- FORESEE -

Future proofing strategies FOr RESilient transport networks against Extreme Events

– Deliverable 6.2 –

IT Case Study #1
A24 Highway (Torano-Carsoli)

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1 INTRODUCTION

The aim of Deliverable 6.2 "*IT Case Study #1*" is to describe the activities that were done within Case Study #1 to test and validate the FORESEE tools, namely this deliverable will consist in the validation of the FORESEE Toolkit in a section of a A24 Highway (linking Carsoli and Torano, Italy) in different hazard scenarios to validate the FORESEE project outcomes in order to select and validate the best technical solutions to increase the level of resilience, and to plan future maintenance, contingency and emergency interventions.

2 CASE STUDY #1 DESCRIPTION

The case study focusses on heavy snow and earthquake hazard scenarios on a section of the A24 Highway (from km 52 to km 73) to evaluate, through the Foresee Tools, taking into account the data coming from past events (e.g. L'Aquila Earthquake of 2009) and trying to use the tools to make a comparison with the previous events.
The idea is to understand to what extent the FORESEE tools are capable to raise the level of resilience, by helping the infrastructure manager in achieving the target identified according to the guidelines developed by ETH (Deliverable D1.1.).

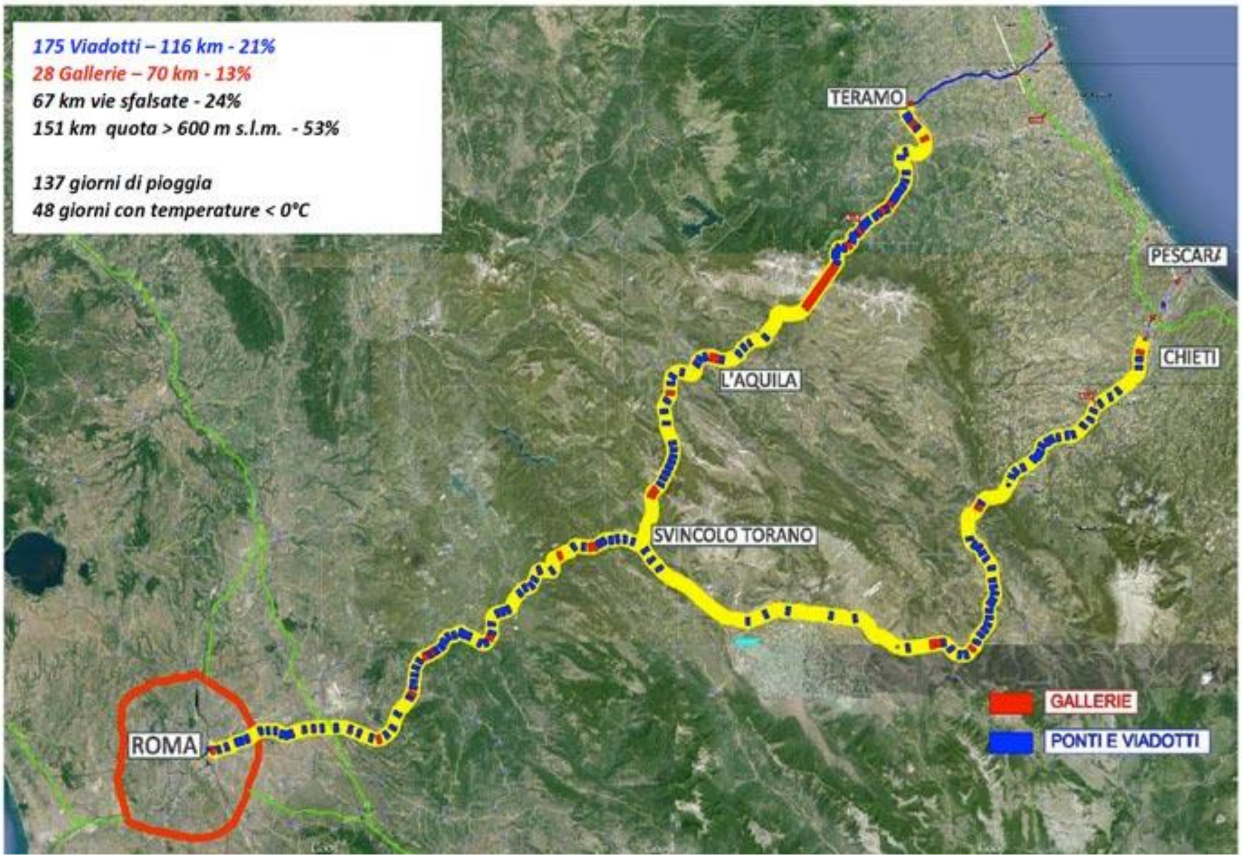


Figure 1 - A24 overview within Central Italy

2.1. DESCRIPTION OF THE INFRASTRUCTURE

The highway A24 or "Strada dei Parchi", is a highway connecting Rome to the Adriatic Sea. First planned in 1973 to connect Tyrrhenian to Adriatic highways, the route currently ends on Teramo and continue by dual-carriageway up to A14 "Teramo-Giulianova" toll road, ending near the Adriatic Sea. The considered section of the A24 highway connects Carsoli and Torano and it is located near the small city of Pietrasecca, in the region of Abruzzo (Italy).

The A24, especially its Apennine section in winter, is particularly prone to bad weather with sudden storms, strong winds, fog and ice. Snow chains on board or snow tyres from 15 November to 15 April are mandatory.

The main characteristics of the Carsoli-Torano section are:

- 21 Km of Highway
- N. 13 bridge
- N. 3 tunnels
- Average Annual Daily Traffic (AADT) 10.705 vehicles

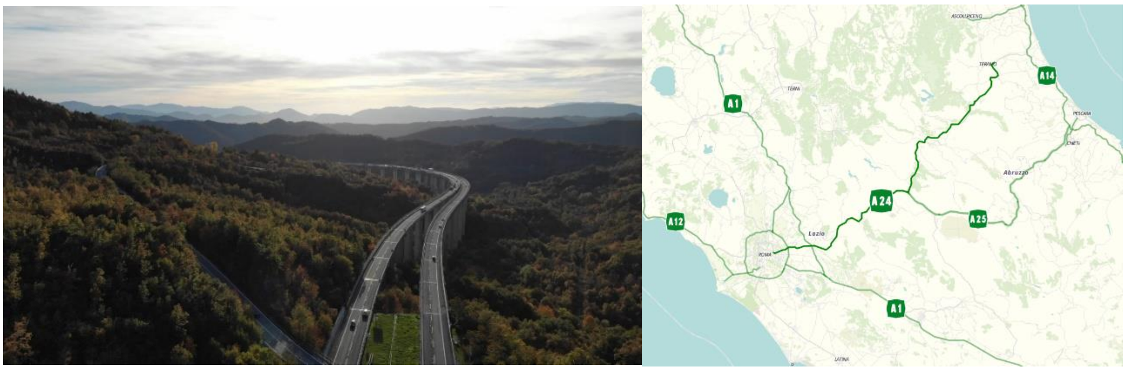


Figure 2 - A24 highway section

2.2 HAZARD DESCRIPTION

Due to the localization of the A24 highway, former extreme events of earthquakes and storms (heavy snow) have been analysed and there are data available regarding risks, damages and reduction of service. As a result of the earthquake occurred near L'Aquila city in 6/4/2009, beside the extreme distruction of the L'Aquila city and many villages nearby with more than 300 death, the A24 was completely closed in the section before the one we are analysing (between Valle del Salto and Assergi) in both directions, and the Rome-Tornimparte section (in which the Carsoli-Torano insist) was totally closed to heavy goods vehicles over 7.5 tonnes for several weeks.

Also the snow hazard generated big slowdown of the viability and closure on the highway, like the storm happened in 4/2/2012, which caused a snow avalanche on the considered highway section, with closure of the highway for several days.

3 SCENARIO CARD & VALIDATION CONDITIONS

3.1 Scenario card for CASE STUDY#1 A24 CARSOLI-TORANO

The highway A24 is an existing route, which corresponds to the life cycle (LC) of the operating and maintenance phase , and we considered on that respect the operation and maintenance aspects.

The A24 section between Carsoli and Torano has been studied in two different scenarios, taking into account two extreme events, which affects the regular service of the highway traffic:

- Earthquake: risk of moderate of severe events which may bring to partial or total closing of the highway to evaluate, through the Foresee Tools, the enforcement of the contingency plan and the emergency procedures.

- Heavy snow: improve the emergency/contingency procedures, to face Heavy snow/avalanche threats. Using the tools for a comparative analysis with a previous disruptive event.

Table 1 – Case Study #1 scenario overview

CS #1	**scenario**	
LC phase	Operation & Maintenance,	**M**
risk	Earthquake, Snow	E, S
transport	Road,	R
scale	National,	N
location	Italy,	I
	LC phase (M), risk (E, S), transport (R), scale (N), location (I)	

3.2 VALIDATION METHODOLOGY AND PROCEDURE

In the following, the output from the newly developed FORESEE tools and the procedure already used in the operativity of the A24 highway maintenance department was comparatively validated with the output from the newly developed FORESEE tools in order to improve the resilience of the highway infrastructure and service in the event of hazards.

For this purpose, the Key Resilience Indicator (KRI) and Key Resilience Targets (KRT) were defined in the first step (see section 3.3) and used for the selection of the FORESEE tools for this Case Study #1.
The information regarding the requirements, modelling and output was theoretically validated mainly on the basis of 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 9).

In the final evaluation, possible suggestions for improvements for the real use and commercialization of the FORESEE tools are pointed out (see section 10) and the results of the validation of CS#1 are summarised once again as a conclusion (see section 11).

The FORESEE tools selected to improve the resilience of this infrastructure are:

Table 2 - FORESEE tools overview for Case Study #1

TOOL	***Name***	***Developer***	
D 1.1	Resilience Guidelines to measure Level of Service & Resilience	ETHZ	√
D 1.2	Set Targets	ETHZ	√
T 2.2	Risk Mapping	UC	√
T 3.4.1	Traffic Module	WSP	√
T 3.4.2	Fragility and Vulnerability Analysis & Decision Support Module	RINA-C	√
T 4.4	Hybrid Data Fusion Framework	ETH	√

T 5.5	Command and Control Center	FRA	√
T 7.1	Definition of framework: use cases, risk scenarios and analysis of impact	CEM	√
T 7.2	Design, construction and remediation plans	CEM	√
T 7.3	Operational and maintenance plans	TEC	√
T 7.4	Management and contingency plans	ICC	√
Solutions catalogue			
T 4.2	Earthquake Platform	CEM	*
T 3.3	Sustainable Drainage System	CEM	*
D 3.5	New Family of PA-pavements	UC	*

3.3 SELECTED FORESEE RESULTS AND ITS POSSIBLE CONNECTION WITH THE PREVIOS KRI IN CS1

After a detailed analysis several indicators were considered starting from the guidelines developed by ETH in Work Package 1 (namely in D1.1. and D1.2). Based on that indicators, we identified the most promising tools that can raise the level of resilience and improving the general situation.

The FORESEE results selected to improve the resilience of this infrastructure are:

Table 3 - FORESEE tools and connection with Scenario and KPI/KRI

TOOL	***Name***	***Developer***	***KPI-KRI connection***	***Case Study 1***	
				SCENARIO	
				Design & Construction , **D**	Operation & Maintenance , **M**
D 1.1	**Resilience Guidelines to measure Level of Service & Resilience**	**ETHZ**	L1-Infrastructure L2 Environment L3 Organization	√	√
D 1.2	**Set Targets**	**ETHZ**	L1-Infrastructure L2 Environment L3 Organization	√	√
T 2.2	**Risk Mapping**	**UC**	1.3.2 3.1.1 3.1.2	√	
T 3.4.1	**Traffic Module**	**WSP**	1.2.2 1.1.3 1.2.4 1.2.5		

T 3.4.2	**Fragility and Vulnerability Analysis & Decision Support Module**	**RINA-C**	3.1.1 3.1.2		
T 4.4	**Hybrid Data Fusion Framework**	**ETH**	Not developed for CS#1		
T 5.5	**Command and Control Center**	**FRA**	Not developed for CS#1	√	√
T 7.1	**Definition of framework: use cases, risk scenarios and analysis of impact**	**CEM**	Framework for T 7.2/3/4	√	√
T 7.2	**Design, construction and remediation plans**	**CEM**	3.1.2 3.1.3	√	
T 7.3	**Operational and maintenance plans**	**TEC**	3.1.2 3.1.3 3.2.4 3.2.5 3.2.6		√
T 7.4	**Management and contingency plans**	**ICC**			√

4 SYSTEM VALIDATION IN CASE STUDY #1 BY CASE STUDY LEADER

In the following figure the logical approach is presented: the validation structure is the same for each case study, in order to give a common approach to all project partners.

The first two action are related to understand the current status: on that respect the

1. Definition of framework: use cases, risk scenarios and analysis of impact
2. Resilience guidelines to measure level of Service & Resilience

helped to have a clear overview on the current status of the infrastructure, by calculating the current resilience level including detailed information, which were peculiar of the case study (e.g. check Annex I of D1.1. , this information includes as an example traffic volume, type of asset, cost for traffic delays, accident, and others), together with the potential risk scenarios.

After this propaedeutic part, we proceeded with the

3. Set of Targets (KRI)

Which fixed the objective in terms of "increased" resilience to be reached after the application of the FORESEE tools.

Then we "validated" all the different tools which were considered strategic and useful to reach the previously identified Key Resilience Targets (KRI), namely

4. Risk Mapping
5. Traffic Module

6. Fragility and Vulnerability Analysis & Decision Support Module
7. Design, construction and remediation plans
8. Operational and maintenance plans

After this phase, we took into account if these tools provided a contribution for increasing the level of resilience, in order to calculate again the level of resilience and assess the net benefit analysis (if possible), bringing to the infrastructure a detailed and quantitative analysis of the potential benefit coming from the adoption and use of the FORESEE selected tools.

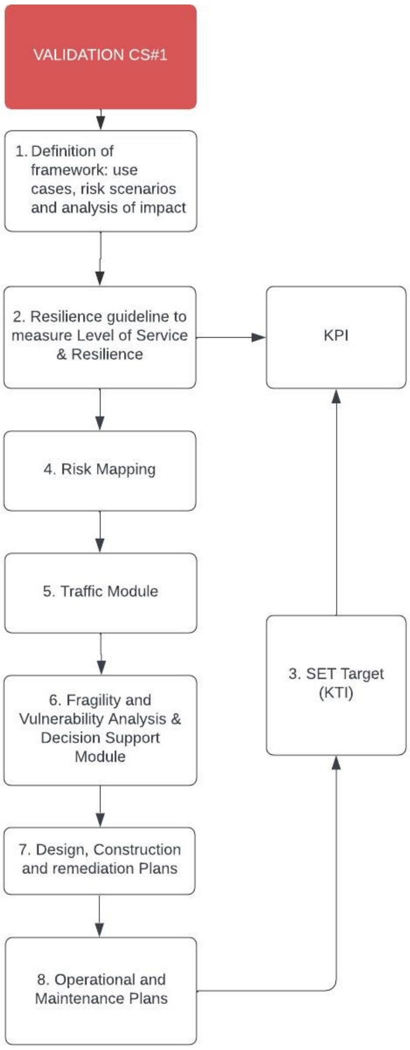


Figure 3 - Case Study#1 Validation flow

5 OUTPUTS COMING FROM THE VALIDATION PHASE

The results of the application of the FORESEE Tools to the CS#1 Carsoli-Torano

Table 4 - FORESEE tools output and KRI

			OUTPUTS	KRI
T 7.1	D7.1	Definition of framework: use cases, risk scenarios and analysis of impact	Definition of a framework to develop the Resilience Plan for the Use Case: Roadway + Snow/ice Highway + Earthquake	Framework for T 7.2/3/4
D 1.1		Resilience Guidelines to measure Level of Service & Resilience	Guidelines and tools for management of assets and infrastructures under different hazards	L1-Infrastructure L2 Environment L3 Organization
D 1.2		Set Targets		
T 2.2	D2.5	Risk Mapping	Hazard maps and risk maps of the infrastructure's area to identify the risks prior to the more accurate and more local scale quantification.	1.3.2 3.1.1 3.1.2
T 3.4.1	D3.3/D3.7	Traffic Module		1.2.2 1.1.3 1.2.4 1.2.5
T 3.4.2	D3.8	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	3.1.1 3.1.2
T 7.2	D7.2/D7.5	Design, construction and remediation plans	develop design, construction and remediation plans in order to adapt and increase the resilience of the infrastructure	3.1.2 3.1.3
T 7.3	D7.3/D7.6	Operational and maintenance plans	increase transport infrastructures' safety, efficiency and productivity factors regarding the occurrence of extreme events	3.1.2 3.1.3 3.2.4 3.2.5 3.2.6

5.1 DEFINITION OF FRAMEWORK: USE CASES, RISK SCENARIOS AND ANALYSIS OF IMPACT (T7.1)

Transport systems are exposed to an increasing wide variety of hazards that could lead to reductions in the provided services, to the acceleration of the deterioration process and ageing, or even to the total collapse of the infrastructures. These trends, together with increasing traffic loads and transport demand, are putting further strain on transport systems.

Through the definition of an integrated framework which can represent a picture of the state of art of the infrastructure, focusing on the characteristic technical aspects of each element of the infrastructure (i.e. all the bridges and tunnels of the highway) and on the impact that each element can be relate to the general integrity of the infrastructure, the resilience in general, using standardized references it's possible to define a more structured management of the infrastructure focused on the improvement of the Resilience Plans.

The framework proposed on the D7.1 therefore allows to define punctually the infrastructure through the definition of the transport system, the hazard, the associated risk assessment and the application of the following resilience plan.

Although this approach is more focused on the planning and design phases of the infrastructure, it can also be exported during the maintenance phase, in order to structure the resilience plans in a more efficient way, especially to give a general and uniform framework of a infrastructure composed by a large number of elements with different age and maintenance status, but that clearly insist in the same geographical place, under the same environmental conditions, so the same hazards.
Below it is possible to find a synthetic comparison between the current situation and the possible application of the Foresee tools, trying also to identify some potential quantitative numbers coming from the adoption of the tools. It is worth to highlight that this numbers are to be considered and expert's approximation, since the FORESEE tools were not used by the infrastructure manager on real application.

Table 5 - FORESEE tool expert evaluation

Was this type of analysis made before FORESEE? How it was made?	The framework is used as basis to drive the steps to evaluate the resilience of a transport system facing an extreme event and to guide the application of the Resilience Plans according to the results from the resilience evaluation. Those operation are made
How does FORESEE improve the results/analysis previously made?	The framework is used as basis to drive the steps to evaluate the resilience of a transport system facing an extreme event and to guide the application of the Resilience Plans according to the results from the resilience evaluation. This integrated approach takes in consideration the infrastructure, the hazard, the resilience evaluation and the implementation of the plans, trying to

	find an harmonised approach, which can gave a benefit in an holistic approach.
How does this FORESEE result improve your infrastructure's management	The same as above
If it was not made, How does this FORESEE result improve your infrastructure's management?	-
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%)	More evaluable in task 7.2-7.3-7.4 in which we can evaluate the Resilience Plan

5.2 RESILIENCE GUIDELINES TO MEASURE LEVEL OF SERVICE & RESILIENCE TO SET OF THE TARGETS - KEY RESILIENCE INDICATOR (KRI) AND TARGETS (KRT)

According to deliverable (D) 1.1 "Guideline to measure Levels of Service and resilience in infrastructures" and deliverable D 1.2 "Guideline to set target levels of service and resilience for infrastructures" the KRIs and KRTs are identified to evaluate the possible variation due to the application of the Foresee tools. The KRI and KRT for CS#1 have been determined in compliance with the D 1.1 and D 1.2 through the following steps.

In the first step, the input variables for the measuring the service are defined. These are classified between event-independent (see annex 3.1) and event-dependent inputs (see annex 3.2).
The event-independent parameters include general theoretical data from the literature, real data and expert knowledge from Strada dei Parchi infrastructure managers.
The event-dependent inputs to measure the service are related to the hazard event of earthquake and snow for CS#1. The comparative data for the hazard assessment are provided here on the one hand by available practical cost and recover data from previous events. On the other hand, the estimation of the average delay after an event is again compared with the results by previous experience.
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 A (and annex 3.3), a distinction is made between intervention, travel time, accident and socio-economic costs.

Table 6 - excerpt from D1.1. application on Case Study #1

Impact on service	Earthquake
Cost	**Cost**
Intervention	14.700
Travel time	62.050
Accident	53.500
Socio-economic	4.380
TOTAL	134.630

Impact on service	Snow
Cost	**Cost**
Intervention	49
Travel time	102
Accident	5.150
Socio-economic	7
TOTAL	5.308

In the second step of the KRI and KRT determination, the current condition state of the CS#1 highway infrastructure and hazard prevention strategies are estimated for the influencing variables provided by literature by ETH. The indicators for measuring snow and earthquake resilience (S, E) are categorised hierarchically into three levels of detail. At the top level "0", a distinction is made between infrastructure (E1, S1), environmental (E2, S2) and organisational (E3, S3) indicators. In the lowest level, the current condition state and with it the possibility to optimize is defined for each of the indicators. For each indicator, a number of possible values are available as a scale. The measure for the current indicator state is defined in CS#1 based on expert knowledge together with the infrastructure manager (see annex 3.4).

For the final analysis of the service and intervention costs with regard to the indicators and targets, two further factors are taken into account. On the one hand, the intervention, travel time, accident and socio-economic cost value presented in in *Table 6 - excerpt from D1.1. application on Case Study #1* 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 3.5). In addition, 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 managers (see annex 3.6).

As an interim, the following *Table **7** - D1.1. earthquake indicators chosen for Case Study #1*shows the evaluation of the LOS as a cost value, taking into account the two weighting factors and depending on the resilience indicators and targets.

Table 7 - D1.1. earthquake indicators chosen for Case Study #1

ID	Indicator	Intervention	Travel time	Accident	Socio-econ.	Total
E.1.1.1	Age / Age of replacement of the warning system	7.350	31.025	26.750	2.190	67.315
E.1.1.2	Age / Age of replacement of safe shut down system	6.615	27.923	24.075	1.971	60.584
E.1.1.3	Condition state of infrastructure (pre-event)	7.149	30.178	26.020	2.130	65.477
E.1.1.4	Condition state of protective structures/systems (pre-event)	4.542	19.170	16.529	1.353	41.594
E.1.1.5	Condition state of assistance alert systems (pre-event)	81	340	293	24	738
E.1.1.6	Expected condition state of infrastructure (post-event)	10.961	46.267	39.892	3.266	100.385
E.1.1.7	Expected condition state of protective structures/systems (post-event)	9.131	38.545	33.233	2.721	83.630
E.1.1.8	Expected condition state of assistance alert systems (post-event)	4.922	20.778	17.915	1.467	45.081
E.1.2.1	The possibility of building a temporary alternative route for vehicles	6.304	26.610	22.943	1.878	57.736
E.1.2.2	The possibility of using another means to satisfy transport demand	13.180	55.635	47.969	3.927	120.711
E.1.2.3	The number of possible existing alternative ways to deviate vehicles	10.501	44.324	38.216	3.129	96.170
E.1.2.4	The presence and functioning of the warning system	1.487	6.275	5.411	443	13.616
E.1.2.5	The presence of a safe shutdown system	6.329	26.716	23.035	1.886	57.966
E.1.2.6	The presence of emergency / evacuation paths	13.629	57.529	49.602	4.061	124.822
E.1.2.7	The presence of special measures to help evacuate persons	2.416	10.198	8.792	720	22.126
E.1.3.1	Complience with the current seismic design code	11.463	48.385	41.718	3.415	104.980
E.1.3.2	Complience with the current slope stability design code	7.386	31.175	26.879	2.201	67.640
E.1.3.3	Strength of construction material used	729	3.076	2.652	217	6.673
E.1.3.4	Presence of systems to reduce seismic effects	5.703	24.074	20.757	1.699	52.234
E.1.3.5	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	11.541	48.715	42.002	3.439	105.697
E.1.3.6	Adequate systems to reduce seismic effects	13.429	56.687	48.876	4.001	122.994
E.1.3.7	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	1.701	7.181	6.192	507	15.582
E.2.1.1	Height	7.745	32.691	28.187	2.308	70.931
E.2.1.2	Accessibility	14.460	61.039	52.628	4.309	132.436
E.2.1.3	Presence of persons/property below the infrastructure	10.084	42.567	36.702	3.005	92.357
E.2.1.4	Extent of past damages due to hazards	1.788	7.546	6.506	533	16.373
E.2.1.5	Hazard zone	2.851	12.033	10.375	849	26.107
E.2.1.6	Duration of past down time due to hazards	1.769	7.468	6.439	527	16.204
E.2.1.7	Land type	13.657	57.648	49.704	4.069	125.078
E.2.1.8	Budget availability	1.834	7.741	6.674	546	16.795
E.2.1.9	Traffic	2.910	12.285	10.592	867	26.654
E.2.1.10	Hazards goods traffic	4.486	18.937	16.328	1.337	41.087
E.2.1.11	Flammable goods traffic	12.343	52.103	44.924	3.678	113.048
E.3.1.1	The presence of a monitoring strategy	11.899	50.227	43.306	3.545	108.978
E.3.1.2	The presence of an maintenance strategy	12.618	53.261	45.922	3.760	115.560
E.3.1.3	The extent of interventions executed prior to the event	1.377	5.811	5.011	410	12.609
E.3.2.1	The presence of an emergency plan	1.165	4.916	4.239	347	10.667
E.3.2.2	Practice of the emergency plan	6.011	25.372	21.876	1.791	55.050
E.3.2.3	Review/update of the emergency plan	14.101	59.520	51.318	4.201	129.140
E.3.2.4	Expected time for tendering	9.739	41.107	35.443	2.902	89.190
E.3.2.5	Expected time for demolition	2.663	11.240	9.691	793	24.387
E.3.2.6	Expecetd time for construction	1.154	4.870	4.199	344	10.566

Table 8 - D1.1. snow indicators chosen for Case Study #1

ID	Indicator	Intervention	Travel time	Accident	Socio-econ.	Total
S1.1.1	Condition state of protective structures/systems	26	55	2.773	4	2.858
S1.2.1	The possibility of using another means to satisfy transport demand	2	4	205	0	211
S1.2.2	The number of possible existing alternative ways to deviate vehicles	10	21	1.068	1	1.101
S1.2.3	The presence of emergency / evacuation paths	35	73	3.661	5	3.774
S1.3.1	Presence of the drainage system	6	13	676	1	697
S1.3.2	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	42	87	4.387	6	4.522
S1.3.3	Adequate dimensioning of the drainage system	12	26	1.300	2	1.340
S1.3.4	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	5	11	560	1	577
S2.1.1	Height	44	91	4.612	6	4.754
S2.1.2	Frequency of past hazards	15	32	1.608	2	1.657
S2.1.3	Severity of past hazards	24	50	2.529	4	2.606
S2.1.4	Expected frequency of future hazards	18	37	1.849	3	1.906
S2.1.5	Expected severity of future hazards	48	100	5.035	7	5.190
S2.1.6	Budget availability	28	59	2.959	4	3.050
S2.1.7	Traffic	39	81	4.073	6	4.198
S2.1.8	Hazards goods traffic	32	66	3.311	5	3.413
S3.1.1	The extent of recent maintenance of surrounding area	17	35	1.755	2	1.809
S3.2.1	The presence of an emergency plan	48	99	5.015	7	5.169
S3.2.2	Practice of the emergency plan	17	35	1.751	2	1.805
S3.2.3	Review/update of the emergency plan	33	69	3.480	5	3.587
S3.2.4	Expected time for execution of work commissioned	17	35	1.755	2	1.809

In the third and final step, the resulting LOS cost values of the resilience indicators in the hazard event of flooding 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 highway infrastructure manager and take into account (if necessary) legal requirements as a minimum target. In terms of a cost-benefit analysis, the resilience indicators and targets shown in *Table **9** - Resilience indicators & target related to earthquake* C provide by far the maximum benefit and are consequently selected as key resilience indicators and targets for CS#1 (the complete comparison can be found in annex 3.7).

Table 9 - Resilience indicators & target related to earthquake

ID	Costs	Target		Max/ actual	Int.	Travel time	Safety	Socio-econ.	Total	B/C	Net benefit
E.1.1.3		4		*Max*	*7.149*	*30.178*	*26.020*	*2.130*	*65.477*		
	0			0	0	0	0	0	0	0,00	0
	10.000			1	1.430	6.036	5.204	426	13.095	1,31	3.095
	10.000			2	1.430	6.036	5.204	426	13.095	1,31	6.191
	12.000			3	1.430	6.036	5.204	426	13.095	1,09	7.286
	12.000			4	1.430	6.036	5.204	426	13.095	1,09	8.382
	15.000			5	1.430	6.036	5.204	426	13.095	0,87	6.477
E.1.1.4		2		*Max*	*4.542*	*19.170*	*16.529*	*1.353*	*41.594*		
	0			0	0	0	0	0	0	0,00	0
	6.000			1	908	3.834	3.306	271	8.319	1,39	2.319
	15.000			2	908	3.834	3.306	271	8.319	0,55	-4.362
	25.000			3	908	3.834	3.306	271	8.319	0,33	-21.044
	35.000			4	908	3.834	3.306	271	8.319	0,24	-47.725
	40.000			5	908	3.834	3.306	271	8.319	0,21	-79.406
E.1.2.6		2		*Max*		*57.529*		*4.061*	*61.590*		
	0			0		0		0	0	0,00	0
	20.000			1		28.765		2.030	30.795	1,54	10.795
	30.000			2		28.765		2.030	30.795	1,03	11.590
E.1.3.1		1		*Max*	*11.463*	*48.385*	*41.718*	*3.415*	*104.980*		
	0			0	0	0	0	0	0	0,00	0
	50.000			1	5.731	24.192	20.859	1.708	52.490	1,05	2.490
	80.000			2	5.731	24.192	20.859	1.708	52.490	0,66	-25.020
E.3.2.1		2		*Max*		*4.916*		*347*	*5.263*		
	0			0		0		0	0	0,00	0
	2.000			1		2.458		174	2.632	1,32	632
	2.000			2		2.458		174	2.632	1,32	1.263

Table 10 - Resilience indicators & target related to snow

ID	Costs	Target		Max/ actual	Int.	Travel time	Safety	Socio-econ.	Total	B/C	Net benefit
S1.1.1		4		*Max*	*26*	*55*	*2.773*	*4*	*2.858*		
	0			0	0	0	0	0	0	0,00	0
	200			1	5	11	555	1	572	2,86	372
	300			2	5	11	555	1	572	1,91	643
	400			3	5	11	555	1	572	1,43	815
	500			4	5	11	555	1	572	1,14	886
	600			5	5	11	555	1	572	0,95	858
S1.2.3		1		Max		73		5	78		
	0			0		0		0	0	0,00	0
	30			1		36		3	39	1,29	9
	50			2		36		3	39	0,78	-2
S3.2.1		1		*Max*		*99*		*7*	*106*		
	0			0		0		0	0	0,00	0
	100			1		50		4	53	0,53	-47
	100			2		50		4	53	0,53	-94

In order to set the target levels of service and resilience of the transport system in case study 1: A24 Highway linking Carsoli and Torano, the following items have been considered:

- - the expected reduction in the level of service following both an earthquake and a snowfall of average intensity,
- - the resilience indicators following both an earthquake and a snowfall, and
- - the maximum expected reduction in the level of service for specific indicator (estimated considering both equal and differentiated weights)

N.5 indicators of resilience are selected to be compliant on managing the earthquake hazard:

- E.1.1.3 Condition state of infrastructure (pre-event)
- E.1.1.4 Condition state of protective structures/systems (pre-event)
- E.1.2.6. The presence of emergency / evacuation paths
- E.1.3.1 Compliance with the current seismic design code
- E.3.2.1. The presence of an emergency plan

N.3 indicators of resilience are selected to be compliant on managing the heavy snow hazard:

- S 1.1.1. Condition state of infrastructure (pre-event)
- S.1.2.3. The presence of emergency / evacuation paths
- S.3.2.1. The presence of an emergency plan

Table 11 - FORESEE tool expert evaluation

Was this type of analysis made before FORESEE? How it was made?	The current procedures are based on the past events' experience, and included in the available plans for emergency towards earthquakes and snow events. However, they are not directly related to the quality of service that the infrastructure manager must have to guarantee to the users*
How does FORESEE improve the results/analysis previously made?	Foresee's resilience target system allow a better correlation between the infrastructure condition and the quality/level of the service
How does this FORESEE result improve your infrastructure's management	Foresee's resilience target system allow a better correlation between the infrastructure condition and the quality/level of the service, which may be used for punctual analysis to structure preventive maintenance activities useful for maintaining or increasing the resilience and the level of service of the different sections of infrastructure
If it was not made, How does this FORESEE result improve your infrastructure's management ?	At the moment, no current tools are available to assess resilience level: it could be a real added value, to be integrated in the current management systems, to proper simulate and evaluate the impact of relevant changes .
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%)	An overall optimization is expected from the use and adoption of this tool.

*The Chart of Services is mainly linked to the quality of the service for all users, in particular it analyzes and records:

- travel safety, linked to communications traveling for the user, such as the timely communication of construction sites along the route that could create delays;
- the regularity of the service, linked to the visibility of the signs and the quality of retroflection;
- the comfort of the service, linked to the presence and functionality of the services in the service areas;
- services available for disabled travelers, if available and functional;
- information for the users, linked to the quality of customer care for requests from the motorway users.

5.3 RISK MAPPING

Within this task a large scale data in relation to weather (rainfall and temperature), elevation, geology, land cover or lithology, among others, have been used to identify areas that are vulnerable to climate-related hazards, to develop a GIS-based application for the identification and prioritising of areas of high vulnerability of disruption caused by extreme natural events, following the scheme above.

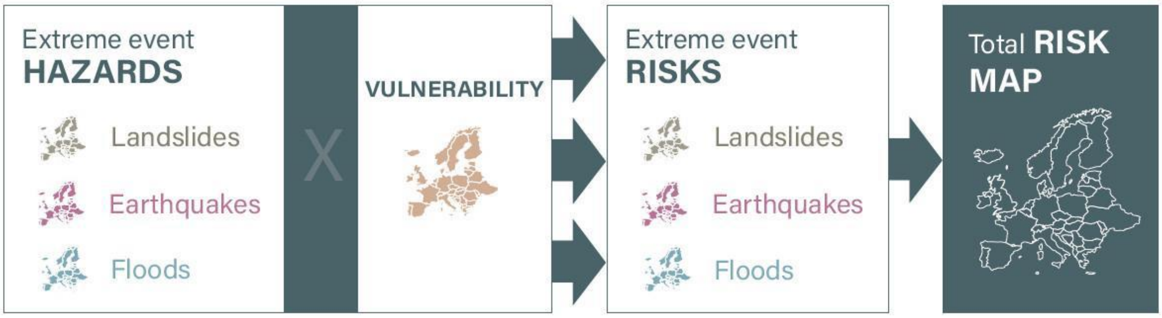


Figure 4 - excerpt from Risk Mapping Tool

The main outcomes that can be obtained from running the GIS-based application developed in this Task (T 2.2) of the FORESEE project are: hazard maps and risk maps. Those results are calculated through a regression models that make use of open source databases as predictor variables and catalogues of past real events in the European territory as response variables.

Currently no predictive or risk classification systems are used in the section/region of the case study 1. What is currently analysed are the same data used by Task 2.2 trying to intervene in advance where a extreme calamitous event is going to happen. Currently for the observation of earthquakes is used the National Institute of Geophysics and Volcanology (IGVN) that keeps track of all seismic events, issuing warnings in case of seismic sequences of concern. As for the extreme snowy events, the reference used is "Viabilità Italia"[1] a National Coordination Centre in the field of

[1] https://www.interno.gov.it/it/ministero/osservatori-commissioni-e-centri-coordinamento/viabilita-italia

road mobility, linked to the Ministry of Interior and Ministry of Transport, that from the data of the weather control units and from historical series provides for technical-administrative coordination and the adoption of rapid and shared decisions in real time and provides for operational interventions, also preventive, to manage crisis situations to the country's road system, arising from adverse weather events or other extreme events.
Foresee's approach is therefore advantageous as it internalises certain risk assessment procedures, increasing the resilience values associated with the adoption of preventive maintenance measures, although the national integrated supervision allows for a more detailed operational approach.

The GIS-based application developed in T2.2 certainly finds the maximum of its application in the design phase of the infrastructure, thus being able to assess in advance a quick and large scale identification of the most important natural risks that may affect the road infrastructures.

Below it is possible to find a synthetic comparison between the current situation and the possible application of the Foresee tools, trying also to identify some potential quantitative numbers coming from the adoption of the tools. It is worth to highlight that this numbers are to be considered and expert's approximation, since the FORESEE tools were not used by the infrastructure manager on real application.

Table 12 - FORESEE tool expert evaluation

Was this type of analysis made before FORESEE? How it was made?	Currently this type of analysis is made in a similar way through specific tools that are deployed by relevant institutions and are available for free (e.g. Earthquake maps are developed by INGV, the Italian National Institute for Physics and Vulcanology)[2]
How does FORESEE improve the results/analysis previously made?	The integrate approach, which analyzes more hazards and give to the infrastructure manager the possibility to make , can give a more objective and wide evaluation
How does this FORESEE result improve your infrastructure's management	Prioritizing the risks the infrastructure manager can manage the hazards in a more predictive way
If it was not made, How does this FORESEE result improve your infrastructure's management ?	-
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's very hard to give a quantification of the benefit, some current activities are made in a similar way in the management phase of the infrastructure. This integrated approach could be more efficient if applied in the design and construction phase to evaluate the opportunity to increase resilience to peculiar hazard after the risk mapping evaluation.

[2] http://esse1.mi.ingv.it/

5.4 TRAFFIC MODULE

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

- MODEL: The Use Case does Not have a Transport demand model available to FORESEE.

- TRAFFIC DATA: 2020-03-25: The Case Study provided AADT figures for wide sections of the concession and the evolution of this figures from 2014 to 2018. It also provided traffic data by vehicle category and traffic flow figures for the first half of 2018.

- SCENARIO/PROBABILISTIC DATA: 2019-11-21: RINA provided a list of 13 bridges and 3 tunnels for which the Annual probability of capacity loss under the earthquake hazard was made available. These 15 network elements fall within only three of the traffic section where AADT values where made available.

The traffic module was used on CS#1 in order to understand the capability to identify alternative routes, linked with the Fragility And Vulnerability Analysis developed by RINA (next paragraph.)

It is not possible to provide a stand-alone evaluation of this tool, since its use and purpose is strictly connected with the tool developed by RINA.

5.5 FRAGILITY AND VULNERABILITY ANALYSIS & DECISION SUPPORT MODULE

The principal aim of this tool, in collaboration with the traffic module, is to make available an helpful instrument to the infrastructure managers and owners in addressing the economic resources in the achievement of the safety levels required. In fact, the fully implementation and performance of the simulation method needs the interaction of the Fragility Functions, Vulnerability Functions and Decision Support Module, described here, and the Traffic Module analysis, described in the Deliverable D 3.7, Final version of Traffic Module. The main architecture of the Tool, the Fragility and Vulnerability Analysis and the Decision Support Module, is composed by two principal parts, The Fragility and Vulnerability Analysis and the Decision Support Module. This because the Traffic Module must be linked to the present Tool in order to enable the transport infrastructures' assessment. The tool was used and applied to the A24 motorway segment between the interchanges of Carsoli and Torano considering the Earthquake as main hazard. The analysis proposed through this framework are compared to past events occurred in this section, e.g. Aquila earthquake occurred in 06/04/2009. In the CS1 two types of asset are considered, bridges and tunnels. The asset are positioned in the infrastructure considering their position.

Figure 5 - A24 Highway layout from the Traffic Module (D3.8 excerpt)

The overall length of CS#1 that was analysed is composed 13 bridges and 3 tunnels, for a 15km distance. On that respect, the database of the infrastructure manager was used to understand all the main characteristics of every single asset, such as number of spans, span length, year of construction, asset construction typologies etc.
This analysis lead to a full picture of the main features related to fragility, vulnerability, costs and restoration.

Table 13 - Overview of Case Study#1 asset details

Asset		Coordinates	Length [m]	Initial km	Final km
Bridge_1	Peschieto 2	42°05'48.7"N 13°04'47.4"E	248	52+677	52+925
Bridge_2	Peschieto 1	42°05'56.9"N 13°04'52.9"E	60	53+054	53+114
Bridge_3	Valle Mura	42°06'18.5"N 13°05'04.5"E	272	53+693	53+965
Bridge_4	Valle Intensa	42°06'54.0"N 13°06'58.4"E	389	56+934	57+323
Bridge_5	Pietrasecca	42°07'33.3"N 13°06'52.6"E	1860	57+649	59+509
Bridge_6	Riasola 1	42°08'36.3"N 13°09'17.1"E	90	62+450	62+540
Bridge_7	Riasola 2	42°08'34.5"N 13°09'42.4"E	90	63+038	63+128
Bridge_8	S. Angelo 1-2	42°09'01.0"N 13°12'53.1"E	382	67+478	67+860
Bridge_9	S. Angelo 5	42°09'06.3"N 13°14'02.4"E	40	69+347	69+387
Bridge_10	Piè di Pgao 1	42°09'05.9"N 13°14'12.9"E	100	69+580	69+680
Bridge_11	Piè di Pgao 2	42°09'01.9"N 13°14'23.9"E	222	69+868	70+090
Bridge_12	Piè di Pgao 3	42°08'58.9"N 13°14'36.3"E	180	70+210	70+390
Bridge_13	Fiume Salto	42°08'56.0"N 13°14'59.9"E	539	70+603	71+142
Tunnel_1	Pietrasecca	42° 7'53.91"N 13° 7'33.74	1115	59+690	60+805
Tunnel_2	Colle Mulino	42° 8'30.12"N 13°10'18.7	1041	63+858	64+899
Tunnel_3	Monte S. Angelo	42° 8'45.29"N 13°11'40.2	1559	65+963	67+522

Below it is possible to find a synthetic comparison between the current situation and the possible application of the Foresee tools, trying also to identify some potential quantitative numbers coming from the adoption of the tools. It is worth to highlight that this numbers are to be considered and expert's approximation, since the FORESEE tools were not used by the infrastructure manager on real application.

Table 14 - FORESEE tool expert evaluation

Was this type of analysis made before FORESEE? How it was made?	At the moment the analysis is carried out using an asset management tool, which basically catalogue and establish an historical database of the features of each relevant element (e.g. bridge, tunnel, viaduct). Every single defect is tracked and monitored, but there is not a correlation between a hazard and its effect on the structure element. The decisions are taken based on the evidence of the analysis, without a direct link between hazard, risk and status of the infrastructure.
How does FORESEE improve the results/analysis previously made?	The current tools do not provide a complete analysis and overview of all the different factors and elements.
How does this FORESEE result improve your infrastructure's management	The main factor is the capability to define asset's vulnerability/fragility against a specific hazard type: the result of this activity can be used to asset's operativity losses for different damage levels scenario make a vulnerability analysis to quantify the potential losses in terms of operativity and traffic continuity.
If it was not made, How does this FORESEE result improve your infrastructure's management ?	The main impact of this tool is related to the possibility to have an estimation in terms of direct economic loss, taking into account all the different elements (e.g. traffic, infrastructure condition state, level of resilience). Moreover, the possibility to have an estimation related to the operativity loss lead to the added value for the infrastructure manager to have a clear idea, in case of a specific event, which are the main affected elements, for how many days there will be a decrease in the operativity, the different risk scenarios and the resilience estimation.
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%)	In the figure below there is a theoretical Comparison between 2009 Earthquake loss of operativity (infrastructure manager data), which represents the added value of using the FORESEE tool, leading to a concrete savings in terms of reduction in the number of workers deployed on-field and also the restoration time.

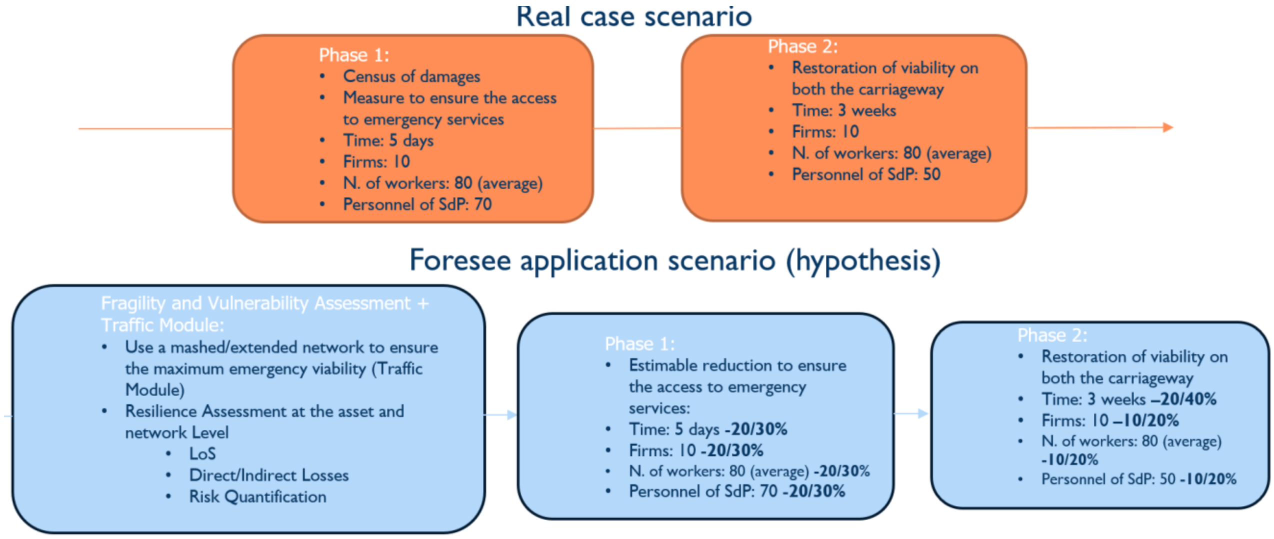


Figure 6 – Simulated scenario applying FORESEE tool

5.6 DESIGN, CONSTRUCTION AND REMEDIATION PLANS

The main objective of the Task 7.2 – defined in the D7.2, is to develop design, construction and remediation plans in order to adapt and increase the LoS and resilience of existing or future infrastructure facing extreme events.
The aim of this task is to develop a design approach based on performance criteria that allows tailoring the design of transport infrastructures to match the level of service demanded by different stakeholders under different risk scenarios.
The first phase of this task has focused on the development of this design approach, developing a catalogue of measures (including FORESEE developments) in the second phase of this task this approach has been redefined, also through the feedback from the Case Studies leaders.

To define Definition of a Design approach based on Resilience Performance Criteria which will allow evaluating the functionality of a transport infrastructure under different **risk scenarios**, in order to set different performance objectives during and after an extreme event, a performance measures have been evaluated. 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 is able to 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 have been established for those hazard levels.

In this document, a methodology has been developed to objectively assess the criticality of a route. The methodology consists of a separate assessment of the following four criteria: C1: Operational and economic relevance; C2: Access to critical infrastructure; C3: Access to essential services; C4: Presence and suitability of alternative routes.

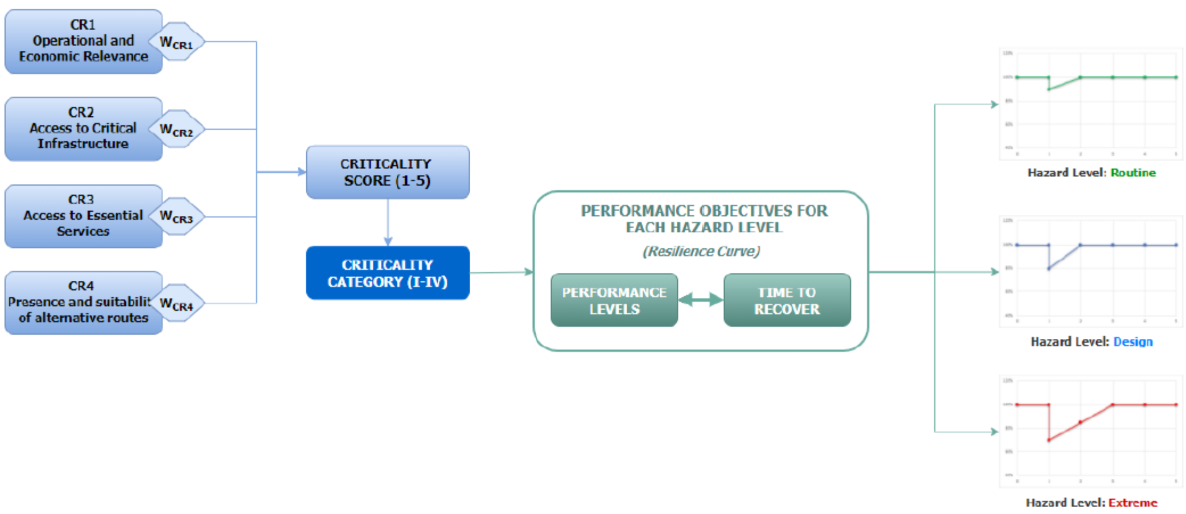


Figure 7 - Methodology workflow overview

The tool developed and shown in the Annex I of this Deliverable, allows the user to enter the desired performance (as a percentage) for each recovery period (within 12 hours, 1-3 days, etc.), then the resilience curve is built from these input parameters.

This tool allows for a simple visualisation of resilience targets for each infrastructure considered. On the one hand, it is a useful tool to highlight among different assets which are the most challenging in terms of resilience and therefore where to focus efforts. On the other hand, for each infrastructure, it also allows to identify whether it is needed to focus on designing for strengthening the robustness of the system (that is minimizing service drop) or for strengthening the capacity to recover (that is speeding the recovery period).

In the following it's possible to appreciate the Performance Based Levels evaluation about the Strada dei Parchi's highway and bridge on the A24 highway for the earthquake hazard:

CRITICALITY EVALUATION

Finally, the criticality of the route is assessed based on the score obtained for each criteria:

Criteria	Score	Weight
CR1. Operational and economic relevance	2,85	0,20
CR2. Access to Critical Infrastructures	5	0,20
CR3. Access to essential services	5	0,20
CR4. Alternative routes	5	0,40

CRITICALITY SCORE	**4,57**

Figure 8 - Case Study#1 criticality evaluation

HAZARD LEVELS

In this page, user can select a hazard and define the return period of the event to be in each of the hazard levels: routine, design and extreme.

HAZARD 1

EARTHQUAKE	**Routine**	**Design**	**Extreme**
Return Period of the event (years)	50	100	500
Probability of being exceeded in 50 years (%)	63,58	39,50	9,53

Figure 9 - Earthquake hazard levels

HAZARD

Hazard Type	**EARTHQUAKE**
Hazard Level	**Extreme**

Return Period of the event (years)	500
Probabiilty of being exceeded in 50 years (%)	9,53

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+
Highway	I	0%	10%	25%	50%	100%				
Bridge	I	0%	10%	25%	50%	75%	100%			

On the figure above it is possible to understand the impact of a specific earthquake on the highway structures, considering specifically the time needed to recover and to ensure the desired performance levels.

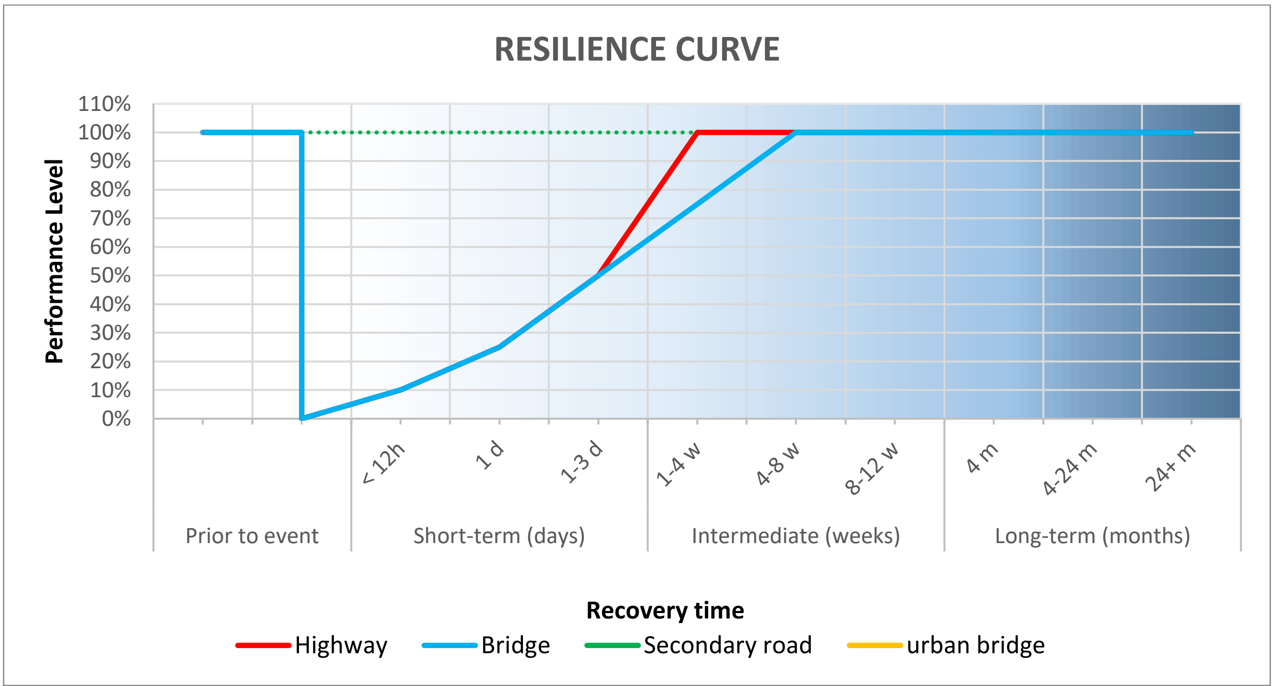


Figure 10 - Resilience curve for Case Study #1

In the figure above it is possible to appreciate the capability to recover, considering the time needed to ensure different performances levels, giving a clear idea to the infrastructure manager on the potential impact of an hazard event.

Question	***Impact***
Was this type of analysis made before FORESEE? How it was made?	At the moment the analysis is carried out using an asset management tool, which basically catalogue and establish an historical database of the features of each relevant element (e.g. bridge, tunnel, viaduct), related to the current status of every infrastructures on the highway. So, currently there is not a correlation between the performance levels of the infrastructure and the time to recover after an extreme event. Of course, there are thresholds of performance-safety levels that each infrastructure must respect, but it's related to the status of the infrastructure, not to an extreme event hazard magnitude nor to the relevance of the infrastructure itself.
How does FORESEE improve the results/analysis previously made?	The Performance Based Levels evaluation is an improvement of the selection of the prioritization of intervention. A catalogue of possible intervention tailored on the different infrastructures on the highway can improve and raise the resilience level on the different asset or at least improve the performance level of a transport infrastructure to reduce the impact of an hazard.
How does this FORESEE result improve your infrastructure's management	The correlation among infrastructure relevance, performance and magnitude of an extreme event can more accurately delineate the intervention need to increase the level of resilience respect the level of service requested by the infrastructure owner.
If it was not made, How does this FORESEE result improve your infrastructure's management ?	The main impact of this tool is related to the possibility to have an estimation in terms of performance level in resilience, to understand where to intervein to improve it. This is a different prospective in comparison of the current approach that is related on the maintaining the same level of service and acting only after the hazard with the related drop of resilience.
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%)	Although it is not easy to calculate direct savings with such an approach, the possibility of adopting solutions that can improve, in a targeted manner, the resilience curve of individual infrastructures along the network can improve the decision-making of the actions to be performed to avoid too long interruptions in the service.

5.7 OPERATIONAL AND MAINTENANCE PLANS

Operational and maintenance plans can 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.

The main purpose of the operational and maintenance tool (part of D7.6 "*Operational and Maintenance Plans(Final)")* is meant to propose a guidelines to deploy resilience schemes, in order to lower the impact and consequences of extreme events for different types of infrastructures covering their whole life cycle; also they suggest how to increase the level of reliability and service for the different risk scenarios that were addressed within the deliverable D7.6.

These plans are based on risk assessment and cost-benefit analysis, and are meant to implement the new FORESEE strategies and tools. In particular they offer a catalogue of how the different FORESEE tools may increase safety, efficiency and productivity in maintenance planning and in daily operation.

For all the main details regarding the tool please refer to D7.6, below there are some considerations after the application of the tool to case Study#1, with a specific focus on earthquake.

The comparison between the current situation and with the (theoretical) use of the FORESEE tools provided a clear and valuable improvement, raising the level of resilience and the efficiency in the response from the infrastructure manager.

INTIAL OP. & MAINTENANCE PLAN

ID	Level	Intervention	Travel time	Accident	Socio-econ.	% OF FULLFILLMENT
	Total	2.113.203	32.992	232.884	2.329	
L1	Infrastructure	958.540	14.965	105.635	1.056	43%
L2	Environment	786.722	12.282	86.700	867	56%
L3	Organization	367.941	5.744	40.549	405	61%
L1.1	CS of the infrastructure	381.568	5.957	42.050	421	58%
L1.2	Protective measures	361.334	5.641	39.821	398	20%
L1.3	Preventive measures	215.638	3.367	23.764	238	57%
L2.1	Context	730.862	11.410	80.544	805	54%
L3.1	Pre-event activities	138.115	2.156	15.221	152	50%
L3.2	Post-event activities	229.826	3.588	25.328	253	65%

Figure 11 - Current status of A24 highway

FORESEE OP. & MAINTENANCE PLAN						
ID	**Level**	**Interventio n**	**Travel time**	**Accident**	**Socio-econ.**	**% OF FULLFILLMENT**
	Total	316.871	8.333	38.173	598	
L1	Infrastructure	157.230	5.303	18.279	384	64%
L2	Environment	93.079	1.991	15.547	141	77%
L3	Organization	66.563	1.039	4.348	73	87%
L1.1	CS of the infrastructure	133.056	2.077	15.615	156	69%
L1.2	Protective measures	0	2.848	0	201	50%
L1.3	Preventive measures	24.173	377	2.664	27	86%
L2.1	Context	93.079	1.991	15.547	141	76%
L3.1	Pre-event activities	39.450	616	4.348	43	83%
L3.2	Post-event activities	27.113	423	0	30	88%

Figure 12 – "Improved" status of A24 highway

Question	***Impact***
Was this type of analysis made before FORESEE? How it was made?	Risk management is carried out within the Strada dei Parchi Company, where risks, impacts and actions to address are clearly are identified. As it concerns operation and maintenance, the tool may be used to improve the level of service, by adding a new step in the existing procedure, leading to an overall risk & resilience-based aproach
How does FORESEE improve the results/analysis previously made?	This tool can be used to better define resilience plans for design and for operation & maintenance purposes in compliance with the risk strategies, objectives and management procedures of the organization.
How does this FORESEE result improve your infrastructure's management	A better traffic management and extreme events management are expected.
If it was not made, How does this FORESEE result improve your infrastructure's management ?	The tool can support and improve the existing procedures, by facilitating the comparison among different risk scenarios.
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%)	An overall optimization of resources (economic, personnel, safety and travel time) is expected. In particular, as far as it concerns the operation & maintenance, it can be seen that a clear reduction of costs is possible both for safety and interventions, leading to a positive ROI.

6 ASSESSMENT OF THE RESILIENCE LEVEL OF THE INFRASTRUCTURE AND IMPROVEMENT AFTER THE USE OF FORESEE TOOLS

The assessment of the resilience level has been done based on the guidelines developed within D1.1 and D1.2 : a two-fold analysis was required in order to assess firstly the current status of the infrastructure, and then it was calculated again considering the impact of FORESEE tools on the identified level of resilience, leading to a potential positive change.

6.1 NET BENEFIT ANALYSIS CS#1

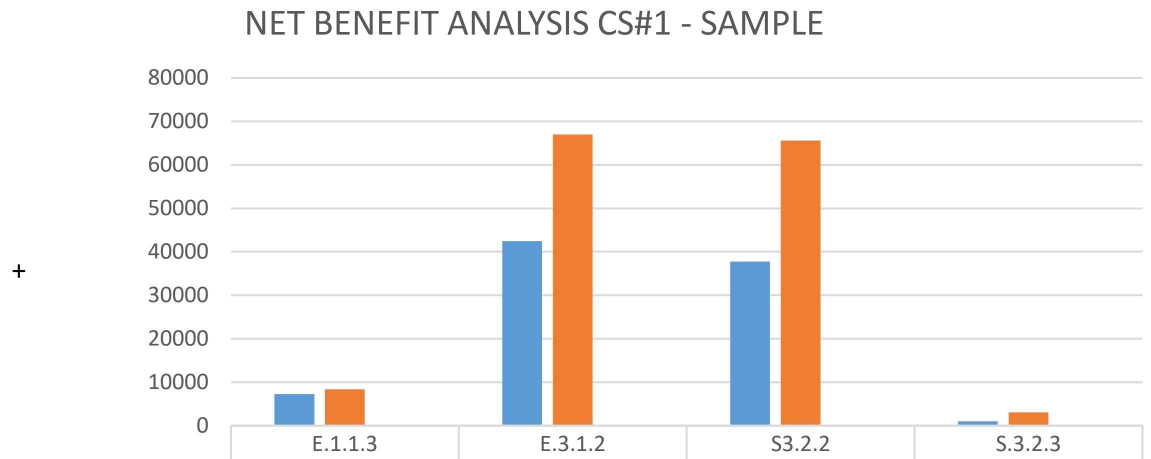
Following the guidelines developed by Work Package 1, we were able to quantify the potential benefits coming from the (theoretical) use of the selected FORESEE tools for Case Study #1.

The analysis has been performed in a qualitative way, trying to reflect together with the infrastructure manager (Strada dei Parchi S.p.A.) the potential outcomes from the different tools: then we tried to quantify these potential results by using the

We tried to couple the Key Resilience Indicators and Targets with the tools, trying to properly connect the impact of the tools on the respective targets: these connections are (again) theoretical, since we were not able to use the tools or apply them, our work is based on the tools' deliverables and their application on the Case Study #1 data and infrastructure (whenever possible and applicable).

Below you can find a graph representing the increase in the resilience level, by boosting the indicators thanks to the use of the tools, together with the total cost requested to fulfill the resilience target, compared with the total benefits achieved by the infrastructure manager.

It is evident that the impact of these countermeasures may results in potential gains with a Benefit/cost ratio positive, leading to an overall positive impact on the infrastructure manager current level of resilience and procedures.



	E.1.1.3	E.3.1.2	S3.2.2	S.3.2.3
Net benefit (Actual) [1k €]	7286,46	42489,14	37780,17	1000
Net benefit (Target) [1k €]	8381,95	66978,29	65560,34	3053,92
Increase	87%	63%	58%	33%

Figure 13 CS#1, Net benefit analysis - SAMPLE

¡Error! No se encuentra el origen de la referencia.3 demonstrates that the net benefit of LoS costs and thus the resilience of the infrastructure to hazards can be increased in a substantial way.

7 POTENTIAL IMPROVEMENTS OF THE TOOLKIT FOR REAL COMMERCIALISATION

A series of improvements are proposed to be implemented in the FORESEE TOOL, in view of the results obtained for the Case Study #1.

According to the Infrastructure manager (Strada dei Parchi), following a detailed feedback that considered the current availability of tools and the user experience with those elements.

FORESEE TOOL	***INFRASTRUCTURE MANAGER FEEDBACK – AREA OF IMPROVEMENT***
Risk mapping	The tool seems to be hardly improvable, maybe it can be properly related to specific country-situation, linking national data with European data to make also a comparison in different boundary conditions
Traffic module	To improve the capability to integrate legacy systems OR to use another commercial tool: at the moment the "traffic module" is not a stand-alone tool but linked to the use of a commercial software, leading to a restricted-usage by users
Fragility and vulnerability analysis & decision support module	The tool is very promising: it can be improved by adding more infrastructure data typologies, and linking the module to legacy systems, making it interoperable and open for integration by the infrastructure manager.
Design, construction and remediation plans	The tool is useful and can be adopted by the infrastructure manager, however it could be tailored to specific type of infrastructure
Operational and maintenance plans	The tool is easy to use and can lead to a general improvement in the current procedure: we highly recommend to make it (as the tool above) integrated in a software suite, in order to link with current systems commercially available and used by the infrastructure manager.

8 CONCLUSION

The Deliverable D6.2 was related to the validation of selected FORESEE tools on case Study#1, which is a section of A24 highway in Italy, which is managed by Strada dei Parchi S.p.A.

It is worth to remind that almost all the selected FORESEE tools could only be evaluated theoretically based on the existing deliverables. The practical application, which is essential for a better understanding of the tools, can only be carried out to a very limited extent at the present status (e. g. only with T.7.2), which affected the comprehension of the outputs and improvements of the developed tools. Therefore, only a qualitative form of validation is possible (if any).

However, it was possible to recognize the preliminary added value of using new tools specifically designed for understanding the current status in terms of resilience and, consequently, selecting specific solutions for a proper prioritization of investment related to critical asset, in order to raise the level of resilience and be better prepared in case of a specific event, starting from the past experience but improving the current procedures with new capabilities and information.

ANNEX 1. TOOL VERIFICATION BY TOOL DEVELOPERS

1.1 Outputs from the FORESEE Tool 2.2 "Risk Mapping"

FORESEE TOOL OUTPUTS: RISK MAPPING

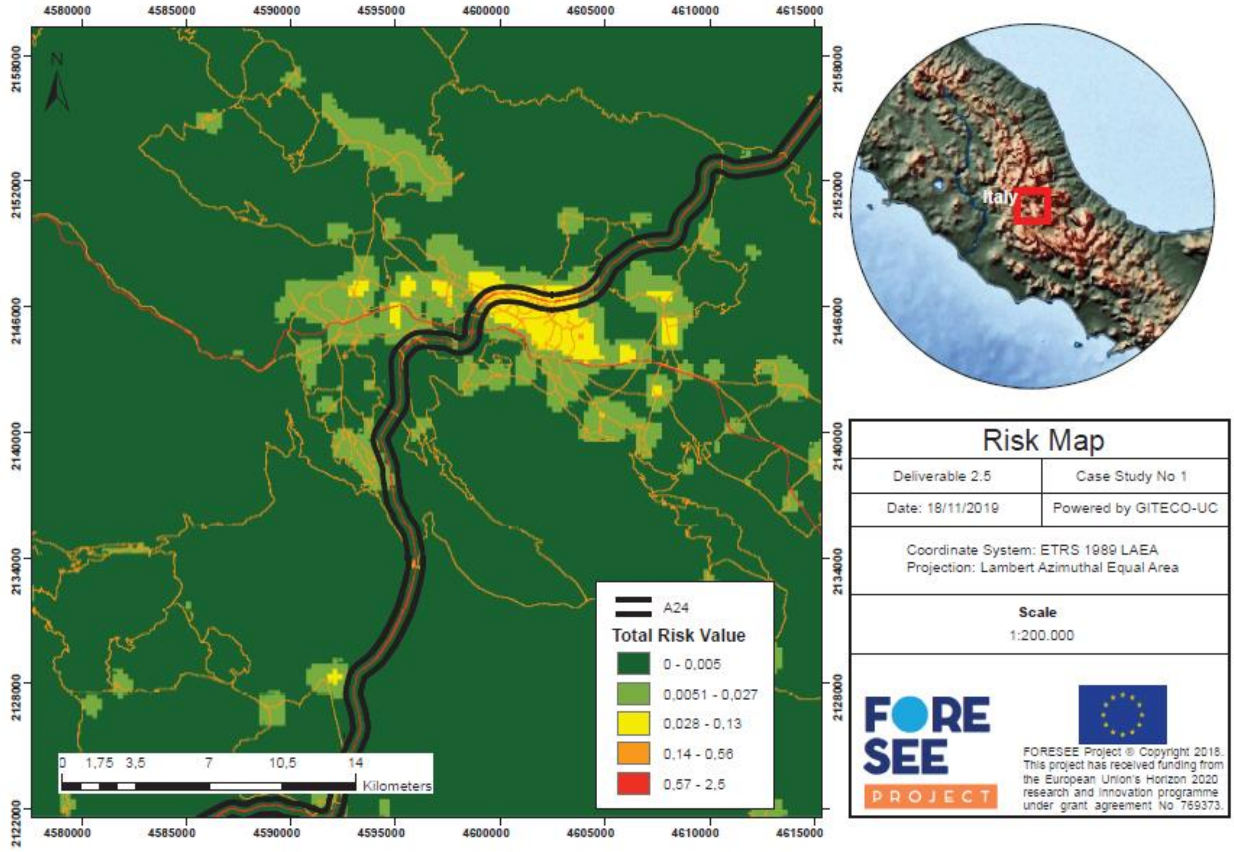


Figure 1. CS#1 Risk Mapping Result

- ✓ Study: No results for specific risk.
- ✓ Proposal: Improvement of scale, and risk type

ANNEX 2. IDENTIFICATION OF KRI AND KRT

3.1 Event-independent inputs to measure the service

Inputs	Symbol	Value
Annual cost of regular maintenance [€/m]	Cm	0,5
Length of the infrastructure [m]*	Li	21500
N. of people traveling per day	P	1000
N. of people traveling per work in a day	Pw	700
N. of people traveling per leisure in a day	Pl	300
Goods travelling per day [trains]	G	10
Cost of work time [€/min]	Cwt	2
Cost of leasure time [€/min]	Clt	1
Socio economic costs per person [€/p.p.]	SECp	0
Socio economic costs for goods [€/train]	SECg	2
Impact of injuries per person [10^3€/p.p.]	Ip	10
Impact of death per person [10^3€/p.p.]	Dp	5000
Speed limit (average between weather condition) [km/h]*	Sl	120
Delay per unit (person or train) per day with no hazard event [min/p.u.]	Dpud_0	5
Property damage probability with no hazard event [%]	Ppd_0	1
Injury probability with no hazard event [%]	Pi_0	1
Death probability with no hazard event [%]	Pd_0	0,01
Property damage per person in case of accident [10^3€/p.p.]	PDp_0	0,5

3.2 Event-dependent inputs to measure the service

Inputs	Symbol	Earthquake [_e]	Snowfall [_s]
Cost of intervention after the event [€/m]	Ci	600	2
Delay per unit (person or train) per day after an event [min/p.u.]	Dpud	100	60
Days to recover in case of accident	D	365	1
Property damage probability per event [%]	Ppd	50	10
Injury probability per event [%]	Pi	10	1
Death probability per event [%]	Pd	1	0,1
Property damage per person in case of accident [10^3€/p.p.]	PDp	5	0,5

3.3 Loss of Service after an earthquake hazard and snow hazard as a cost value

Impact level 1	Symbol	Description	Impact level 2	Symbol	Costs [103^€]			
					Estimate	Computation	Estimate	Computation
Interventions	Ii_e	The impact of executing interventions			12900	(Ci_e*Li)	12900	(Ii_e)
Travel time	Itt_e	The impact of the additional travel time on passengers	Work	Itt.w_e	51100	(Pw*Dppd_e*Cwt*D_e)	62050	(Itt.w_e+Itt.l_e)
			Leisure	Itt.l_e	10950	(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	2500	((Ppd_e/100)*PDp_e*P)	53500	(Is.pd_e+Is.i_e+Is.d_e)
			Injury	Is.i_e	1000	((Ppd_e/100)*Ip_e*P)		
			Death	Is.d_e	50000	((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	3650	(P*Dppd_e*D_e*SECp)	4380	(Ise.p_e+Ise.g_e)
			Goods	Ise.g_e	730	(P*Dppd_e*D_e*SECg)		
Total					132830	(Ii_e+Itt_e+Is_e+Ise_e)		

Earthquake

Impact level 1	Symbol	Description	Impact level 2	Symbol	Costs [103^€]			
					Estimate	Computation	Estimate	Computation
Interventions	Ii_s	The impact of executing interventions			43	(Ci_s*Li)	43	(Ii_s)
Travel time	Itt_s	The impact of the additional travel time on passengers	Work	Itt.w_s	84	(Pw*Dppd_s*Cwt*D_s)	102	(Itt.w_s+Itt.l_s)
			Leisure	Itt.l_s	18	(Pw*Dppd_s*Clt*D_s)		
Safety	Is_s	The impact on the users and affected public due to the user being involved in an accident	Property damage	Is.pd_s	50	((Ppd_s/100)*PDp_s*P)	5150	(Is.pd_s+Is.i_s+Is.d_s)
			Injury	Is.i_s	100	((Ppd_s/100)*Ip_s*P)		
			Death	Is.d_s	5000	((Ppd_s/100)*Dpp_s*P)		
Socio-economic activities	Ise_s	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_s	6	(P*Dppd_s*D_s*SECp)	7	(Ise.p_s+Ise.g_s)
			Goods	Ise.g_s	1	(P*Dppd_s*D_s*SECg)		
Total					5302	(Ii_s+Itt_s+Is_s+Ise_s)		

Snow

3.4 Scale and measures of resilience indicators for earthquake and snow

Level 0	ID	Level 1	ID	Indicator	Scale	Measure	Impact: Intervention	Impact: Travel time	Impact: Accident	Impact: Socio-econ.
Infrastructure	E1.1	CS of the infrastructure	E.1.1.1	Age / Age of replacement of the warning system	3	1			X	X
			E.1.1.2	Age / Age of replacement of safe shut down system	3	1			X	X
			E.1.1.3	Condition state of infrastructure (pre-event)	5	3	X	X	X	X
			E.1.1.4	Condition state of protective structures/systems (pre-event)	5	3	X	X	X	X
			E.1.1.5	Condition state of assistance alert systems (pre-event)	5	1	X	X	X	X
			E.1.1.6	Expected condition state of infrastructure (post-event)	3	2	X	X	X	X
			E.1.1.7	Expected condition state of protective structures/systems (post-event)	3	2	X	X	X	X
			E.1.1.8	Expected condition state of assistance alert systems (post-event)	2	2	X	X	X	X
	E1.2	Protection measures	E.1.2.1	The possibility of building a temporary alternative route for vehicles	2	2		X		X
			E.1.2.2	The possibility of using another means to satisfy transport demand	2	1		X		X
			E.1.2.3	The number of possible existing alternative ways to deviate vehicles	1	0		X		X
			E.1.2.4	The presence and functioning of the warning system	3	1		X		X
			E.1.2.5	The presence of a safe shutdown system	1	1		X		X
			E.1.2.6	The presence of emergency / evacuation paths	2	0		X		X
			E.1.2.7	The presence of special measures to help evacuate persons	2	1		X		X
	E1.3	Preventive measures	E.1.3.1	Complience with the current seismic design code	2	1	X	X	X	X
			E.1.3.2	Complience with the current slope stability design code	2	1	X	X	X	X
			E.1.3.3	Strength of construction material used	3	1	X	X	X	X
			E.1.3.4	Presence of systems to reduce seismic effects	1	1	X	X	X	X
			E.1.3.5	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	1	1	X	X	X	X
			E.1.3.6	Adequate systems to reduce seismic effects	1	1	X	X	X	X
			E.1.3.7	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	1	1	X	X	X	X
Environment	E2.1	Context	E.2.1.1	Height	2	1			X	
			E.2.1.2	Accessibility	3	2	X			
			E.2.1.3	Presence of persons/property below the infrastructure	1	0			X	
			E.2.1.4	Extent of past damages due to hazards	3	1	X			
			E.2.1.5	Hazard zone	2	1	X	X	X	X
			E.2.1.6	Duration of past down time due to hazards	3	1	X			
			E.2.1.7	Land type	3	0	X		X	
			E.2.1.8	Budget availability	2	2	X	X	X	X
			E.2.1.9	Traffic	3	3	X	X	X	X
			E.2.1.10	Hazards goods traffic	2	1			X	
			E.2.1.11	Flammable goods traffic	1	1			X	
Organization	E3.1	Pre-event activities	E.3.1.1	The presence of a monitoring strategy	2	1	X	X	X	X
			E.3.1.2	The presence of an maintenance strategy	2	2	X	X	X	X
			E.3.1.3	The extent of interventions executed prior to the event	2	1	X	X	X	X
	E3.2	Post event activities	E.3.2.1	The presence of an emergency plan	2	0		X		X
			E.3.2.2	Practice of the emergency plan	4	2		X		X
			E.3.2.3	Review/update of the emergency plan	2	2		X	X	X
			E.3.2.4	Expected time for tendering	3	1	X	X		X
			E.3.2.5	Expected time for demolition	3	3	X	X		X
			E.3.2.6	Expecetd time for construction	3	1	X	X		X
					101	54				

Earthquake

ID	Indicator	ID	Indicator	ID	Indicator	Scale	Measure	Impact: Intervention	Impact: Travel time	Impact: Accident	Impact: Socio-econ.
S1	Infrastructure	S1.1	CS of the infrastructure	S1.1.1	Condition state of protective structures/systems	5	3	X	X	X	X
		S1.2	Protection measures	S1.2.1	The possibility of using another means to satisfy transport demand	2	1		X		X
				S1.2.2	The number of possible existing alternative ways to deviate vehicles	2	0		X		X
				S1.2.3	The presence of emergency / evacuation paths	2	0		X		X
		S1.3	Preventive measures	S1.3.1	Presence of the drainage system	2	1	X	X	X	X
				S1.3.2	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	1	1	X	X	X	X
				S1.3.3	Adequate dimensioning of the drainage system	1	1	X	X	X	X
				S1.3.4	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	1	1	X	X	X	X
S2	Environment	S2.1	Context	S2.1.1	Height	2	1			X	
				S2.1.2	Frequency of past hazards	3	2		X	X	X
				S2.1.3	Severity of past hazards	3	0		X	X	X
				S2.1.4	Expected frequency of future hazards	3	1		X	X	X
				S2.1.5	Expected severity of future hazards	3	1		X	X	X
				S2.1.6	Budget availability	2	2	X	X	X	X
				S2.1.7	Traffic	3	3	X	X	X	X
				S2.1.8	Hazards goods traffic	2	1			X	
S3	Organization	S3.1	Pre-event activities	S3.1.1	The extent of recent maintenance of surrounding area	3	2	X	X	X	X
		S3.2	Post event activities	S3.2.1	The presence of an emergency plan	2	0		X		X
				S3.2.2	Practice of the emergency plan	4	3		X		X
				S3.2.3	Review/update of the emergency plan	2	2		X	X	X
				S3.2.4	Expected time for execution of work commissioned	3	1	X	X		X
						51	27				

snow

3.6 Impact factor for using differentiated resilience weights

Impact on the service	ID	Indicator	Intervention	Travel time	Accident	Socio-econ.	Total
50%	E.1.1.1	Age / Age of replacement of the warning system	7.350	31.025	26.750	2.190	67.315
45%	E.1.1.2	Age / Age of replacement of safe shut down system	6.615	27.923	24.075	1.971	60.584
49%	E.1.1.3	Condition state of infrastructure (pre-event)	7.149	30.178	26.020	2.130	65.477
31%	E.1.1.4	Condition state of protective structures/systems (pre-event)	4.542	19.170	16.529	1.353	41.594
1%	E.1.1.5	Condition state of assistance alert systems (pre-event)	81	340	293	24	738
75%	E.1.1.6	Expected condition state of infrastructure (post-event)	10.961	46.267	39.892	3.266	100.385
62%	E.1.1.7	Expected condition state of protective structures/systems (post-event)	9.131	38.545	33.233	2.721	83.630
33%	E.1.1.8	Expected condition state of assistance alert systems (post-event)	4.922	20.778	17.915	1.467	45.081
43%	E.1.2.1	The possibility of building a temporary alternative route for vehicles	6.304	26.610	22.943	1.878	57.736
90%	E.1.2.2	The possibility of using another means to satisfy transport demand	13.180	55.635	47.969	3.927	120.711
71%	E.1.2.3	The number of possible existing alternative ways to deviate vehicles	10.501	44.324	38.216	3.129	96.170
10%	E.1.2.4	The presence and functioning of the warning system	1.487	6.275	5.411	443	13.616
43%	E.1.2.5	The presence of a safe shutdown system	6.329	26.716	23.035	1.886	57.966
93%	E.1.2.6	The presence of emergency / evacuation paths	13.629	57.529	49.602	4.061	124.822
16%	E.1.2.7	The presence of special measures to help evacuate persons	2.416	10.198	8.792	720	22.126
78%	E.1.3.1	Complience with the current seismic design code	11.463	48.385	41.718	3.415	104.980
50%	E.1.3.2	Complience with the current slope stability design code	7.386	31.175	26.879	2.201	67.640
5%	E.1.3.3	Strength of construction material used	729	3.076	2.652	217	6.673
39%	E.1.3.4	Presence of systems to reduce seismic effects	5.703	24.074	20.757	1.699	52.234
79%	E.1.3.5	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	11.541	48.715	42.002	3.439	105.697
91%	E.1.3.6	Adequate systems to reduce seismic effects	13.429	56.687	48.876	4.001	122.994
12%	E.1.3.7	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	1.701	7.181	6.192	507	15.582
53%	E.2.1.1	Height	7.745	32.691	28.187	2.308	70.931
98%	E.2.1.2	Accessibility	14.460	61.039	52.628	4.309	132.436
69%	E.2.1.3	Presence of persons/property below the infrastructure	10.084	42.567	36.702	3.005	92.357
12%	E.2.1.4	Extent of past damages due to hazards	1.788	7.546	6.506	533	16.373
19%	E.2.1.5	Hazard zone	2.851	12.033	10.375	849	26.107
12%	E.2.1.6	Duration of past down time due to hazards	1.769	7.468	6.439	527	16.204
93%	E.2.1.7	Land type	13.657	57.648	49.704	4.069	125.078
12%	E.2.1.8	Budget availability	1.834	7.741	6.674	546	16.795
20%	E.2.1.9	Traffic	2.910	12.285	10.592	867	26.654
31%	E.2.1.10	Hazards goods traffic	4.486	18.937	16.328	1.337	41.087
84%	E.2.1.11	Flammable goods traffic	12.343	52.103	44.924	3.678	113.048
81%	E.3.1.1	The presence of a monitoring strategy	11.899	50.227	43.306	3.545	108.978
86%	E.3.1.2	The presence of an maintenance strategy	12.618	53.261	45.922	3.760	115.560
9%	E.3.1.3	The extent of interventions executed prior to the event	1.377	5.811	5.011	410	12.609
8%	E.3.2.1	The presence of an emergency plan	1.165	4.916	4.239	347	10.667
41%	E.3.2.2	Practice of the emergency plan	6.011	25.372	21.876	1.791	55.050
96%	E.3.2.3	Review/update of the emergency plan	14.101	59.520	51.318	4.201	129.140
66%	E.3.2.4	Expected time for tendering	9.739	41.107	35.443	2.902	89.190
18%	E.3.2.5	Expected time for demolition	2.663	11.240	9.691	793	24.387
8%	E.3.2.6	Expecetd time for construction	1.154	4.870	4.199	344	10.566

Earthquake

Impact on the service	ID	Indicator	Intervention	Travel time	Accident	Socio-econ.	Total
54%	S1.1.1	Condition state of protective structures/systems	26	55	2.773	4	2.858
4%	S1.2.1	The possibility of using another means to satisfy transport demand	2	4	205	0	211
21%	S1.2.2	The number of possible existing alternative ways to deviate vehicles	10	21	1.068	1	1.101
71%	S1.2.3	The presence of emergency / evacuation paths	35	73	3.661	5	3.774
13%	S1.3.1	Presence of the drainage system	6	13	676	1	697
85%	S1.3.2	Presence of protection barries (e.g. to rockfalls, snowfalls, etc.)	42	87	4.387	6	4.522
25%	S1.3.3	Adequate dimensioning of the drainage system	12	26	1.300	2	1.340
11%	S1.3.4	Adequate protection barries (e.g. to rockfalls, snowfalls, etc.)	5	11	560	1	577
90%	S2.1.1	Height	44	91	4.612	6	4.754
31%	S2.1.2	Frequency of past hazards	15	32	1.608	2	1.657
49%	S2.1.3	Severity of past hazards	24	50	2.529	4	2.606
36%	S2.1.4	Expected frequency of future hazards	18	37	1.849	3	1.906
98%	S2.1.5	Expected severity of future hazards	48	100	5.035	7	5.190
57%	S2.1.6	Budget availability	28	59	2.959	4	3.050
79%	S2.1.7	Traffic	39	81	4.073	6	4.198
64%	S2.1.8	Hazards goods traffic	32	66	3.311	5	3.413
34%	S3.1.1	The extent of recent maintenance of surrounding area	17	35	1.755	2	1.809
97%	S3.2.1	The presence of an emergency plan	48	99	5.015	7	5.169
34%	S3.2.2	Practice of the emergency plan	17	35	1.751	2	1.805
68%	S3.2.3	Review/update of the emergency plan	33	69	3.480	5	3.587
34%	S3.2.4	Expected time for execution of work commissioned	17	35	1.755	2	1.809

Snow