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MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Claudio Martani

Research associate

martani@ibi.baug.ethz.ch

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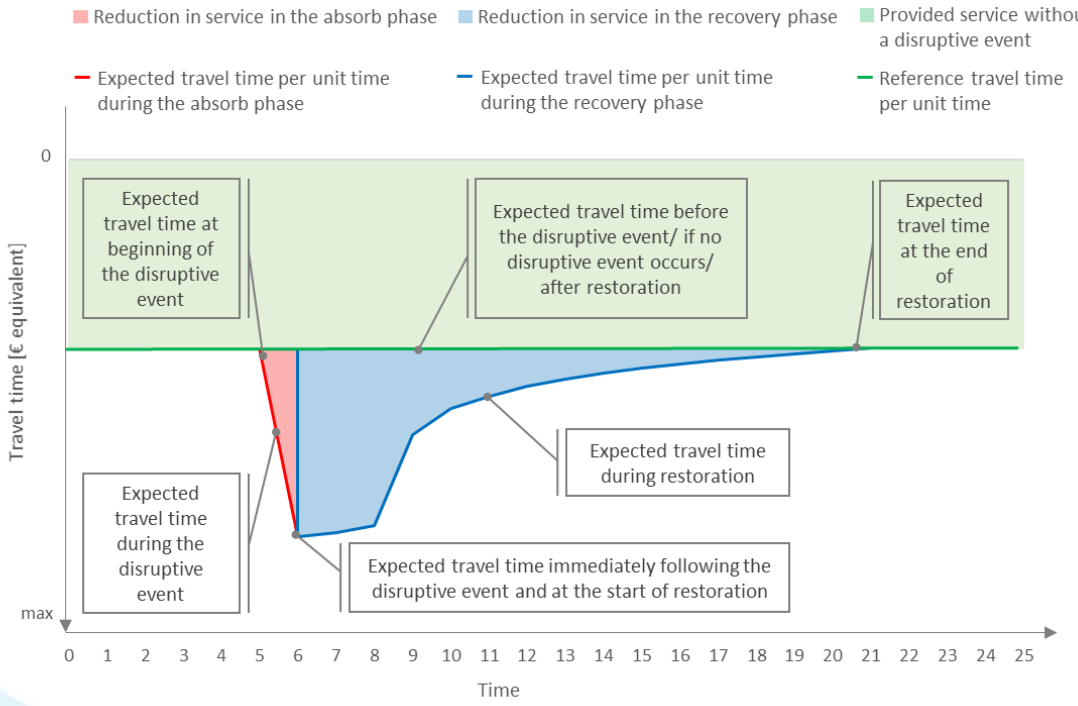
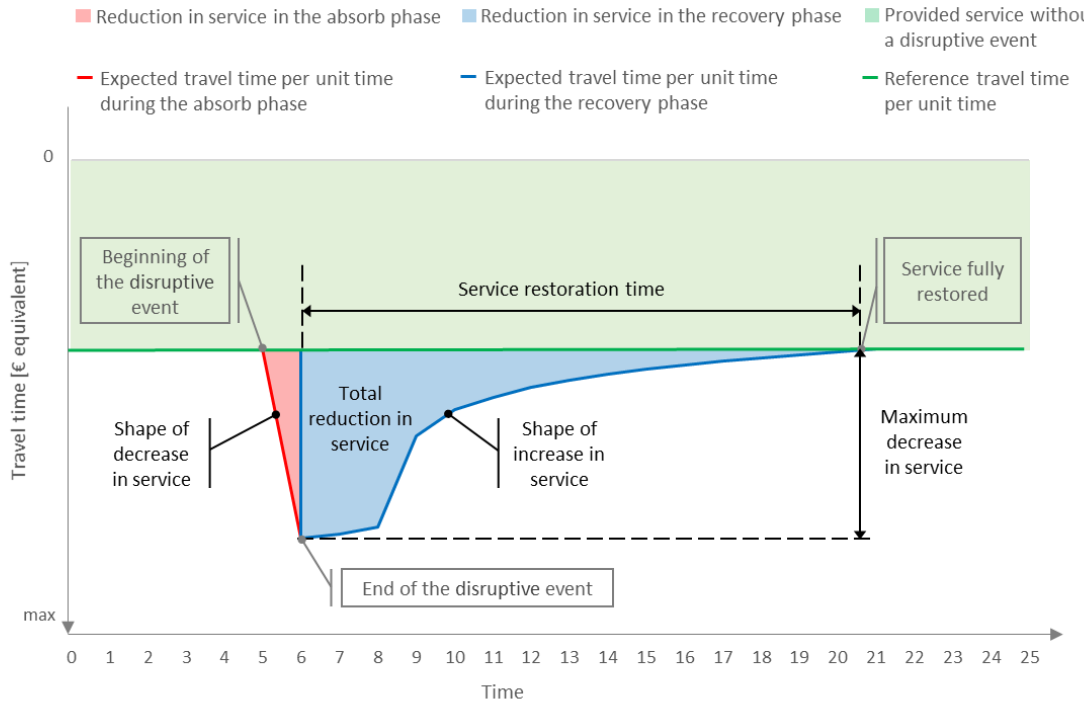
Resilience



Resilience targets

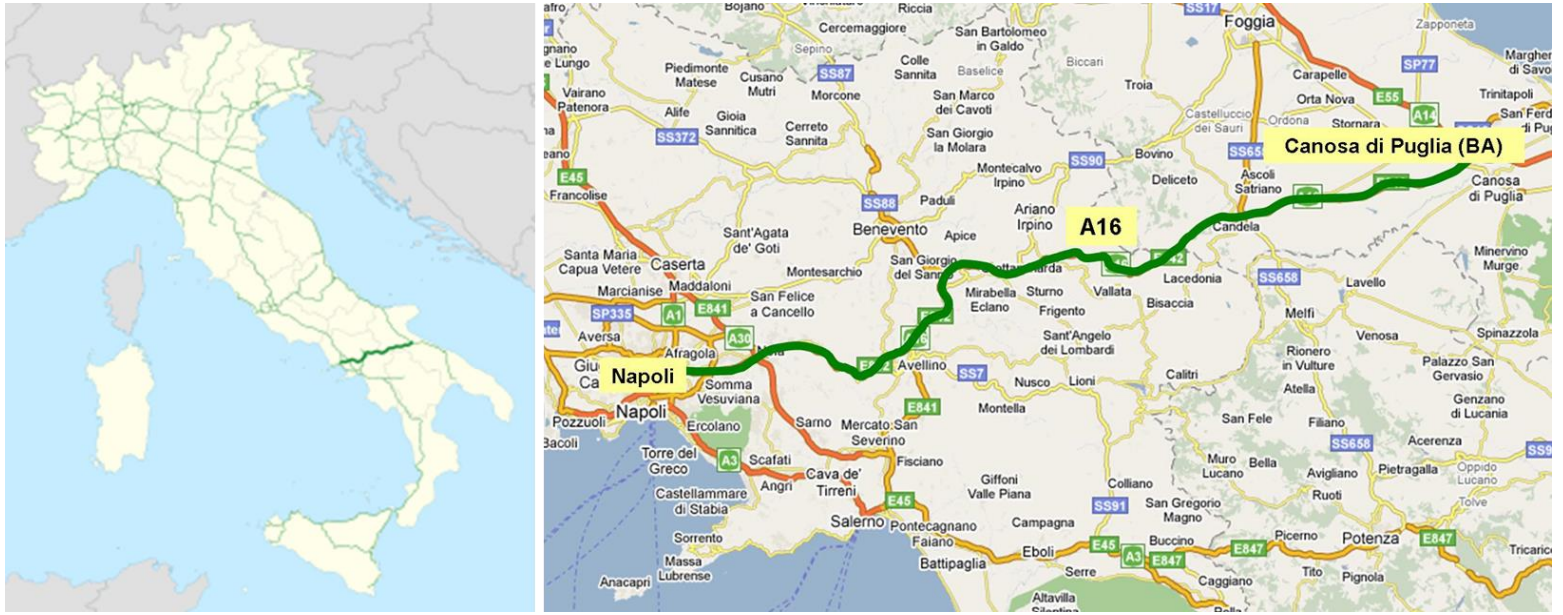


MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Step	Description
Define the transportation system	The measure of service and resilience require taking into consideration many characteristics of the transport system, including characteristics of: (i) the infrastructure (ii) the environment, and (iii) the organization. The exact characteristics to be taken into consideration depend on the specific transport system to be analysed.
Measure the service	Once the transport system is defined, the service can be measured. Measuring the service provided by transport infrastructure over time requires modelling: (i) how the service required from the infrastructure is expected to change in the future, and (ii) how the infrastructure is likely to change in the future.
Measure the resilience	Measuring the resilience of infrastructure requires measuring the difference between the service provided over time, when no hazard event occurs, and when a hazard event occurs. Measuring resilience requires estimating what will happen from the point in time that a hazard occurs to the point in time that the required service is once again provided, which depends on many different factors. Due to this complexity, measuring the resilience of transport infrastructure in detail might not be worthwhile, i.e. the gain in information may not be worth the effort. Instead, it might be worthwhile to use resilience indicators, i.e. indicators of how service will be affected due to a hazard event. The indicator set used will need to adequately capture the performance of all relevant aspects of the transport system.
Set resilience target	Setting targets of service and resilience requires that all relevant stakeholders involved with the decisions on the service and resilience to be provided determine: (i) the boundaries of the decisions, i.e. the legal and stakeholders requirements, (ii) agree on the method to define the targets and (iii) use the method agreed on to define the service and resilience targets. Targets can be set for either intervention costs or a measure of service, combinations of intervention costs and measures of service, and multiple hazards.

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Demonstration using the A16 highway, in Italy



Disclaimer: The work presented in this presentation is a mere exercise, for which the vast majority of inputs have been set based on authors' assumptions, i.e. the inputs are realistic, but fictive and as such does not reflect the current situation of the highway chosen for the present application. Therefore the results cannot be in any way connected to the actual resilience of the real transport infrastructure.

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Measures of resilience - Maximum expected restoration intervention costs and reductions in service following the event

Intervention costs / Measure of service	Description	Costs [10^3€]		
		Estimate	Equation	Estimate
Intervention costs (Ii)	The impact of executing restoration interventions	12'040	$(Ci \cdot Li)$	12'040
Travel time (Itt)	The impact of travel condition in terms of time lost the impact of travel condition on the vehicle cost for work and leisure	2'430	$(Pw \cdot Dpud \cdot Cwt \cdot D)$	2'970
		540	$(Pw \cdot Dpud \cdot Clt \cdot D)$	
Safety (Is)	The impact due to the user being involved in an accident divided by property damage, injury, deaths	3'000	$\left(\left(\frac{Ppd}{100}\right) \cdot PDp \cdot P\right)$	54'000
		1'000	$\left(\left(\frac{Ppd}{100}\right) \cdot Ip \cdot P\right)$	
		50'000	$\left(\left(\frac{Ppd}{100}\right) \cdot Dpp \cdot P\right)$	
Socio-economic activities (Ise)	The impact of people and goods not being able to travel	450	$(P \cdot Dpud \cdot D \cdot SECp)$	1'260
		810	$(G \cdot Dpud \cdot D \cdot SECg)$	
Total		70'270	$(Ii + Itt + Is + Ise)$	70'270

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Measures of resilience - Resilience indicators

ID	Level 0	ID	Level 1	ID	Indicator	Scale	Measure
L.1	Infrastructure	L.1.1	Protective measures	1.1.1	The possibility of building a temporary alternative route for vehicles	2	0
				1.1.2	The possibility of using another means to satisfy transport demand	2	1
				1.1.3	The number of possible existing alternative ways to deviate vehicles	1	1
				1.1.4	The presence of a warning system	2	2
				1.1.5	The presence of a safe shutdown system	1	0
				1.1.6	The presence of emergency / evacuation paths	2	1
				1.1.7	The presence of special measures to help evacuate persons	2	0
		L.1.2	Preventive measures	1.2.1	Compliance with the current slope stability design code	2	2
				1.2.2	Presence of protection barriers	1	1
				1.2.3	Adequate protection barriers	1	1
		L.1.3	Condition state of the infrastructure	1.3.1	Age / Age of replacement of the warning system	3	2
				1.3.2	Condition state of infrastructure	5	4
				1.3.3	Condition state of protective barriers	5	2
				1.3.4	Condition state of assistance alert systems	5	2
				1.3.5	Expected condition state of infrastructure	3	1
				1.3.6	Expected condition state of protective barriers	3	2
				1.3.7	Expected condition state of assistance alert systems	2	2
				3.2.6	Expecetd time for construction	3	2
L.2	Environment	L.2.1	Physical	2.1.1	Height	2	1
				2.1.2	Accessibility	3	2
				2.1.3	Presence of persons/property below the infrastructure	1	0

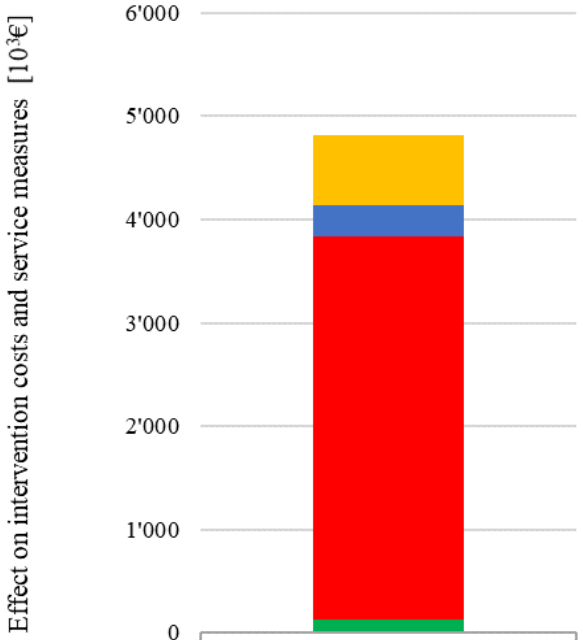
MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Measures of resilience - Example of measures of resilience for 4 condition indicators

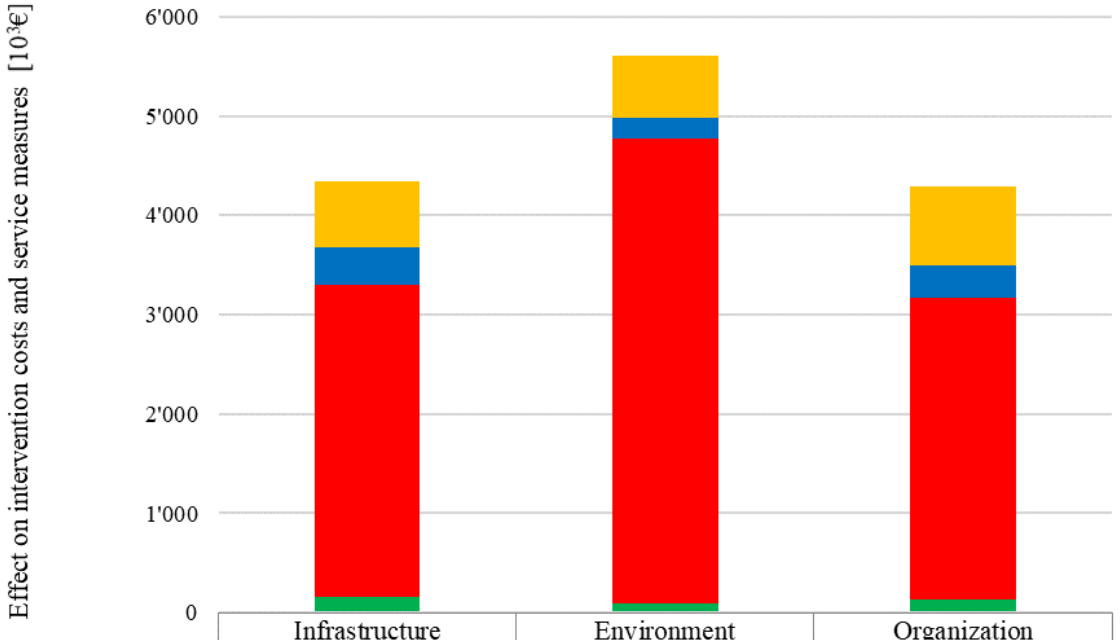
Indicator	Item	Measures of resilience (10^3€)				
		Intervention cost	Reductions in service			Total
			Travel time	Safety	Socio-econ.	
1.3.1 - The age / age of replacement of the warning system	Max	Not relevant	Not relevant	14'273	333	14'606
	Actual			4'758	111	4'869
	Difference			9'515	222	9'737
1.3.2 - The condition of the infrastructure providing service	Max	12'040	2'970	54'000	1'260	70'270
	Actual	2'408	594	10'800	252	14'054
	Difference	9'632	2'376	43'200	1'008	56'216
1.3.3 - The condition of protection barriers	Max	9'391	2'317	42'120	983	54'811
	Actual	5'635	1'390	25'272	590	32'886
	Difference	3'756	927	16'848	393	21'924
1.3.4 - The condition of the assistance alert systems	Max	2'190	540	9'824	229	12'783
	Actual	1'314	324	5'894	138	7'670
	Difference	876	216	3'929	92	5'113

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Measures of resilience - For the whole transport system (left) and for the infrastructure, environment and organisation indicator categories (right)



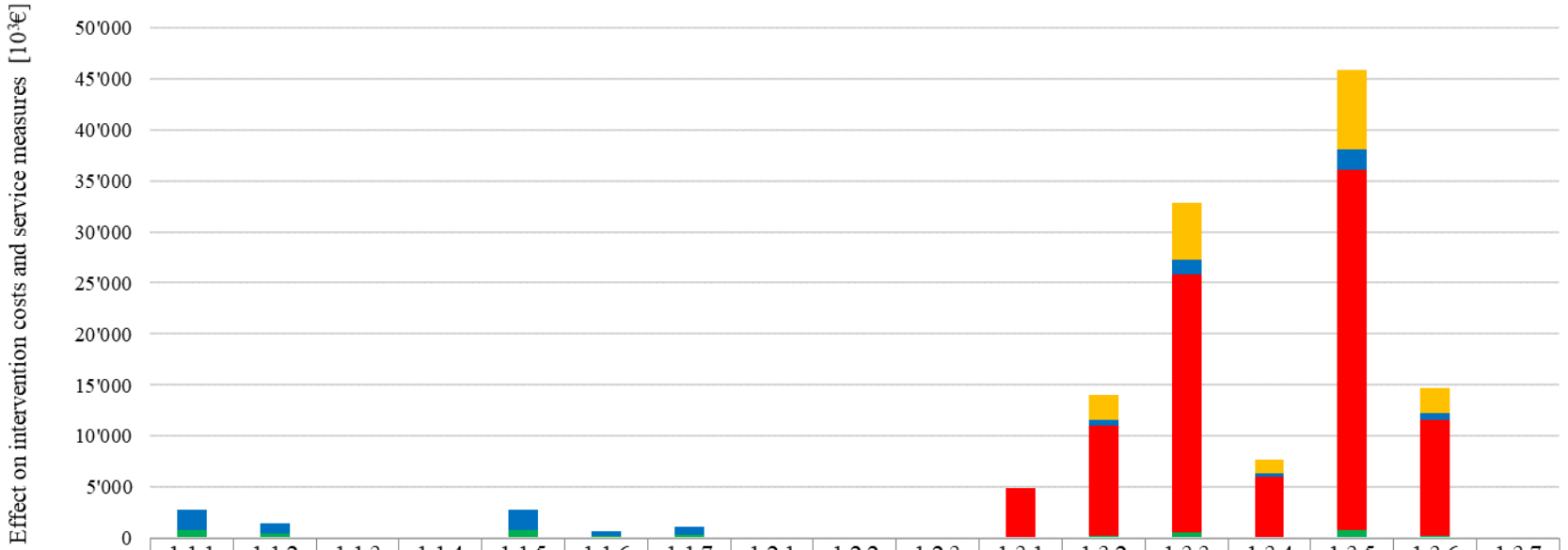
	Total
Intervention	677
Travel time	302
Safety	3'704
Socio-economic	130



	Infrastructure	Environment	Organization
Intervention	664	624	799
Travel time	374	212	322
Safety	3'138	4'684	3'030
Socio-economic	162	90	137

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Measures of resilience - For all indicators: Infrastructure



	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.6	1.1.7	1.2.1	1.2.2	1.2.3	1.3.1	1.3.2	1.3.3	1.3.4	1.3.5	1.3.6	1.3.7
Intervention	0	0	0	0	0	0	0	0	0	0	0	2'408	5'635	1'314	7'866	2'528	0
Travel time	1'931	1'040	0	0	1'961	520	802	0	0	0	0	594	1'390	324	1'940	624	0
Safety	0	0	0	0	0	0	0	0	0	0	4'758	10'800	25'272	5'894	35'280	11'340	0
Socio-economic	819	441	0	0	832	221	340	0	0	0	111	252	590	138	823	265	0

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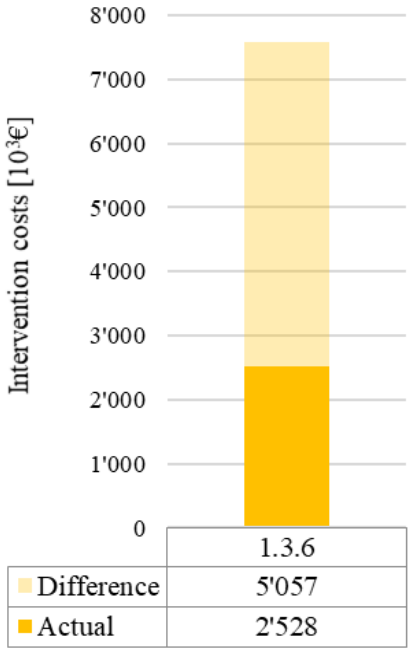
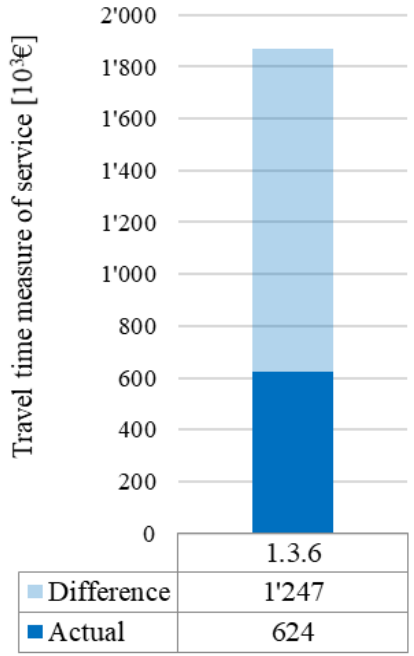
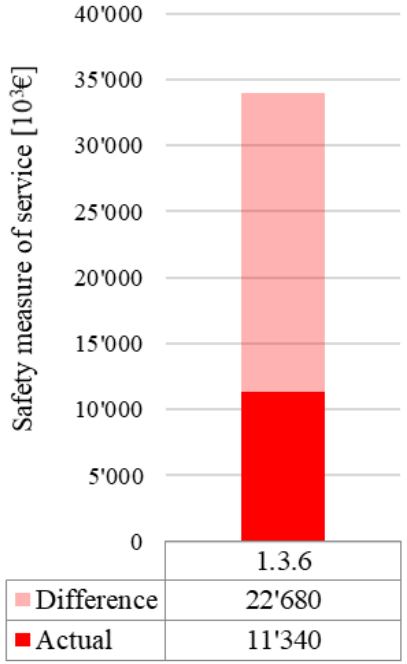
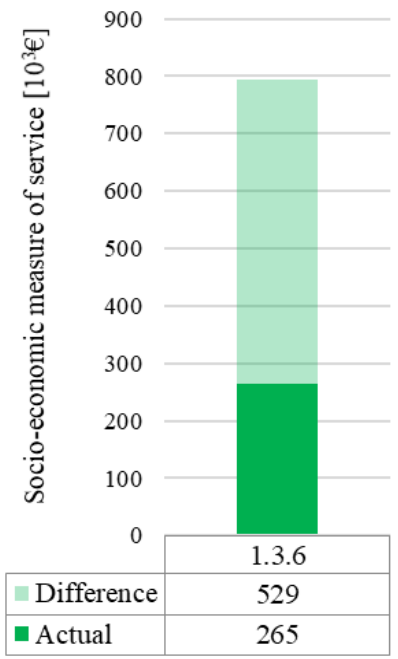
Measures of resilience - Difference between measures of resilience for the indicator expected condition state of protective barriers (1.3.6)









MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Setting the targets

Possible values	Costs (10^3€)	Target	Max/ per value	Measures of resilience (10^3€)						Net benefit (10^3€)
				Avoided intervene-tion costs	Avoided reductions in service				B/C	
					Travel time	Safety	Socio-econ.	Total		
		5	Max	9'391	2'317	42'120	983	54'811	N/A	N/A
0	0		0	0	0	0	0	0	0.00	0
1	3'000		1	1'878	463	8'424	197	10'962	3.65	7'962
2	5'000		2	1'878	463	8'424	197	10'962	2.19	5'962
3	5'000		3	1'878	463	8'424	197	10'962	2.19	5'962
4	7'000		4	1'878	463	8'424	197	10'962	1.57	3'962
5	10'000		5	1'878	463	8'424	197	10'962	1.10	962

MEASURING THE RESILIENCE OF, AND PRIORITIZING INTERVENTIONS FOR, ROAD TRANSPORT SYSTEMS USING EXPERT OPINION – Part 1/2

Setting the targets – sample of targets set

ID	Indicator	Scale	Actual value	Target value	Costs to reach target	Benefit of reaching target	B/C	Net benefit of reaching
					103€	103€		(103€)
1.3.1	Age / Age of replacement of the warning system	3	2	0	0	0	0.00	0
1.3.2	Condition of infrastructure	5	4	3	0	0	0.00	0
1.3.3	Condition of protective barriers	5	2	5	30'000	54'811	1.10	24'811
1.3.4	Condition of assistance alert systems	5	2	1	2'500	2'557	1.02	57
1.3.5	Expected condition of infrastructure	3	1	2	35'000	45'910	1.15	10'910
1.3.6	Expected condition of protective barriers	3	2	0	0	0	0.00	0
1.3.7	Expected condition of assistance alert systems	2	2	0	0	0	0.00	0
3.1.1	The presence of a monitoring strategy	2	1	0	0	0	0.00	0
3.1.2	The presence of an maintenance strategy	2	1	2	25'000	33'193	1.11	8'193
3.1.3	The extent of interventions executed prior to the event	2	1	1	20'000	28'287	1.41	8'287
3.2.1	The presence of an emergency plan	2	1	2	9'000	36'912	3.08	27'912
3.2.2	Practice of the emergency plan	4	2	1	3'000	3'021	1.01	21

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The presentation was based on:

- CEN Workshop Agreement CWA 17819 - Guideline for resilience assessment of transport infrastructures. Available at:

  https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/cwa17819_2021.pdf.
- Adey, B. T., Martani, C., Kielhauser, C., Urqulijo Robles, I, Papathanasiou, N. and Burkhalter, M., Beltran-Hernando, I. (2020). FORESEE project Deliverable D1.1: Guideline to measure Levels of Service and resilience in infrastructures.
- Kielhauser, C., Martani, C., Adey, B. T. (2020). FORESEE project Deliverable D1.2: Guideline to set target levels of service and resilience for infrastructures.

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