



Smart Transportation Alliance

Towards climate- resilient transportation infrastructures

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1. Introduction

Back in 2005, Hurricane Katrina, the costliest natural disaster in the history of the United States, claimed more than 1,800 lives and caused an estimated \$75 billion dollars in damage. Needless to say, the storm had a devastating impact on much of the transport network of southern Mississippi, Louisiana and Alabama.

It was a “wake-up” call for the world, making clear that climate change is real and that transportation infrastructure is not ready to cope with extreme weather conditions. Hurricane Katrina showed us, for the first time in a high-developed country, how much climate change could negatively impact transportation infrastructure, and furthermore, how relevant it was to set up a framework to prevent and protect it.

There is an urgency to develop international best-practice guidelines detailing how to adapt transportation infrastructures to climate change, since many countries (in particular BRICS and Next Eleven countries), are implementing multi-billion national plans in infrastructure projects for the next 10 years. Moreover, adaptation of infrastructure to climate change affects the whole process of planning, design, construction, operation and maintenance of transportation infrastructures.



Figure 1 – Roadway damaged by hurricane Katrina
Source: NASA (2005)

2. The changing climate system – A point of stress

The fact that the climate system is experiencing stresses unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea levels have risen, and the concentrations of greenhouse gases have increased (Intergovernmental Panel on Climate Change, 2013).

According to the European Commission, weather stresses represent from 30% to 50% of current road maintenance costs in Europe (8 to 13 billion €/year). More frequent extreme precipitations and floods (river floods and pluvial floods) as expected in different regions in Europe could result in an extra cost for transport infrastructures (50-192 million €/year, period 2040-2100).

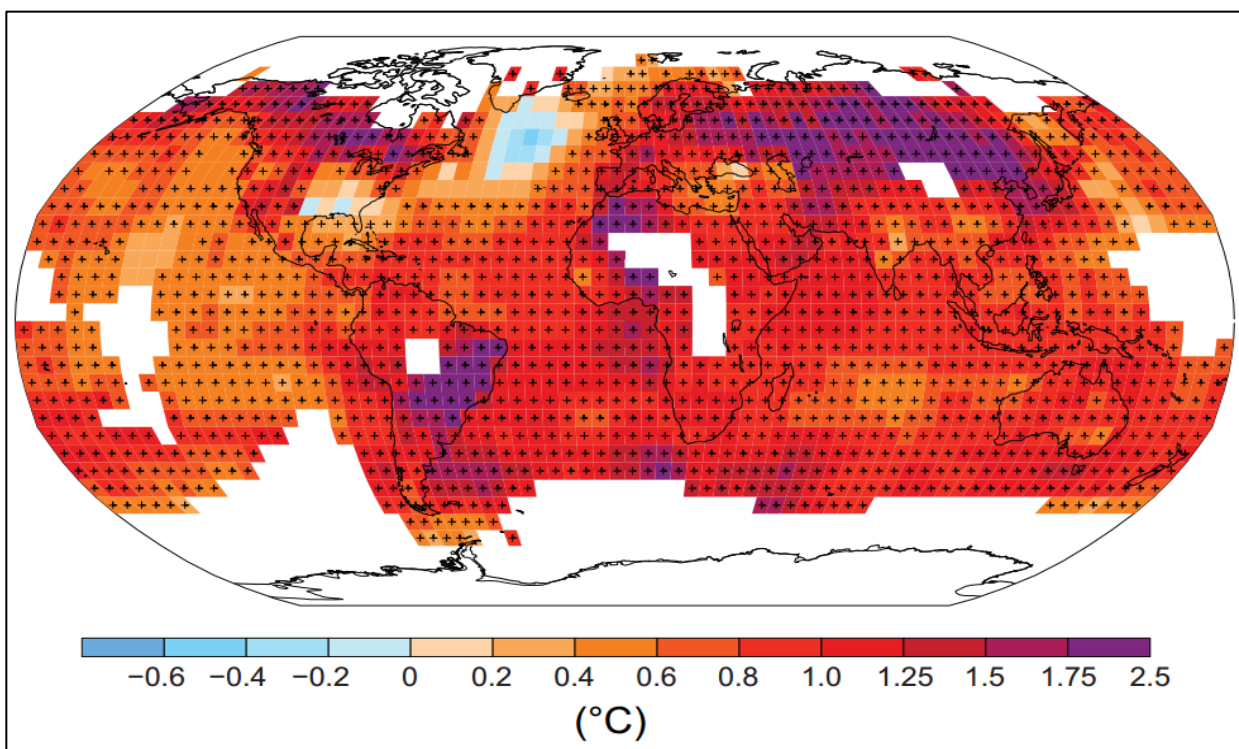


Figure 2 - Observed change in surface temperature 1901–2012
 Source: Intergovernmental Panel on Climate Change (IPCC) (2013)

Milder winter conditions are projected to result in reduced costs for the specific case of road infrastructure (-170 to -508 million €/year), as stated by the Institute for Prospective Technological Studies of the European Commission in 2012. On the other hand, increasing average temperature all over Europe could require changes in maintenance operations and practices and represent extra costs.

Climate change is a global problem, but it eventually results in local effects that differ from region to region. The effects of climate change on infrastructure can have different dimensions. They can be revealed as major incidents (1) because of extreme weather situations that occur more often (a 100-year event design can occur in much shorter timeframes).

However, climate change can also result in small and incremental changes (2) that over the years result in deteriorating and eroding transportation quality. Adaptation of infrastructure to climate change requires taking in account every stage of the infrastructure management process: planning, design, construction, operation and maintenance, to cope with these changing circumstances.

Given the complex nature of the infrastructure management ownership – the use of Private Public Partnerships is becoming a usual practice in many countries - it is mandatory to go beyond “creating awareness” for climate change. This article aims to consolidate this awareness by highlighting the current need of an “Adaptation Framework”, containing standard procedures and technical specifications in order to assist decision-makers and steer projects throughout their planning and implementation.

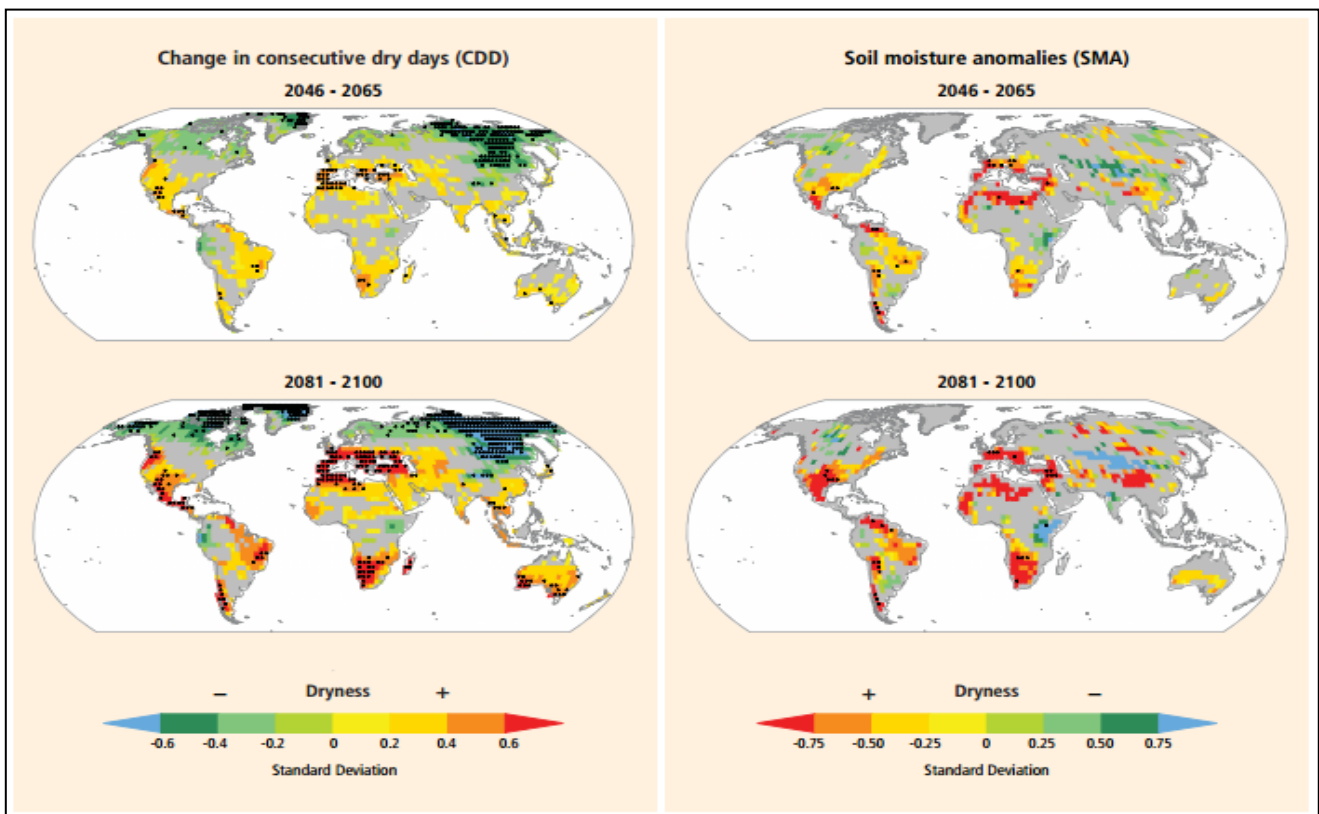


Figure 3 - Projected annual changes in dryness assessed from two indices

Source: World Meteorological Organization (WMO) (2012)

Changes in the climate over the recent past, identified by researchers, involve changes in temperature, precipitation, storm activity, sea level, wind speeds and more. These effects can in turn lead to impacts on transportation infrastructure, such as weakened bridges and road beds, expanded rail tracks, delays and disruption in ports due to sea levels rise or damaged airstrips.

Back in 2010, the US Federal Highway Administration (FHWA) published a report that intended to support US Departments of Transportation when they deal with the relation climate change-infrastructure. The document, prepared under the name of “Regional Climate Change Effects: Useful Information for Transportation Agencies”, identified the main impacts on the road infrastructure system across the United States.

In doing so, the climate effects that affect transportation infrastructure were divided in three key categories:

1. **Changes in temperature**
2. **Changes in precipitation and storm events**
3. **Sea-level rise**

However, and additionally to the ones mentioned by the FHWA, a large number of effects and impacts on the transportation infrastructure must be considered. In order to implement all a global –but local at the same time- approach, variables such as **4) relative humidity** and **5) extreme cold events** are also relevant.

A comprehensive breakdown of all specific impacts caused by the five above-mentioned climate effects would require a more extensive article. For instance, in the case of roads, some representative impacts have been listed below:

- Rise in asphalt temperature may compromise pavement integrity (e.g., softening asphalt and increasing rutting from traffic) and cause thermal expansion of bridge joints, adversely affecting bridge operation and increasing maintenance costs.
- Increases in flooding of roadways and tunnels
- Drainage systems likely to be overloaded more frequently and severely, causing backups and street flooding
- Increased susceptibility to wildfires, causing road closures due to fire threat or reduced visibility
- Increased risk of floods, landslides, slope failures and damage to roads if precipitation changes from snow to rain in winter and spring thaws.
- Exposition of more areas to effects of storm surge/wave action due to sea-level rise, causing more frequent interruptions to coastal and low-lying roadway travel

- As the sea-level rises, the coastline will change and highways that were not previously at risk to storm surge and wave damage may be exposed in the future
- When fog occurs, people generally drive somewhat slower, but simultaneously keep a shorter following distance to the vehicle in front of them. In combination with the decreased field of vision, this increases the risk of crashes (Fokkema, 1987; Oppe, 1988).
- More freeze-thaw conditions, creating frost heaves and potholes on road and bridge surfaces and resulting in load restrictions on certain roads to minimize damage.

3. Methodology

The proposed adaptation process sets out to be implemented periodically as a part of the local/regional/national transportation network decision-making process. It has been designed to be able to respond to the user's demands, depending on the degree of detail of their input into the analysis. Anyhow, it could be a useful planning tool both for large and small transportation administrators, complement a larger Climate Change Adaptation Scheme or become a whole Adaptation Plan itself. This methodology intends to be useful for the main transportation stakeholders: National and Regional Transportation Authorities, international institutions, other transportation authorities and experts.

Since National and Regional Transportation Authorities deal on a daily basis with transport performance issues related to climate change impacts, it might be helpful to conduct a survey/questionnaire before implementing this methodology. Furthermore, their specialists and their correspondent opinions would play an essential role in the preparation of the specific strategy, since they provide high-value knowledge gained on the spot. Consulting other transportation stakeholders or undertaking a review process of relevant literature are recommended options to support the methodology defined below.

This methodology provides a process methodology to identify, analyse and mitigate risks related to the impact of climate change on transportation infrastructure.

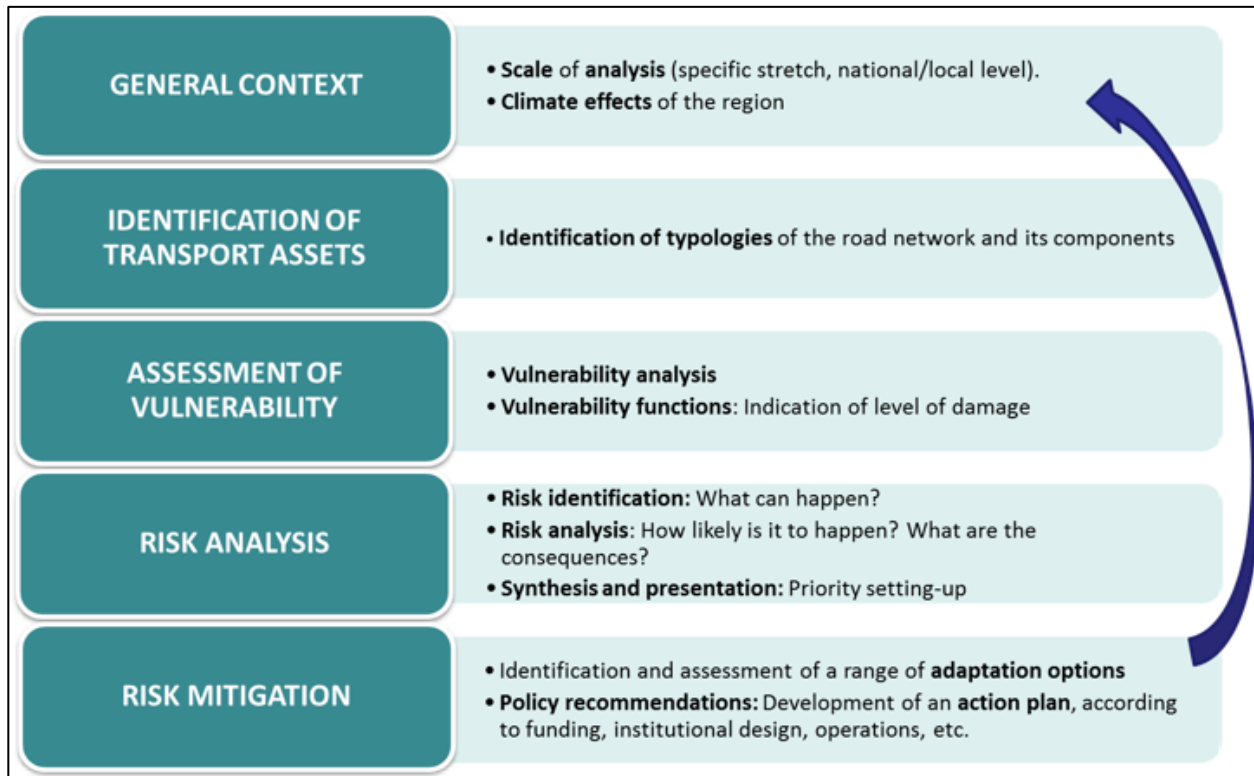


Figure 4 – Methodology: adaptation process

Source: prepared by the author

3.1. General Context

The first step of the adaptation process should involve the global identification of the context where the intervention takes place. The availability of relevant information and data is essential to provide the users with the proper environment in which they can fit their specific cases according to their individual inputs and parameters. Thus, the users would classify their cases against:

3.1.1. Scale of analysis

Type of intervention, guidelines and responses will differ depending on the scale of the transportation infrastructure that must be adapted. Depending on:

- *Scale of the intervention*
 - Specific Transportation Infrastructure
 - Larger Transportation Network
- *Scope*
 - National level
 - Regional level

- Local level

3.1.2. Climate effects of the region

One of the key aspects is the identification of the climate effects more likely to happen within each one of geographical areas. Such effects will be classified as following:

Key climate effects

- Changes in temperature
- Changes in precipitation and storm events
- Sea-level rise

Other climate effects

- Relative humidity
- Extreme cold events

The final framework should allow transportation infrastructure planners and operators to build up a comprehensive picture of the potential climate impacts in their area. In support of this approach, a compilation of representative case studies having taken place in their geographical areas or those with similar conditions, should couple the analysis.

3.2. Identification of transportation assets: typologies of the Transportation network and its components

The second phase should be based on the identification of those infrastructure assets that could be endangered by the climate effects previously identified. Some factors to be considered when characterizing endangered infrastructure include: location, traffic volume, reconstruction costs, type of structure, relative importance maintenance and rehabilitation works undergone, redundancy level, etc.

Taking again the example of the road sector, the following classification for a given network and its potential vulnerability would be proposed:

- Unpaved roads
- Paved roads
- Bridges

3.3. Assessment of vulnerability

The vulnerability analysis will derive from the interrelation of the two previous steps, and should be assessed in an iterative procedure. Transportation decision-makers should have

a practical tool to assess the vulnerability of infrastructure assets, allowing them to easily link their assets to potential impacts. After that, identified critical assets should be examined by identifying cost-effective solutions of adaptation. The criteria used in selecting the preferred approaches include availability, accessibility, transparency, reasonableness, scalability, robustness, cost-effectiveness, and modularity. Both budgetary and climate conditions are variable and hence have to be taken into account when assessing the vulnerability of our transportation infrastructure asset.

Following with the roads example, the vulnerability overview could be squared as it shows the following template chart:

		Unpaved Road	Paved Road		Bridges	
			Class A	Class B	Class A	Class B
Planning	Medium-term					
	Long-term					
Construction	Vulnerability level 1					
	Vulnerability level 2					
	Vulnerability level 3					
Operation	Vulnerability level 1					
	Vulnerability level 2					
	Vulnerability level 3					
Maintenance	Vulnerability level 1					
	Vulnerability level 2					
	Vulnerability level 3					

Table 1 – Overview of road assets vulnerability

Source: Author’s own elaboration

Focusing on climate related impacts, a breakdown of vulnerabilities should set national/regional priorities. Vulnerability functions would indicate the level of damage on each transportation infrastructure asset.

This represents an integrated and iterative approach to vulnerability assessment. This analysis provides a clear perspective of problems and hence leads to more relevant solutions.

3.4. Risk Analysis

The previous stage has determined the damage, depending on the potential climate impact, for each type of infrastructure. The next step in the adaptation process should entail a probabilistic model of risk triggered by type of climate impact identified.

Clear identification of risk per type of infrastructure and geographic area will be relevant for discussion with road managers and subsequent definition of priorities. Robustness of the cost assumptions and estimations will be reviewed as part of Risk Mitigation activities. The following questions should be answered:

3.4.1. Risk identification: what can happen?

The vulnerability study will only cover part of climate change effects. In this stage concrete risks for each range of scenarios will be identified.

3.4.2. Risk evaluation: how likely is it to happen? What are the consequences?

The likelihood of occurrence corresponding to each risk would be estimated. Such estimation should be based on climate change trends (expected pace of climate change), practical experience of climate change effects over the past years in the region and expert judgment. In order to gather all these inputs together, a checklist with the key indicator will be used, achieving an accurate approach. The consequences of each risk will also be estimated.

3.4.3. Synthesis and presentation

Making use of the methodology above described, the users of the final framework would be able to obtain information containing the main risks, related to climate change, to their transportation network or infrastructure. The main risks would be established according to an appropriate prioritization.

3.5. Risk mitigation

New policies are key tools in order to build climate resilient transportation infrastructure. Having identified the general context, transport assets, vulnerability and risks, the last stage of the adaptation process entails the mitigation of those climate change-related risks.

Thus, with the purpose of building effectively resilient transportation networks, and in line with the last IPCC 2014 recommendations, a scheme of options is available within the framework, taking into account:

- i. *Implementation of action plans.*

- ii. *Monitor, re-plan and capitalize*: Regular monitoring and review, re-plan in the event of new data or a delay in implementation, built on experiences of both climatic events and progress of implementation.
- iii. *Planning approach*: Integration of adaptation into planning and decision-making can promote synergies with development and disaster risk reduction. Poor planning, overemphasizing short-term outcomes, or failing to sufficiently anticipate consequences can result in maladaptation.
- iv. *Local focus*: Decision support is most effective when it is sensitive to context and the diversity of decision types, decision processes, and constituencies.
- v. *Knowledge sharing*: Organizations bridging science and decision-making, including climate services, play an important role in the communication, transfer, and development of climate-related knowledge, including translation, engagement, and knowledge exchange.
- vi. *Budgetary planning*: There is a need for a better assessment of global adaptation costs, funding and investment.
- vii. *New funding schemes*: Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts. Instruments include public-private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms.
- viii. *Awareness against constraints*: Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. Common constraints are: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks, etc.
- ix. *Mitigation-adaptation synergies*: Significant co-benefits, synergies, and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions.

4. Conclusions

In order to secure climate change is also addressed in future infrastructure projects, the whole process of planning, design, construction, operation and maintenance of transportation infrastructure needs to be reviewed, and changes will be required in procedures, technical standards, specifications and common practices.

Assessment of climate change risks will need to become part of wider risk management processes carried out by transportation authorities. Moreover, the design of Smart Transportation Infrastructures would systematically mitigate climate change risks at every stage of the infrastructure management process: planning, design, construction, operation and maintenance.

Understanding and proactively addressing the potential impacts of climate change can help avoiding the potential damage, disruption in service, and safety concerns that climate change may cause.

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