FORESEE – D1.2: Guideline to set target levels of service and resilience for infrastructures

Report

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– Deliverable *1.2*–

Guideline to set target levels of service and resilience for infrastructures

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

EXECUTIVE SUMMARY

The functioning of society depends on the functioning of multi-modal transport infrastructure networks. These networks are designed and managed to be used to transport persons and goods in specific ways, e.g. within specific amounts of time, and with the probabilities of being hurt or injured being below specified thresholds. When extreme events occur, their ability to provide this service can be reduced. To counteract this, a network can be modified to be more resilient and to provide specified levels of service during and following the occurrence of extreme events. In order for managers to set these specified, i.e. target, levels of service and resilience during and following the occurrence of extreme events, it is useful to have a structured and consistent way to set them.

The guideline you are now reading has been written to allow managers to do this, taking into consideration the fact that there are many different specific multi-modal transport infrastructure networks. These networks are embedded in many different physical and organisational environments and are managed by many different organisations. The guideline sets out the principles and basic steps to be used. It emphasises that setting target levels of service provided by, and the resilience of, multi-modal transport infrastructure requires a clear definition of the transport system and the way resilience and service is measured on it (see Deliverable D1.1).

Once the method of measuring service and resilience is defined at an acceptable level of detail, the targets can be set either for service and resilience or for resilience indicators, both with and without cost-benefit analysis. The choice of target setting method depends on the specific problem to be addressed, the time frame at disposition, the expertise available, the availability of data, and how the level of service and resilience are measured.
The steps proposed in the guideline, and the ways to set target levels of service and resilience, are explained using the same simple and understandable example as in Deliverable D1.1. The guideline has been used to develop targets for service and resilience for all measures developed in D1.1 for the six case studies in FORESEE. The final target levels of service and resilience for each case study will be made public by the end of the project.

For clarity, the guideline does not provide generic lists of level of service or resilience targets. If the reader is interested in these, they are encouraged, after identifying their specific situation of interest, and determining how the level of service and resilience are to be measured, to consult the large and growing body of appropriate literature in these respective areas, including future FORESEE deliverables.

"The authors of the report in particular and the members of the FORESEE project in general, would like to express our special gratitude to the members of the Stakeholder Reference Group (Appendix A) for their helpful contributions and suggestions on the contents of this document."

1 INTRODUCTION

The functioning of society depends on the functioning of multi-modal transport infrastructure networks. These networks are designed and managed so that persons and goods can be transported in specific ways, e.g. within specific amounts of time, and with the probabilities of being hurt or injured being below specified thresholds. When extreme events occur, their ability to provide this service may reduce. To counteract this, a network can be modified to be more resilient and to provide specified levels of service during and following the occurrence of extreme events. In order for managers to set service and resilience targets during and following the occurrence of extreme events, it is useful to have a structured and consistent way to set them.

The setting of targets for service and resilience of infrastructure implies the ability to 1) measure service and resilience, 2) define a process to set the targets and 3) use it to define specific targets. Some works exists already on each of these research areas.

Literature for the general process of setting targets is, however, scarce. While in many of the literature sources concerning service and resilience specific indicators performance goals, targets or others are mentioned, the way of setting actual values for those targets is not shown (e.g. it is mentioned, that one could set a target like "the availability of the system should be above X percent", but the way of coming up with an actual number for "X" is not shown.) Nevertheless, as setting targets is a well-known part of general decision making, high-level concepts can be found in appropriate literature, for example in classic decision-making literature such as *Decisions with multiple objectives* (Keeney, R. L., & Raiffa, H., 1993), or *Cost-benefit analysis* (Layard, P. R. G., 1994) and *Cost-benefit analysis and the environment* (Pearce, D., Atkinson, G. & Mourato, S., 2006)

Although there is no method of coming up with actual target values, literature has, however, collected target values for specific parts of transport systems. For example, Stipanovic, I., et al, (2016) provide an overview of existing performance goals for bridge structures. Tingvall, C., et al. (2014) investigates safety targets that have been set for a road transport system, and Patra, A. P., Kumar, U., and Larsson Kråik, P. O. (2010) investigate availability targets for railway infrastructure. All these actual targets are, however, tailored to the specific problem investigated with a specific transport system (or part thereof) in mind and should therefore only serve as a starting point when developing own targets.

In summary, considerable work has been done in the areas of measuring service and resilience of transportation infrastructure. This work is highly useful in improving managers understanding how their transportation infrastructure performs both regularly and following the occurrence of extreme events. Furthermore, targets have also been developed for specific parts of transport infrastructure. Something that is missing in the current state-of-the-art, is a consistent process to rigorously define targets for service and the resilience of infrastructure, i.e. how to come up with actual values for targets following a structured and repeatable process.

The FORESEE project provides the guideline to do so with this deliverable. **The guideline is to be used by managers to establish targets for the service provided by, and the resilience of, multi-modal transportation infrastructure, especially when the desire is to have a standardised, repeatable and comparable process.** The guideline can be used to ensure that there is complete and systematic way of setting service and resilience targets in any infrastructure management decision-making situation throughout the life-cycle of the infrastructure. While the following guideline focuses, for clearer understanding, on the part of the life-cycle that assumes that the infrastructure is already built, it can be easily applied to all other life-cycle phases.

2 THE GUIDELINE

2.1 GENERAL

This guideline is to be used to determine how to set service and resilience targets of transport infrastructure. It includes

1) the definitions of the service and resilience targets used in this document,
2) the concepts of how service and resilience targets can be set, and
3) the steps to set service and resilience targets.

2.2 DEFINITION OF TARGET

Target is defined in the Oxford dictionary as

"An objective or result towards which efforts are directed"

In this guideline, "**target"** is defined as

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

Based on the above definition and the definitions of service and resilience introduced in Deliverable D1.1, service and resilience targets of a transport system can be set. An example of a measure of resilience for the measure of service "travel time", taken from Deliverable D1.1 is shown in Figure 1.

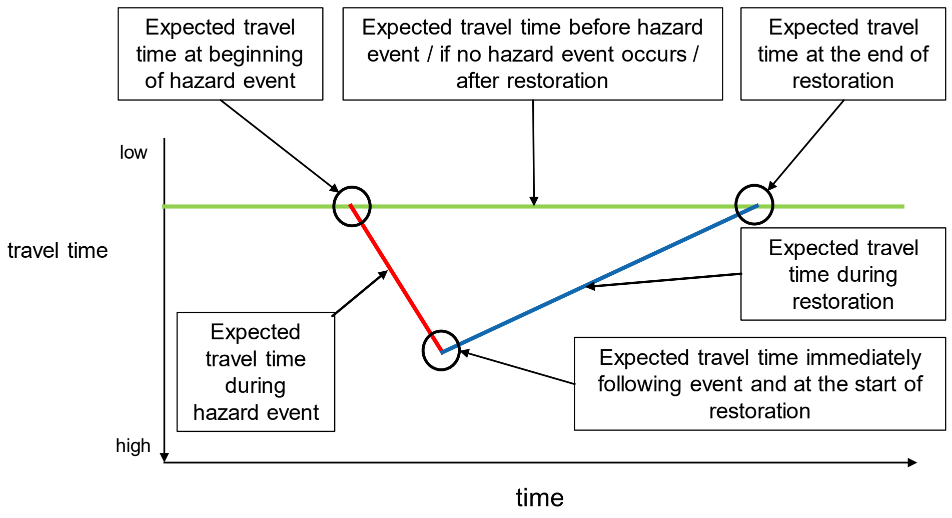

Figure 1. Illustration of resilience, using the measure of service expected cumulative yearly travel time of infrastructure enabling the transport of goods and persons from A to B for a scenario where a single hazard event occurs and the infrastructure is restored so that it provides the same level of service as it did before the hazard event

In Figure 1, resilience is shown using the measure of service "expected cumulative yearly travel time of goods and persons being transported from A to B". The green line shows the amount of expected travel time if there is no hazard event. The red line shows how the travel time is expected to increase from the moment a specific hazard event begins to the moment that hazard event ends. The blue line shows how travel time is expected to decrease from the moment the hazard event ends, until the moment that the cumulative yearly travel time of goods and persons travelling from A to B is again as it was before the hazard event, i.e. service is restored. The same representation of resilience can also be applied to any other type of service, as explained in the Deliverable D1.1.

Figure 1 can be used to show the types of service and resilience targets that can be set (Figure 2). They are listed in Table 1. In Figure 2, the maximum decrease in service from the beginning to the end of the hazard event is indicated with the red line, and the gradual restoration of the service to the expected level is indicated with the blue line.

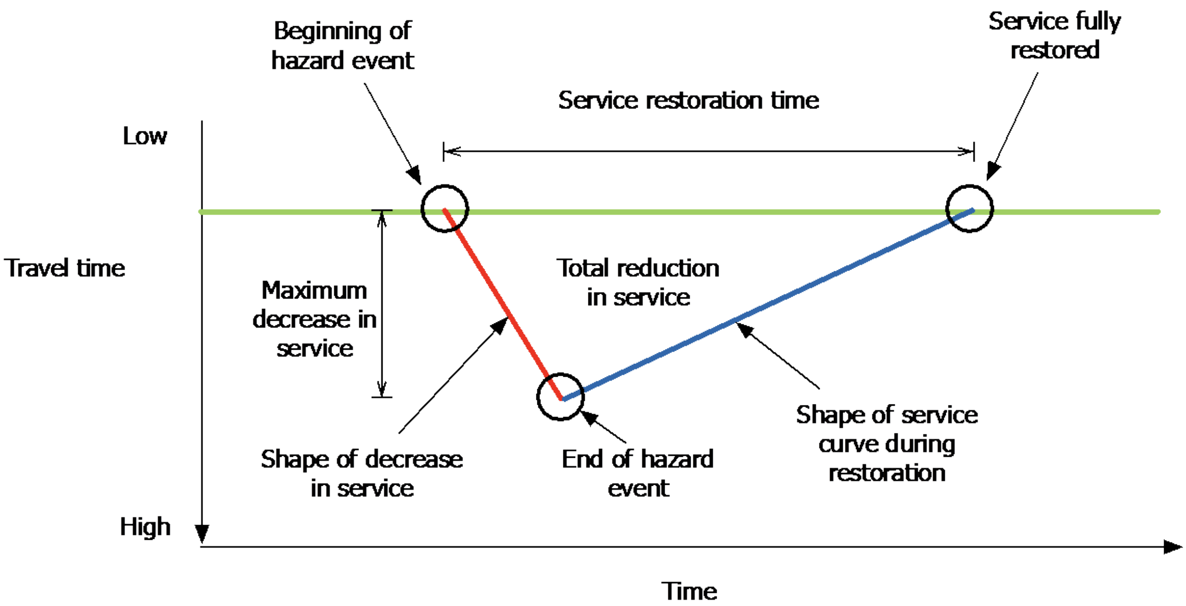

Figure 2. Illustration of resilience using the measure of service travel time, as in Figure 1, showing the various types of targets, i.e. maximum decrease in service, shape of decrease in service, shape of service curve during restoration, service restoration time and total reduction in service.

Table 1. Different types of service and resilience targets

Type of target	Description
Maximum increase in intervention costs or decrease in service	Maximal allowed increase in intervention costs or reduction in service after a hazard event, e.g. no more than X additional hours of travel time
Shape of increase in intervention costs or decrease in service	Shape of the intervention costs increase or service decrease curve, e.g. within the first 20 minutes of the hazard event, the travel time is only allowed to increase by X hours, but if the hazard duration is longer, further increases in travel time are permissible.
Shape of intervention costs or reductions of service curve during restoration	Shape of the service restoration, e.g. the service should be restored to 80% of full service within X days, but it is permissible to restore the remaining 20% in Y weeks
Maximum allowed restoration time	A target can be set on the service restoration time, e.g. the service has to be restored fully within X weeks from the beginning of the hazard event.
Maximum total intervention costs or reductions in service	A target can be set on the area underneath the service reduction and restoration curve (which represents the total reduction of service), e.g. the area should be no more than X.

Targets can be set for

1) either intervention costs or a measure of service. For example, one can concentrate only on the travel time measure of service and set a target for the maximum decrease following the beginning of the hazard event and the time until vehicles can once again travel as they could before the event.
2) combinations of intervention costs and measures of service. For example, one can consider intervention costs and the travel time measure of service and set a target for the total intervention and travel time costs following the beginning of the hazard event.
3) multiple hazards. For example, one can set the maximum additional travel time per week following the beginning of either a 500-year earthquake hazard event or a 500-year flood event.

2.3 SETTING TARGETS

In general the process to set service and resilience targets comprises the follow four basic tasks:

1) gather all relevant stakeholders,
2) determine legal requirements,
3) determine stakeholder requirements, and
4) set targets.

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

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

If service and resilience are measured using simulations, targets are set for the target types described in Table 1. If service and resilience is measured using indicators, targets are set on the values of the indicators. Targets are set either with or without cost-benefit analysis. The choice of whether to use cost-benefit analysis depends on how service and resilience are to be measured, the information available, and the time and expertise available. If the information, time, and expertise are available cost-benefit analysis should be used. If they are not available, targets are to be set using expert opinion.

Each general task is explained in the following sections.

3 TASK 1: GATHER ALL RELEVANT STAKEHOLDERS

In this task, all relevant stakeholders are gathered, whose opinion on setting the service and resilience targets, or the resilience indicator targets, should be considered. This is greatly dependent on the transport system itself, and the potential scope of the service and resilience targets, or the resilience indicator targets. For example, if service and resilience targets are only to be set based on intervention costs, the relevant stakeholders will only encompass those managing the infrastructure and those providing financial contributions. If, however, service and resilience targets are to be set based on intervention costs and travel time, the group of relevant stakeholders will be larger, and will include, for example, the users of the network. As transport is an integral part of society, the stakeholders will probably also include political representatives.

Table 22 and Chapter 4 of Deliverable 1.1 can be used, at least as a starting point, to determine the relevant stakeholder groups. It may be the case that stakeholder groups wish to send experts on their behalf. From the viewpoint of setting targets this is encouraged, as it often helps in speeding up the following tasks.

4 TASK 2: DETERMINE LEGAL REQUIREMENTS

In this task, the legal requirements for service and resilience targets, or resilience indicator targets, are determined. Examples of legal requirements from laws or contractual agreements that prescribe service or resilience targets are:

1) levels of redundancy in transport networks,
2) limits on the maximum number of expected accidents, and
3) speed limits to control the amount of NO_x gases that are emitted.

Examples of legal requirements for resilience indicator targets are:

1) the condition of a bridge has to be 4 or better,
2) the design resistance has to be at least that specified in a specific national code, and
3) the frequency of monitoring has to be every 2 years or less.

As these originate from various sources, e.g. general laws and concessionaire contracts, and obtaining a complete list often requires a considerable effort, legal specialists should be tasked with identifying these requirements. All service and resilience targets, or resilience indicator targets, have to at least fulfil all legal requirements.

Example legal requirements for the example indicators used in Deliverable D1.1 (shown in Table 10 of D1.1) are shown in Table 2.

Table 2. Legal requirements for indicators (adapted from D1.1, indicators without legal requirements are omitted)

Part	Indicator	Values from best to worst	Meaning	Target
Infrastructure	Design resistance to hazard	5	Design code level 5	Legal requirement: Value 2, Concessionaire's contract: Value 3
		4	Design code level 4	
		3	Design code level 3	
		2	Design code level 2	
		1	Design code level 1	
	Condition state of bridge	5	Like new	Legal requirement: Value 2
		4	Slightly deteriorated	
		3	Average	
		2	Poor	
		1	Alarming	
Organisation	Quality of emergency plan	3	Bridge specific plan	Legal requirement: Value 2
		2	Generic plan	
		1	No plan	

5 TASK 3: DETERMINE STAKEHOLDER REQUIREMENTS

In this task, the requirements of the stakeholders, besides legal requirements, are determined. Examples influencing the service and resilience targets are:

1) restrictions on the types of restoration interventions that can be executed due to the design of the transport network,
2) restrictions on the type of equipment that can be used in restoration activities because of accessibility,
3) specifications on the type of monitoring activities required following the occurrence of a natural hazard,
4) specifications on the number of staff required per restoration activity,
5) specifications as to the number of emergency response teams available in extreme situations, and
6) expectations that connectivity is to be restored as fast as possible following a hazard.

Examples for resilience indicators targets are:

1) the condition state of a bridge must be above 3.
2) the design resistance of all bridges must be better than that prescribed by the most recent code.

There are resilience indicators for which it is meaningless to set a target. For example, the seismic zone in which a bridge is located is an indicator of the level of service that it will provide following a hazard event, and of its resilience, but as it cannot be changed, it makes little sense to set a target seismic zone for the bridge

It is helpful to think along the lines of the stakeholders defined in task 1, e.g. first think about the additional (i.e. not already legally determined) requirements of the infrastructure managers, the users, the directly affected public and the indirectly affected public.

6 TASK 4: SET TARGETS

In this task, the targets are set. The next 4 subsections show the different methods, depending on whether service and resilience is measured directly or with indicators, and whether or not cost-benefit analysis should be used.

6.1 SERVICE AND RESILIENCE TARGETS WITHOUT COST-BENEFIT ANALYSIS

In this method, the service and resilience targets are set taking into consideration the requirements defined in the previous two tasks, and by using direct measures of service and resilience without cost-benefit analysis. The previously defined requirements set limits on possible targets. Setting targets requires the opinion of domain experts and the involved stakeholders. As this is often a highly iterative task, sufficient time should be planned to reach a widely supported agreement.

The targets should be set, or consciously not set, for

1) each type of target (Table 1),
2) each type of intervention costs and measures of service,
3) each combination of intervention costs and measures of service, and
4) each combination of type and intensity of hazards considered.

In setting the targets, the interdependencies between the intervention costs and measures of service should be considered, e.g. it may not be wise to target very low intervention costs following a hazard event and very low amounts of additional travel time.

Once the targets are set, it should be determined how they are measured. An example of targets and methods of measurements are shown in Table 3 for the earthquake event from Deliverable D1.1. This task should conclude with a set of targets that are broadly accepted by the stakeholders.

Table 3. Example service and resilience targets for an earthquake event

Intervention costs / Service measures	Target type	Description	Target	Measurement
Intervention costs	Maximum increase in intervention costs or decrease in service	The costs of the emergency measures	Maximum emergency budget: € 2’000’000 per event	via the bookkeeping system of the infrastructure owner
	Maximum total intervention costs or reductions in service	The total costs incurred until the travel time service is returned to normal	Maximum total costs: € 4’500’000 per event	
Travel time	Maximum increase in intervention costs or decrease in service	The increase of travel time after an earthquake event	Below 45 min. per trip	via automated traffic flow monitoring system
	Shape of intervention costs or losses of service curve during restoration	The way in which travel time returns to normal after an earthquake event	Within 1 week after the earthquake: Max. delay of 30 min. per trip; Within 3 weeks after the earthquake: Max. delay of 15 min. per trip	
	Maximum allowed restoration time	The total time from onset of the earthquake event until normal travel time	Within 12 Weeks after the earthquake: no traffic delays.	

In summary, setting service and resilience targets without cost-benefit analysis can be summarised as collecting all necessary expert opinion to formulate a broadly accepted set of service and resilience targets that take into consideration all aspects of the transport system that are deemed important, including the interdependencies between intervention costs and levels of service. The targets are formulated so that it is clear how they are to be measured.

6.2 RESILIENCE INDICATOR TARGETS WITHOUT COST-BENEFIT ANALYSIS

In this method, the resilience indicator targets are set, taking into consideration the requirements defined in the previous two tasks and by using resilience indicators without cost-benefit analysis. The previously defined requirements set limits on possible targets, i.e. due to some of the requirements some targets may not be possible. Setting targets requires the opinion of domain experts and the involved stakeholders. As this is often a highly iterative task, sufficient time should be planned to reach a widely supported agreement.

The targets should be set, or consciously not set, for
1) each resilience indicator, and
2) each combination of resilience indicators

For example, Table 4 shows a list of consciously included and excluded resilience indicators, together with a reason for inclusion or exclusion.

Table 4. Example included and excluded target indicators (adapted from D1.1)

Part	Indicator	Decision	Reason
Infrastructure	Design resistance to hazard	Include	Legal requirement present
	Condition state of bridge	Include	Legal requirement present
Environment	Seismic zone	Exclude	Outside the sphere of influence of the infrastructure operator
	Regulatory framework	Exclude	
Organisation	Frequency of monitoring	Include	Increases awareness of problems
	Quality of emergency plan	Include	Legal requirement present

In setting the targets, the interdependencies between the indicators should be considered, e.g. one might agree to have bridges in a moderate condition state if they have a high design resistance whereas they should be in a good condition state if they have a moderate design resistance.

Once the targets are set, it should be determined how they are to be measured. An example of targets and methods of measurements are shown in Table 5, for one earthquake event within 3 years, i.e. the targets should be met for one single earthquake and another happening 4 years later, but need not to be met if the second earthquake happens 2 years after the first. This task should conclude with a set of targets that are broadly accepted by the stakeholders.

Table 5. Example resilience indicator targets

Part	Indicator	Values from best to worst	Meaning	Target	Measurement
Infrastructure	Design resistance to hazard	5	Design code level 5	Legal requirement: 2 Agreed upon target: 3	A one-time inspection by an external expert
		4	Design code level 4		
		3	Design code level 3		
		2	Design code level 2		
		1	Design code level 1		
	Condition state of bridge	5	Like new	Legal requirement: 2 Agreed upon target: 3	Yearly inspection by an external expert
		4	Slightly deteriorated		
		3	Average		
		2	Poor		
		1	Alarming		
Organisation	Frequency of monitoring	4	Regular frequent monitoring	Agreed upon target: 4	An external audit every 5 years
		3	Regular but infrequent monitoring		
		2	Irregular monitoring		
		1	No monitoring		
	Quality of emergency plan	3	Bridge specific plan	Legal requirement: 2 Agreed upon target: 3	An external audit every 5 years
		2	Generic plan		
		1	No plan		

Setting resilience indicator targets without cost-benefit analysis can be summarised as collecting all necessary expert opinion to formulate a broadly accepted set of resilience indicator targets, including the interdependencies between resilience indicators. The targets are formulated so that it is clear how they are to be measured.

6.3 SERVICE AND RESILIENCE TARGETS WITH COST-BENEFIT ANALYSIS

In this method, the service and resilience targets are set, taking into consideration the requirements defined in the previous two tasks, and the benefits and costs of achieving the targets. It is similar to that described in section 6.1, with the exception that the costs and benefits of achieving the targets are explicitly estimated. The sub-tasks required to do this are:

1) select the types of targets to be set for restoration intervention costs and each measure of service,
2) develop possible sets of targets, keeping in mind the legal restrictions,
3) determine the scenarios of how the targets in each target set are to be reached,
4) estimate the costs of achieving the targets sets and the benefits of each scenario in terms of the restoration intervention costs and measures of service, and
5) evaluate the ability of each scenario to achieve the target sets taking into account the legal requirements and select the best one with respect to the benefits and costs.

In the first sub-task, possible types of targets to be set are selected, e.g. for a 100-year flood event, targets might be set on the maximum increase in restoration intervention costs, and the maximum allowed time until the amount of travel time incurred by the users should be restored to normal. The types of targets should be selected for all the restoration intervention costs and measures of service that stakeholders consider important. In selecting the possible types of targets, the effort required to develop, and evaluate, whether the sets of targets have been achieved, should be considered. For example, if specific levels of additional travel time reduction over the restoration period is targeted, which is a specific shape of restoration curve for the travel time measure of service, the effort required to estimate the reduction in additional travel time during the restoration period must be considered. Example types of targets are shown in Table 6.

Table 6. Example service and resilience target types for a 100-year flood event

Restoration intervention costs or measure of service	Target type	Description
Restoration intervention costs	Maximum increase in restoration intervention costs	The amount of money required to finance the activities of the emergency response team
	Maximum total restoration intervention costs or reductions in service	The total amount of money spent on interventions from the beginning of the hazard event until the users can once again travel as they could prior to the hazard event
Travel time	Maximum decrease in service	The maximum increase of travel time per day following a 100-year flood
	Restoration curve shape	The way in which travel time returns to normal following a 100-year flood
	Restoration time	The total amount of time from onset of the 100-year flood until users can once again travel as they could prior to the hazard event

In the second sub-task, possible sets of targets are determined while taking into account the legal restrictions. These sets of targets consist of a combination of one or more targets for one or more types of targets. An example set of targets is shown in Figure 3 for the travel time measure of service. The green horizontal line represents the expected travel time. The black line represents the additional travel time following the hazard event. The grey dashed lines below and above the black line represent the uncertainty related to the reduction of service (black line). The red dotted line represents the legal requirements to be fulfilled. The blue dotted lines and the blue letters show the targets included in the example target set, i.e.:

a) the maximum reduction of service,
b) the total restoration time,
c) the slope and shape of reduction of service,
d) the slope and shape of the service restoration, and
e) the area under the curve, i.e. the total lost travel time from the beginning of the event until full restoration of service.

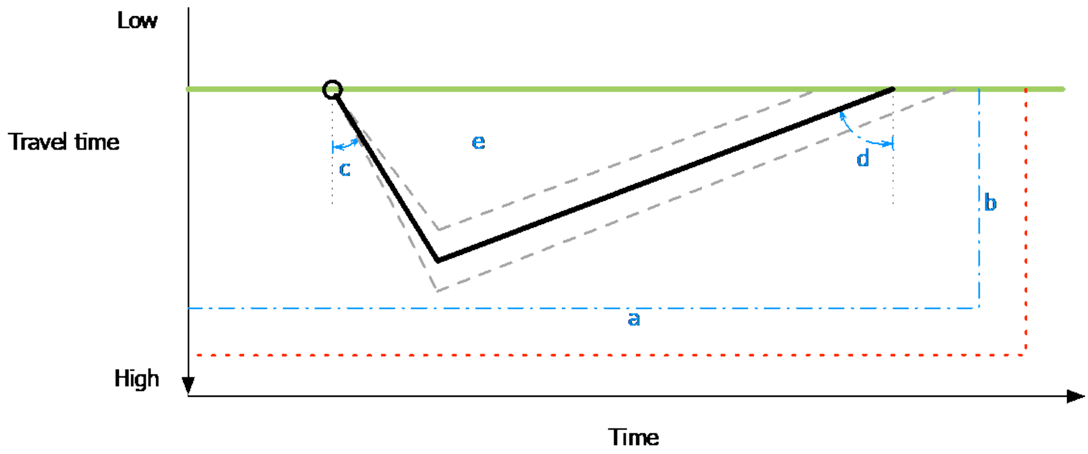

Figure 3. Example target types for the travel time measure of service

Although Figure 3 shows a target set for only one measure of service, they can include targets on the restoration intervention costs and all measures of service. An example is shown in Figure 4, which includes targets on the "travel time" measure of service (a-c) and the restoration intervention costs (e), or more specifically:

a) the maximum reduction of the measure of service of travel time,
b) the maximum restoration time,
c) the slope of the reduction of the measure of service of travel time following the event, and
e) the maximum restoration intervention costs.

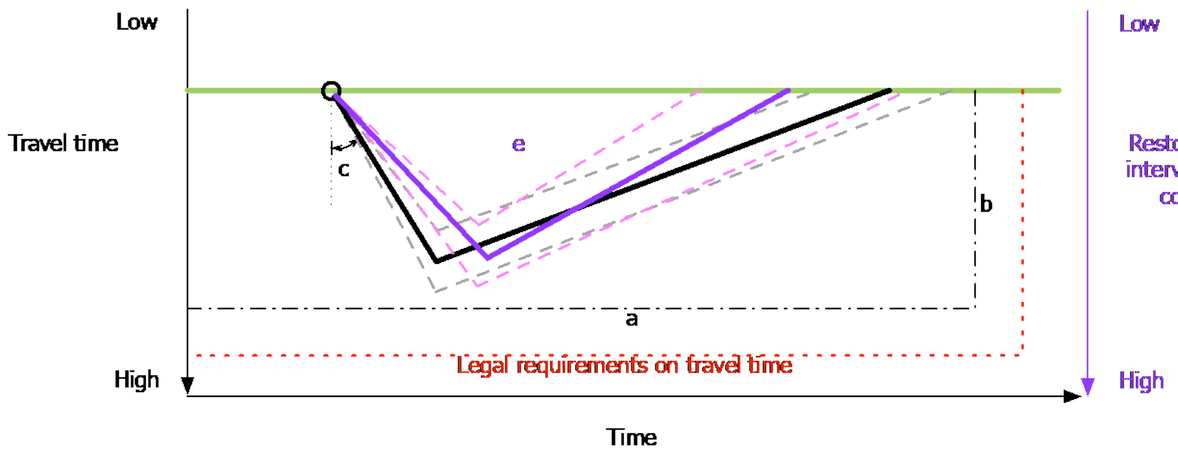

Figure 4. Example of types of target for the travel time measure of service and the restoration intervention costs

An example of multiple possible target sets is given in Table 7 and Figure 5 to Figure 7. Figure 5 shows that there is to be no additional travel time incurred and no restoration intervention costs following the event. Figure 6 shows that the additional travel time incurred should be kept within legal limits, i.e. the maximum allowed reduction of service. There are no constraints placed on the restoration intervention costs. Figure 7 shows that the restoration intervention costs are to be kept with a specified budget limit. There are no constraints placed on the additional travel time. Although, there is uncertainty in all cases whether targets will be met, the probabilities of them not being met should be negligible. The costs associated with each target set are given in Table 8.

Table 7. Example target sets

Target set	Label	Description	Targets per type of target			Illustration
			maximum reduction of the service of travel time	the maximum restoration time	the maximum restoration intervention costs	
1	No changes in service	There is no change in travel time given a 100-year flood occurs	none	Not specified	Not specified	Figure 5
2	Legal minimum	All legal requirements for travel time are fulfilled	Largest legally permitted	Largest legally permitted	Not specified	Figure 6
3	Restoration budget	The available budget will be used fully, in order to maximise the service achievable with the money available	Not specified	Not specified	Under the specified restoration budget	Figure 7

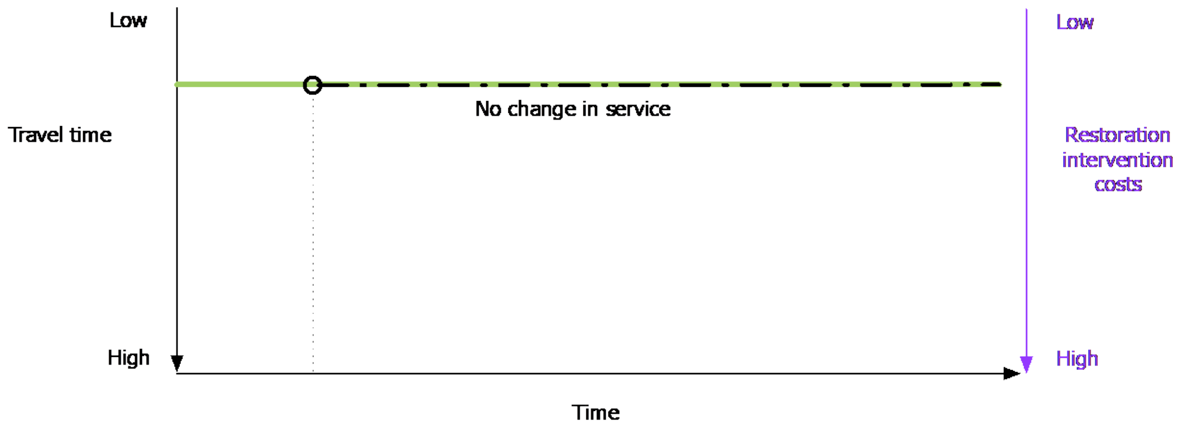

Figure 5. Graphical representation of target set 1

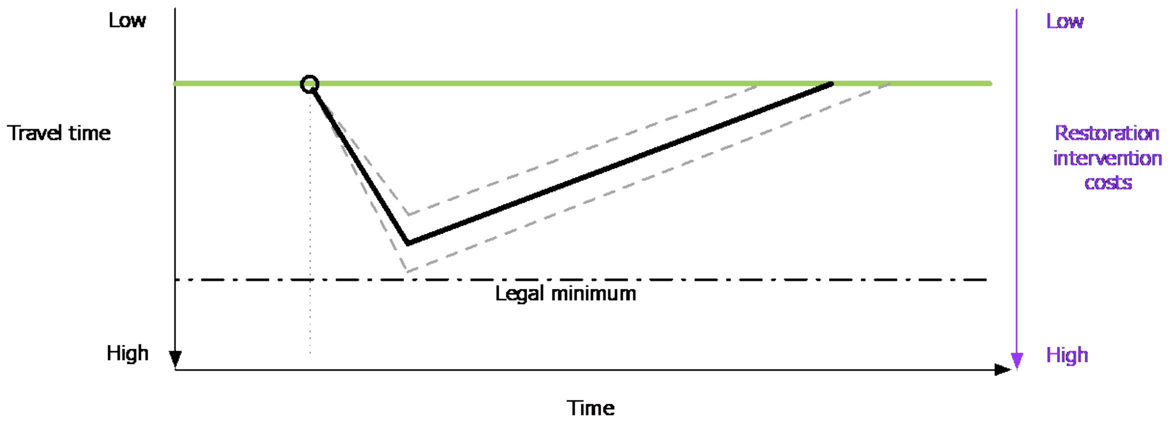

Figure 6. Graphical representation of target set 2

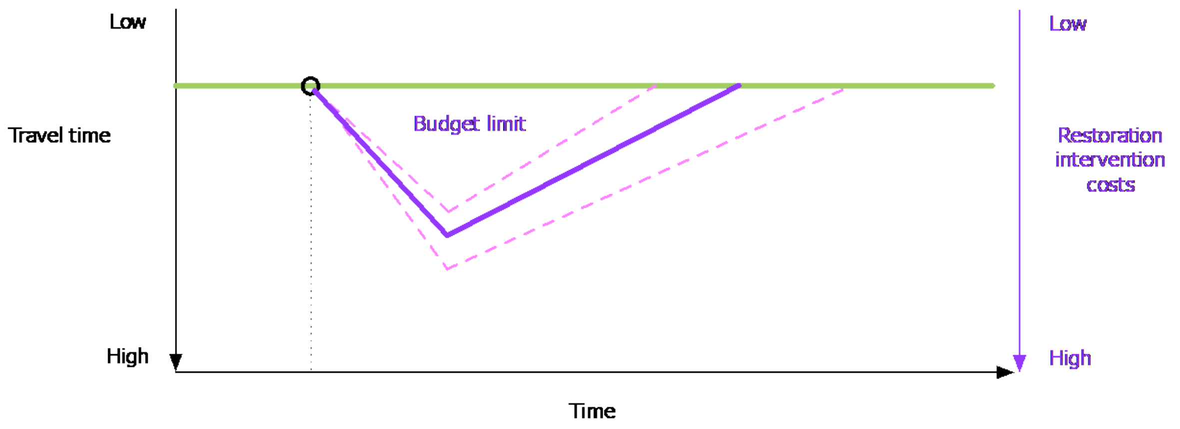

Figure 7. Graphical representation of target set 3

In the third sub-task, how these target sets are to be achieved is determined, e.g.:

1) To ensure that the users of transport infrastructure experience no increase in travel time if a 100-year flood event occurs, a second bridge to design code level 5 will be built.
2) To ensure that the legal requirements are met, the existing bridge will be strengthened.
3) To ensure that restoration intervention costs remain within a specified budget, the existing bridge will be strengthened in a way that makes it easy to rehabilitate following the occurrence of a natural hazard.

If it is realised during the determination of how the target sets could be achieved, that achieving a target set is not possible, e.g. there is not enough money for the second bridge, it should be excluded from further consideration.

In the fourth sub-task, the costs of attempting to achieve the targets sets, and the effect of each of the scenarios on the restoration intervention costs and the measures of service are estimated. This requires estimating how the modified transport system will behave following the hazard event. This is done using a combination of available data, expert opinion, models and simulations. It is advised to use ranges of values for all uncertain variables.

For example, constructing a second bridge designed to code level 5, might cost € 10’500’000 (low estimate), € 13’000’000 (medium estimate), or € 16’500’000 (high estimate). It might, however, yield benefits in terms of the reduction in restoration intervention costs and the measure of service travel time, that are needed due to the state of the object after the event. For example, the costs of restoring the bridge could be reduced by € 150’000 (low estimate), € 160’000 (medium estimate), or € 170’000 (high estimate), and the additional travel time incurred during the restoration period could be reduced by € 28’000’000 (low estimate), € 31’000’000 (medium estimate), or € 34’000’000 (high estimate). Table 8 contains, for all three example target sets, examples of ranges of costs to achieve targets, restoration intervention costs, and effects on the travel time measure of service.

Table 8. Expected costs of achievement of target set, effects on restoration intervention costs and effect on the travel time measure of service

Costs / Measure of service	Estimate	Costs and benefits of the target sets		
		Target set 1 "No changes in service"	Target set 2 "Legal minimum"	Target set 3 "Restoration budget"
Costs of achievement of target set	Low Medium High	€ 10'500'000 € 13'000'000 € 16'500'000	€ 9'600 € 9'600 € 9'600	€ 20'000 € 30'000 € 40'000
Benefit in terms of reduction in restoration intervention costs	Low Medium High	€ 150'000 € 160'000 € 170'000	€ 17'000 € 18'000 € 19'000	€ 12'000 € 13'000 € 14'000
Benefit in terms of reduction in additional travel time costs	Low Medium High	€ 28'000'000 € 31'000'000 € 34'000'000	€ 17'550 € 19'500 € 21'450	€ 95'400 € 106'000 € 116'600
Benefit	Low Medium High	€ 28'150'000 € 31'160'000 € 31'417'000	€ 34'550 € 37'500 € 40'450	€ 34'550 € 37'500 € 40'450
Net benefit	Worst (low benefits – high costs) Medium (medium benefits – medium costs Best (high benefits – low costs)	€ 11'650'000 € 18'160'000 € 23'670'000	€ 30'850 € 27'900 € 24'950	€ 67'400 € 89'000 € 110'600

In the fifth sub-task, the ability of each scenario to achieve the sets of possible targets is evaluated and the one with the highest net-benefit is selected, with the selected set of targets having broad support from the stakeholders. To do this, the costs of achieving the target sets are compared with their benefits, in terms of the reduction in restoration intervention costs and the effects on the measures of service for which targets are set. The level of precision of the estimates can vary depending on the sophistication of the analysis.

Three simple examples of how this works are shown in Table 8. The bottom row shows the net-benefit for the three target sets, divided into worst, medium and best case. For target set 1, for example:

- the worst net-benefit is € 11'650'000 = (€ 28'000'000 + € 150'000) - € 16'500'000),
- the medium net-benefit is € 18'160'000 = (€ 31'000'000 + € 160'000) - € 13'000'000
- the best net-benefit is € 23'670'000 = (€ 31'417'000 + € 170'000) - € 10'500'000.

It can be seen from Table 7 that target set 1 gives the highest net-benefits.

If target set 1 is selected, one should proceed with the construction of the second bridge to withstand a 100-year flood event, i.e. to ensure that there are no restoration intervention costs and no additional travel time costs following 100-year flood event.

Setting service and resilience targets with cost-benefit analysis can be summarised as collecting all necessary expert opinion to formulate sets of service and resilience targets that take into consideration all aspects of the transport system that are deemed important. This includes the interdependencies between intervention costs and measures of service and selecting the scenario and set of targets that has broad stakeholder support and yields the maximum net-benefit. The targets are formulated so that it is clear how they are to be measured.

6.4 RESILIENCE INDICATOR TARGETS WITH COST-BENEFIT ANALYSIS

In this method, the resilience indicator targets are set, taking into consideration the requirements defined in the previous two tasks, and based on the assumption that the net-benefit, i.e. the benefits – the costs should be maximised. It is similar to that described in section 6.2, with the exception that the costs of achieving the targets is explicitly evaluated regarding the benefits of reaching the targets.

The targets should be set, or consciously not set, for

1) each resilience indicator, and
2) each combination of resilience indicators

The method is based on an incremental benefit/cost ratio calculation that investigates the benefit/cost ratio of increasing the indicator target by one level. Choosing the highest indicator target with a positive benefit/cost ratio yields the indicator target with the highest overall net-benefit. The sub-tasks required to set targets when reflecting on the costs and benefits of changing indicator values are:

1) select the resilience indicators for which targets are to be set, e.g. the emergency plan resilience indicator
2) each target is set to the lowest value possible, e.g. the emergency plan indicator should have a value of 2 (meaning for example that the emergency plan is practised every 2 years) if according to law it has to be 2.
3) estimate the additional costs of each unit increase in the value of each indicator from the lowest legally allowed value, e.g. the additional costs of increasing the emergency plan indicator from
    a. 2 to 3, i.e. practising the emergency plan every year instead of every two years, is € 0.8 million due to the higher number of hours spent on practising, and
    b. 3 to 4, i.e. practising the emergency plan every 6 months instead of every year, is € 2.0 million due to the even higher number of hours spent on practising that requires extra personnel to be hired to coordinate and fill in the missing hours in normal work,
4) estimate the additional benefits of each unit increase in the value of each indicator from the lowest legally allowed value, e.g. the additional benefits of increasing the emergency plan indicator, due to increases in the probability that all organisations involved in emergency actions will act as expected leading to reduced restoration times, from
    a. 2 to 3, is € 1.9 million due to less travel time costs as the restoration time is shorter
    b. 3 to 4, is € 1.95 million due to even less travel time costs as the restoration time is now as fast as possible.
5) estimate the benefit/cost ratio for each unit increase for each indicator to determine if each increase is worthwhile, e.g. the benefit/cost ratio from
    a. 2 to 3 is 1.9 / 0.8 = 2.375 which is greater than 1, meaning that it is worthwhile to increase the value of the emergency plan indicator from 2 to 3

   b. 3 to 4 is 1.95 / 2.0 = 0.975 which is less than 1, meaning that it is not worthwhile to increase the value of the emergency plan indicator from 3 to 4.

6) set targets for all indicators based on the estimated benefit/cost ratios, the available resources and the opinions of the stakeholders, which should be able to broadly support the targets, e.g. the target for the emergency plan indicator is 3.

Using the example from section 6.2, targets for the resilience indicators "condition state of object" and "frequency of monitoring" are shown in Table 9, along with the legal requirement for the indicators (col. "Legal req".), the possible values of the indicators, and the increment costs (for the condition state indicator due to executing more interventions to keep the condition state better, and for more frequent monitoring due to higher monitoring costs), increment benefits (due to lower restoration intervention costs and less travel time because of the better state of the object following the event due to the initial condition of the object, and faster restoration due to better information because of frequent monitoring), benefit/cost ratio of increasing the value of the indicator by one are shown. The last column shows the total net-benefit, i.e. the sum of the upgrade benefits from indicator level 1 to the respective indicator level minus the sum of the associated upgrade costs. For example, the net-benefit for the condition state of object, level 3 is (€ 12'913 + € 10'505)-(€ 8'000 + € 10'000)= € 5'418.

Table 9. Costs and effects on service of increases in the values of resilience indicators

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

To follow the incremental process, and because there is no legal requirement for the condition state of the object, the incremental process starts at level 1, and with a benefit/cost ratio of 1.61, is moved to level 2 as a target. As the benefit/cost ratio for moving from level 2 to level 3 is 1.05, the target is further moved to level 3. Even more, as the benefit/cost ratio to upgrade from level 3 to level 4 is 1.01, and thus larger than 1.0 (but barely), the target is moved to level 4. The move from level 4 to level 5, however, is not done with the benefit/cost ratio being 0.83 and thus smaller than 1. This signifies that for every extra Euro spent, there is only a return of 0.83 Euros. Therefore, the target should stay at level 4. The associated net-benefit, which is the highest, is € 5'539.

For the indicator "frequency of monitoring" the process starts at level 2, which is the legal requirement. The benefit/cost ratio to upgrade to level 3 is 1.02, and so the target is moved to level 3. As the further upgrade from level 3 to level 4 has a benefit/cost ratio of 0.68, the target stays at level 3. The associated net-benefit, which is the highest but still negative, is € -1'000.

With this, the target for the indicators should be set to level 4 of 5 for the indicator "condition state of object" and level 3 of 4 for the indicator "frequency of monitoring".

Setting resilience indicator targets with cost-benefit analysis can be summarised as a process that takes the level of an indicator first to the legal minimum, and then incrementally upgrades the level step-by-step upwards to the maximum level, if the benefit/cost ratio of the specific upgrade step is larger than 1.0. This also results in the indicator target with the highest net-benefit.

7 CONCLUSION

This guideline is to be used to set service and resilience targets. It is to be used by all individuals to set service and resilience targets for transport systems, irrespective of the level of detail included in the estimation of the levels of service and resilience, i.e. from qualitative estimations to detailed simulation-based quantitative estimations. The examples used in this guideline are extensions of the ones in Deliverable D1.1.

The four different methods to be used to set service and resilience targets, or resilience indicator targets, are:

1) setting service and resilience targets without cost-benefit analysis,
2) setting resilience indicator targets without cost-benefit analysis,
3) setting service and resilience targets with cost-benefit analysis, and
4) setting resilience indicator targets with cost-benefit analysis.

The method to be selected depends on:

1) the way service and resilience are measured (Deliverable D1.1), i.e. directly, or indirectly using indicators, and
2) the availability of information on the costs of interventions, i.e. if the costs of interventions can be reasonably estimated, then one of the methods using cost-benefit analysis should be used and otherwise not.

Before using this guideline to set targets, it is important to have a clear objective to do so, i.e. to determine the way the targets should be set, to provide all necessary information, and to ensure that all relevant legal and contractual requirements are known.

Targets should also be achievable; therefore, consideration of the available or obtainable budget is necessary to set realistic achievable targets.

As measures of service and resilience as well as their targets are only useful if used in regular infrastructure management decision making, examples of how this can be done will be given in D1.3 "Examples of the use of measures of service and resilience in the governance of transport infrastructure".

8 LITERATURE

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9 APPENDIX A: MEMBERS OF THE STAKEHOLDER REFERENCE GROUP

Table 10 shows the entities that have contributed to Deliverable D1.2, either attending 2nd SRG webinar (November 14th, 2019) or/and sending written comments after this webinar.

Table 10. Members of the stakeholder reference group contributing to D1.2

Organisation	Contact person	Country
Asfinag	Karl Engelke	Austria
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IFSTTAR	Sylvain Chateigner, Andre Orcessi	France
Kraton Polymers	Laurent Porot	US/Europe
NCSR Demokritos	Thanasis Steftsos	Greece
Rijkswaterstaat	Sander Borghuis	The Netherlands
Tecnalia	David Sánchez	Spain
Tecnalia	Jesús Díez	Spain
Trafikverket	Johan Jonsson	Sweden
Transport for London	Mehdi Alhaddad	UK
Transport Infrastructure Ireland	Billy O'Keeffe	Ireland
UIC (The World Railway Organization)	Pinar Yilmazer, John Dora	
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University of Zagreb	Damir Bekic	Croatia
Virginia Tech. University	Gerardo Flintsch	US
ZAG	Stanislav Lenart	Slovenia
SRG chairman	Jesús Rodríguez	Spain