RESILIENCE OF TRANSPORT INFRASTRUCTURE IN EUSALP REGIONS

EUSALP AG 4 – THEMATIC AREA 3: RESILIENCE

EUSALP AG4 Mobility

Developed in the frame of the 2023-2025 mandate under the thematic area 3 (TA3) Resilience. Derived from examples submitted by the AGs members.

EUROPAREGION EUREGIO Tirol Südtirol Trentino Tirolo Alto Adige Trentino

RÉGION SUD PROVENCE ALPES CÔTE D'AZUR

1. Introduction

As outlined in the EUSALP Work Plan 2023 – 2025, the Work Plan of Action Group 4 (AG4 - Mobility) encompasses the topic of resilience of transport infrastructure within the EUSALP macro-region, under Thematic Area 3 (TA3).

Complying with the superordinate EU legislation, such as the Green Deal, with the Alpine Convention, and with the primary sustainability objectives of EUSALP, is mandatory for all endeavours and deliberations within the scope of TA3. With this in mind, **"resilience"**, in the broader sense of TA3, is described as the ability of a structure or even of the whole infrastructure system:

- to withstand or overcome unexpected external impacts (see Topic 1)
- to cope with unexpected and/or planned disruptions (see Topic 2)

Regarding the impacts of climate change, resilience is the capacity to prepare for, respond to, and recover from the impacts of hazardous climatic events while incurring minimal damage to societal wellbeing, the economy and the environment (See also: https://climate-adapt.eea.europa.eu/en/help/glossary). This entails a range of actions across policy, infrastructure, services, planning, education and communication. As such, building climate resilience requires a holistic and multi-dimensional approach to enhance social, human, natural, physical and financial capacities to cope with and recover from the impacts of climate change.
In this regard, it is important for the work of AG4 to include results already achieved by other working groups within EUSALP and beyond, in order to avoid duplication of work and to ensure consistency.

There is a wide range of challenges, not directly linked to climate change impacts or natural hazards, to which transport infrastructure may be exposed, due to unforeseen impacts because of:

- earthquakes (which do occur with higher frequency in some Alpine areas),
- bridge collapses,
- major accidents,
- vandalism, (cyber)terrorism, war,
- etc.

Although impacts caused by natural phenomena, such as those mentioned below, have always occurred in the past, **climate change** is making them more frequent and severe, putting transport infrastructure at serious risk:

- rising temperature,
- drought,
- storms,
- heavy rainfalls,
- rock falls, landslides and mudslides at growing extents;
- etc.

In **Alpine regions**, this is happening to a significantly higher than average extent and intensity, for the following reasons:

- The increase in temperature due to climate change has been significantly higher in Alpine regions than the global average, with Alpine regions being more sensitive to changes of their climatic conditions. The consequences range from large-scale melting of glaciers and permafrost soils to increased thermal stresses on road and rails.
- Mountains generally induce heavier and/or more concentrated rainfalls and the topography increases the danger of flash floods, in particular after long dry periods, when soils have a reduced capacity to absorb sudden rainwater masses.
- The danger of avalanches may increase at high altitudes, in particular if avalanche protection forests have weakened due to global warming;
- Slopes tend to lose stability when soppy or when permafrost is thawing, which may lead to rockfalls, landslides and mudslides.
- In addition, the lower density of the transport network and the limited availability of local alternatives in Alpine territories may increase the need for large-scale bypasses, even to other corridors. This also applies to planned disruptions, e.g. for maintenance or repair, since the effects of the infrastructure disruptions are equal.

Although such events are not always capable of directly harming human lives or damaging properties directly, they may increasingly damage and temporarily disrupt important transport links, isolating entire valleys from the outside world.
The **growing frequency and extent of natural disasters**, with ever-increasing socio-economic costs, require intensified adaptation measures to protect and reinforce transport infrastructure, in order to avoid disruptions as far as possible and economically viable. Anyway, it will never be possible to achieve absolute safety.

The following table gives a tight overview of the most important causes and types of impacts on transport infrastructure and corresponding adaptation measures, as they have proved successful in practice. It has been adapted from a similar table in a publication[1] of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), presented in the 24th AG4 Meeting on 11 October 2023, in Innsbruck. It provides a structured overview of the main hazards and threats resulting from climate change, along with potential local, mainly preventive, responses aimed at safeguarding infrastructure. Additional information on adaptation measure in the transport sector is available on the EU Climate Adapt platform.[2]

CLIMATE RESILIENT TRANSPORT INFRASTRUCTURE				
Hazards and Threats				Counteraction
Growing Temperatures, Heat	Primary dangers and damages		Damaged road covers	Shadowing, application of innovative heat-resistent road surfacing
			Lateral track buckling	White painting
			Blackout of electronic devices	Cooling of dashboards
			Hazards or impairment of passengers	Shading and sheltering stopping stations
	Secondary dangers and damages	Decline of glaciers and permafrost	Rockfalls	Falling object protective structures, e.g. protective lattices, galleries
		Damaged protection forests	Landslides	
		Aridity, drought	Soil cracks, soil destabilisation; forest, bush and grassland fires	Soil watering, planting
Storms	Primary dangers and damages		Broken trees	Keeping strips along transport infrastructure free from trees
			Bowled down traffic signs	Stronger foundation or anchoring
			Bowled down noise protection walls	
			Hazards or impairment of passengers	Warning, protective structures
	Secondary dangers and damages	Windthrow	Catenary damages	Keeping strips along transport infrastructure free from trees
			Power blackouts	Redundant power supply
Thunderstorms, Heavy Rain, Wet Snow	Primary dangers and damages		Flood damages	Increasing road/track elevation, drainage, substructure fortification
			Lightning damages	Lightning protection
			Avalanches, crushes due to heavy snow	Avalanche barriers, strips free from trees
			Hazards or impairment of passengers	Rain shelters at train/tram/bus stops
	Secondary dangers and damages	Soil maceration; destabilisation of slopes	Landslides	Slope Drainage,
			Mudslides	Retaining Walls,
			Flood debris accumulation	Tunnels to Bypass Dangerous Sections
			Log jams	Sufficient Clearance of Bridges

[1] Verkehrsinfrastruktur im Klimawandel –
Warum wir die Verkehrsinfrastruktur klimafit gestalten müssen.
Medieninhaber, Verleger und Herausgeber:
Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, Abteilung VI/1 Allgemeine Klimapolitik
Radetzkystraße 2, 1030 Wien
www.bmk.gv.at
Autorinnen: Astrid Felderer, Maria Balas, Sonja Völler (Umweltbundesamt);
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[2] https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-options

Preventive resilience measures, which mitigate potential risks and minimize damages (ex ante) should be preferred to post-event repairs (ex post). This means taking possible climate change impacts into account already in the design stage of the infrastructure. In the case of infrastructure already existing, upgrading ("climate-proofing") may be an option as far as possible and affordable.

Generally, a dense multimodal network should provide for alternative infrastructure to divert traffic flows temporarily onto other links or corridors or to shift them to another mode of transport. Exceptions are cases where the only access of a valley is affected. In such cases, helicopters may be the only option to maintain all utility services for those affected.
With this in mind and focussing on AG4 activities in the context of TA3, **two different aspects (topics) of resilience can be distinguished:**

Topic 1 ("local resilience"):
Local resilience is the capacity of a particular infrastructure, e.g. a local section, to withstand natural hazards and/or to recover from external impacts.

Regarding climate change, resilience needs to be increasingly taken into account in the Alpine region, by providing appropriate adaptation and protection measures to compensate or mitigate impacts, as shown in the table above. AG4 can support the exchange of knowledge and experiences on potential impacts of climate change on transport infrastructure and adaptation measures, as well as the analysis of further future-proofing protection measures.

Topic 2 ("systemic resilience"):
Systemic resilience (infrastructure redundancy) is the capacity of the transport network to enable traffic flows to continue operating smoothly during infrastructure disruptions, by providing an alternative routing and/or mode of transport.

This effect, in its functional principle, is the same in the case of unforeseen disruptions and in the case of planned infrastructure closures due to maintenance, rehabilitation or renovation works. Alpine States and regions will increasingly focus on capacity management to absorb anticipated increases in traffic volumes, both in terms of freight and passengers' transport.

TA3 pays special attention to major road and rail infrastructure disruptions or closures along the transalpine corridors, leading to redistribution effects between corridors and modes and possibly affecting neighbouring regions. This applies to disruptions or closures, unforeseen or planned, in the past, ongoing or expected in the coming years.

2. Activities of AG4 in the field of TA3 (resilience), examples submitted by AG4 Members and results:

In order to create a broad knowledge of measures to adapt transport infrastructure to climate change, in line with the EUSALP AG4 Work Plan, the activities of AG4 in the field of TA3, reflect the above described two topics, by collecting best practice examples (information and data) from AG4 Members categorised into local (Topic 1) and systemic (Topic 2) resilience, as well as projects with impact on both local and systemic resilience (Topic 1 & 2). A brief description of the category shall be an introduction to the examples given below:

Topic 1:
Best practice examples in the Alpine Region regarding climate resilient transport infrastructure ("local resilience") were collected:

- how existing transport infrastructure could be strengthened against the increasingly frequent impacts of heat, storm, heavy rain, flooding, landslide, rockfall, etc.:
- whether/how these impacts would already be taken into account in advance (at the planning phase of new infrastructure);
- the additional costs directly attributed to the adaption of transport infrastructure to climate change.

This was needed to enable AG4 Members to exchange experience and learn from each other how best to deal with climate change or other unexpected impacts during the infrastructure design phase (new projects and upgrades). As far as available, this information had also to include the inherent additional costs due to the consideration of resilience aspects.

The following examples serve to illustrate the underlying principles of transport infrastructure resilience and to determine the corresponding additional costs. The goal of this exercise is to facilitate mutual knowledge exchange and learning among stakeholders. These examples, which are compiled in the table Annex I, will also be uploaded on the "Platform of Knowledge".

Ex. 1: Examples for local resilience (topic 1):

Ex. 1.1: Electrification and upgrading of the Venosta/Vinschgau railway line:
Securing a section that had been destroyed by mudslides

Ex. 1.2: Ciclovia turistica nazionale "Tirrenica":
While the railway sections Ospedaletti – San Lorenzo al Mare and San Lorenzo al Mare – Andora were replaced by a more resilient line, the decommissioned sections were converted into a cycle path.

The outcome has contributed to a better visibility of infrastructure measures and additional funding needs in the context of climate change adaptation.

Topic 2:

Best practice examples of unforeseen external impacts and planned transport infrastructure measures with a significant (large-scale) influence on the traffic flow of the transport corridors were collected:

With a focus on the main transalpine corridors, the following data and information were collected:

- past serious accidents on infrastructure that have caused the closure of the respective section and temporary deviations of traffic flows or modal shift,
- past, ongoing and/or planned interventions, e.g. due to maintenance or repair works, causing temporary deviations or modal shift.

This task comprised major temporary infrastructure closures (in particular on TEN-T corridors), either unexpected – like natural disasters or accidents in the past – or planned for maintenance or repair works, including measures to divert large-scale traffic flows to other corridors or to shift them to another mode of transport.

While for the past and present, both unexpected incidents and planned measures causing temporary closure were to be reported, for the future this applied only to planned measures (e.g. maintenance, repair, etc.).

This was needed to provide AG4 Members with examples of possible large-scale impacts of infrastructure closure on traffic flows (deviations and/or modal shift), as the basis for a better common understanding of the issue, for the continuation of the work and the exchange of experience in the coming work period.

Ex. 2: Examples for systemic resilience (topic 2):

Ex. 2.1: Temporary closure of Tauern railway tunnel; rail replacement buses and other compensation measures:

Long distance transport: replacement bus Bischofshofen – Spittal-Millstätter See, Short distance transport: replacement buses Schwarzach-St.Veit – Badgastein and Badgastein – Obervellach; Alternative (to avoid daily commuting): accommodation of commuters from Carinthia in Gastein Valley

Ex. 2.2: FVG's Region's measures to develop intermodal freight transport:

Modal shift of transport of steel slabs to rail and short sea shipping between the port of Monfalcone and the industrial area of Aussa Corno (San Giorgio di Nogaro) to avoid road accidents.

Ex. 2.3: Closure of Semmering mountain railway for maintenance:

Long distance transport: replacement buses Wiener Neustadt – Mürzzuschlag.

Ex. 2.4: Closure of A9 motorway section St.Michael – Deutschfeistritz due to flooding and landslides:

Deviation of traffic via S6 and S35 expressways (via Bruck/Mur).

Ex. 2.5: Rehabilitation of Arlberg road tunnel:
Local deviation of traffic via Arlberg pass road (restrictions for heavy good transport), Large-scale deviations for great part of heavy good transport via Munich, Gotthard, San Bernardino.

Combination of topics 1 & 2

Some examples, submitted by AG4 Members, have an impact on both local and systemic resilience. They are separated from topic 1 and 2 and are presented below. These examples consist of several combined measures under one project which are individually assigned to either topic 1 or 2.

Ex.3: Examples for combined local and systemic resilience (topics 1 and 2):

Ex. 3.1: "Nuova galleria ferroviaria del Virgolo":
Topic 1: Construction of new tunnel at a place exposed to rockfall,
Topic 2: A third track for the Venosta railway line will increase capacity and improve operation.

Ex. 3.2: Early warning Sismico Milano – Venezia:
Installation of an early warning system in a region with frequent earthquakes:
Topic 1: to increase local safety of operation,
Topic 2. to secure the undisturbed function of a key section of the Italian railway network.

AG 4 Members were asked to bear in mind that the ultimate objective of this exercise was not to delve into the reasons behind unexpected or planned disruptions, but rather to illustrate how such events have prompted discussions on enhancing the resilience of the entire transport infrastructure. This included considering future measures to bolster resilience, with particular attention to the impacts of climate change on the EUSALP macro-region.
The outcome has contributed to an overview of relevant road and rail infrastructure works and their effects on traffic flows and capacity management during disruptions.
These examples have yielded quite some insights of how unforeseen incidents and planned infrastructure closures can be met by appropriate measures, which has enabled to draw the general conclusions listed in chapter 3 below. However, there are still relevant gaps regarding both the whole set of such climate change related incidents as listed in the table on page 3 above and targeted interventions to tackle with intended infrastructure closures. This will require collecting additional best practice examples on this issue, which is hence foreseen in the Work Plan 2026 – 2028.

3. Conclusions of TA3 (Lessons learned for the benefit of all AG4 regions):

Despite different situations reflected in the individual examples, it was possible to draw the following general conclusions with relevance for resilient infrastructure planning in the Alpine regions:

- Progressing climate change will lead to an increase in importance of locally and systemically resilient transport infrastructure.
- This will require giving local resilience growing attention in planning of new projects or in upgrading existing infrastructure.
- As significant stretches of the existing road and rail infrastructure in the Alpine Region have an age of more than 30 years, repair and rehabilitation works gain importance, causing closure of infrastructure sections, with corresponding deviations.
- Inherent costs will grow considerably and limit the economic capacities for the construction of new infrastructure.[3]
- In view of the increasing risks posed by natural hazards to transport infrastructure and the potential closures and diversions, cross-border cooperation, direct communication and coordination between road and rail infrastructure managers continue to play an important role in the Alpine Region to ensure not only accessibility at a local and regional level but also connectivity at a transalpine scale.

[3] European Commission (2024) Support study on the climate adaptation and cross-border investment needs to realise the TEN-T network. *Online:* *[Investments in climate adaptation should be an integral part of the trans-European transport network, study shows - Mobility and Transport]*