Critical infrastructure in mountain areas in the era of climate change – a multifaceted challenge
Risk Management – Business continuity and disaster recovery in the road sector

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Abstract

Roads and territory

Since Roman times, the conquest of territories has been linked to the construction of roads. Without the latter, not only can people not be moved, but not even goods and everything necessary to "conquer" the territory. For this reason, the conquest (and the subsequent development and use) of mountain territories has in the past been linked to the creation of transit axes.

Together with the transit of people and goods, in the times of industrialization the use of roads has been increasingly linked to the distribution of electricity, thermal, data or ducting, leading to an increasingly close connection between road transit axes and energy distribution axes. Hence the interoperability of infrastructures that thus become "multifactorial" critical infrastructures.

Over time, moreover, the modes of transit are transformed, both in terms of the type of mobility (public or private transport, road or rail, slow or fast mobility, ...) and in terms of size or quantity. Suffice it to say that over time road freight transport has gone from animal-drawn wagons, to 28-ton trucks, to 40-ton trucks and now we are talking about 64-ton Gigaliners.

These changes in transport modes are challenges that the planner must take into account every time he goes to plan a new road axis or a modification of it, as from a road project there will be a multitude of constraints on the rest of the spatial planning. Traffic, and with it the infrastructures that contain it, is a complex issue in which the variation of a single parameter activates the effects on the rest of the territory.

Keywords: Roads and Transportation System / Risk Management, Business Continuity, Disaster Recovery, Critical Infrastructure

Introduction

Climate change and infrastructure

Just as road infrastructure, however, has repercussions on a multitude of other aspects, the infrastructure itself must also consider being impacted by various factors, both natural and anthropogenic. When it comes to mountain areas and natural hazards, the challenges of climate change cannot be overlooked at the moment.

Floods, water bombs, snow and avalanches, landslides, are just some of the possible dangers with which mountainous terrain can impact the infrastructure that resides there. For this reason, every infrastructure must be constantly monitored and subjected to constantly updated risk analysis based on internal and external changes.

A classic example, which will follow us several times throughout this article, is the flooding event that occurred on 29.06.2024 in Vallemaggia[i] and which led to the destruction of the Visletto Bridge and beyond[ii].

1. Risk Management - Multifactorial Risk Analysis

As mentioned, road infrastructure can be both target and source of risk, which is why it is important that a risk analysis analyzes in "Butterfly" style both all the effects that could impact it and all the damage it could generate. The following are some examples of things that can be analyzed.

As a starting analysis document, a good basis to take into account is the Hazard Catalogue of the Swiss Confederation[iii] in addition to the experiences considered.

1.1. Safety from natural hazards

1.1.1. Infrastructure

Natural hazards in an Alpine environment can be of different types and intensity, such as water hazards (floods, river floods, thunderstorms, water bombs, etc.), gravitational hazards (landslides, avalanches, landslides, rockfalls, etc.) or other hazards (tsunamis, earthquakes, etc.).

Some of these have the intensity to be able to seriously damage or destroy the infrastructure, making it partially or totally unusable, as happened in several points of the Maggia Valley.

An optimal risk mitigation methodology can be the one used in the field of occupational safety in which the STOP system (Substitution, Technical, Organizational, Personnel) is adhered to.

For this reason, correct planning in the planning phase can lead to the avoidance of the danger zone (Replacement) or to the introduction of risk mitigation measures such as protection valleys or rockfall protection nets (Techniques).

In view of the definition of these measures, however, the assessment of the risk areas is of fundamental importance, in order to understand whether the measure undertaken is economically sustainable.

1.1.2. Users

Some of the dangers considered, on the other hand, have a lower intensity such as not to damage the infrastructure itself but to have an impact on any users. Also, in this case it is necessary to take all the necessary measures to protect users. In addition to the above, in fact, additional measures such as traffic lights and (Organizational) traffic bans can have an effect on users. Clearly, compliance with these measures, as well as users' understanding of the risks, are part of the mitigation measures (Personnel).

1.1.3. Of the surrounding environment

Finally, the infrastructure itself can become an element that can change the effects of any natural hazards. It is therefore important to assess that the infrastructure and all the measures put in place to protect it do not modify the territory by creating dangers for the surrounding environment.

1.2. Safety from anthropogenic hazards

Clearly, natural hazards are not the only ones that must be taken into account in the risk analysis of a building. Particular attention must be given to all "artificial" or man-made hazards that could impact the infrastructure, the road user, or the surrounding environment.

1.2.1. Infrastructure

First, let's talk about the infrastructure. The same, as seen in the previous chapter, can be hit by weather events that can damage or destroy it. However, there are also man-made dangers. Examples of citable anthropogenic hazards can be considered in the following list:

- "Culpable" human activities:
    - Road accidents (minor or major)
    - Construction site accidents

  - Industrial or human activity in the vicinity of the infrastructure
  - Deficient projects
  - Lack of maintenance
  - Traffic problems
  - Blackout
- "Malicious" human activities
  - Sabotage
  - Events
  - Wars

In the list above, we are not always talking about events that can irreparably damage an infrastructure, but also about events that could make this infrastructure temporarily (or permanently) unusable, even if it has not suffered any obvious damage.

1.2.2. Users

Like the infrastructure, those who use it must also be safe if we talk about "integral security", i.e. 360°. To ensure this safety, it is necessary that the conformation of the road and its use (accidents and near misses) are constantly under control. Therefore, different aspects of the design and operation must be constantly analyzed to ensure continuous improvement of the road.

Some of the tools used in Switzerland are the ISSI (Infrastructure Safety Tools) and the OPIR (Major Accident Prevention Ordinance) analyses.

The first (ISSI tools[iv]), are a collection of 6 standardized techniques that analyze the impact on user safety of the different variants of a preliminary project, the impact of the different elements introduced in the different design phases, the state of maintenance and operation to assess compliance with the standards, as well as the analysis of accidents, whether they are scattered on the different road axes or concentrated in specific black spots. Finally, events of particular importance can lead to a reanalysis of the rules as happened in the case of a bus accident on a pier of a tunnel in Sierre[v], causing the death of several children. This event caused an international sensation by defining new ways of designing tunnel accesses and road niches.

The second tool mentioned instead (OPIR Analysis[vi]), consists in the analysis of possible accidents caused by the transport of dangerous goods to the surrounding environment, whether it is a "human" environment (number of possible direct deaths), or environmental (pollution of aquifers or waterways). In this case, the system assesses the possibility that some explosion or pollution scenarios will cause damage to the surrounding environment on the basis of accidents. Similarly, the surrounding environment, if industrial with chemical risks, can itself be a source of danger and must consider the surrounding road infrastructure as a target of damage.

1.2.3. Of the surrounding environment

The infrastructure itself, however, is to be considered as an artificial element inserted in a larger environment. So here it can become, for how it is made but also for the users who use it, a source of danger for the external environment. These interactions are also to be considered in a multidisciplinary environment, in order to assess the risks and the necessary measures to be taken.

Here, as mentioned above, an OPIR-type event could create damage to those who reside on the side of the road or due to damage to the surrounding environment if it were to be polluted.

A further possible impact given by the infrastructure to the external environment is represented by the event of the collapse of the Morandi bridge in Genoa[vii] where the collapse of this infrastructure involved 2 industrial warehouses under it, although fortunately none of the buildings located below it was damaged.

As we said at the beginning of the article, however, road infrastructures are often interconnected with other infrastructures, such as water collection (meteorological or industrial). A further example of impact occurred precisely in the event of the collapse of the Visletto bridge (Maggia Valley), in which following the collapse, the canalization that passed through the bridge was torn, pouring the sewage content into the water of the river below, polluting it and making the water of much of the territory downstream of the event undrinkable.

2. Business Continuity - Security of connected zones

What we saw in the previous chapters focused on the impact of different types of hazards at the "micro" or "mini" level, i.e. focusing only on the impact that these hazards could have on the infrastructure itself and on the environment connected to it.

The road infrastructure, however, as repeatedly indicated, is an element of transit, of passage, which serves to connect the most disparate places. Here, therefore, a complete analysis of the importance of this infrastructure must also evaluate any aspects at the "medium" and "maxi" level.

As anticipated, in an alpine environment, often an infrastructure, so difficult to "wedge" into the mountains and valleys, is the only axis of passage to connect environments that would otherwise be very difficult to connect. The uniqueness of the passage can be given by the fact that there is no room to make other transit axes, or by cost issues, or by the characteristics associated with it. It is therefore necessary to evaluate, in a correct risk analysis, what the aspects of uniqueness are or, if there is no such uniqueness, what impact the loss of this part of the infrastructure could cause.

Some examples, in the short or medium term, that can be taken into consideration, are related to simple snowfalls throughout the Alps, which block the transit of goods for days, to meteorological events, perhaps occurring in conjunction with construction sites or other events on alternative axes.

Some examples range from a "smaller" dimension such as the case of the Maggia Valley, to much larger dimensions involving the whole of Europe, such as what happened both during the weather events of 2024 and during events such as the fire in the Gotthard in 2001[viii] or the railway closure of the Gotthard railway axis (Uri side) in 2006[ix] or the Alptransit accident in 2024[x].

In all the cases indicated above, the aspect of transit, whether of people or goods, is to be considered and there comes the need to evaluate, both in the project and in response to events, alternative solutions.

Going to analyze the case of the Gotthard railway axis, for example, ADR (transport of dangerous goods) goods, normally transported on the rail axis, had to find solutions to be able to travel by road, even if this was not normally allowed (Gotthard and San Bernardino tunnels classified ADR category E). In the case of the 2024 weather events, on the other hand, the closure of the San Bernardino road axis, in conjunction with landslides on the main Alpine passes and with the closure of Alptransit due to the railway accident, put freight traffic in crisis, creating problems of freight transit at the European level.

A recent example

Returning instead to the more limited case of the Maggia Valley, at first, the entire valley found itself confronted with a very complex situation of discomfort generated by the bad weather that raged in the region.

The first problem encountered was the impossibility of getting in touch, during the night, with the areas where the storm was in progress. Arriving on the spot for the check, the intervention forces discovered that the road bridge had collapsed, the only access to an entire valley that winds, in addition to its side valleys, for more than 20 km.

Figure 1- The collapsed Visletto bridge - source: Wikipedia (https://de.wikipedia.org/wiki/Ponte_di_Visletto)

With the collapse of the same, the electricity supply of the entire valley, as well as the telephone lines that allowed the connection with the various people in the valley, had been compromised. It may seem strange, in an era connected via smartphone, but the absence of power to the entire valley also had the impact of the disabling of the entire mobile telephone network. To continue, as already anticipated, the sewer connection was also compromised.

In the meantime, there was, among other things, a summer camp and a football tournament with concerts in the area, so it was also necessary to check and contact the people present in the valley to check that everyone was okay despite the various landslides that occurred during the night.

3. Disaster recovery – restoration of the road network and more

In a situation like the one reported above, it requires immediate prompt intervention, to ensure the safety of the entire population present on the site but also the functioning of the entire territory.

From an event such as the one indicated, i.e. of a destructive type, it is first necessary to at least partially restore the functioning of the infrastructure, and then bring it back to full capacity, improving the service and safety of the same. Speaking of an environment such as the public one, often the speed with which you can move clashes with bureaucratic procedures, which is why it becomes important to have "streamlined" procedures that allow you to adapt to emergency situations, but at the same time "solid" that allow you to ensure that you are following legal regulations.

Specifically, the intervention appears to have been divided into several phases (it should be noted that the intervention is still ongoing).

3.1. Event Stage

3.1.1. Event detection and situation analysis:

Firstly, the lack of information from the area required the need to go to the site to check what happened. At this stage, since everything is still unknown, it is important to be sure to operate safely in order not to take unnecessary risks during the inspection. It is only thanks to this inspection, in fact, that the information necessary to understand the size of the event and how to act can be obtained.

3.1.2. Organize for the immediate intervention

To cope with these events, the Ticino law indicates how it is necessary to structure oneself to guarantee the direction of the event to the Police, with a consequent structure of analysis and command and the ability to intervene throughout the territory. In fact, the Regional Command Staff was established which, thanks to the participation of all the bodies and partners (police, ambulances, firefighters, civil protection, army, technical services, water protection offices, ...) allowed the correct conduct of operations in the acute phase.

3.1.3. Securing the intervention/rescue axis and interventional planning in general

As indicated, access to the valley was compromised, hence the need to find alternative solutions, in accordance with the priorities of intervention and safety situations. Clearly, as soon as possible, the intervention by air made it possible to get an extended idea of the situation (also through Rapid Mapping, see reference i) as well as to intervene with censuses, search and rescue. Personnel were then taken over the bridge to allow "antennas" to be on site. In addition to these measures, action began to be taken to ensure accessibility and viability.

The first emergency measure to partially restore the service consisted of making a ford in the river (in the meantime back on its banks) and restoring a passage by transforming a cycle bridge that fortunately had been restored a couple of years earlier. Here, however, this passage made it possible to connect the area, albeit with a limitation of a maximum of 3.5 tons. Clearly, given the situation throughout the area (residents excluded), access was restricted to avoid onlookers and allow to facilitate the intervention that took place in the following weeks.

In addition to transit, it was necessary to ensure the restoration of sources of power, communication and other things that had been compromised in the meantime.

3.1.4. Ensuring viability

At this point work began to restore the road network. Thanks to the assistance of the army and its disaster relief services, it was possible to cope with the various disasters in the area for material evacuation and restoration of the internal road network. In addition to this, the construction of a new temporary bridge, the result of the work of the cantonal services coordinated with the army, also made it possible to restore the interrupted axis, albeit with a performance reduced to 30-40% of the original one. Already at this stage, however, the information obtained from the disaster had to be supplemented, so as to ensure that no one could be endangered by any other flood situations. The bridge, although a single lane, with the addition of the ford, today make it possible to guarantee complete accessibility to the entire region.

Figure 2- Military Bridge Installation - Drone Photo

Figure 3 - Ford (top), footbridge, collapsed bridge and military bridge - photo Ticino online (https://www.ticinonews.ch/ticino/da-domani-alle-11-il-ponte-di-visletto-sara-transitabile-senza-limitazioni-398122)

3.1.5. Restore service

At the same time as the partial restoration interventions, it was necessary to evaluate the situation and start by designing a solution that would be valid in the long term. For this reason, a process of design, selection and assignment of mandates that would normally last 4-6 years has been condensed into less than 1 year, allowing less than a year from the event to assign the works, with the aim of delivering the new bridge within a further year. In the meantime, this bridge had to be designed with criteria that answered all the questions that arose in compliance with the steps explained in the previous chapters of the article.

The new bridge will have to take into account the new information obtained in a way that ensures the safety of road users, infrastructures and natural hazards, based on what has been learned over the years.

Figure 4 - rendering of the Vislè Bridge rehabilitation project – (source https://www4.ti.ch/tich/area-media/comunicati/dettaglio-comunicato/?NEWS_ID=243212)

4. Lesson Learned – Conclusions

Paraphrasing the famous saying "Si vis pacem, para bellum" (Latin proverb, if you want peace, prepare for war), one could say that one must always be ready to intervene in any situation.

In an environment characterized by constant change, be it technological or climatological, it is no longer just to be ready to intervene, but more ready to adapt, to learn from the past, not to replicate, but to change one's behavior in the management of events, in constant improvement in order to no longer follow decisions of the past that, in reality, they only worked in an environment that could no longer be replicated, since everything changes and situations can never be twice the same.

Notes

[i] Weather event map Vallemaggia - https://s.geo.admin.ch/llj5bs80cypw

[ii] Blog Meteoswiss event Vallemaggia - https://www.meteosvizzera.admin.ch/chi-siamo/meteosvizzera-blog/it/2025/06/alluvione-altavallemaggia1.html

[iii] Swiss Hazards Catalogue Federal Office for Civil Protection - https://www.babs.admin.ch/it/catalogo-dei-pericoli-base-per-lanalisi-dei-pericoli-e-dei-rischi

[iii] FEDRO Instruments ISSI - https://www.astra.admin.ch/astra/it/home/servizi/vollzug-strassenverkehrsrecht/strumenti-per-la-sicurezza-dell-infrastruttura-issi.html

[iii] FEDRO incident intranet page Sierre - https://www.astra.admin.ch/astra/it/home/temi/strade-nazionali/sicurezza-nelle-gallerie/incidente-di-autobus-del-13-marzo-2012-nella-galleria--sierre-.html

[iii] FOEN website Major accidents - https://www.bafu.admin.ch/bafu/it/home/temi/incidenti-rilevanti/diritto/stoerfaelle-vzh.html

[iii] Italian Fire Brigade – Morandi bridge collapse Genoa - https://www.vigilfuoco.it/chi-siamo/memoria-storica/notizie-storiche/il-crollo-del-ponte-morandi

[iii] FEDRO page Gotthard fire event 2001 - https://www.astra.admin.ch/astra/it/home/temi/strade-nazionali/sicurezza-nelle-gallerie/incendio-gottardo.html

[iii] Report of the Canton of Ticino on the impact of the closure of the Gotthard railway 2006 - https://m4.ti.ch/fileadmin/DT/temi/aria/documenti/BER_Umleitung_A2_Juni_2006.pdf

[iv] SISI Alptransit Accident Report - https://www.sust.admin.ch/inhalte/BS/2023081002_GBT_Media_I.pdf