AM4INFRA

DELIVERABLE REPORT

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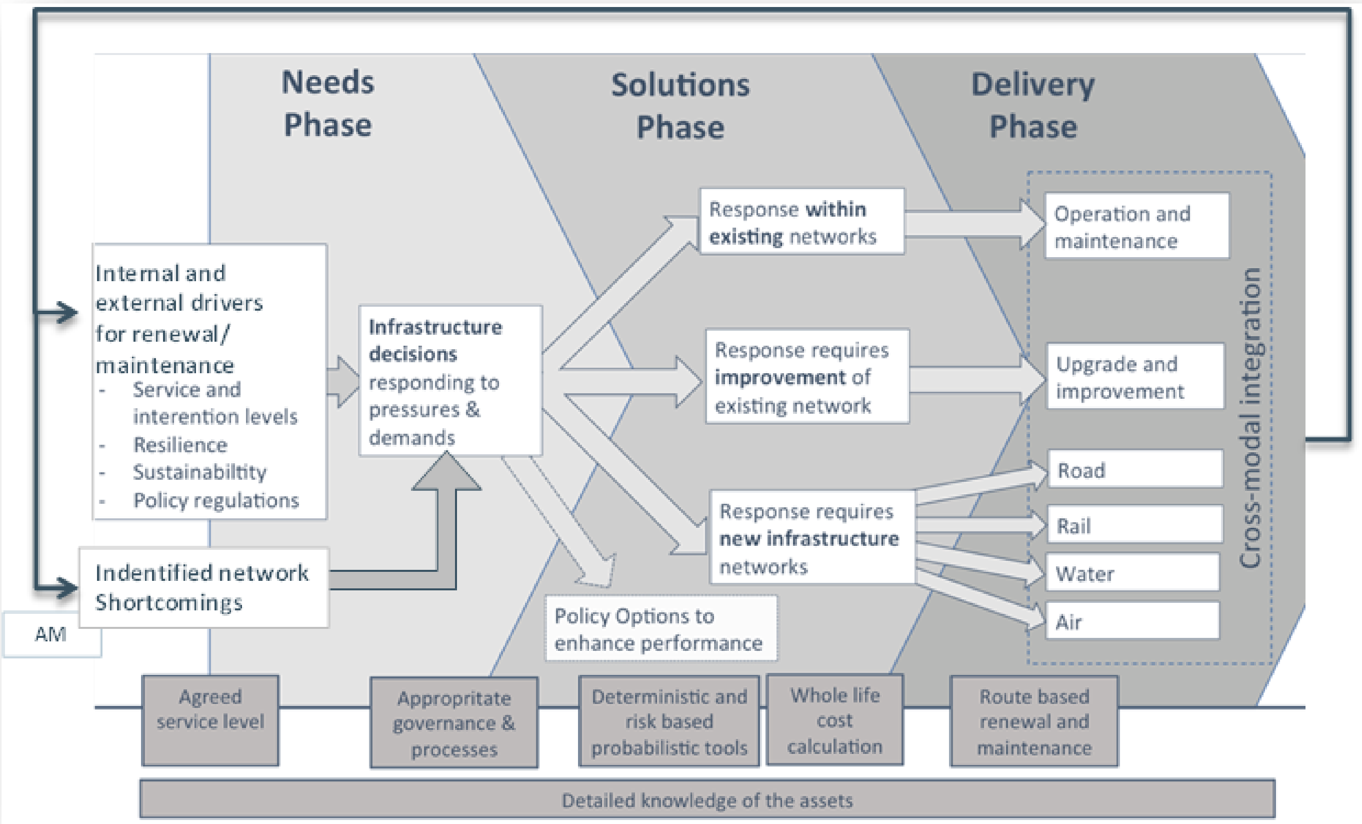
Publishable Executive Summary

Transport infrastructure is one of the main pillars of European society and economy. The design of infrastructure influences choices of transportation modes and thus is closely linked to social issues such as availability and affordability of mobility, to environmental aspects such as greenhouse gas emissions and nature protection, or health issues.

Asset Management (AM) is faced with the challenge to achieve higher efficiencies and enhance the productivity of the transport infrastructure. The asset manager relies on a variety of tools and methods in order to optimize the performance of existing networks and to optimize the value proposition of new infrastructure investments. Such optimization needs to be placed in a context of wider policy ambitions including concepts like resilience and sustainability.

To ensure an effective and efficient use of resources, a framework could be instrumental. In this document the most elemental set of building blocks is described in order to create a common basis for European NRAs, NIAs and alike and provides guidelines for the use of this framework. This document is based on deliverable D1.1 (Framework architecture), and includes the elements and structure as provided though the work packages on Life Cycle Management (WP2) and Data (WP3).

The framework architecture on smart governance of infrastructure network (deliverable D1.1) is expanded with the phases: needs, solutions and delivery, whereby the needs phase is driven by internal and external demands.



The three phases are linked to 6 building blocks:

1. Agreed service level
2. Appropriate governance and processes

3. Deterministic and probabilistic tools
4. Whole life cost calculation
5. Route based renewal and maintenance
6. Detailed knowledge of the assets

Societal value is an external demand that requires to be maximized by the asset manager in order achieve maximum benefits from infrastructure projects. To this effect, AM uses direct costs as well as indirect costs in whole life cost calculations (see D2.1).

In the optimization process, a balance between life cycle costs and the level of service is struck. Asset management thus underpins infrastructure decision making**.**

For asset managers, considering external demands and requirements in early stages of decision making provides the following benefits:

- It reveals potential conflicts between policy fields and reduces planning risks and operational costs
- It avoids costly re-alignments of infrastructure projects in later stages of planning and construction
- It improves reputation and credibility of asset managers and asset owners
- It avoids social and political resistance and resulting time delays e.g. from lawsuits

It opens financial support options such as climate adaptation funds.

AM actors (asset owners, asset managers, decision makers) need to plan for the required level of service they need and for how they will use the available funds to maintain, operate, repair, update and renew their assets. The tools available to them are listed and their use in optimization is explained. Significant effort has been accomplished in developing tools for specific corridors and modal needs; however, the cross-modal / cross-border view has not to date been sufficiently developed.

Policy integration aims to maximise societal benefits and returns of investment by taking into account demands from civil society and policy objectives from policy fields beyond transportation. The Lack of inter-departmental and cross-level cooperation is considered a main obstacle for the adoption of sustainable transport schemes.

The maximisation of societal value – i.e. the provision of an agreed level of service, the minimisation of environmental and social impacts, and the fostering of low-carbon innovations – requires appropriate governance processes.

Integrated assessments are established tools to foster coherence of actions towards broader societal goals and may avoid resources spent on demands going beyond the immediate responsibility of asset managers, perceived to be a waste of public money.

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1 Purpose of the document

1.1 DOCUMENT STRUCTURE

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1.2 DEVIATIONS FROM ORIGINAL DESCRIPTION IN THE GRANT AGREEMENT ANNEX 1 PART A

1.2.1 DESCRIPTION OF WORK RELATED TO DELIVERABLE IN GA ANNEX 1 – PART A

To provide a guideline on the basis of the common framework architecture which helps to translate the optimized infrastructure decisions and resilience elements as described under 1.1 into actionable strategic policy goals, network service level agreements and asset performance levels. This guideline will enable NIA's to translate the framework into context specific actionable strategies. In other words: the results of the collective welfare and resilience optimization need guidance on how to transfer this into results on the ground. On the basis of the results from task 1.1, tradeoffs and dilemmas become clear. The following steps will be taken in order to build the guideline:

- Provide guidance on how to enrich and support the individual institutional and political action arenas (respecting democratic legitimation of decision making, staying away from technocratic blueprint thinking, but at the same time enabling decision makers to provide best answers to public concerns related to infrastructure networks)
- Provide a portfolio of best practices, methods and tools which strengthen cross-modal and cross-border optimization.
- Provide a portfolio of best practices, methods and tools to increae resilience of transportation networks
- Analyze strengths and weaknesses of these strategies in terms of the ability to translate integrally optimized programs into effective actions on the ground. This will be done in a workshop prepared and hosted by the Center for Advanced Infrastructure and Transport (USA) to assess the possibilities and provide these with pro's and con's. On the basis of this overview a common framework will be drafted. In a follow-up focus group session validation and further adjustment and refinement will take place.
- Draft a guideline
- Stakeholder group discussion of draft results and sharing and dissemination of findings (see also WP4)

1.2.2 TIME DEVIATIONS FROM ORIGINAL PLANNING IN GA ANNEX 1 – PART A

In agreement with the PO (Mr. Sergio Escriba) It was decided to suspend final delivery of this document until 25 October 2017 in order to allow a integrated consultation of the stakeholder group meeting on this document combined with deliverables D2.2 and D3.2.

1.2.3 CONTENT DEVIATIONS FROM ORIGINAL PLANNING IN GA ANNEX 1 – PART A

No content deviations from original planning.

It should be noted that this document is subject to eventual review following on the outcomes of the verification in the three living labs (Rome, London, Eindhoven).

2 Introduction / background

Transport infrastructure is the backbone of national economies, providing connections for people and goods, access to jobs and services, and enabling trade and economic growth. This highlights the role of infrastructures as one of the main pillars of European society and economy. Transportation networks are indispensable for the smooth functioning of society acting as important lifelines linking communities and goods. A coherent transport network determines cross-border combined transport services establishing common acceptable standards and considering also regional planning objectives, as well as social and environmental factors and criteria. However, transport networks are fragile and vulnerable to natural and man-induced disasters, which can disrupt their vital functionality.

Based on the White Paper on Transport from 2011, the European Commission sets the target of a functional core network on all modes by 2030. This trend is also enhanced by the recent economic recession and as a result innovative cost-effective and environmentally friendly solutions attract the attention of European transport ministries and National Infrastructure Authorities (NIAs). Higher efficiency and increased productivity of transport infrastructure constitute major challenges that asset management (AM) has to deal with. AM is a core activity for sustainable development since it offers a better understanding to NIAs of their assets, describing how they perform and determining the funding they need (Department of Transport, 2013).

Transport infrastructure is complex

Transport and transport infrastructures play a central role in many policy fields beyond transportation, e.g. environmental and climate policy, social policy, cohesion, innovation policy, economic and industry policy and has to respond to the respective demands. Decisions about these networks will inevitably have a variety of effects, short- and long-term, and will in their turn influence the use of these networks. The design of infrastructure influences choices of transportation modes and thus is closely linked to social issues such as availability and affordability of mobility, to environmental aspects such as greenhouse gas emissions, emissions of nitrogen oxide, or nature protection, or to health issues.

For mentioned reasons infrastructure networks can be considered as complex. Due to the high number of parameters in play and uncertainties about current state or future situation maintaining and optimizing infrastructure networks is a challenging task. Practice, however, has delivered a variety of tools and methods to face this challenge. These tools and methods can optimize current networks according to specific aspects and optimize the value proposition for new infrastructure investments. Such optimization needs to be placed in a wider context of policy ambitions covering a wider set of issues including concepts like resilience and sustainability.

A framework could therefore be instrumental

To avoid a high degree of 'muddling through' and ensure effective and efficient use of resources, a framework could be instrumental. Such a framework could help balancing efforts, avoid losses by network incompatibilities and push symbiotic functioning of networks. In this document the most elemental set of building blocks is described in order to create a common basis for European NRAs, NIAs and alike and provides guidelines for the use of this framework. This document is based on deliverable D1.1 (Framework architecture), and includes the elements and structure as provided though the workpackages on Life Cycle Management (WP2) and Data (WP3). This document first reiterates the elements as shown in D1.1 (section 3), and then provides a further refined version of this framework architecture. On the basis of this refined version the guidelines on how to use the framework architecture are shown (section 4). The guidelines show tools and methods as well as best practices on the concepts as shown.

3 Framework architecture on smart governance of transportation networks

In the first deliverable (D1.1), a framework on smart governance of infrastructure networks is provided. The framework brings management of existing networks and new investments together into a context of major concepts which may be integrated in the decision making process. The issues concerned are cross-modal optimization, cross-border optimization, sustainability, resilience and data coordination. These concepts are not exclusive for a specific type of transport network, but relate to all types including roads, rail and waterways. Once implemented, these concepts provide vital connections for ports and airports, whereby all surface and non-surface modalities are connected. These elements are presented as a framework (figure 1). The logic of the framework is as follows;

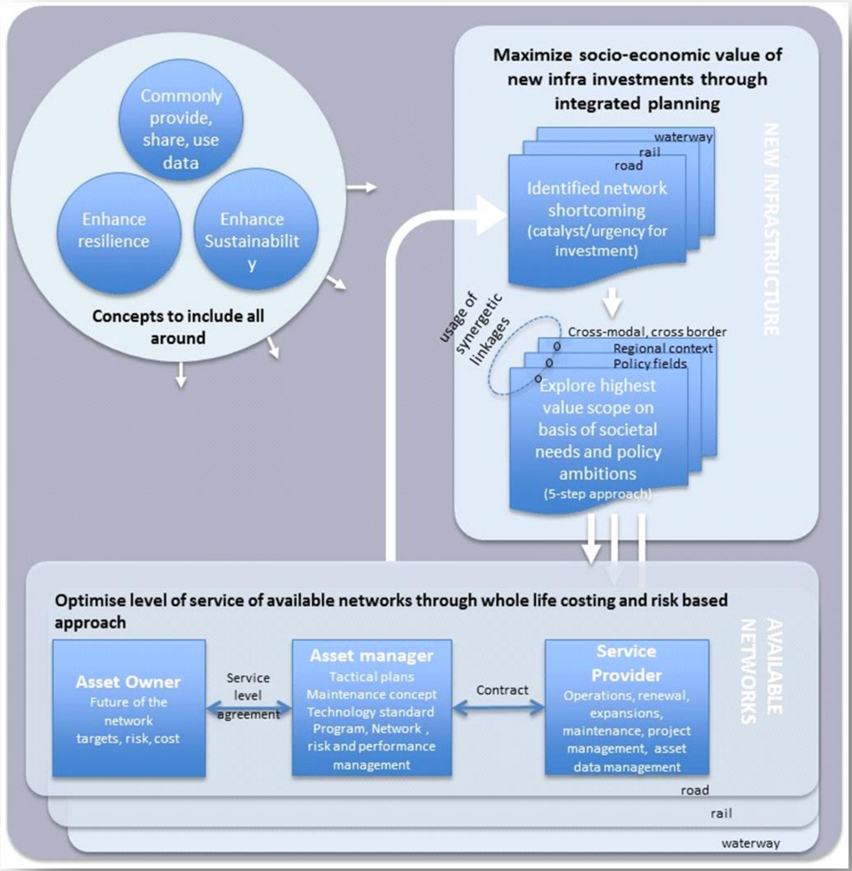


Figure 1: Framework architecture as provided in D1.1, in which asset management is responsible for optimizing the level of service.

- **Asset management is the foundation of the system**. Balancing performance, costs and risk aims to optimize the service to the public given the available resources. By defining an asset owner, an asset manager and a service provider role, responsibilities and tasks are allocated clearly. At some point either the owner or the asset manager or the service provider may encounter a situation which requires new investment. Preliminary studies, cost benefit analysis and other commonly used methods can provide objective justification for the investment, which may form a solid base for any subsequent political decisionmaking process. When according to (national) rules and regulations it is determined that the network failure needs to be resolved, the scoping of the project will take place. This is a crucial step in the process where the scope determines to what extent elements of the failure the entire failure, or the wider context of a problematic region will be addressed. Here lies an opportunity to determine the best value proposition for the agency and for society as a whole (see 5-steps in section 3.2 in D1.1) to ensure transport and mobility is efficiently and effectively supported, externalities are minimized and effective institutional arrangements are being selected.
- **Common concepts like use of data, resilience and sustainability will have to be taken into account in all steps of network management, network enhancement and network expansion**.

4 Guideline for the framework architecture

4.1 GUIDELINE STRUCTURE

During the development of D1.2 the framework architecture, shown in section 3 of this document, was tuned and aligned to the results of WP2 and WP3. This section seeks to explain how the framework architecture has evolved and has been adapted. As shown in D2.1, infrastructure management generally follows three phases. In the 'needs phase' it is determined what problems need to be addressed. The 'solutions phase' focusses on what to do, and the 'delivery phase' is about the implementation of the solutions.

In good asset management these phases are supported by six building blocks. These building blocks are part of the asset management system, supporting sound decision making in infrastructure maintenance and development with respect to whole life costs and risks. These building blocks are:

1. Drivers for renewals
2. Appropriate governance and processes
3. Deterministic and probabilistic tools
4. Whole life cost calculation
5. Route based renewal and maintenance
6. Detailed knowledge of the assets

These building blocks cover all aspects and components of an AM system[1] and do not necessarily following each other sequentially. They are interrelated. For instance, deterministic and risk-based probabilistic tools provide input for appropriate governance and processes, which in turn may form the basis for route-based renewal and maintenance, whereas detailed knowledge of the assets feeds into all of the building blocks. This is depicted in figure 2.

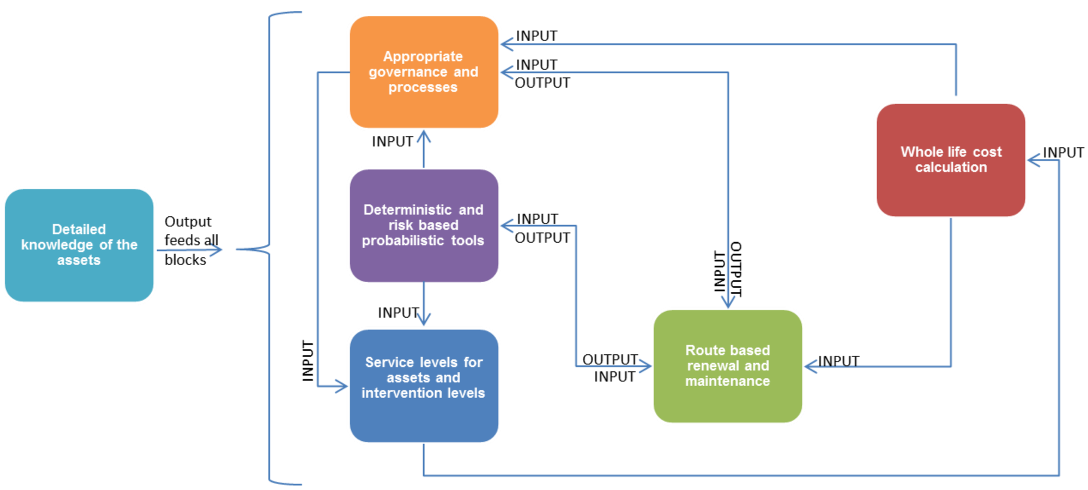


Figure 2: Relation between the building blocks.

[1] In case stakeholders identify an aspect which they cannot directly link to a building block for reason that it is not explicitly named as such, they are advised to place it in the most appropriate building block in order to deal with that aspect in a coherent fashion. In addition, as this framework captures recently acquired knowledge and insights, the authors are keen to learn from stakeholder experiences in applying the framework.

By taking the original framework architecture and merging this with the phases of infrastructure management together with the building blocks that support decision-making, an enhanced framework emerges (figure 3).

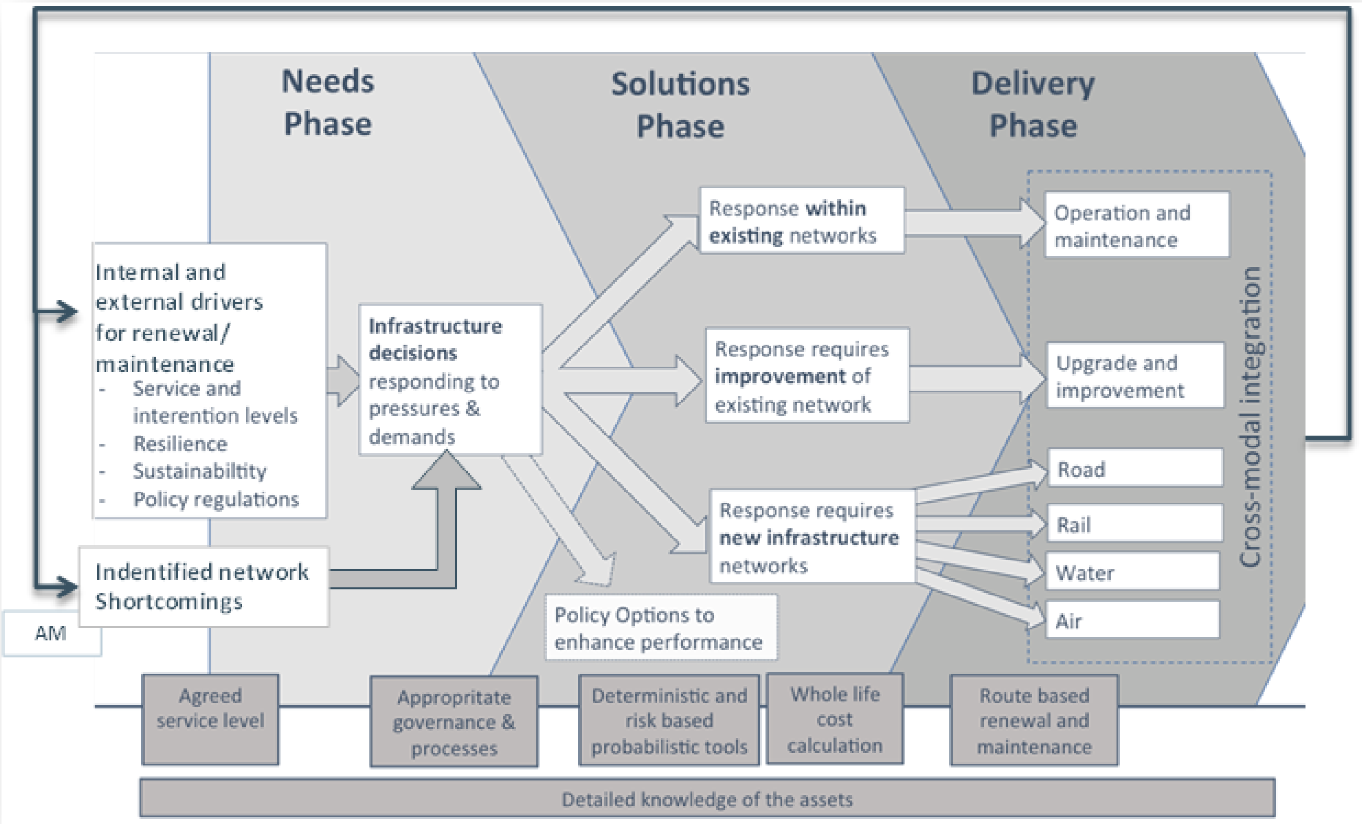


Figure 3: Enhanced framework, merging the D1.1 framework with the three development phases and the 6 building blocks.

In the end, the delivery phase feeds into the needs phase as good AM requires continuous monitoring and improvement, with a closed Plan-Do-Check-Act loop. On the basis of this information, the asset manager identifies possible shortcomings within the network and may subsequently consider further course of action addressing the needs phase This loop elevates the AM architecture within the NIA, putting the asset manager in a position to add significant value to process.

4.2 INFRASTRUCTURE DECISIONS RESPONDING TO NEEDS AND PRESSURES

The needs phase may be initiated by internal and/or by external pressures. Internal pressures may relate to the provision of an agreed service level or intervention level by the service level provider to the asset manager or asset owner, as specified in AM4INFRA D2.1 and D2.2. External pressure can come from:

(1) considerations of *resilience*, such as anticipating potential disasters or more extreme weather events as a result of climate change;
(2) demands from *external policy fields* such as environmental, climate, innovation, or social policy;
(3) experience *users* may have on a given section of the network.

Examples for external demands on transport infrastructures from EU policies

- The 2011 White Paper "Roadmap to a Single European Transport Area" stresses that transport infrastructure investments can have positive impacts on economic growth, accessibility and mobility but have to be planned in order to maximize economic growth and minimize negative environmental impact. EU-funded transport infrastructure, thus, should *'take into account energy efficiency needs and climate change challenges'* such as climate resilience of the overall infrastructure, refuelling/recharging stations for clean vehicles, or the choice of construction material etc. and to achieve a 60 % cut in greenhouse gas emissions below 1990 levels by 2050.
- Funding for transport and transport infrastructure under the European Structural and Investment Fund is increasingly targeted towards the "promotion of low-carbon transport with the aim of achieving by 2050 a significant reduction in CO_2 emissions, in line with the relevant Union CO_2 reduction targets. The European Noise Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for major roads, major railways, and major airports.
- The European Action Plan for the Circular Economy highlights the "use of recycled materials in products and infrastructure".
- The 7^{th} Environmental Action Programme urges to integrate resource efficiency, climate change and energy efficiency concerns into other key sectors, such as transport and buildings. For example, *"The envisaged expansion of energy and transport networks (…) will need to be compatible with protection of nature and climate adaptation needs and obligations"*.
- The 2015 European environment - state and outlook report identifies the development of grey infrastructure as one key pressure on biodiversity.

In consideration of the internal and external pressures and demands **maximising the societal value of transport infrastructure** requires taking into account the impacts of transport systems on society, economy, and the environment. Internal and external pressures have to be accommodated in an optimized way. Depending on the specific demand, those that may need to take action may be asset owners, asset managers or decision makers on the design of a transport network.

Societal value equates to the added value of infrastructure projects minus their costs to society. It is important to note that socio-economic costs and benefits can either be direct or indirect. **Direct costs** are mostly related to construction and maintenance and are immediately perceptible for infrastructure owners and managers. In contrast, **indirect costs and benefits** often are not clearly visible and relate to policy fields beyond infrastructure development. Negative externalities, such as the cost of climate change, the loss of habitats or air pollution also need to be accounted for in **whole life cost calculations (→ D2.1)**. Asset management is considered sustainable if no net loss of societal value is incurred, i.e. if the net benefits for all members of society are equal or larger than the total costs (going beyond financial costs). The European TEN-T Regulation defines 'socio-economic cost-benefit analysis' as „quantified ex-ante evaluation, based on a recognised methodology, of the value of a project, taking into account all relevant social, economic, climate-related and environmental benefits and costs“ (Article 3 (t)).

Take-away messages for asset owners, decision-makers and managers

Taking existing demands into account and anticipating developments in the broader societal, political and economic environment will increase the societal value of transport infrastructures and avoids costly re-alignments of projects in the future.

Definition of Societal Value

- **Societal value** equates to the added value of infrastructure projects (benefits) minus their costs to society.
- Costs and benefits can either be direct or indirect.
  - **Direct costs** are mostly related to construction and maintenance activities and are immediately perceptible to infrastructure owners and managers.

  - **Indirect costs and benefits** often are not clearly visible and may relate to policy fields beyond infrastructure development.

- Negative externalities, such as the cost of climate change, the loss of habitats or air pollution also need to be accounted for in **whole life cost calculations** (as specified in D2.1).
- This requires a "whole of society" perspective that goes beyond the transport realm and also considers environmental and social issues (OECD 2008, S. 6). Asset management is considered sustainable if the net benefits to all members of society are larger than the total costs.

Societal value of infrastructure projects = benefits from infrastructure projects – direct costs – indirect costs

AM4INFRA aims at the **maximisation of societal value** from transport infrastructure management.

4.3 EXISTING NETWORKS

Internal demands for certain level of service (LoS) and external pressures (such as environmental and social needs) drive decision making on infrastructure interventions of transport networks locally, nationally and at cross modal and/or cross border level. These interventions could be either addressed by existing transportation networks or new infrastructure investments utilizing methods and tools for life cost calculations of the assets.

In defining an asset management strategy and resilience planning for existing networks, AM actors (defined as asset owners, asset managers and decision makers) should consider how they will optimize the level of service and address the needs of their users into the future. AM strategy and resilience planning will enable AM policies to be executed and ensure the integration of the long term strategic plans about transportation networks.

Strategic AM objectives are common across all AM actors:

- Safety: for mitigating the risk of asset failure and renew critical assets before the end of their required LoS
- Risk management: response plans and mitigation actions to deal with severe events
- Strategic planning: comply with legislation and industry requirements
- Reliability & Responsiveness: ensure the required LoS to the users of the transportation network
- Environmental management: prioritize sensitive issues to promote environmental friendly solutions and minimize environmental impacts
- Growth management: align investment priorities with long term demands
- Communication with stakeholders: communicate and inform AM stakeholders and other relevant user groups
- Customer service: service requests are responded to in relation to the urgency and importance
- Business efficiency: optimize the use of existing infrastructure

In order to optimize the LoS of the existing transportation network, the questions:

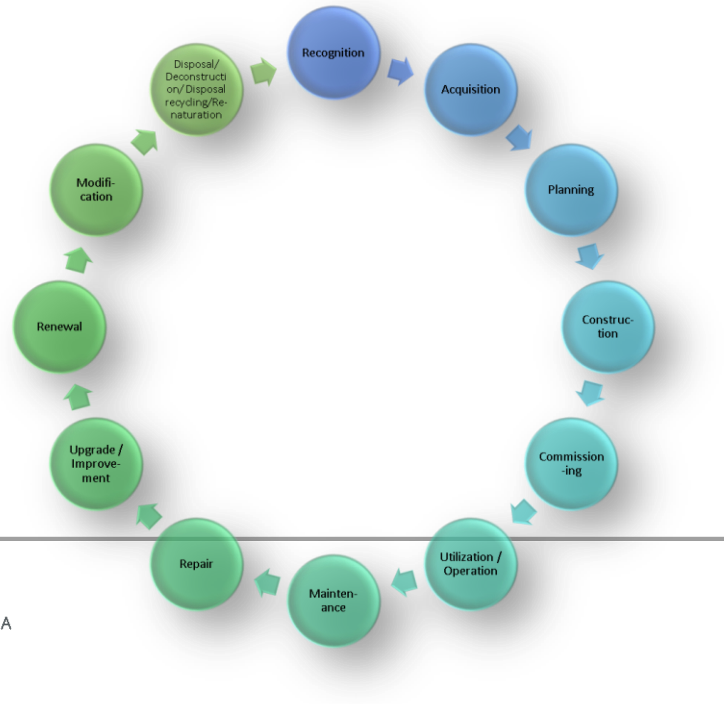
- What is the current situation?
- Where do we want to be?
- How will we get there?

…should be answered according to the whole life cost and risk based approach provided in D2.1. This risk based approach can be used to prioritize assets in existing networks and to align maintenance actions to ensure the desired LoS. In particular, asset management policies and strategies should be planned by (i) reviewing the capacity of the existing networks, (ii) assessing their performance and (iii) improving their capacity to continue to deliver the required LoS. Therefore, AM actors have to ensure they have the necessary information and data that provides them with sufficient knowledge about their assets and an understanding of the long term issues faced on their transportation networks. To achieve this, the updating process of asset data and information should follow a systematic approach of information and data management as described in D3.1.

An effective asset management planning requires a clear understanding of asset life cycle costs (LCC). According to the CEDR report (Conference of European Directors of Roads, 2013), LCC constitutes the basis of a comprehensive AM approach since different planning phases require different actions to be taken (Davis, 2012). It involves phases from recognition to disposal and describes that assets have a life cycle even though their duration may not be the same. It covers renewal as well as maintenance, albeit that the definition of some of the elements may vary across the EU. A broad depiction of the AM lifecycle is provided in figure 4.

The AM Lifecycle phases are defined as per below based on the Local Government & Municipal Knowledge Base (2017).

- **Recognition:** the process of recording assets owned or controlled by an organization and their values.
- **Acquisition:** the process of deciding when new assets need to be created and existing assets need to be upgraded.
- **Planning:** the process of considering possible futures and putting into place organization actions.
- **Construction**: the process of creating new assets or upgrading the existing assets owned or controlled by an organization.
- **Commissioning:** the process by which an asset is tested to verify if it functions according to its design objectives or specifications.
- **Utilization / Operation:** the process to which an asset is being productively used.
- **Maintenance:** the process of ensuring that an asset is able to deliver the expected level of service.
- **Repair:** the process of removing or reducing a risk arising from a defect in an asset.
- **Upgrade / Improvement:** the process carried out on an existing asset to provide a its current function to a higher level of service.
- **Renewal:** the process by which an asset is replaced or an existing asset (or component) refurbished with a new asset (or component) capable of delivering the same level of service as the existing asset.



- **Modification:** the process by which an asset is changed or altered to address other functions than its current function.
- **Disposal** / **Deconstruction / Disposal recycling/ Re-naturation:** the process by which an unwanted, unserviceable and/or decommissioned asset is disposed (both physical and the associated accounting treatment).

AM actors need to plan for the LoS they need and how they will use the available funds to maintain, operate, repair, update and renew their assets. This decision is a core activity in managing infrastructure assets in order to continue to provide the required LoS. As such, it includes service delivery options and funding alternatives. Priorities and objectives are defined and a financial plan including budget projections could be made. Legal obligations should also be considered and key performance indicators and performance targets are used to support decision making. A GAP analysis could provide useful information about the additional assets required and a Fiscal Policy could ensure the LoS to be "financially sustainable".

Significant efforts have been put into the development of tools for corridors and modal needs. According to research as well as industry expert groups (PIARC, 2008; Conference of European Directors of Roads, 2013; Department of Transport, 2013; FHWA, 2013), the available instruments and methods of asset management and resilience planning can be summarized as follows:

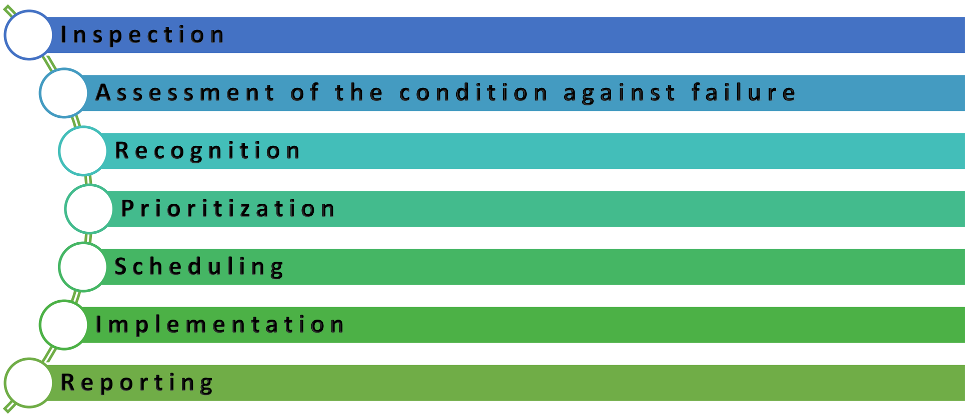
- Legislation and policies
- Management contracts
- Information sharing and communication
- Integrated accounting and technical systems
- Transparent communication with relevant stakeholders (i.e. National Authorities, Ministries, etc.)
- Direct and frequent interaction (reports, meetings, co-working, etc.)
- Forecasts on future development (scenario analysis, tools, etc.)
- Decision support tools (accounting, financial, operational)
- Risk analysis
- Service level agreements
- Investment Strategies
- Gap analysis
- Functionality assessment
- Monitoring KPIs

Although these tools are also applicable to cross-border / multi-modal aspects, designated cross-border / multi-modal tools, that support decision making across modes / borders are not sufficiently developed.

4.3.1 MAINTENANCE, OPERATION/UTILISATION AND REPAIR

The selection of appropriate maintenance actions is crucial to minimize asset costs and achieve the required service level for a prolonged period of time. Maintenance actions involve a multidisciplinary approach and include the regular on-going work that is required to keep assets operating effectively. It also includes repair actions to make assets operational again in case of failure. In addition, it is necessary to plan for maintenance to deal with the assets when changes and disturbances occurred. These contingency plans should be made in order to quickly restore transportation infrastructure in case operating effectiveness drops below the LoS.

The main maintenance actions should be undertaken on a regular basis and they typically include i) Inspection, ii) Assessment of the condition against failure, iii) Recognition, iv) Prioritization, v) Scheduling, vi) Implementation and vii) Reporting.



Infrastructure assets are capital intensive investments and take time to realize. As such, AM actors are responsible for managing the funding efficiently and effectively. Monitoring provides important information about direct costs and the actions taken as part of the maintenance process. This information may include:

- maintenance costs (i.e. €/km, €/day, €/m^2 etc.)
- frequency (i.e. count/km, count/day or month, count/EU route etc.)
- maintenance schedule (i.e. date and/or time)
- advanced investment strategies (i.e. risk tolerance)

4.3.2 IMPROVEMENT/UPGRADE OF EXISTING INFRASTRUCTURE AND NEW INFRASTRUCTURES

Improvement / upgrade is considered a core activity for infrastructures in order to provide the required LoS. The process to which an asset is being used productively should include regular assessments to evaluate if the asset reaches the end of its effective level of service. From an AM viewpoint, large upgrades are no different from constructing new infrastructure apart from the latter requiring more extensive stakeholder consultations and (spatial) planning. Decisions about renewing an asset use priority rankings and should consider (i) the elapsed time of the asset brought into service, (ii) the cost of replacement, and (iii) the expected end of effective level of service. Asset data and information are necessary to determine the condition of an asset and plan renewal/renovation actions. The aim is to utilize the available information to restore the service potential of the asset at a minimum cost by renewing, renovating or upgrading processes. Therefore, maintenance records and reports are important to collect the proper data accurately and regularly for making decisions about asset renewal.

AM actors commit to manage the risk of assets and renew them before their effective LoS or replace them reactively. The renewal approach should also include resilience planning which indicates proactive intervention with the aim to get the right balance between planned and reactive renewals. This depends on the asset condition and takes into consideration risk, cost and LoS. Similarly to maintenance and operation activities, decisions for renovating, renewing and upgrading the assets are based on quality information and data. Therefore, data analysis, analysis of operation and maintenance history are required to plan and refine the current renewal strategy.

Take-away messages for existing networks

- Asset management underpins infrastructure decision making
- Asset Management strategies must be defined and optimized so as to consider a balance of life cycle costs and level of service - ***Optimization considers a balance of life cycle costs and level of service.***
- AM actors need to plan for the LoS they need and for how they will use the available funds to maintain, operate, repair, update and renew their assets.
- Significant effort has been accomplished in developing tools for specific corridors and modal needs; however, the cross-modal / cross-border view has not to date been sufficiently developed.

4.4 BEST PRACTICES, METHODS AND TOOLS

4.4.1 SUSTAINABILITY

Maximising the economic and social benefits of transport infrastructure (whole life cost calculation) requires taking into account direct and indirect effects of transport systems. Benefits are understood as the added value of infrastructure projects minus their costs to society. As described in 4.2, an action is sustainable if the net benefits for all members of society are larger than the total costs – considering all likely impacts on all members of society (OECD 2008, S. 6).

As previously cited, the European White Paper on transport 2011 stresses that transport infrastructure investments can have positive impacts on economic growth, accessibility and mobility but have to be planned in a way to minimize negative environmental impact. EU-funded transport infrastructure should 'take into account energy efficiency needs and climate change challenges' such as climate resilience of the overall infrastructure, refuelling/recharging stations for clean vehicles, or the choice of construction material etc. Innovative low carbon transport solutions (ITS) can provide economic advantages such as cost savings from fuel efficiency, or the creation of new markets. More than 10 years ago, the European Commission's Steering Group on trans-European networks concluded that…

"Investment in ITS should be considered as a strategically important element in all new trans-European transport networks projects, and in projects for refurbishing existing networks and links. Moreover, ITS offers a set of tools for co-modality and environmental sustainability" and "recommends that investment in Intelligent Transport Systems (ITS), representing typically a few percent of the infrastructure cost, should be included from the beginning in the planning of all new TEN-transport projects, as well as considered as an essential element for all infrastructure improvement and refurbishment projects."[2]

Transport infrastructures are long-lasting assets. As such they define development pathways for mobility technologies and enable, foster, or restrict the uptake of low-carbon innovations in the transport sector (European Commission 2012c): On the one hand, infrastructures can create path dependencies and hinder the diffusion of innovations (Creutzig et al. 2015; Sims et al. 2014). On the other hand, targeted infrastructure investments can offer additional options for market actors and foster the uptake of innovations. For example, the provision of charging infrastructure is one key requirement for the mainstreaming of e-mobility solutions.

[2] Communication from the Commission - Trans-European networks: Towards an integrated approach {SEC(2007) 374} COM/2007/0135 final.

The maximisation of societal value – i.e. the provision of an agreed level of service, the minimisation of environmental and social impacts, and the fostering of low-carbon innovations – requires **appropriate governance processes.** As all public institutions asset managers are charged with specific tasks, they tend to respond to their specific concerns rather than seeking to maximise broader societal value. Resources spent on demands beyond their immediate responsibility may be perceived as waste of public money. Integrated assessments are established tools to foster coherence of actions towards broader societal goals. Depending on the stage of infrastructure development and the depth of intervention of the proposed solution, these assessment mechanisms will take different forms (Figure 5):

- Strategic Environmental Assessments (SEA) that relate **to public plans, programmes, and investment strategies**;
- Environmental Impact Assessments (EIA) that aim at ex-ante estimating impacts of large scale infrastructure **projects**;
- Life Cycle Assessments (LCA) that are used for specific **procurement decisions.**

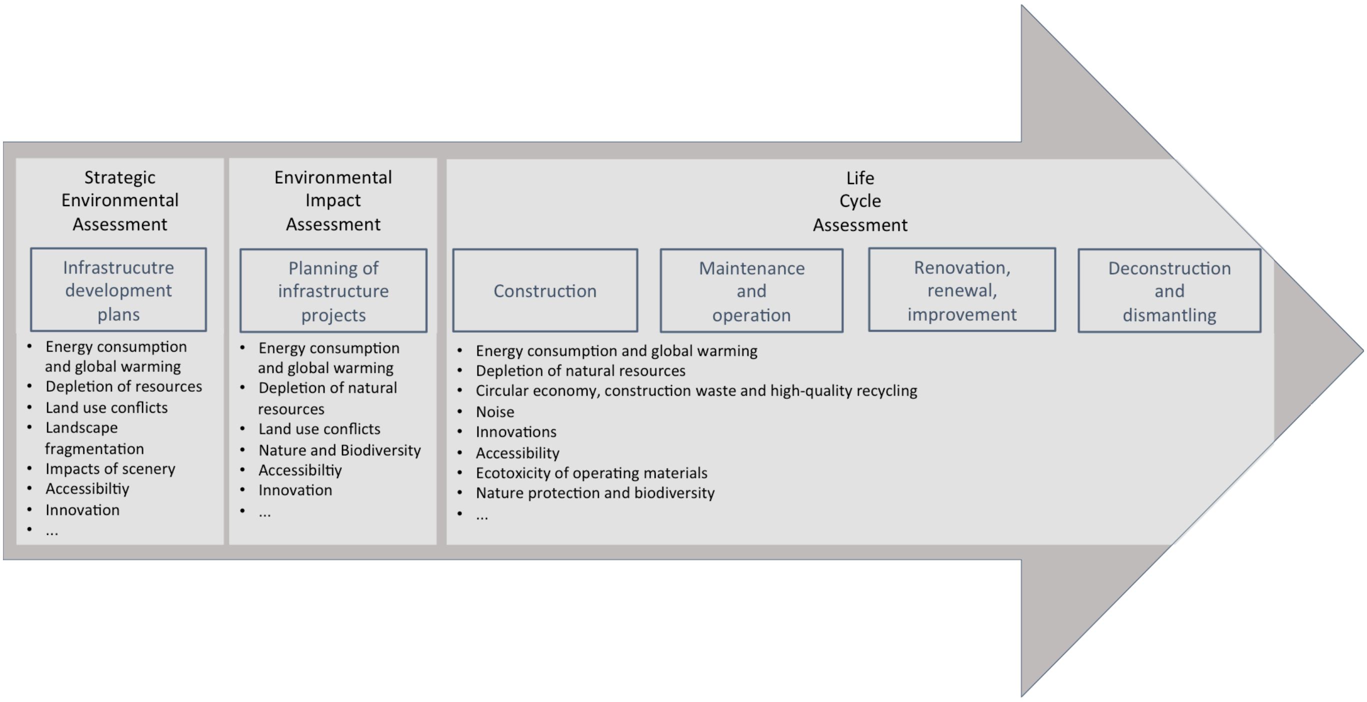


Figure 5: Integrated assessment tools for the maximisation of societal value[3].

Sustainability and Environmental Impacts Related to Existing Networks

Environmental impacts related to infrastructure assets that can be influenced during routine operations such as **operation, maintenance and repair** mostly relate to the choice of materials and methods. Examples are the high-grade use of recycled material to reduce the exploitation of sand and gravel or the avoidance of herbicides that endanger the state of nearby ecosystems and the health of employees. High concentrations of herbicides such as Glyphosate can often be found in highway runoff (Opher und Friedler 2010). Another aspect might be to enhance near-natural and bio-diverse roadside

[3] Note that the aspects that are listed are non-limitative. As such, SEA may in addition cover population health, regionally balanced development and integration, EIA may cover emissions and green procurement, whereas LCA may also cover integration, connectivity and reliability of LoS.

greenery. Note that measures might be synergetic but might also be conflicting both among each other and/or with other objectives of asset management. This would for example be the case when the preferential treatment of recycled content leads to increased transport distances for building material. A careful consideration of options and their synergies and trade-offs requires a sound knowledge base of the assets.

Examples for sustainability aspects that can be influenced during routine activities (operation, maintenance and repair)

- use of energy and the emission of GHGs, pollutants, and noise through the selection of road pavement
- use of energy and the emission of GHGs through the use of energy-saving lighting;
- depletion of natural resources through the recycling of construction waste and high grade use of recycled aggregates and asphalt;
- ecotoxicity through banning or efficient use of herbicides;
- ecotoxicity through storage of hazardous materials within safe containments and at safe distance from sensitive areas;
- soil: limitation of soil disturbance current work areas;
- biodiversity through bio-diverse roadside greenery;
- social: decent working conditions in procurement and contracting, avoid hiring contractors that have violated labour or other occupational laws.

Depending on national practices for outsourcing, asset managers often contract private companies for renovation, renewal, upgrading, or deconstruction of infrastructures. The formulation of procurement and tender documents for products and services is a lever to foster sustainability in repair, renovation, or upgrade activities. Contracts should enable innovation , sustainability and enable efficient delivery. Green procurement should be considered as a mechanism of improving sustainability of projects and reducing energy consumption. Tendering documents could prefer for example the high-grade use of recycled material from local sources. Using quality/ price quality , MEAT, experience and expertise in the tendering process as outlined in the EU Public Procurement Directive Directive 2014/24/EU] enable the procuring authority to take account of criteria that reflect qualitative matters rather than relying upon price alone

As noted in Figure 4 one method to determine the sustainability of products and services is Life Cycle Assessment (LCA). LCA is an analytical tool to inform decision makers about environmental impacts of a product or a service and thus can complement whole life cost calculation as specified in D2.1. LCAs are most often applied in specific decision situations such as the choice between different building materials or road pavements. It can also be used to assess impacts of specific asset components such as bridges (examples: Huang et al. 2009; Santero et al. 2011). The assessment covers the entire life cycle of the product or service including the extraction and processing of raw materials, construction and production, distribution, use, maintenance, demolition, up to recycling and disposal (see Annex). System boundaries, relevant impact categories and indicators will vary depending on the scope of the study.

The carbon footprint of transport infrastructures (GHG emissions) will most likely be part of the assessment: According to the European TEN-T Regulation (23), the greenhouse gas impacts of projects of common interest in the form of new, extended or upgraded transport infrastructures should be assessed. The relevance and selection of other criteria will depend on the specific project under consideration as determined in the scoping and screening stage of LCAs. A table that provides a non-comprehensive list of impact areas is provided in the annex.

Sustainability and Environmental Impacts during Improvement and Construction of New Infrastructure

The construction and operation of new infrastructure assets is related to negative environmental and social implications. Most environmental impacts occur during the use phase of infrastructures, but are determined during the early planning stages. The choice of the road corridor, for example, influences energy use from transport activities and road maintenance to a great deal. The ECRPD Project, for example, estimates energy saving potentials of up to 47 % for road construction, up to 20 % for road operations if the impacts on energy use would be considered in early planning stages (Energy Conservation in

Road Pavement Design Project, 2010). The long service life of infrastructures creates path dependencies and determines mobility and transport patterns in the long term.

Examples for sustainability impacts that can be influenced during planning, improvement and construction activities

- use of energy and the emission of GHGs, pollutants, and noise through the selection of road pavement and the choice of corridor;
- use of energy and the emission of GHGs through the use of energy-saving lighting;
- depletion of natural resources through the recycling of construction waste and high grade use of recycled aggregates and asphalt;
- accessibility: enhancing the accessibility through the integration with existing regional transport networks;
- nature protection: avoiding interference with protected areas through the appropriate choice of corridors;
- innovations: the fostering of and adaptability to technological innovations such as e-mobility, smart metering, or intelligent traffic management through the provision of pre-installations;
- social: consider decent working conditions in procurement and contracting, avoid hiring contractors that have violated labour or other occupational laws.

The Lack of inter-departmental and cross-level cooperation is considered a main obstacle for the adoption of sustainable transport schemes. There is an increasing demand for participation and transparency from civil society. Without prior consent, infrastructure projects risk being delayed or need to be re-planned. Policy integration means that public and private actors involved in infrastructure related decisions take objectives from other policy fields and societal concerns into account. The rationale behind this is to avoid conflicts between transport infrastructure development and external policy goals in early stages of decision-making and to anticipate future (environmental) legislation. Article 50 of the TEN-T Regulation states that

> *“projects of common interest relate to all directly concerned stakeholders. These may be entities other than Member States, which may include regional and local authorities, managers and users of infrastructure as well as industry and civil society.”*

In this context, sustainability assessments such as (Strategic) Environmental Assessments can enhance the legitimacy of planners and asset managers by contributing to the evidence base of choices. Active participation of stakeholders and public deliberation avoids costly re-adjustments of infrastructures in later stages, avoids time delays during planning and construction stages e.g. from lawsuits, facilitates synergies between policy fields and thus increases net societal benefits of infrastructure projects. Potential measures comprise, for instance changes in the size or technical design of projects, the choice of transport modes, the selection of corridors for transport infrastructure, or appropriate mitigation and compensation measures (European Commission 2012a, S.6).

Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) have been promoted as tools for preventive environmental management – and carrying out an Environmental Assessment is a legal requirement for most infrastructure projects in the EU. The TEN-T Regulation states that

> *“projects of common interest for which Union funding is sought should be the subject of a socio-economic cost-benefit analysis based on a recognised methodology, taking into account the relevant social, economic, climate-related and environmental benefits and costs. The analysis of climate-related and environmental costs and benefits should be based on the environmental impact assessment carried out pursuant to Directive 2011/92/EU of the European Parliament and of the Council”*

Environmental assessments, however, should not be regarded as yet another task to be fulfilled. Environmental assessments should be regarded as an opportunity to enhance societal value of infrastructure assets, to gain support for large-scale infrastructure projects and thus to avoid time-consuming and costly delays and adaptations in later development stages. They can also contribute to the selection of appropriate mitigation measures.

Strategic Environmental Assessments

Decisions on the need for new infrastructures mostly are taken at a political level and form part of strategic plans. Strategic Environmental Assessment (SEA, according to Directive 2001/42/EC) is used in early planning stages with the aim to proactively integrate environmental aspects into the preparation and adoption of public **plans, programmes or investment strategies** such as transport plans (Partidário 2012). SEAs are mandatory for most strategic public plans and programmes which 'set the framework for future development consent of projects listed in the EIA Directive' (see below). This includes strategic plans for infrastructure development. With the introduction of the SEA Directive in 2001 the European Commission also aimed at achieving 'a certain degree of consistency and minimum-quality standards among EU member states' (Fischer 2006).

Environmental Impact Assessments

Environmental Impact Assessment (EIA, according to Directive 2011/92/EU and 85/337/EEC) aims at assessing environmental impacts of **large-scale infrastructure projects.** Annex I of the EIA Directive provides a list of all projects that are considered as having significant effects from the outset and thus have to undergo an EIA. The list explicitly mentions inter alia inland waterways and ports, long-distance railway lines, motorways and express roads, and airports with a basic runway length over 2100 m. Annex II provides a list of projects for which Member States' national authorities have to decide whether an EIA is needed or not. More specifically, Annex I and Annex II of the EIA Directive mention:

- Construction of motorways and express roads;
- Construction of a new road of four or more lanes, or realignment and/or widening of an existing road of two lanes or less so as to provide four or more lanes, where such new road or realigned and/or widened section of road would be 10 km or more in a continuous length;
- Construction of roads;
- Any change or extension of projects listed in Annex I or this Annex [II], already authorised, executed or in the process of being executed, which may have significant adverse effects on the environment (change or extension not included in Annex I);
- Construction of railways and intermodal transhipment facilities, and of intermodal terminals (projects not included in Annex I);
- Construction of roads, harbours and port installations, including fishing harbours (projects not included in
- Annex I);
- Inland-waterway construction not included in Annex I, canalisation and flood-relief works.

Assessments should be conducted on the basis of information supplied by the public authority which initiates a project or by the applicant for authorization for a private project ('the developer')[4]. This implies that asset managers will have to ensure that those involved in projects have sufficient and adequate expertise to conduct the EIA and to provide relevant data. Basic questions to ask as part of an EIA are whether a new infrastructure asset is needed at all, which transport mode would be best suited to meet the demand, how it is integrated with other transport modes, which corridor to choose, or which dimensions a project should have to adequately fulfil the demands. The EIA might also consider mitigation or compensation

[4] EIA Directive, Art.1 2. (b)

measures to prevent or reduce negative impacts and/or compare different alternatives. The Annex of this guideline document provides a non-comprehensive list of impact areas, relevant factors, and measures for enhancing sustainability of infrastructure plans and projects.

Take-away messages for asset owners, decision-makers and managers

- Policy integration aims to maximise societal benefits and returns of investment by taking into account demands from civil society and policy objectives from policy fields beyond transportation.
- The Lack of inter-departmental and cross-level cooperation is considered one main obstacle for the adoption of sustainable transport schemes
- The maximisation of societal value –i.e. the provision of an agreed level of service, the minimisation of environmental and social impacts, and the fostering of low-carbon innovations – requires **appropriate governance processes.**
- Integrated assessments are established tools to foster coherence of actions towards broader societal goals and may avoid resources spent on demands going beyond the immediate responsibility of asset managers, perceived to be a waste of public money.
- For asset managers, considering external demands and requirements in early stages of decision making provides the following benefits:
  - It reveals potential conflicts between policy fields and reduces planning risks and operational costs
  - It avoids costly re-alignments of infrastructure projects in later stages of planning and construction
  - It improves reputation and credibility of asset managers and asset owners
  - It avoids social and political resistance and resulting time delays e.g. from lawsuits
  - It opens financial support options such as climate adaptation funds.

4.4.2 RESILIENCE

Resilience entails an ability to absorb disruptions invoked by external drivers and to recover from shocks in an adaptive fashion. This often requires a transformation of organizational structures to counteract long-term stress and uncertainty. Resilience addresses a variety of aspects and appropriate tools should be in place to deal with specific cases. On a global level, resilience is gaining importance.

AM4INFRA focuses on the resilience of transport infrastructure (i.e. roads, bridges, airports, rails, water supply, telecommunications and energy services) in an attempt to ensure the viability of economies in the EU region. Resilient transport infrastructures have the ability to retain their performance during and after disasters undergoing little to no loss and return to the normal state of operation quickly after disasters. The Organisation for Economic Cooperation and Development (OECD, 2014) defines resilience as a priority for efficient and successful systems and networks that covers cross border actions.

Resilience cycle

There are four stages in the resilience cycle: normality, breakdown, self-annealing, and recovery. The resiliency cycle is shown in Figure 1 based on Heaslip et al. (2009; 2010):

- Normality: When the network is functioning under normal or standard conditions without the effect of any disturbances or disruptions, this phase is called normality. A system operates with maximum efficiency in this stage.
- Breakdown: When disruptions or disturbances occur within the system, the network experiences a reduction in performance. This stage is called the breakdown stage. Disruptive events may be sudden or gradual. After the system breakdown, performance drops to its minimum level. The ability to resist this performance loss is defined as robustness.
- Self-annealing: After breakdown, network users attempt to carry on their movements by attempting to identify alternate routes or alternate modes of transport. Emergency management practices put into place by network authorities may ease their movements in this stage compared to the breakdown.
- Recovery: During this stage, damages caused by disruptive events are repaired, obstructions are removed, and facilities are restored or replaced. The speed of recovery or rate of improvement with respect to recovery time can be defined as rapidity. The rate of recovery depends upon resourcefulness, which is defined as the availability of both resources and technology, and the ability or managerial capacity to mobilize them with a reasonable speed to repair, renovate, rehabilitate, replace, and restore the facilities in the system. The recovery stage results in a new normality, which may or may not have the same level of performance as the pre-event normality. Some systems may even use consequent recovery works required after disruptions as an opportunity to fix the preexisting deficiencies in the system leading to a performance level better than the preexisting system (Cimellaro et al., 2010).

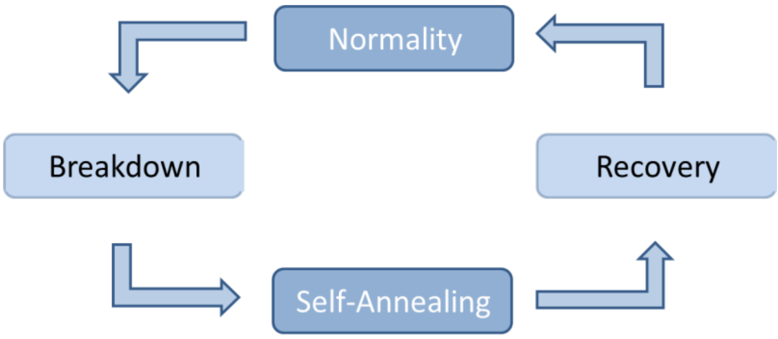


Figure 1: Transportation network resilience cycle (Heaslip et al., 2009)

Resilience dimensions and principles

The concept of resilience is broad and from the transport systems perspective may cover various sectors extending from natural disasters to covering the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and growth over time. Two main dimensions could be identified according to Bruneau et al. (2003):

- **Technical dimension:** The ability of the physical system(s) to perform to an acceptable/desired level when subject to a hazard event.
- **Organizational dimension:** The capacity of an organization to make decisions and take actions to plan, manage and respond to a hazard event in order to achieve the desired resilient outcomes.

Each dimension has three core principles (with a range of indicator subsets) which help define resilient organizations and which are proposed to form the basis of the framework to measure the resilience of the transport system. These principles are described in the Table 1 below. Furthermore, a resilient organization is one that is *'still able to achieve its core objectives in the face of adversity'* (Seville et al., 2006). There are three aspects to building resilience in organizations: a) reducing the size and frequency of crises (vulnerability), b) improving the ability and speed of the organization to manage crises effectively (adaptive capacity), and c) an acute awareness of risk and an ability to manage strategic risks as a process and not an event.

Table 1: Proposed principles of resilience for the transport system

Dimension	Principle	Definition
Technical	Robustness	Strength, or the ability of elements, systems and other units of analysis, to withstand a given level of stress or demand without suffering degradation or loss of function
	Redundancy	The extent to which elements, systems, or other infrastructure units exist that are substitutable, ie capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality
	Safe-to-fail	The extent to which innovative design approaches are developed, allowing (where relevant) controlled, planned failure during unpredicted conditions, recognizing that the possibility of failure can never be eliminated. This may involve new approaches to design, to complement traditional, incremental risk-based design
Organizational	Change readiness	The ability to sense and anticipate hazards, identify problems and failures, and to develop a forewarning of disruption threats and their effects through sourcing a diversity of views, increasing alertness, and understanding social. Also involves the ability to adapt (either via redesign or planning) and learn from the success or failure of previous adaptive strategies.
	Networks	The ability to establish relationships, mutual aid arrangements and regulatory partnerships, understand interconnectedness and vulnerabilities across all aspects of supply chains and distribution networks, and; promote open communication and mitigation of internal/external silos.
	Leadership and culture	The ability to develop an organizational mind-set/culture of enthusiasm for challenges, agility, flexibility, adaptive capacity, innovation and taking opportunity.

Source: Hughes and Healy (2014)

Resilience attributes

There is a series of eight "attributes" which help guide the definition and application of resilience in practice according to Hughes and Healy (2014).

- **Service delivery:** There is a focus on national, business and community needs in the immediate and longer term. Resilient infrastructure delivers a level of service sufficient to meet public and private needs, ensuring community viability.
- **Adaptation:** National infrastructure has the capacity to withstand disruption, absorb disturbance, act effectively in a crisis, and recognises changing conditions over time.
- **Community preparedness:** Infrastructure providers and users understand the infrastructure outage risks (hazards) they face and take steps to mitigate these. Aspects of timing, duration, regularity, intensity and impact tolerance differ over time and between communities, and must be taken into account.
- **Responsibility:** Individual and collaborative responsibilities are clear between owners, operators, users, policy-makers and regulators. Responsibility gaps are addressed.
- **Interdependencies:** A systems approach applies to identification and management of risk (including consideration of interdependencies, supply chain and weakest link vulnerabilities).

- **Financial strength:** There is financial capacity to deal with investment, significant disruption and changing circumstances. This includes available funds, the awareness of financiers and insurers, continuing capital investment and maintenance expenditure.
- **Continuous:** On-going resilience activities provide assurance and draw attention to emerging issues, recognizing that infrastructure resilience will always be a work in progress. Includes effective, on-going monitoring and auditing processes feeding back into continuous improvement.
- **Organizational performance:** Leadership and culture are conducive to resilience, including resilience ethos, situational awareness, management of keystone vulnerabilities and adaptive capacity. Future skills requirements need to be addressed.

Measuring resilience

There is a wide range of hazards, hazard types and failure modes that could affect a given piece of infrastructure or the transportation network. However, a resilience assessment also requires an awareness that the hazard itself may be unpredictable (Park et al. 2013) and the organization needs to think beyond typical disaster scenarios (Brunsdon and Dalziell 2005). As such, it is useful to move from consideration of hazards (either via probability or scenario analysis) to consideration of consequences which specifically relate to the loss of service as well as other impacts. These consequences can relate to a non-specified hazard event, which could apply to any (or all) hazard types. Brunsdon and Dalziell (2005) provide some consequence scenarios which are considered applicable and have been adapted for the transport context:

- **Regional event:** significant physical damage to transport infrastructure, coupled with severe disruptions to other lifeline services such as electricity, water and telecommunications. An example of this type of event may be a major earthquake or flood.
- **Localized event:** a transport-specific incident resulting in loss of life, severe disruption to normal operations and reputation impacts. The intense focus of media and regulatory agencies requires the organization to focus on managing stakeholder perception as well as the physical response and recovery from the event. Examples may be a collapse of a transport structure, or a hazardous spill affecting the immediate locality.
- **Societal event:** a societal event which may cause unexpected impacts or demand on the transport system. In this case, all physical infrastructure is intact; however, the transport system is unable to cope with demand. Examples may include: 1) a surge in traffic demand due to a specific event, or a major gathering of people, 2) growth in demand over time, 3) growth in public transport demand due to, say, fuel price rises, 4) an illness pandemic (eg influenza or SARS), meaning operational staff are unavailable.
- **Distal event:** impacts transport operations through key suppliers or interdependencies. This consequence scenario can identify the ways the transport system and related organizations may be affected through its networks of inter-organizational relationships. Examples may be the failure of a key dependent utility (power, telecommunications, water), failure of a key supplier, or an international shortage of key resources.

To summarize the above, merit in undertaking both an all-hazards approach as well as a specific-hazard approach is considered, depending on the context of the evaluation.

An all-hazards approach to resilience would involve a high-level assessment looking at resilience measures in response to all hazards in general, and would consider a relevant event scenario as detailed above (regional, local, societal, distal).

A specific-hazard assessment would be more detailed, however, and therefore might be appropriate for certain critical assets. This would involve identifying the complete range and type of potential scenarios as described above, and assessing the risk (likelihood and consequence) of them occurring. The resilience assessment and response could then be tailored accordingly. Appropriate methods could be used to identify hazards due to known 'rare events' and also non-linear modes of failure involving interdependencies.

In summary, the approach to undertaking the resilience assessment is as follows:

- Determine the context of the assessment:
- all-hazards or specific hazards (including shock or stress event, rare events etc)
- scale: asset/network/regional context
- shock or stress event.
- Undertake the assessment using the questions relative to the context above and select scores for each.
- Apply weightings to the scores, as required.
- This will generate resilience scores for categories, principles and dimensions and a total score.

Take-away messages for asset owners, decision-makers and managers

- **Resilience** is the ability of the system to absorb the consequences of disruptions, to reduce the impacts of disruptions, and maintain mobility.
- Covering resilience requires addressing the technical dimension (robustness, redundancy and safe-to-fail) as well as the organizational dimension (change readiness, networks, leadership & culture).
- A resilience assessment should be considered, adopting either an 'all-hazard' approach or looking at specific hazards.

4.4.3 CROSS-BORDER

Cross border optimisation of networks involves at least two institutions, one at both sides of the border. In order to make such optimisation possible these institutions should find a smart way to cooperate. This cooperation should aim to find a good balance in coordinating activities to make the networks function together as one entity whilst avoiding to add complexity to the ongoing operations of the individual entities. Managing networks is challenging enough even without having to coordinate and optimise activities with neighbouring NIAs. To find such a balance, the following four questions need to be addressed:

1. Which ***maintenance activities*** deliver most value when optimized over the national borders?
2. How can ***you 'cross-border' optimize these activities*** respecting the national institutional settings and systems (e.g. use of metadata and AM building blocks)?
3. What ***officers should collaborate*** on this in the future to succeed in cross-border optimization
4. What are ***other success factors*** identified by stakeholders?

Take-away messages for asset owners, decision-makers and managers

Cross-border cooperation should aim to find a good balance in coordinating activities to make the networks function together as one entity whilst avoiding to add complexity to the ongoing operations This balance needs to address:

- the ***maintenance activities*** that deliver most value when optimized over the national borders;
- how to optimize ***'cross-border',*** respecting the national institutional settings and systems;
- the officers that should collaborate;
- ***other success factors*** identified by stakeholders.

AM4INFRA covers several cross-border initiatives. For instance the Living Lab E34-Eindhoven aims to optimize the E34 motorway which connects the Belgium seaport of Zeebrugge, past the Dutch city of Eindhoven, with Bad Oeynhausen in North Rhine-Westphalia. Another example is the collaboration on cross-border indicators between Rijkswaterstaat from the Netherlands and Trafikverket from Sweden. Both initiatives bring together asset managers leading to cross-border understanding of each other's management strategies and practices from which commonalities and opportunities for alignment of maintenance activities currently are being explored.

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6 Annexes

6.1 ANNEX 1: TOOLS FOR SUSTAINABILITY ASSESSMENTS OF TRANSPORT INFRASTRUCTURES

Due to their high consumption of natural resources, land use and land sealing, and the emission of GHG and other pollutants during their operation infrastructure projects have significant impacts on the environment and on social aspects such as health issues. Most fundamental impacts of infrastructures are defined in the planning stages of projects with definition of needs, the determination of transport mode, the definition of the corridor, or the determination of asset design and material. Each infrastructure planning and project has to comply with national and European legislation on environmental issues such as climate protection, noise, soil, water and the protection of endangered species, habitats, and biodiversity (European Commission 2012b).

Sustainability assessments are established methods for integrating environmental and other concerns into decision-making on infrastructure projects – during the planning and construction stage and during its operation. The following chapters introduce different kinds of assessments: Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), and Life cycle analysis (LCA).

Strategic Environmental Assessment

Strategic environmental assessment (SEA) is used in early planning stages. It is a procedural tool for preventive environmental management and aims at integrating environmental aspects into the preparation of public **plans, programmes or investment strategies** with the objective of more sustainable processes and solutions (Partidário 2012). Conducting a SEA is mandatory for most public plans and programmes which 'set the framework for future development consent of projects listed in the EIA Directive'. Typical use cases for SEA are transport infrastructure planning or regional mobility plans. With the introduction of the SEA Directive in 2001 the European Commission also aimed at achieving 'a certain degree of consistency and minimum-quality standards among EU member states' (Fischer 2006).

According to the United Nations Economic Commission for Europe (UNECE), SEA means 'the evaluation of the likely environmental, including health, effects, which comprises the determination of the scope of an environmental report and its preparation, the carrying-out of public participation and consultations, and the taking into account of the environmental report and the results of the public participation and consultations in a plan or programme' (UNECE 2012)[5].

Stages of SEA comprise screening and scoping; the preparation of environmental report; public participation, consultation of concerned parties, decision-making, taking into concern potential concerns, and the information of the public (UNECE 2012).

Since SEAs are mostly relevant for strategic political decisions on the overall design of the transport network, they are not outlined in depth in this document. The process, however, resembles the Environmental Impact Assessment as lined out below.

5 UNECE Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context http://www.unece.org/fileadmin/DAM/env/eia/documents/legaltexts/protocolenglish.pdf

Environmental Impact Assessment

EIA assesses the environmental impacts of **specific projects.** It is a procedural tool for assessing and informing descision makers and the public on potential environmental (and social) impacts of a planned **project** and its alternatives. A typical use case is the construction or the upgrade of a road or the selection of a specific transport corridor (Arts and Faith-Ell, 2012 CHALMERS 2014) (CHALMERS Thorne et al., 2014).

EIA is a process that consists of subsequent tasks:

- Screening, i.e. the determination whether a project requires an EIA
- Scoping, i.e. the identification of most relevant impact areas and factors to be covered in the assessment
- Environmental studies, i.e. the preparation of studies on environmental and the collection of information on potential impacts according to Annex IV of the EIA Directive;
- Submission of environmental information to the competent authority´ in the respective Member State;
- Consultation with environmental authorities, other interested parties, and the public. Other affected Member States have to be consulted if transboundary impacts can be expected.
- Consideration of the environmental information and the results of the consultations by the competent authority
- Decision-making and announcement of decision

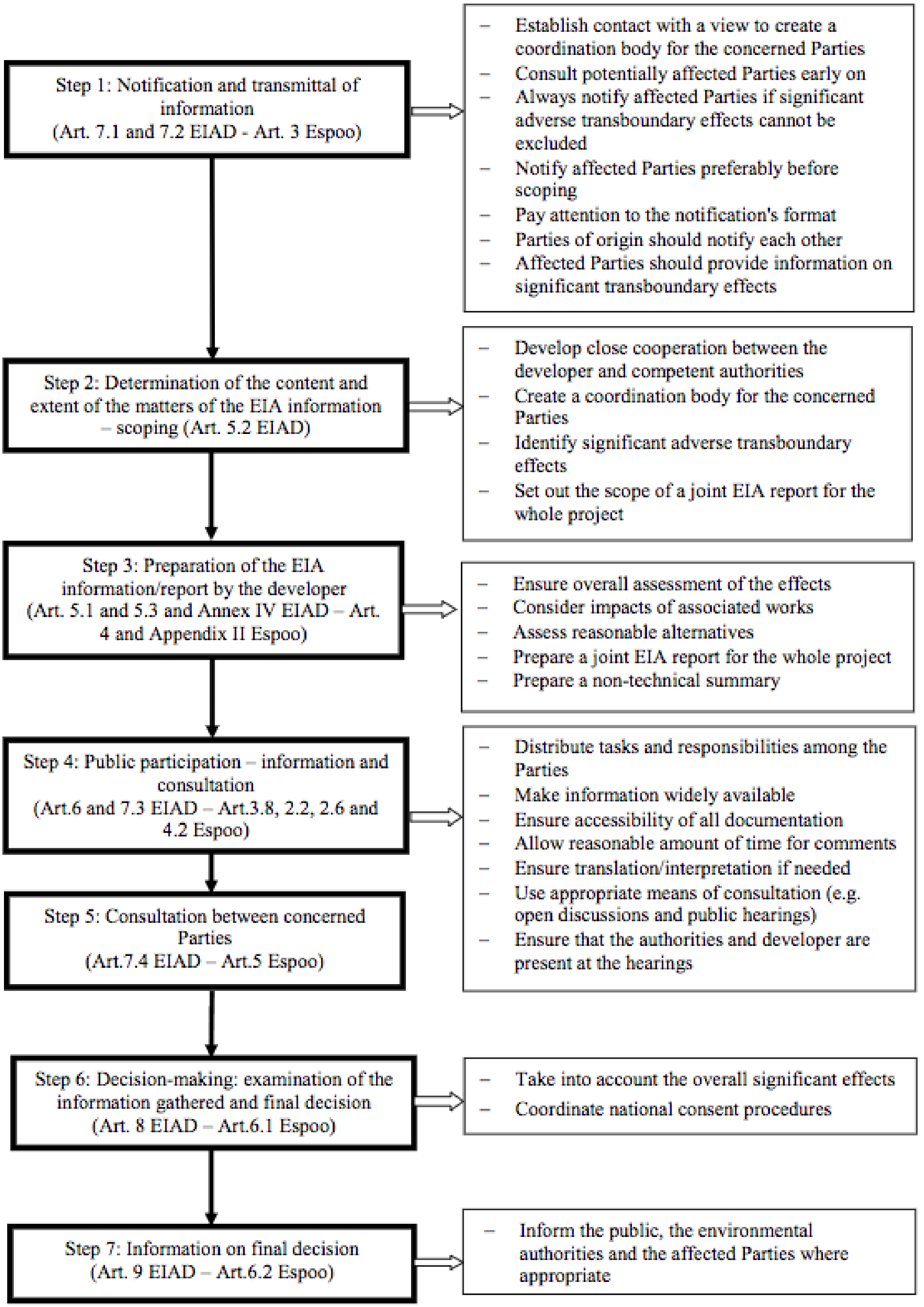


figure 6: Flow Chart of the EIA procedure. Source: (European Commission 2013)

The European EIA Directive (2011/92/EU 85/337/EEC) makes EIA mandatory for large-scale infrastructure projects: Annex I of the Directive provides a list of all projects that are considered as having significant effects from the outset, including inland waterways and ports, long-distance railway lines, motorways and express roads, and airports with a basic runway length over

2100 m. Annex II provides a list of projects for which Member States' national authorities have to decide whether an EIA is needed or not. Since environmental impacts are project and site-specific, each project has to be assessed on an individual basis. Even in cases where EIA is not mandatory, assessment of environmental impacts and their likely significance will be useful to inform planning, to select options, to gain public support and to facilitate the implementation of the project.

Table 2: Non-comprehensive list of impact areas, relevant factors, and measures to consider during the planning of new infrastructure

Impact Areas	Relevant Factors	Measures for enhancing sustainability
Energy consumption and GHG emissions	Energy consumption and GHG emissions from transport activities during the operation of the infrastructure	Choice of transport mode
		Choice of transport corridor and alignment (profile)
		Lightning of roadways, airports, stations
	Emissions related to Earthwork during construction	Choice of transport corridor and alignment
Use of Resources and Circular Economy	Exploitation of sand, gravel, limestone, bitumen, etc.	High-quality use of recycled material
Noise	Noise from transport activites	Choice of transport corridor
		Choice of transport mode
Water	Water pollution	Water pollution control components
	Flooding	Water retention systems
	Interference with groundwater bodies	Choice of corridor
Air Pollution	Emissions of NO_x, SO_2, SO_4, CO, PM, etc.	Choice of transport mode
Land use	Land uptake and sealing	Adequate dimension of the project
	Land use conflicts with: settlement, agriculture, forestry, recreation, nature protection	Choice of corridor
Nature and Biodiversity protection	Fragmentation of habitats	Choice of corridor; Viaducts for large and small wildlife
	Interference with protected areas	Choice of corridor
Innovation Adaptability to smart and electric mobility solutions	Inhibiting or fostering innovations towards a low-carbon transport system	Preparing for future assets

Table 3 Design of mitigation measures. Source: http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-05-28.pdf

TABLE 1: Design of Mitigation Measures

Approach	Examples
Avoid	Change of route or site details, to avoid important ecological or archaeological features
Replace	Regenerate similar habitat of equivalent ecological value in different location.
Reduce	Filters, precipitators, noise barriers, dust, enclosures, visual screening, wildlife corridors, and changed time of activities
Restore	Site restoration after construction
Compensate	Relocation of displaced communities, facilities for the affected communities, financial compensation for the affected individuals etc.

The successful implementation of Environmental Assessments depends to a large degree on the governance mechanisms and organisational approaches employed. EIAs will generally be prepared by external professionals and consulting companies. A comparison of environmental impact assessments of infrastructure projects (Chi et al. 2016) found that the success of EIAs in light of the above described aspects depends on:

- the provision of sufficient time for the assessment;
- the qualification of evaluators: multidisciplinary teams with proven experience and expertise in engineering, natural science (atmospheric science, geology, biology, etc.) but also social sciences.
- a high level of active public participation and deliberation in early stages, using different channels such as the provision of information via project websites and newspapers, individual and group communication with affected persons through the organisation of public hearings or updates for local administrations and elected officials, and the provision of EIA records to the public.
- Assigning clear responsibilities between EIA experts and the political / administrative level, including conflict resolution mechanisms and external evaluation through a diverse set of experts.

Best practice guidance

Official Sources and guidance documents

European Commission SEA guidance documents

- European Commission 2005 Manual on Strategic Environmental Assessment of Transport Infrastructure Plans
- European Commission 2001: Strategic Environmental Assessment of Transport Corridors. Lessons learned comparing the methods of five Member States
- European Commission 2001: Strategic Environmental Assessment in the Transport Sector: An Overview of legislation and practice in EU Member States
- UNECE Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context
- COST350 Integrated Assessment of Environmental Impact of Traffic and Transport Infrastructure

Official EIA guidance documents

- 2013 Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment
- 2013 Guidance on the Application of the Environmental Impact Assessment Procedure for Large-scale Transboundary Projects
- 2012 Interpretation suggested by the Commission as regards the application of the EIA Directive to ancillary/associated works
- 2001 Guidance on Screening and Screening checklist
- 2001 Guidance on scoping and scoping checklist
- European Commission: Guidance document on sustainable inland waterway development and management in the context of the EU Birds and Habitats Directives
- Highways Agency et al. 2009: Design Manual for Roads and Bridges: Volume 11: Environmental Assessment
- Swedish Transport Administration 2011: Environmental Impact Assessment: Roads and Rail Handbook. Methodology
- JASPERS – Joint Assistance to Support Projects in European Regions: Sectorial EIA Guidelines
    - 2013 Motorway and Road Construction Projects
    - 2013 Railway Construction Projects

Example

- Construction of the European standard gauge public railway infrastructure line Rail Baltica: Summary of the environmental impact assessment report

Life Cycle Assessment

Life cycle assessment (LCA) is a analytical tool for assessing the environmental impacts associated to a product, process or system. LCAs can be used to determine whether modifications to a (transport) system lead to decreased environmental impacts over all life-cycle stages; to identify unwanted shifts of burdens in time or to other parts of the system; or to select one option over another, e.g. different routes, transport modes, or pavements. *As such they can form part of whole life cost calculation as specified in as specified in D 2.1* or be used in Environmental and Strategic Impact Assessments. Note that LCAs will generally be prepared by external professionals.

LCAs are mostly used for more specific decisions such as the procurement of vehicles (e.g. the choice between diesel powered or electric busses) or the assessment of specific components of transport infrastructure such as bridges or road pavements (examples: Huang et al. 2009; Santero et al. 2011). The assessment covers the entire life cycle including the extraction and processing of raw materials, construction and production, distribution, use, maintenance, reuse, recycling and disposal. LCAs can, however, also be applied to large-scale decisions such as entire transport systems. Scope and system boundaries of an LCA will vary considerably depending on the subject of evaluation and the goal of the analysis. LCAs, for example, can be used to optimise the environmental performance of a road and its components or for the optimisation of transport services (Peuportier et al. 2011).

Attributional LCA (ALCA) describes the environmental properties of a specific product such as a road pavement or a bridge along its life cycle. ALCA uses well-defined, narrow system boundaries and focuses on the direct impacts of a product related to its raw material input, its production process and related transport activities, up to its disposal (Peuportier et al. 2011). This ‘classical’ LCA approach is suited for enhancing or comparing the environmental performance of specific products. Typical use cases for ALCA are environmental product declarations or procurement decisions.

Consequential LCA (CLCA) is a more recent approach that aims at assessing the interactions between a (large-scale) product and its environment, regardless of whether these impacts occur within or beyond the narrow product system. Goal of the assessment is to determine how environmentally relevant flows (e.g. energy, GHG emissions, building materials, etc.) will change as a result of a specific decision (Ekvall et al. 2016). For decisions on infrastructure, for example this implies not only to include emissions during the construction phase but also to consider energy use, GHG emissions or the emission of NO_x from actual transport services during the use phase of a road. Decision makers can employ CLCAs to compare different options to respond to given and estimated future transport needs. These options might differ in their cost efficiency, and in their environmental and social performance (=external costs).

A meta-study on assessments of road projects (Alam et al. 2013; Santero et al. 2011) found that early stages of life cycles – material extraction and construction including construction equipment – are typically well covered in LCAs. In contrast, the use phase, maintenance and traffic congestion due to road works are rarely regarded; the same applies to the end of life stage. Before this background Alam et al. (Alam et al. 2013) point to the need to define consistent system boundaries for related LCA studies.

ISO 14040 provides guidelines for performing a LCA. According to ISO 14040 LCA can help to identify opportunities for the improvement the environmental performance of a product or service; to inform decision makers in industry, government, and non-government organizations in making informed strategic decisions; and to select relevant indicators of environmental performance. An encompassing assessment of infrastructure projects requires taking into account (1) the physical assets as such but also (2) impacts from downstream (deconstruction, recycling, disposal) and upstream activities (from extraction of raw materials to construction). If an LCA is used for comparing different alternatives it also needs to consider (3) impacts during the use phase of infrastructures such as GHG emissions related to mobility and transport activities.

Stages of a LCA according to IS0 14040 comprise:

1) the goal and scope definition phase: defining adequate system boundaries and impact categories for the specific LCA. A LCA relates to a specific product system, which performs one or more defined functions (in this case: the transport of passengers and goods). It is important to note that the definition of the system boundary and adequate indicators depends on the objective of the study.
2) the inventory and analysis phase: establishing an inventory (LCI) of relevant data with regard to the system to be studied;
3) the impact assessment phase (LCIA): providing additional information to help assess and interpret captured life cycle data; and
4) the interpretation phase in which findings from LCI and LCIA are discussed and recommendations for decision-making are provided. It is explicitly noted that “there is no scientific basis for reducing LCA results to a single overall score or number, since weighting requires value choices” (ISO 2006: 4.3 j)).

ISO 14040 does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the assessment.

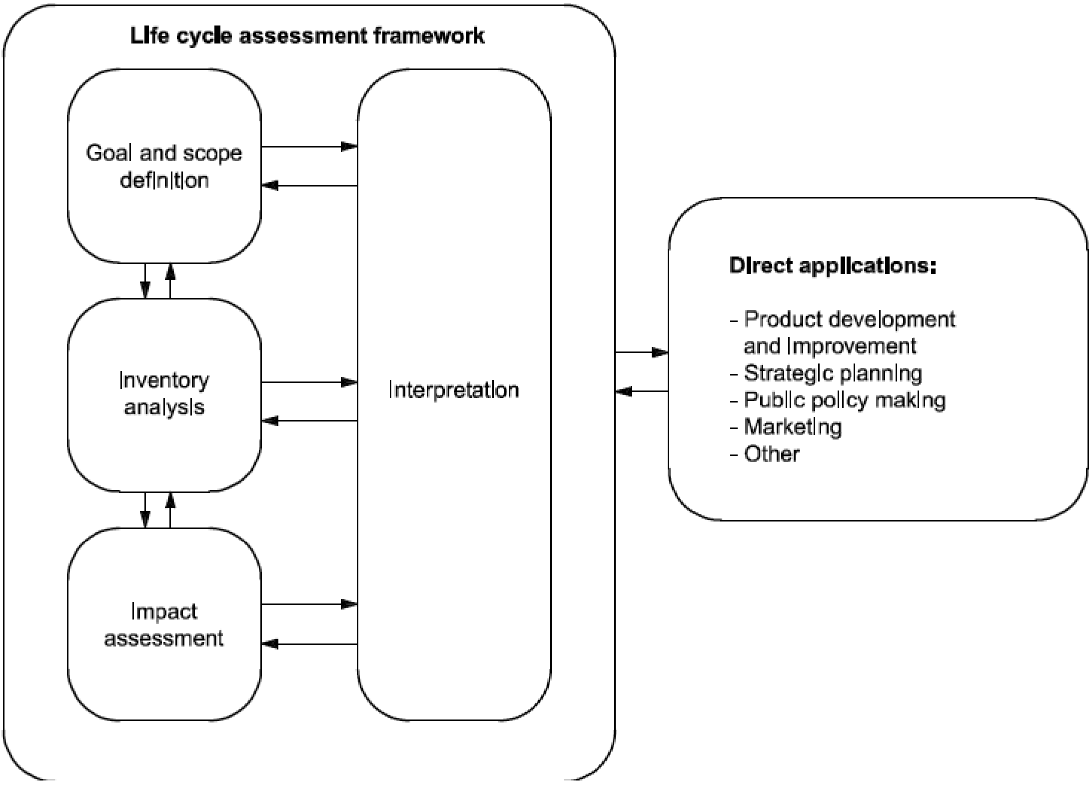


Figure 7: Stages of an LCA according to ISO 14040: 2006 (ISO 2006)

Goal and scope definition

Depending on the scope and goal of the study, the LCA practitioner must define a functional unit of the analysis. There is no one-size-fits-all approach to LCA and the scope of the assessment must be defined on a case-by-case basis reflecting the project and its environment over which significant effects can be expected. It is important to keep in mind that impacts can also occur beyond the immediate surrounding of the project (e.g. impact of GHG emissions). In any case it is necessary to clearly state the function of the system to be studied. This functional unit serves as reference for the assessment. Depending on the goal of the study, the functional unit might be framed as the provision of a transport service (expressed in vehicle kilometres, passenger kilometres, or good transport kilometres), as a road / railway section (e.g. with the length of 1 km), an asset (e.g. a port), or a component of infrastructures (e.g. 1 km of road pavement). When comparing alternatives it is necessary to use consistent system boundaries and functional units. For road infrastructure, Santero and Horvath suggest a 50-years analysis period since this allows the impacts to fully materialise (Santero und Horvath 2009).

Strategic decisions on the design of future infrastructures (e.g. rail vs. road) require a CLCA approach that considers the entire transport system – including the provision of vehicles, emissions from transport activities, and energy production (Rodrigue et al. 2017). Total energy demand and emissions during the operation phase vary across modes. Electric mobility, for example, emits no exhaust gases, but causes emissions upstream from electricity generation. Thus changes in energy provision system (energy mix and GHG intensity) also need to be considered when assessing GHG emissions related to transport infrastructures. Thus, an encompassing LCA of transport infrastructures consists of two parts – an LCA of the infrastructure and the LCA of the related transport vehicles (including energy production). This implies that the to parts of a LCA must be designed in complementary way, i.e. using a common definition of the functional unit and similar parameters (Stripple und Erlandsson 2004, S. 10).

Table 4: Non-comprehensive list of impact areas and indicators related to transport activities and infrastructures. Key indicators that should always be considered are marked with '*'

Impact Area	Examples
Economic	
Direct costs of construction*	Costs related to construction, maintenance, and deconstruction activities
Energy consumption*	Energy intensity of building materials Energy use from road, station, or airport lighting
Adaptability to innovations	Preparation for low-carbon mobility
Traffic congestion	Avoid traffic congestion due to construction and maintenance activities
Environmental	
Carbon footprint: emissions of GHG*	Emissions related to construction, maintenance and deconstruction activities
Abiotic resource depletion*	Use of recycled material in construction activities
Waste and Circular Economy	Foster high quality recycling of construction waste High-quality use of recycled material
Innovative materials and processes	Use of innovative, low-carbon or resource-light material
Social	
Health and Safety of workers	
Working contracts	

The **Life Cycle Inventory** (LCI) stage is about collecting and validating relevant data. While some impact indicators are relatively easy to measure and to quantify (such as CO_2 emissions or NO_x emissions), other impact areas such as biodiversity are harder to include into a LCA model. As an alternative to quantification, such qualitative aspects might be covered using checklists (Stripple und Erlandsson 2004, S. 10). The LCI stage also comprises modelling including the use of background data e.g. on the development of the energy mix and its GHG intensity or information on recycling potentials.

Life cycle impact assessment (LCIA) relates the LCI data to relevant impact categories and indicators. This also comprises the calculation of the potential environmental impacts in the identified impact areas

Interpretation is a continuing, iterative process of completeness, sensitivity and consistency checks. The interpretation stages produces conclusions from the LCI and LCAI stage on most significant issues while considering limitations of the study such as uncertainty, or the scope of the analysis.

Best practice guidance

Official Documents

2013 European TEN-T Regulation

Guidance Documents

- International Reference Life Cycle Data System (ILCD) handbook 2010
- Life-Cycle Assessment for TransportatLife-Cycle Assessment for Transportation Decision makingion Decision making
- Ekvall, T. et al. (2016): Attributional and consequential LCA in the ILCD Handbook
- Transport Innovation Deployment for Europe TIDE: Impact assessment methodology for urban transport innovations - A handbook for local practitioners

- Transport Innovation Deployment for Europe TIDE: Methodologies for cost-benefit and impact analyses
- Literature Review of Practices in Sustainability Assessment of Transport Infrastructures

Useful links and inventories:

- Update of the Handbook on External Costs of Transport
- EMEP/EEA air pollutant emission inventory guidebook – 2016

Examples

- Environmental impact assessment of rail freight intermodality

6.2 ANNEX 2: RESILIENCE

In the field of transportation engineering, some of the mostly used definitions of resilience are given below.

> *'The ability of systems to accommodate variable and unexpected conditions without catastrophic failure' (VTPI, 2010)*

Corrective actions outline the **resilience** of the transportation networks which can be defined as ''the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required

> *'The ability for the system to absorb the consequences of disruptions, to reduce the impacts of disruptions, and maintain freight mobility' (Goodchild et al., 2009)*

operations under both expected and unexpected conditions'' (Hollnagel, 2011). In other words, the ability of transportation systems to retain performance during and after disasters undergoing little to no loss and their ability to return to the normal state of operation quickly after disasters defines their resilience. Hollnagel (2011) phrases this in terms of four cornerstones of resilience (Figure): knowing what to do, what to look for, what to expect, and what has happened.

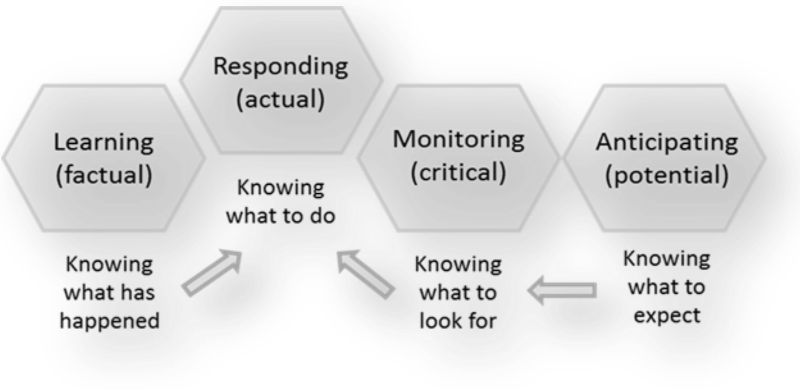


Figure 8: The four cornerstones of resilience (Hollnagel, 2011)

NIAs need to understand the degree of resilience within the transportation system under their jurisdiction and plan for improvements (Pant, 2012).

The Organisation for Economic Cooperation and Development (OECD, 2014) defines resilience as a priority for efficient and successful systems and networks that covers cross border actions. A conceptual framework for resilience systems analysis is provided (**Figure** 9) which indicates that resilience planning helps the system a step further using information derived by risk analysis and programming actions.

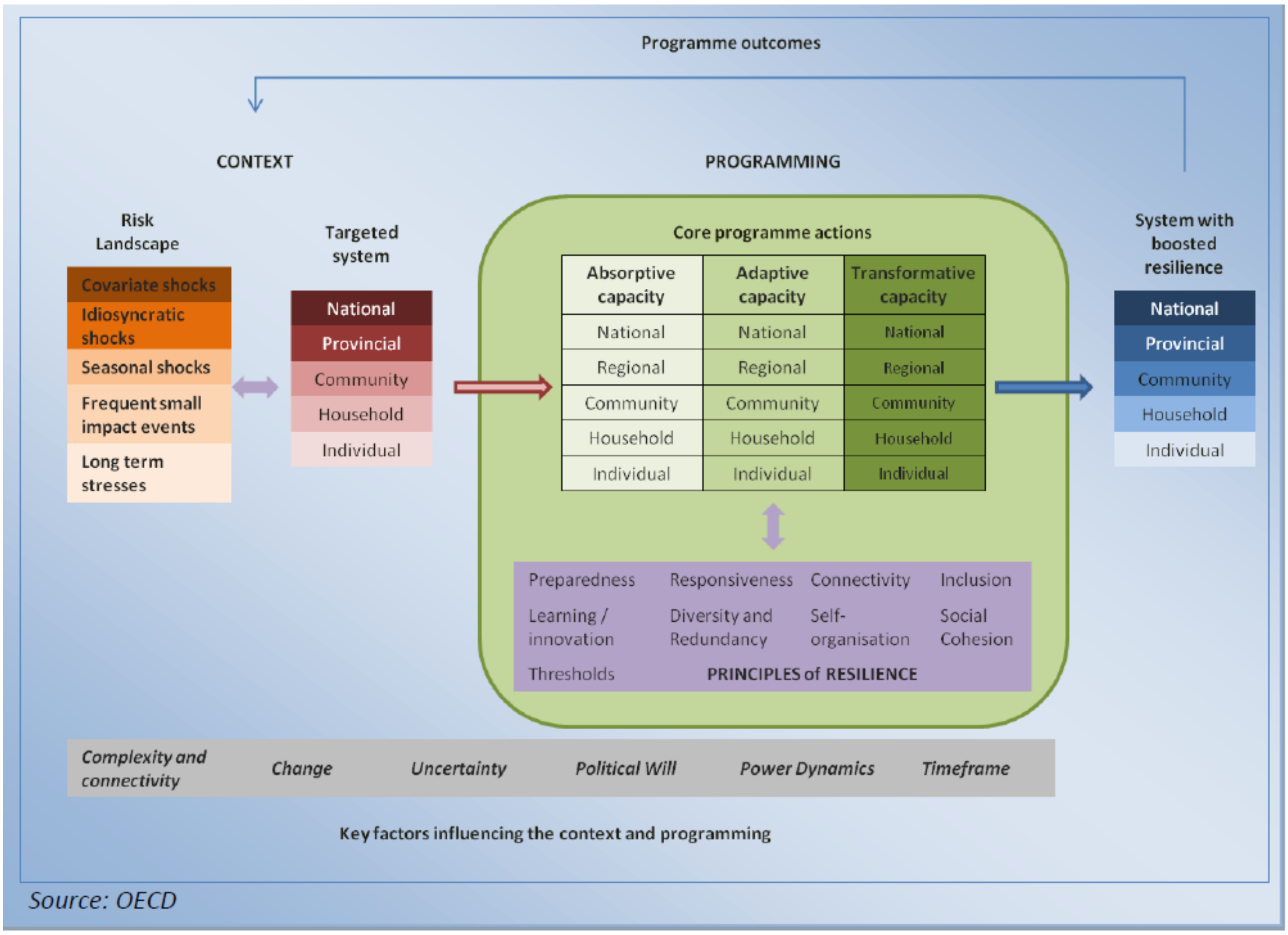


Figure 9: Conceptual framework for the resilience systems analysis

Resilience enhances the capacity of transport networks. The scoping of a resilience system analysis is presented in Figure 10 and defined by:

- the identification of the system's type
- the identification of the type of groups of individuals or geographical entity resilience is relevant to
- the identification of the types of risks, taking a multi-hazard approach, including geo-political, economic and natural and environmental risks
- and the identification of the timeframe that is appropriate for the system to correspond to possible threats

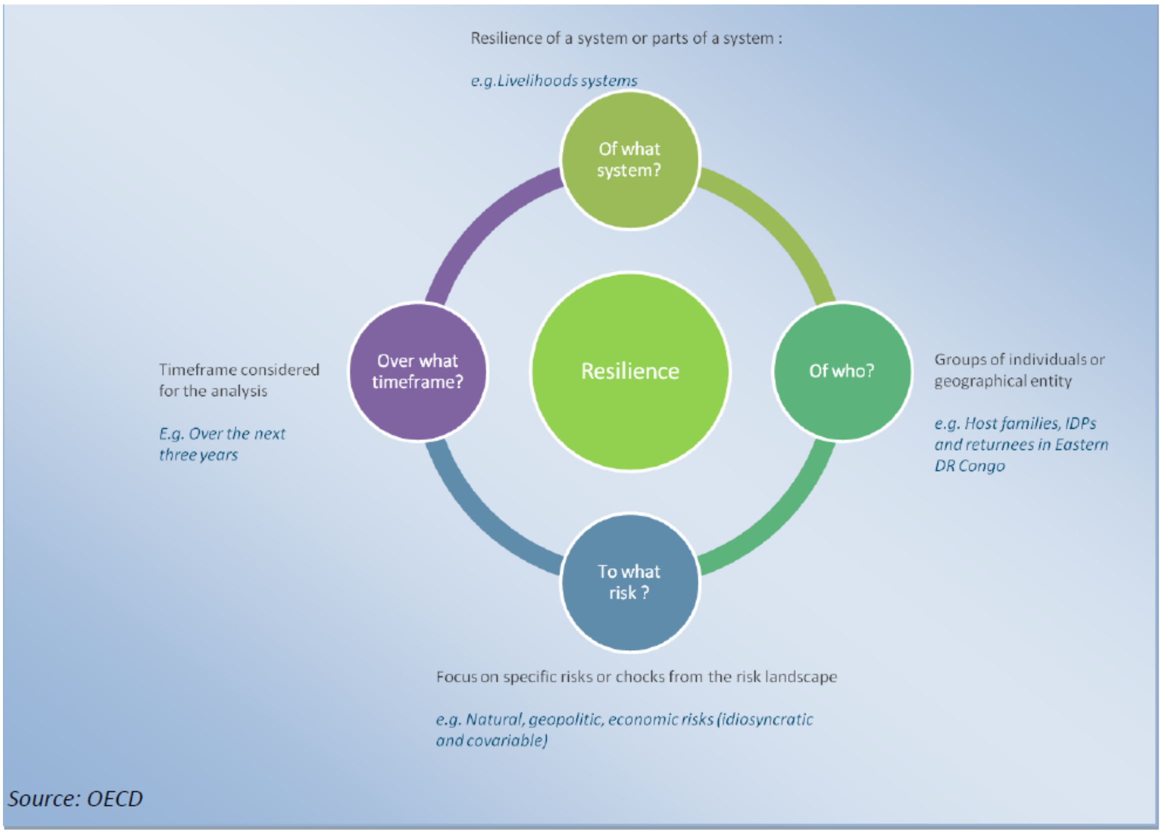


Figure 10: The 4 dimensions of the scoping for a resilience systems analysis

EU Initiatives

Based on the 2017 Management Plan for Mobility and Transport (Directorate – General for Mobility and Transport, 2016), the European Commission (EC) sets the target of resilient transport infrastructures. This initiative is also enhanced by the current Annual Management Plan for DG MOVE, in which increasing resilience is defined as a prerequisite to move towards an innovative transport sector.

Resilience measures

A range of measurement categories are suggested based on the six resilience principles. Within these categories, specific measures have been developed. It is significant to note that each category covers a range of parameters associated with that measure.

Table 2: Description of measurement categories

Principle	Measurement category	Description
Technical		
Robustness (covers attributes: service delivery, adaptation, interdependencies)	Structural	Physical measures relating to asset/network design, maintenance and renewal
	Procedural	Non-physical measures relating to existence, suitability and application of design codes, guidelines
	Interdependencies	This relates to upstream dependencies and their relative robustness in both a structural and procedural sense

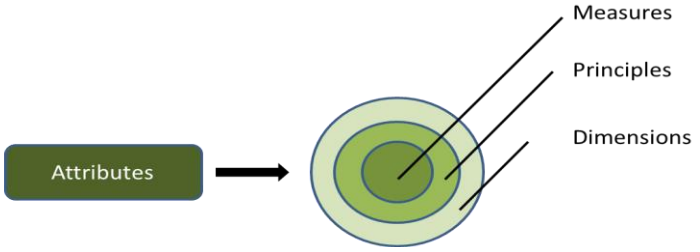
Redundancy (covers attributes: adaptation, interdependencies)	Structural	Physical measures relating to network redundancy, alternate routes and modes and backup supplies/resources
	Procedural	Non-physical measures relating to existence of diversion and communication plans
	Interdependencies	This relates to upstream dependencies and their relative redundancy in both a structural and procedural sense.
Safe-to-fail (covers attribute: adaptation)	Structural	The extent to which innovative design approaches are implemented, allowing controlled failure during unpredicted conditions. This may complement traditional, incremental risk-based design
	Procedural	The extent to which safe-to-fail designs are specified in design guidelines.
Organizational		
Change readiness (covers attributes: community preparedness, responsibility, interdependencies, financial strength, organizational performance)	Communication and warning	This relates to the existence and effectiveness of communication and warning systems
	Information and technology	This relates to the use of technology to monitor events, communicate, share data, assess resilience etc.
	Insurance	This relates to the adequacy of insurances for hazard events
	Internal resources	The management and mobilization of the organization's resources to ensure its ability to operate during business-as-usual, as well as being able to provide the extra capacity required during a crisis. Also relates to ensuring roles and responsibilities of all internal stakeholders are clear and that coordination is effective.
	Planning strategies	The development and evaluation of plans and strategies to manage vulnerabilities in relation to the business environment and its stakeholders
	Clear recovery priorities	An organization-wide awareness of what the organization's priorities would be following a crisis, clearly defined at the organization level, as well as an understanding of the organization's minimum operating requirements
	Proactive posture	A strategic and behavioural readiness to respond to

		early warning signals of change in the organisation's internal and external environment before they escalate into crisis.
	Drills and response exercises	The participation of staff in simulations or scenarios designed to practice response arrangements and validate plans.
	Funding	Extent to which funding is available for all elements of resilience planning including technical and organisational.
	Adaptation	Constant vigilance and situation awareness (see below) allows adaptation strategies to be developed. These may be procedural/planning focused/organisational or technical (increased robustness, redundancy, or designing for 'safe-to-fail' modes).
	Learning	Past actions and adaptation strategies are observed and evaluated in terms of their success in mitigating hazards. Appropriateness of actions can be assessed and iterations and changes made.
Networks (cover attributes: interdependencies)	Breaking silos	Minimization of divisive social, cultural and behavioral barriers, which are most often manifested as communication barriers creating disjointed, disconnected and detrimental ways of working.
	Leveraging knowledge (internal and external)	Critical information is stored in a number of formats and locations and staff have access to expert opinions when needed. Roles are shared and staff are trained so that someone will always be able to fill key roles.
	Effective partnerships (external)	An understanding of the relationships and resources the organization might need to access from other organizations during a crisis, and planning and management to ensure this access. Also relates to clear coordination and understanding between organizations, and clarity of roles and responsibilities.
Leadership and culture (cover attributes: organizational performance)	Situation awareness (sensing and anticipation)	Staff are encouraged to be vigilant about the organisation, its performance and potential problems. Staff are rewarded for sharing good and bad news about the organisation. Early warning signals are quickly reported to organisational leaders. Newly incorporated knowledge gained from vigilance is used to foresee/anticipate crises. This can be used to develop adaptation strategies.
	Leadership	Strong crisis leadership to provide good

		management and decision making during times of crisis, as well as continuous evaluation of strategies and work programs against organisational goals.
	Staff engagement and involvement	The engagement and involvement of staff who understand the link between their work, the organisation's resilience, and its long-term success. Staff are empowered and use their skills to solve problems.
	Decision-making authority	Staff have the appropriate authority to make decisions related to their work and authority is clearly delegated to enable a crisis response. Highly skilled staff are involved in, or are able to make, decisions where their specific knowledge adds significant value, or where their involvement will aid implementation.
	Innovation and creativity	Staff are encouraged and rewarded for using their knowledge in novel ways to solve new and existing problems and for utilising innovative and creative approaches to developing solutions.

Source: Hughes and Healy (2014)

The correlation among resilience attributes, dimensions, principles and measures is indicated below:



Source: Hughes and Healy (2014)

A summary 'dashboard' allows the user to view the various scores and weightings used.

Table 3: Example of resilience measures (for the "robustness" principle)

ROBUSTNESS				Weighted robustness score			2.3
Category	Measure	Measurement	Measurement scale	Individual score	Category average	Weighting (%)	Weighted score
Structural	Maintenance	Processes exist to maintain critical infrastructure and ensure integrity and operability – as per documented standards, policies & asset management plans (eg roads maintained, flood banks maintained, stormwater systems are not blocked. Should prioritise critical assets as identified.	4 – Audited annual inspection process for critical assets and corrective maintenance completed when required. 3 – Non-audited annual inspection process for critical assets and corrective maintenance completed when required. 2 – Ad hoc inspections or corrective maintenance completed, but with delays/backlog. 1 – No inspections or corrective maintenance not completed.	3.0	2.8	33.33%	94.4
	Renewal	Evidence that planning for asset renewal and upgrades to improve resilience into system networks exist and are implemented.	4 – Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated and implemented. 3 – Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed. 2 – Plan is not linked to resilience and an ad hoc approach is undertaken. 1 – No plan exists and no proactive renewal or upgrades of assets.	4.0			
	Design	Percentage of assets that are at or below current codes	4 – 80% are at or above current codes 3 – 50-80% are at or above current codes 2 – 20-50% are at or above current codes 1 – Nearly all are below current codes	3.0			
		Assessment of general condition of critical assets across region	4 – 80% are considered good condition 3 – 50-80% are considered good condition 2 – 20-50% are considered good condition 1 – Nearly all poor condition	3.0			
		Percentage of assets that are in zones/areas known to have exposure to hazards	4 – <20% have some exposure to known hazards 3 – 20-50% are highly exposed, or >50% are moderately exposed 2 – 50-80% are highly exposed 1 – 80% are highly exposed to a hazard	2.0			
		Percentage of critical assets with additional capacity over and above normal demand capacity	4 – 80%+ of critical assets have >50% spare capacity available 3 – 50-80% of critical assets have >50% available 2 – 20-50% of critical assets have >50% spare capacity 1 – 0-20% have spare capacity.	2.0			

Source: Hughes and Healy (2014)

Resilience assessment context

Apart from resilience attributes, measures, principles and dimensions, there are a number of cross-cutting themes that influence the context and approach of the resilience assessment. These are summarized in the table below.

Table 6: Description of Cross-cutting themes

Cross-cutting theme	Context
All hazards/specific hazard approach	The assessment can be undertaken in one of two ways: 1 An all-hazards assessment – based on an event due to any (unspecified) hazard/failure, which could be either known or unknown. The event could be regional, local, societal or distal 2 A hazard-specific assessment could be undertaken. This would involve identifying the relevant known hazard types and assessing the resilience to each
Scale of assessment	The framework will allow assessment at various scales: regional, network or asset. Measures have been developed for each and the user can filter the questions accordingly. Regional assessments could

	be aggregated to a national indicator for NIU purposes.
Shock event or stress event	The framework will be able to evaluate both short-term shock events (eg earthquakes and tsunamis) and longer-term stress events (eg climate change related). Stress events should be considered as part of a hazard-specific assessment (see above) and if required, a risk-assessment could be undertaken as well to understand likelihood and consequence of occurrence

Source: Hughes and Healy (2014)

As a stand-alone assessment, the resilience measurement framework can be applied to generate a relative score that could be used to compare resilience across assets/networks or regions. However, to provide additional rigor, other steps could be applied determining:

- 1. Which infrastructure should be assessed for resilience?
- 2. What level of resilience is appropriate for a given asset/network?

In order to answer these questions, we need to have an understanding of the criticality of a given asset, and, if required, an understanding of the risk of a particular hazard occurring. Note, this links directly with the choice of whether a general 'all-hazards' or a 'hazard-specific' assessment is chosen.

Figure 11 and 12 summarize the two alternative approaches.

Figure 11: All-hazards: criticality and resilience assessment (Hughes and Healy, 2014)

Figure 12: Hazard specific: detailed risk assessment and resilience assessment (Hughes and Healy, 2014)

The all-hazards approach would involve an assessment of criticality to determine which assets should be focused on for the resilience assessment. The related questions within the measurement framework would be those applicable across all hazard types (or, in other words, as the consequence of a regional, local, societal or distal event).

The criticality assessment would identify which assets merited a certain 'desired' level of resilience, and then following a resilience assessment for these assets, related improvements or interventions could be targeted. The translation from criticality to 'desired' level of resilience is summarized in Table 6.

Table 6: Example translation of criticality score to „desired" level of resilience

Criticality score	Desired level of resilience
Highly critical	Very high (4)
Medium	High (3)
Low	Moderate (2)
Not critical	Low (1)

Source: Hughes and Healy (2014)

If further detail is required, a hazard-specific assessment could be undertaken. This would require understanding which types of hazards would be relevant and their associated likelihoods. In this case, the output of the risk-assessment would determine the 'desired' level of resilience.

Taking consideration all the factors mentioned above, wended up to a framework for the assessment of transport system resilience. This assessment uses a resilience score from 4 to 1 and specifically:

4: Very high resilience – meets all requirements

3: High resilience – acceptable performance in relation to a measure(s), some improvements could be made

2: Moderate resilience – less than desirable performance and specific improvements should be prioritised

1: Low resilience – poor performance and improvements required

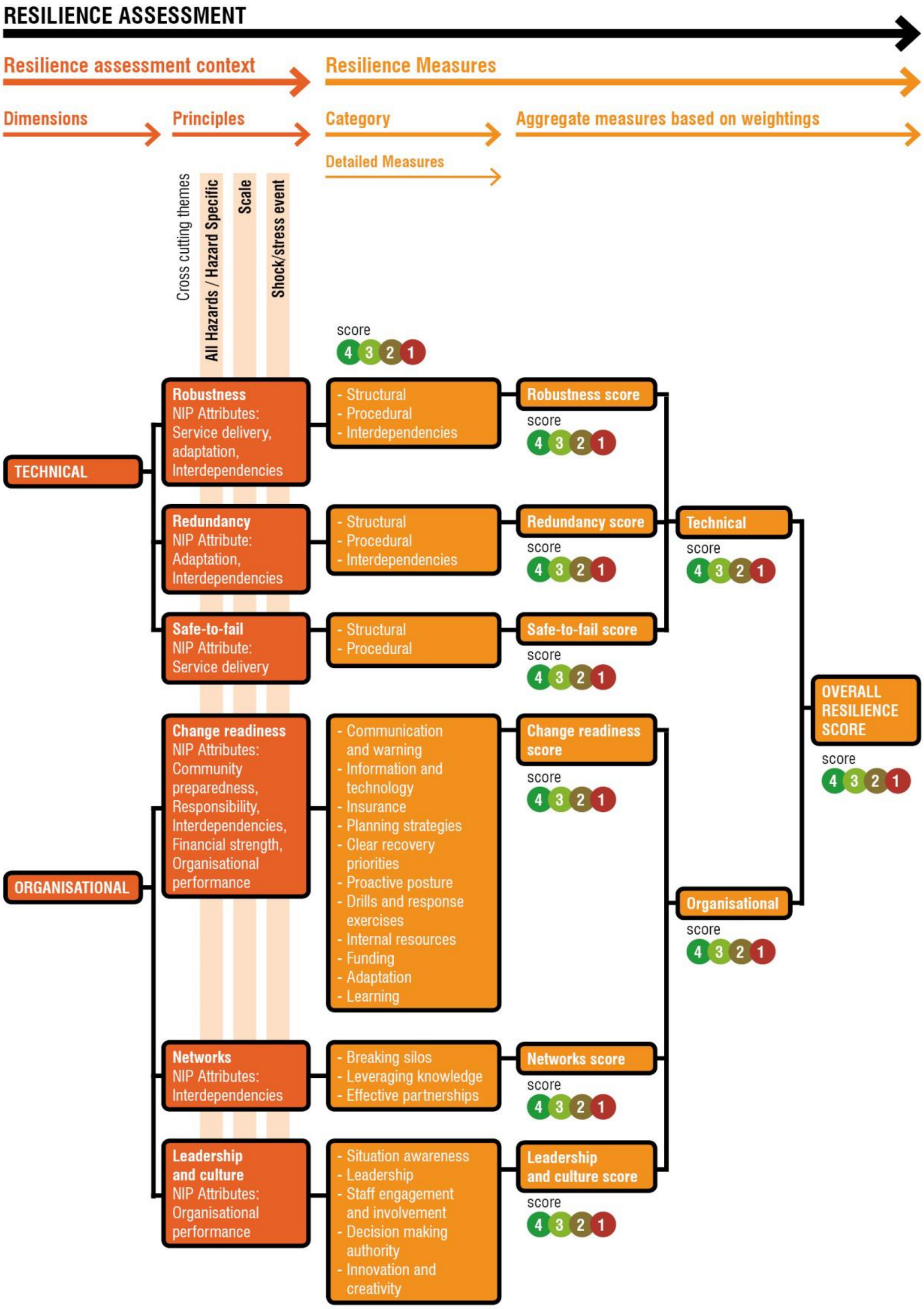


Figure 13: Proposed resilience assessment (Hughes and Healy, 2014)

Global Initiatives

The resilience of transport infrastructure has also attracted attention from the academic/scientific community at a global level. Several organizations studied the resilience of transport systems and produced valuable insights and outcomes.

- The New Zealand Transport Agency ('the Transport Agency') has a key interest in resilience ensuring transport infrastructure assets and services, function continuality and safely. A definition of the resilience concept is provided and guidelines developed to support how resilience could be measured and improved across the transport system. As such, the Transport Agency engaged AECOM (a global network of experts) to develop a framework to measure the resilience of the New Zealand transport system (Hughes and Healy, 2014).
- In Canada, the Victoria Transport Policy Institute created an evaluation scheme of transport resilience and propose best practices for its enhancement (VTPI, 2010).
- In USA, the Department of Transportation, convened notable and influential voices from the field of transportation system resiliency and climate change, to present the current state of climate science and discuss challenges, opportunities and fresh approaches related to the pressing multi-modal, multi-sector issues (Barami, 2014). Moreover, the Federal Highway Administration appears an intense activity in resilience of transport infrastructure proposing directives to establish policies to enhance preparedness and resilience by undertaken actions to handle impacts (FHWA, 2014).

6.3 ANNEX 3: LIST OF EU-FUNDED PROJECTS PROVIDING GOOD PRACTICES ON 'RESILIENCE' IN TRANSPORT NETWORKS

Funding Programme	Project	Duration	Brief description
SEVENTH FRAMEWORK PROGRAMME	PEARL (Preparing for Extreme And Rare events in coastaL regions)	4 years (2014-2018)	The PEARL project aims at developing adaptive risk management strategies for coastal communities focusing on extreme hydro-meteorological events, with a multidisciplinary approach integrating social, environmental and technical research and innovation (http://www.pearl-fp7.eu/)
SEVENTH FRAMEWORK PROGRAMME	STREST (Harmonized approach to stress tests for critical infrastructures against natural hazards)	3 years (10/ 2013 – 09/ 2016)	The STREST project, aimed at designing an innovative stress test framework for non-nuclear critical infrastructures, with the development of models for the hazard, risk and resilience assessment of extreme events, and with applications to six critical infrastructures (http://www.strest-eu.org)
SEVENTH FRAMEWORK PROGRAMME	SEAHORSE (Safety Enhancements in transport by Achieving Human Orientated Resilient Shipping Environment)	3 years (11/ 2013 – 10/ 2016)	The SEAHORSE project proposes to address human factors and safety in maritime transport by transferring the well proven practices and methodologies from air transport to maritime transport in an effective, collaborative and innovative manner (http://www.seahorseproject.eu).
SEVENTH FRAMEWORK PROGRAMME	HARMONISE (Holistic Approach to Resilience and SysteMatic ActiOns to Make Large Scale UrbaN Built Infrastructure SEcure)	3 years (06/ 2013 – 05/ 2016)	The central aim of HARMONISE (A Holistic Approach to Resilience and Systematic ActiOns to Make Large Scale UrbaN Built Infrastructure SEcure) is to develop a comprehensive, multi-faceted, yet mutually-reinforcing concept for the enhanced security, resilience and sustainability of large scale urban built infrastructure and development. (http://harmonise.eu/)
SEVENTH FRAMEWORK PROGRAMME	TURAS (Transitioning towards Urban Resilience and Sustainability)	5 years (10/ 2011 – 09/ 2016)	The "TURaS" project aims to bring together urban communities, researchers, local authorities and SMEs to research, develop, demonstrate and disseminate transition strategies and scenarios to enable European cities and their rural interfaces to build vitally-needed resilience in the face of significant sustainability challenges. To ensure maximum impact, the TURaS project has developed an innovative twinning approach bringing together decision makers in local authorities with SMEs and academics to ensure meaningful results and real

			change are implemented over the duration of the project (http://www.turas-cities.org/)
SEVENTH FRAMEWORK PROGRAMME	DRIVER (DRiving InnoVation in crisis management for European Resilience)	4 years (05/2014 – 10/2018)	DRIVER has the goal of enhancing crisis management capabilities and societal resilience in Europe. It provides guidance and support for resilience and innovation in these areas by helping practitioners articulate their needs in a structured dialogue with researchers and industry. In doing so, it also fosters flexibility and adaptability to future threats and changing crisis situations (http://driver-project.eu/)
SEVENTH FRAMEWORK PROGRAMME	CORFU (Collaborative research on flood resilience in urban areas)	4 years (04/2010 – 06/2014)	The overall aim of CORFU is to enable European and Asian institutions to learn from each other through joint investigation, development, implementation and dissemination of strategies that will enable more scientifically sound management of the consequences of urban flooding in the future. Flood impacts in urban areas – potential deaths, damage to infrastructure and health problems and consequent effects on individuals and on communities – and possible responses will be assessed by envisaging different scenarios of relevant drivers: urban development, socio-economic trends and climate changes. The cost-effectiveness of resilience measures and integrative and adaptable flood management plans for these scenarios will be quantified (http://www.corfu7.eu/)
HORIZON 2020	SMR (Smart Mature Resilience)	3 years (06/2015 – 05/2018)	SMR will develop and validate Resilience Management Guidelines, using three pilot projects covering different CI security sectors, as well as climate change and social dynamics. The Resilience Management Guidelines will provide a robust shield against man-made and natural hazards, enabling society to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of essential structures and functions (http://smr-project.eu/)
HORIZON 2020	RESILENS (Realising European ReSiliencE for CritIcaL INfraStructure)	3 years (05/2015 – 04/2018)	RESILENS will develop a European Resilience Management Guideline (ERMG) to support the practical application of resilience to all CI sectors. Accompanying the ERMG will be a Resilience Management Matrix and Audit Toolkit which will enable a resilience score to be attached to an individual CI, organisation (e.g. CI provider) and at different spatial scales (urban, regional, national and transboundary) which can then be iteratively used to direct users to resilience measures that will increase

			their benchmarked future score. Other resilience methods including substitution processes and measures to tackle cascading effects will also be developed (http://resilens.eu/)
HORIZON 2020	RESOLUTE (RESilience management guidelines and Operationalization appLied to Urban Transport Environment)	3 years (05/2015 – 04/2018)	RESOLUTE considers resilience as a useful management paradigm, within which adaptability capacities are considered paramount. Rather than targeting continuous economic and financial growth of businesses and market shares, organisations must generate the ability to continuously adjust to ever-changing operational environments. RESOLUTE is answering those needs, by proposing to conduct a systematic review and assessment of the state of the art of the resilience assessment and management concepts, as a basis for the deployment of an European Resilience Management Guide (ERMG), taking into account that resilience is not about the performance of individual system elements but rather the emerging behaviour associated to intra and inter system interactions. making process (http://www.resolute-eu.org/)