Tool.

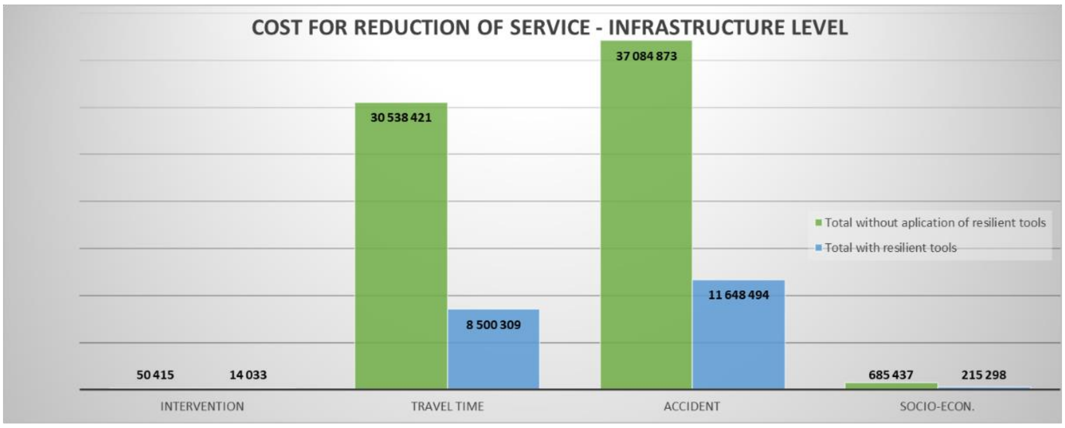

Figure 47. CS#6, Costs for Reduction of Service – Infrastructure Level (with and without application of FORESEE Tools), extracted from Tool.

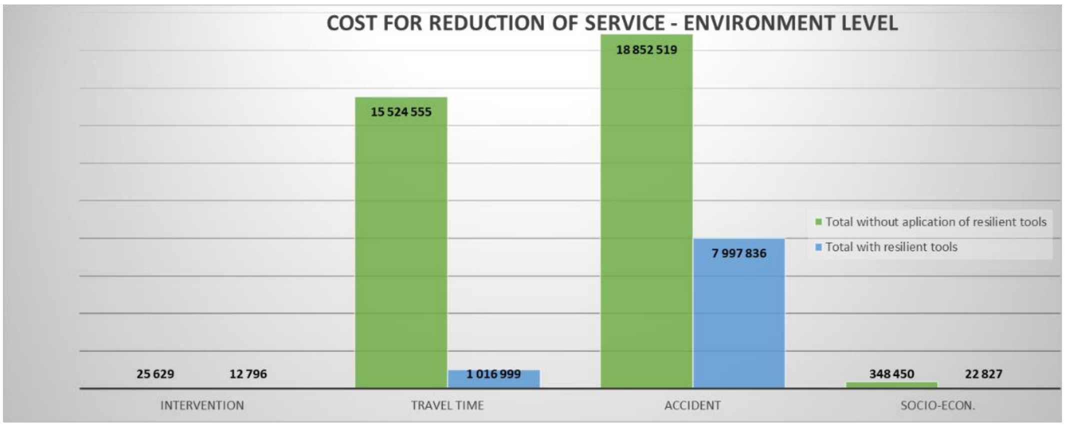

Figure 48. CS#6, Costs for Reduction of Service – Environment Level (with and without application of FORESEE Tools), extracted from Tool.

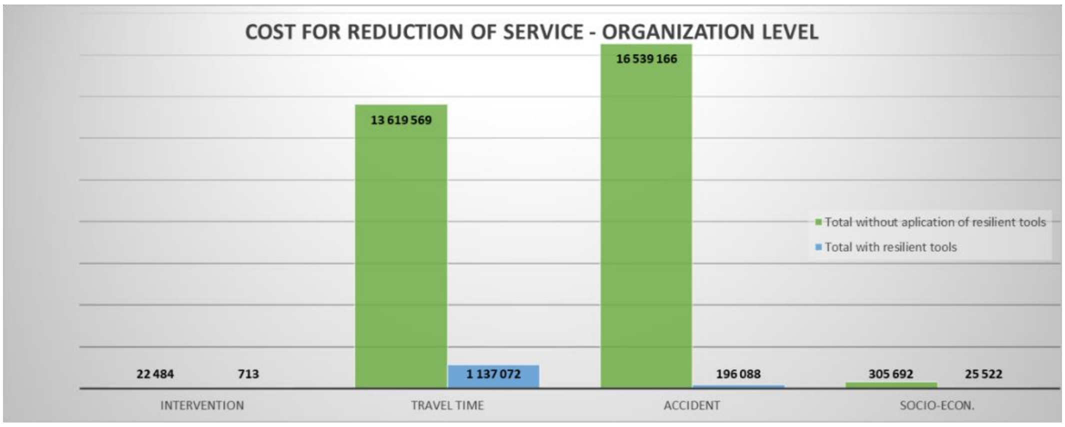

Figure 49. CS#6, Costs for Reduction of Service – Organization Level (with and without application of FORESEE Tools), extracted from Tool.

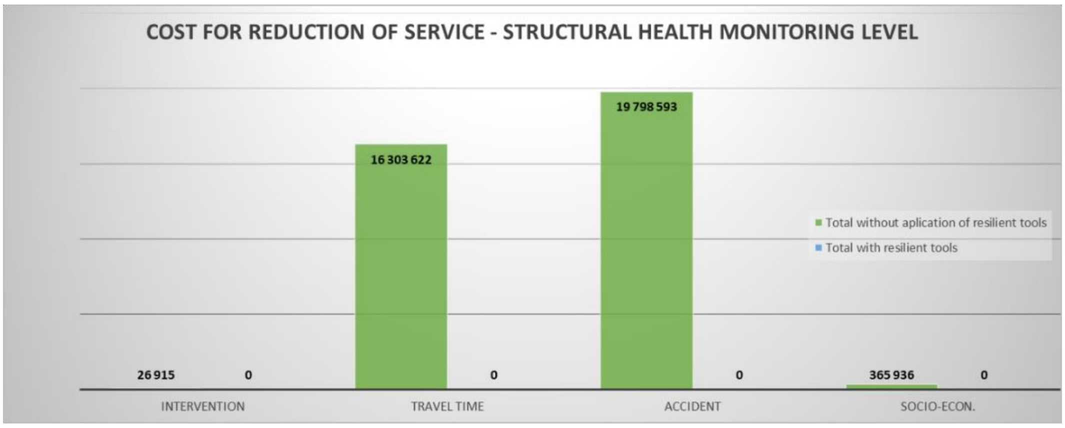

Figure 50. CS#6, Costs for Reduction of Service – Structural Health Monitoring Level (with and without application of FORESEE Tools), extracted from Tool.

Figure 51. CS#6, Costs for Reduction of Service – Inspection Level (with and without application of FORESEE Tools), extracted from Tool.

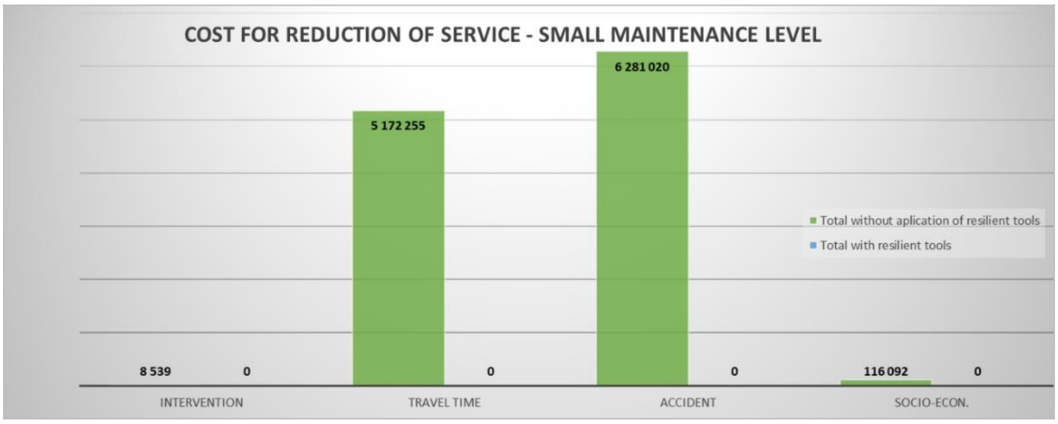

Figure 52. CS#6, Costs for Reduction of Service – Small Maintenance Level (with and without application of FORESEE Tools), extracted from Tool.

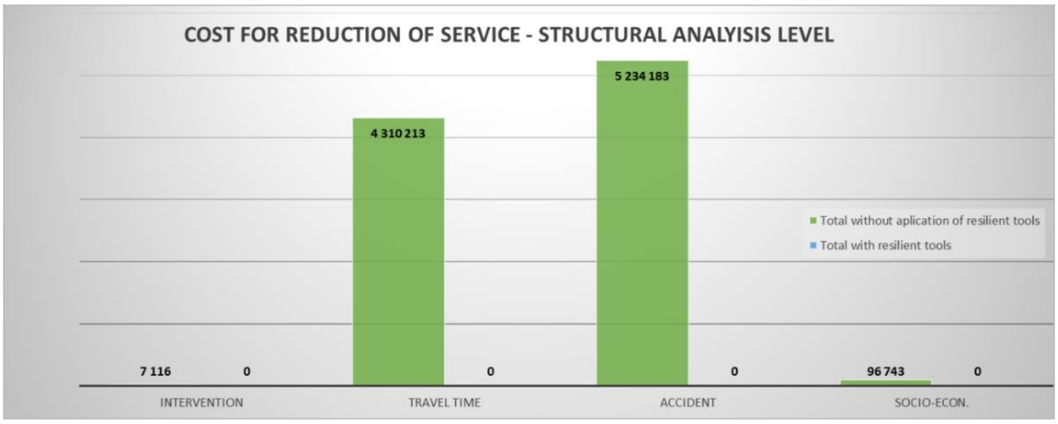

Figure 53. CS#6, Costs for Reduction of Service – Structural Analysis Level (with and without application of FORESEE Tools), extracted from Tool.

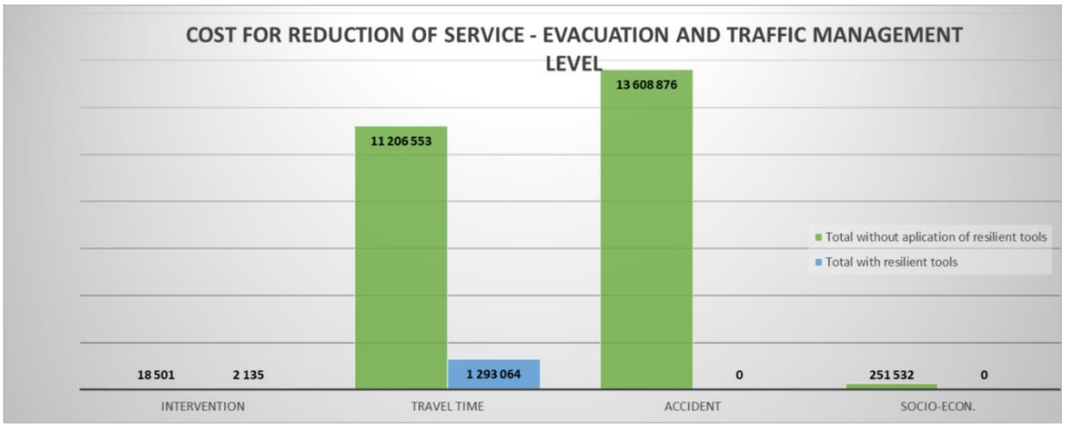

Figure 54. CS#6, Costs for Reduction of Service – Evacuation and Traffic Management Level (with and without application of FORESEE Tools), extracted from Tool.

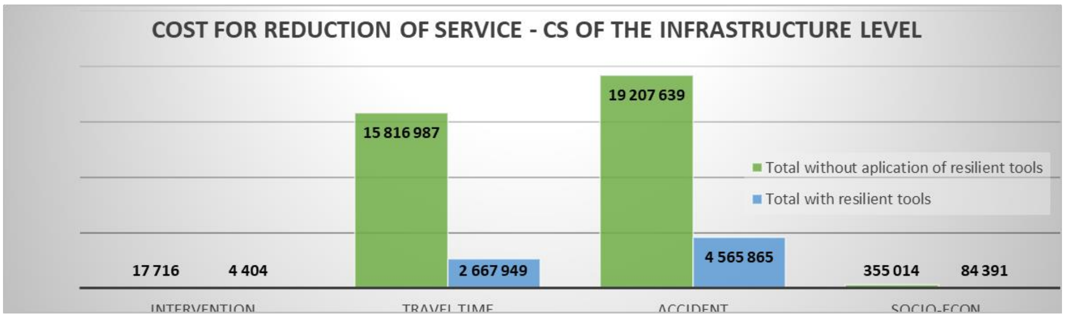

Figure 55. CS#6, Costs for Reduction of Service – CS of Infrastructure Level (with and without application of FORESEE Tools), extracted from Tool.

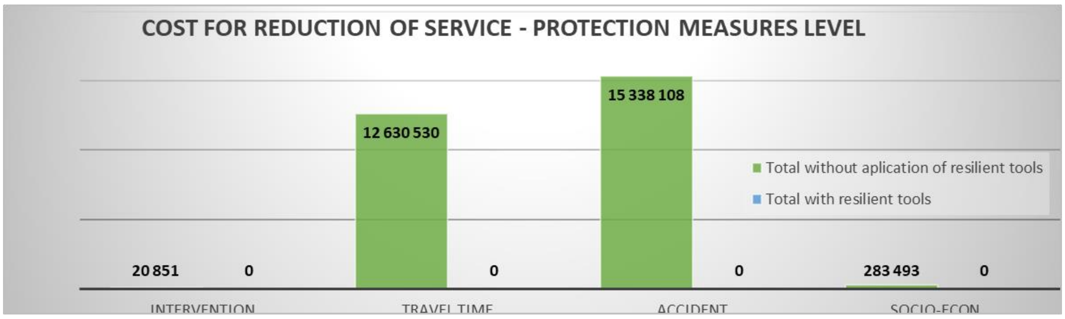

Figure 56. CS#6, Costs for Reduction of Service – Protection Measures Level (with and without application of FORESEE Tools), extracted from Tool.

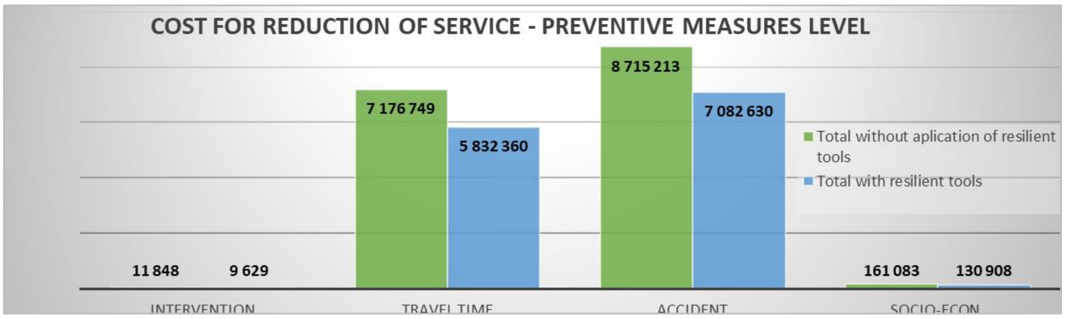

Figure 57. CS#6, Costs for Reduction of Service – Preventive Measures Level (with and without application of FORESEE Tools), extracted from Tool.

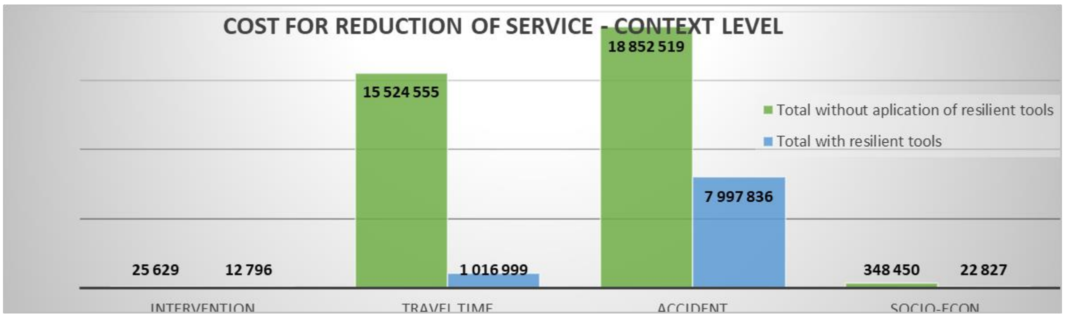

Figure 58. CS#6, Costs for Reduction of Service – Context Level (with and without application of FORESEE Tools), extracted from Tool.

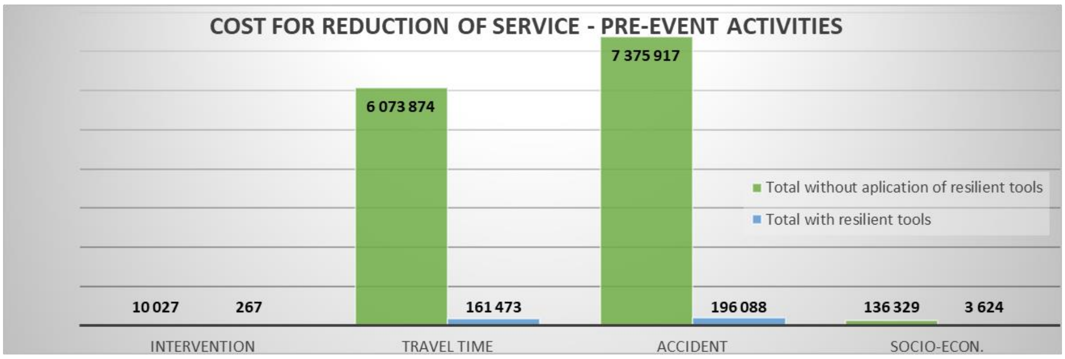

Figure 59. CS#6, Costs for Reduction of Service – Pre-Event Activities Level (with and without application of FORESEE Tools), extracted from Tool.

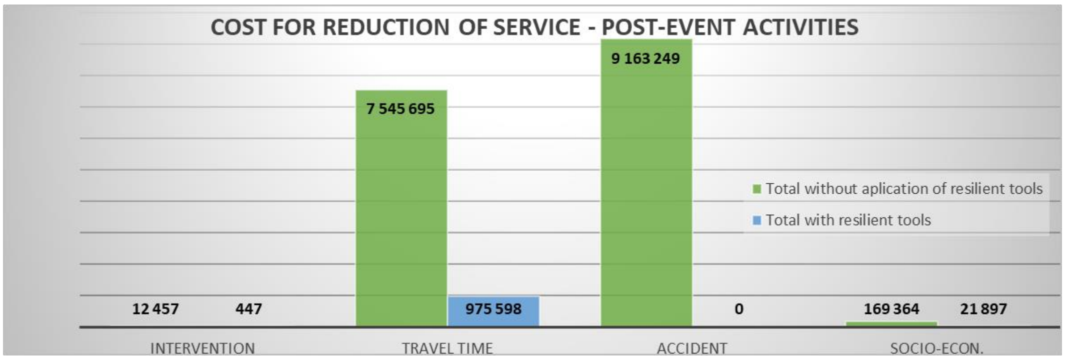

Figure 60. CS#6, Costs for Reduction of Service – Post-Event Activities Level (with and without application of FORESEE Tools), extracted from Tool.

Figure 61. CS#6, Costs for Reduction of Service – SHM Availability Level (with and without application of FORESEE Tools), extracted from Tool.

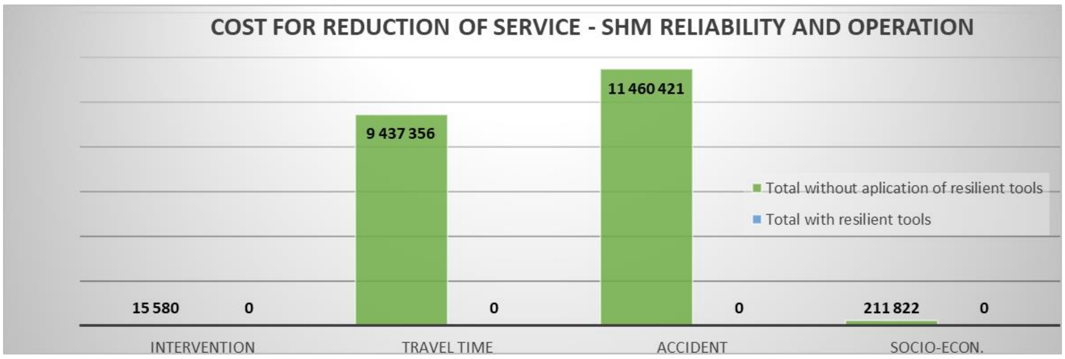

Figure 62. CS#6, Costs for Reduction of Service – SHM Reliability and Operation Level (with and without application of FORESEE Tools), extracted from Tool.

Figure 63. CS#6, Costs for Reduction of Service – Inspection Plan Level (with and without application of FORESEE Tools), extracted from Tool.

Figure 64. CS#6, Costs for Reduction of Service – Inspection Operation Level (with and without application of FORESEE Tools), extracted from tool.

Figure 65. CS#6, Costs for Reduction of Service – Maintenance Level (with and without application of FORESEE Tools), extracted from Tool.

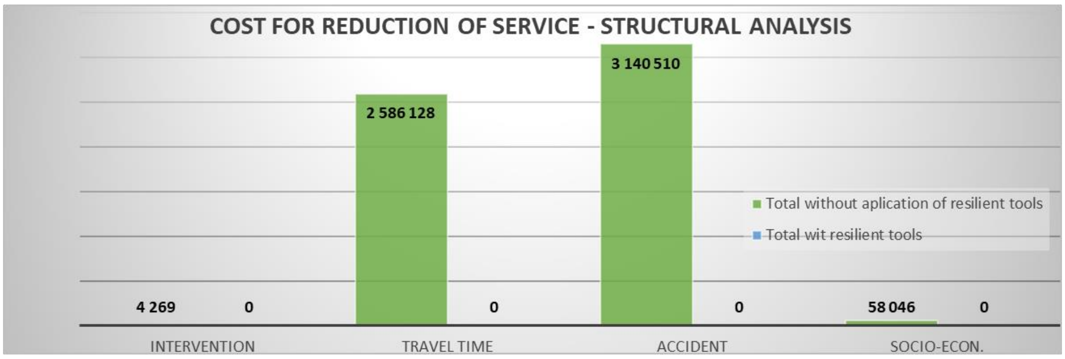

Figure 66. CS#6, Costs for Reduction of Service – Structural Analysis Level (with and without application of FORESEE Tools), extracted from Tool.

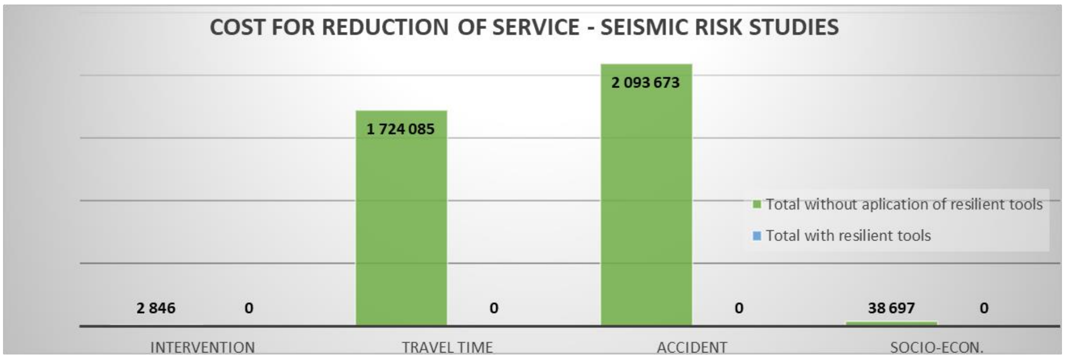

Figure 67. CS#6, Costs for Reduction of Service – Seismic Risks Studies Level (with and without application of FORESEE Tools), extracted from Tool.

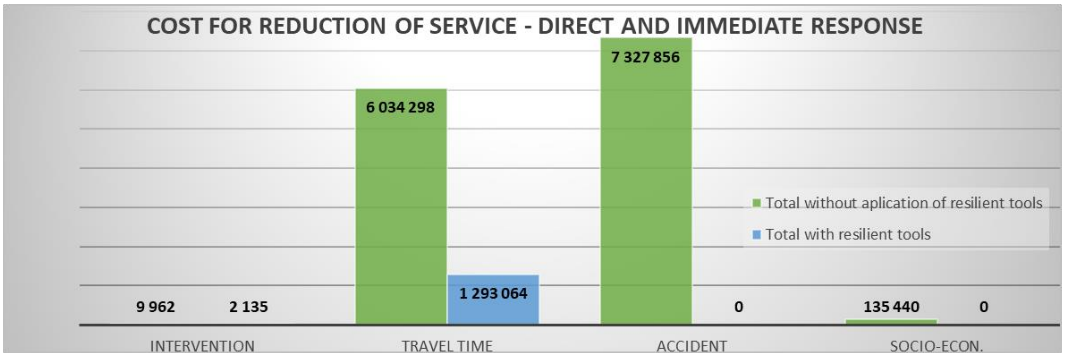

Figure 68. CS#6, Costs for Reduction of Service – Direct and Immediate Response Level (with and without application of FORESEE Tools), extracted from Tool.

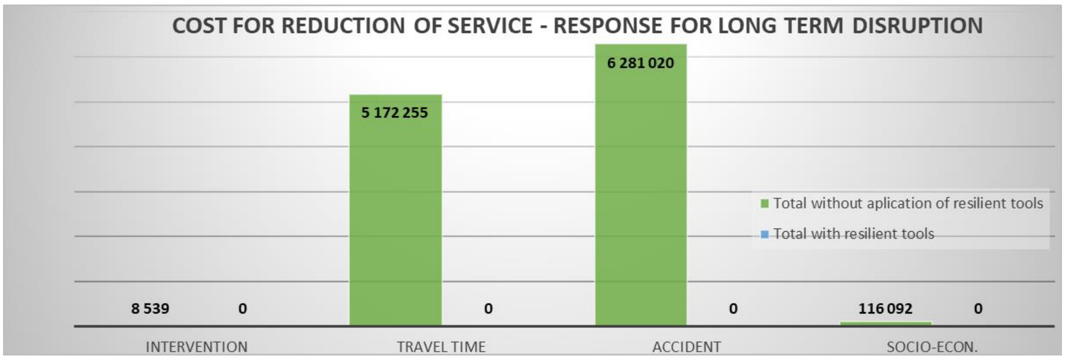

Figure 69. CS#6, Costs for Reduction of Service – Response for Long Term Disruption Level (with and without application of FORESEE Tools), extracted from Tool.

9. REFERENCES

Adey, Bryan T., Claudio Martani, Clemens Kielhauser, Ignacio Robles, Natalia Papathanasiou, and Marcel Burkhalter. "Deliverable D1.1: Guideline to measure Levels of Service and Resilience in infrastructures." FORESEE Project, 2019.

Adey, Bryan T., Claudio Martani, Clemens Kielhauser. "Deliverable D1.2: Guideline to set target levels of service and resilience for infrastructures." FORESEE Project (FORESEE Project), 2019.

Pérez Hernando, M. A. et al., 2020. Deliverable D1.3 Examples of using Levels of Service and resilience in governance., s.l.: FORESEE Project.

Robles, Ignacio, Gonzalo Antolín, Antonio Herrera, Montesclaros Gutiérrez, and Víctor Centeno. Deliverable D3.7. Final version of the Traffic Module. FORESEE Project, 2020.

Roldán, Alex, Pablo Pascual, Daniel Jato, Pedro Serrano, Francisco Ballester, and Fernando Cañizal. Deliverable D2.5: GIS risk analysis platform generating prioritised ranked site/asset risk map." FORESEE Project, 2019.

Cademartori, Marcello, Saimir Osmani, Daniele Partorelli, Sara Fozza, and Claudio Bellini. Deliverable D3.4. Fragility Functions, Vulnerability Functions and Decision Support Module (DSM)." FORESEE Project, 2020.

Cademartori, Marcello, Saimir Osmani, Daniele Partorelli, Sara Fozza, Claudio Bellini and Vincenzo Cerreta Deliverable D3.8. Fragility Functions, Vulnerability Functions and Decision Support Module (DSM)." FORESEE Project, 2021.

Toribio-Díaz, C., Jiménez-Redondo, N., Beltrán, I. & Tarrago, N., 2021. Deliverable D7.1 Framework for the application of FORESEE Resilience PLans, based on use cases, risk scenarios and analysis of impacts.

Toribio-Díaz, C. et al., 2021. Deliverable D7.5 Design, construction and remediation plans, s.l.: FORESEE Project.

Álvarez, María Calvete. et al., 2021. Deliverable D7.4 Management and Contingency plans, s.l.: FORESEE Project.

Jiménez, José Carlos. et al., 2021. Deliverable D7.6 Operational and Maintenance plans, s.l.: FORESEE Project.