ISSN: 2634 - 8845

Journal of Earth and Environmental Sciences Research

Review Article

Open Access

Road Adaptation to Climate Hazards: Guidelines for Cost-Effective Measures

Anastasios Mouratidis

Dr.Ing. Civil Engineer

ABSTRACT

Climate change and extreme weather events present a significant challenge to the safety, reliability, effectiveness and sustainability of every transportation system. Extreme weather events such as tsunami waves, wildfires, floods and hurricanes constitute a big risk for the integrity of the road transport system, since they can severely harm the infrastructure and its assets. Far more disastrous is the eventual direct impact on passengers, vehicles and goods, suddenly and unforeseeably hit by the weather event while moving on the roadway. In the field of road adaptation to climate threats, different scientific approaches have been developed but they have not produced, so far, the expected results, as the road transport sector still suffers from extreme climate hazards. The present scientific paper investigates the reasons for this failure and suggests a different perspective for realistic and cost-effective measures of proactive character to reinforce the road infrastructure and to increase its resilience to climate threats. It makes distinction between preventive and protective measures, including intercepting engineering assets and digital alarm systems. Moreover, the scientific paper introduces several key-points, in terms of fundamental recommendations of a different perspective of the climate change impact on the road infrastructure. In this regard, it may constitute a useful tool for transport authorities and operators to rationally plan interventions on a road network scale.

***Corresponding author**

Anastasios Mouratidis, Dr.Ing. Civil Engineer, E-mail: anmourat@civil.auth.gr

Received: July 13, 2020; **Accepted:** July 23, 2020; **Published:** August 21, 2020

Keywords: Road, Climate Change, Adaptation, Measures

Introduction

Climate change and extreme weather events present a significant challenge to the safety, reliability, effectiveness and sustainability of every transportation system. Extreme weather events, such as tsunami waves, wildfires, floods and hurricanes constitute a big risk for the integrity of the road transport system, since they can severely harm the infrastructure and road assets [1]. Far more disastrous is the eventual direct impact on passengers, vehicles and goods, suddenly and unforeseeably hit by the weather event, while moving on the roadway [2].

Road infrastructure is typically designed to withstand local weather and climate. Road designers take into account historical data on weather events to provide sufficient strength and capacity to structures, culverts and geotechnical assets. However, it seems that, recently, historical data are no longer a reliable predictor of future impacts [3]. Near term climate projections have a tighter range of possibilities, while distant climate projections have wider range of possibilities [4]. Any projections of future climatic conditions are subject to this uncertainty, but that does not have to prevent transportation agencies from identifying adaptation strategies that increase resilience in a range of potential future conditions [2].

Moreover, weather threats have become more severe and extreme events are nowadays more frequent, a phenomenon probably associated with climate change. With regard to road traffic and infrastructure, climate threats constitute a major concern. Roads are important to economic growth and to social activities in every region and in every country under ordinary conditions, but they become much more important and crucial under a state of emergency due to climate or other hazards. Ambulances, fire-brigade and emergency vehicles must be able to move freely on the road network to help citizens and to restore assets and activities to prior-to-event condition.

In search of effective measures of adaptation and resilience of the road infrastructure to climate threats, previous research has focused on traffic operations and safety on the network, at a first stage, and on maintenance of the infrastructure, at a second stage. The relevant report of TRB (USA) “Adapting Transportation to the Impacts of Climate Change, State of the Practice, 2011”provided an overview of the operational impacts of climate change on roads [5].

In 2008, the RIMAROCC European project was initiated within the ERA-NET ROAD Coordination Action [6]. The findings and the outcome of this project created one of the most effective and complete methods of risk assessment and proactive planning to face natural hazards. The framework consists of seven steps, namely, Context analysis, Risk identification, Risk analysis, Risk evaluation, Risk mitigation, Implementation of action plans, Monitor/re-plan/capitalise. Risk is considered as a function of Threat, Vulnerabilities and Consequences. For each specific risk, the framework aims to evaluate its probability and the consequences to traffic and to the infrastructure. The respective action plan consists of technical operations, financing options, socio-economic analysis and time schedule. The list of probable measures includes actions to address threats to the traffic and to the infrastructure. The framework is exhaustive and well-structured, though, probably, too complicated for engineers managing highways of limited extent.

In the frame of CEDR (European Conference of Road Directors) activities, a group of experts attempted an investigation on engineering measures to reinforce the infrastructure and composed a comprehensive report on "Acting on Climate Change" [7].

A PIARC group of experts developed a report on "Climate Change Adaptation Framework for Road Infrastructure" and the World Bank issued a report on "Integrating Climate Change in Road Asset Management" [8, 9]. The PIARC framework is explicit and complete. Its engineering aspect is prevailing. It was developed through extensive research and consultation with road authorities globally and designed to facilitate steps to increase resilience of road infrastructure. It consists of four stages, namely, Identifying scope, variables, risks and data (Stage 1), Assessing and prioritizing risks (Stage 2), Developing and selecting adaptation responses and strategies (Stage 3), Integrating findings into decision making processes (Stage 4). The risk assessment is performed in terms of likelihood of the climatic event and the prospective impact to the infrastructure. With regard to potential hazards, the framework considers sea level rise, increase in precipitation, increased drought, increased wind strength, increased temperatures, changes to snowfall, permafrost, ice coverage and suggests, accordingly, suitable adaptation measures. While PIARC's Report provides the methodological detail supporting each stage of the refined PIARC Climate Change Adaptation Framework, it also refers to case study examples [8,10].

A quite different approach has been elaborated by the International Union for Conservation of Nature [11]. Ecosystems and ecological assets are designated to provide valuable protective services, including buffers, such as mangrove forests and coastal wetlands.

It seems, however, that all these attempts and many other, especially, with regard to risk identification and assessment are hardly effective in terms of accuracy. Research conducted in the Aristotle University (AUTH) proved that the aforesaid models cannot identify the probable risk accurately, estimating risk factors R=6,0-6,5, on a scale of 0-10, in cases of extreme events and road closures. Moreover, either because of their complexity, or, because of their ineffectiveness, these models have not produced yet the expected results: the road transport sector still suffers from extreme climate hazards. The challenge of a guide for realistic and cost-effective, proactive measures to reinforce the road infrastructure and increase its resilience to climate threats still remains.

The present research paper aims to respond to this challenge by presenting an alternative perspective of facing natural hazards and by suggesting suitable preventive and protective measures of proactive character. The comprehensive method, presented herewith, is based on an empirical risk assessment by site engineers of each network. The method is innovative and easily applicable. In this regard, it may constitute a useful tool for road operators, public administration and private firms aiming to preserve the road infrastructure and the road environment by effective engineering and non-engineering measures and to keep the transport system open and safe at adverse weather conditions.

Implementing measures and preventing risks: a failing balance

Since the early 2000', road adaptation to climate change has been a persistent challenge to National Road Authorities in Europe and in other industrialized countries. Gradually, the concern about climate hazards has been amplified and respective action plans have been elaborated at national and international levels [8]. Protective measures, especially against flooding, implemented in various countries, United Kingdom, Denmark, France and other, are reported to have produced beneficial, yet still insufficient, effects on the network integrity [12-15]. Best practices from the field in the USA, dealing with preventive and protective actions against hurricanes, heat waves and ice storms, are outlined in a FHWA report, 2015 [2].

However, it must be clearly stressed that the current situation in the industrialized world is far from being ideal or even significantly improved [16]. During summer 2017, severe wildfires broke out in the Iberian Peninsula and ravaged roads and travellers while, in the following years, wildfires devastated Sweden and Siberia. In wintertime, and practically every year, destructive floods are observed all over Europe, ruining roads and bridges and causing fatalities. In the same line, floods in Japan, in July 2018, generated serious deterioration of the road network and provoked many landslides with a disastrous record.

In addition to the gradual rise of average temperature, climatic variability and extremisation must be considered [17]. Under the circumstances of climate changes occurring throughout the world, in the last decades, winter season hazards have grown in many areas. In March 2018, major transport links, including motorways and airports, were closed following heavy snowfall in Europe.

The reasons for failure, in the fight against climate hazards and disasters, may be classified by origin:

A Road authorities and stakeholders may exhibit a loose engagement in a climate change adaptation policy which does not pay back in short term. Moreover, lack of financing may be responsible for poor engineering interventions to protect the infrastructure [18,19].

B Road operators may encounter difficulties in applying existing models of adaptation of the infrastructure to climate change prior to planning and implementing suitable measures. Some measures proposed by these models, frameworks, etc. may be inapplicable or unrealistic in some cases (i.e. raise red line of roads, pavement heat conduits) while, in other cases, measures taken may prove ineffective or insufficient.

C Undoubtedly, some climatic events, as those mentioned in a previous paragraph, are really harsh and disastrous. Sometimes, it seems that nature is unbeatable. On the other hand, scientists argue that climate changes at an increasing rate and, consequently, weather projection models should be adequately revised in order to provide reliable forecast features.

Climate Stressors, Hazards and Impact on Roads

Climate stressors are climatic factors of extreme values. Long and heavy precipitation, rainstorms, snowstorms, heat-wave temperature, tornados, storm surges and other, are climate stressors generating hazards of harmful impact on the road infrastructure. Hazards associated with climate stressors are floods, landslides, slope erosion, wildfires, droughts and other, which have multiple impacts on roads, traffic and environment [1].

There is a variety of methods to identify potential climate threats and subsequent impacts on roads. A quite extensive description of risk assessment methods has been presented by Axelsen et al. (2016). Most methods use input from climate projection models to assess climate threats and from actual site conditions to define contextual factors. They may also process road and traffic characteristics to estimate potential impacts on road serviceability. In most existing methods, the risk assessment by road stretch is performed for each natural hazard separately. The road engineer must, at a preliminary stage, identify potential hazards that may cause damage to the examined infrastructure. Before performing a risk assessment, it is necessary to accurately define the climate stressor-hazard relevance, that is, the process which turns an extreme climatic event to a threat to networks, properties and individuals.

In fact, natural hazards are generated by climate stressors in combination with contextual factors. On a road network scale, the impact of the hazard on the road infrastructure and traffic will depend on the intensity and duration of the hazard but also on the road exposure and vulnerability. Road authorities and engineers can hardly affect the occurrence of a climate stressor but they can moderately adapt and transform the road environment to significantly diminish exposure and vulnerability of the road infrastructure.

An adaptation method based on a different perspective

Looking at images of catastrophic weather events, the feeling of helplessness may easily be sensed. Sometimes, searching for engineering adaptation measures, in a severely ravaged context, may be regarded as a pointless issue. However, despite the occasional ineffectiveness or inadequacy of engineering measures for road adaptation, research efforts and strong commitment in this direction must go on. A somehow different perspective of an adaptation approach to extreme climatic events, synthesized in the form of an adaptation method, herewith presented, may prove, to some extent, beneficial.

It must be clearly stated that the method hereafter presented is only an adaptation method and not a strategic plan for adaptation of transport infrastructure to climate change, absolutely necessary to competent National Authorities with view to strengthening the resilience of roads and railways to extreme weather events.

At times of extreme events, it is crucial for public authorities to keep most channels of communication and transport open. Whether a disaster lasts only some seconds or many hours, the impact may be mitigated if the transport network stays safe and operational. This may lead to a mandate or to an alert to all transport authorities that they shouldadequately strengthen the infrastructure after conducting risk assessment against probable climate threats. If this sounds reasonable in the case of motorways and major railway links, it seems quite difficult and rather unrealistic in the case of networks of minor importance. Competent authorities of regional, but even, of national, networks can hardly deal with sophisticated computational exercises and afford costly engineering interventions. What is much more realistic is to proceed to establishment of simple guidelines and respective measures of low cost to effectively protect the infrastructure from aggressive weather events.

This different perspective is outlined through several key-points, in terms of fundamental recommendations:

Assess the road design and exposure

As by general rule, correctness and completeness of the road design is a prerequisite for the operational integrity of the infrastructure. By contrast, incomplete or inappropriate design may generate risks. This is, for instance, the case of low embankments in flood-prone plains, where this option is totally inadequate and can hardly prevent inundation of the roadway (Figure 1). Roads adjacent to river banks or lakes, in thick woods, at avalanche-prone areas need extensive consideration and measures.

Figure 1: Plain flood in Epirus, Egnatia Motorway inundated (2010): Low embankment in flood-prone area

Make distinction between rainstorm and long rainfall, two climatic phenomena so much alike and yet so different with regard to the impact on the environment and the road infrastructure. A rainstorm, that is, a sudden and excessively heavy rain will produce floods, since rainfall water cannot infiltrate the ground. On the contrary, rainwater from long (and heavy) rainfall will gradually penetrate the ground and generate excessive pore pressure, loss of shear strength and, consequently, landslides.

Restore Initial Balance

The road environment may have probably been altered and degraded by human intervention. It is advisable to restore, as much as possible, the road context and try to remove obstacles and harmful assets. Indicative actions restoring initial balance may be as: place pipelines of sufficient capacity under roads constructed over old water streams, backfill abandoned quarries, restore capacity of dumped watercourses, convert paved to unpaved surfaces, revive tree groves, remove flammable assets. These measures are mandatory, in every case, and do not depend on any risk assessment, investigation etc.

Process realistic solutions and propose effective measures
Consider "value for money" measures, i.e instead of demolishing a culvert of insufficient capacity and building a new larger one, consider the "twinning" solution, construct removable waterproof panels on the roadside (for temporary surge) instead of raising road red line, plant succulents on engineered slopes to fight against wildfires.

Moreover, conventional recipes are also to be taken into consideration
Define priorities over the network and plan interventions in accordance with available budget This recommendation is well-known and should be respected in all cases. Rank road links by traffic importance and social needs, identify roads with no alternative routes, elaborate emergency plans, etc.

Use new technologies for vigilance and communication: satellite information, drones, ITS, VMS. In case of hazards, difficult to face and manage by engineering measures, such as blizzards and wildfires, continuous monitoring and alertness may constitute the only powerful means against climate threats. The application of information technology systems (ITS) for monitoring climate threats and for early warning of road users may prove extremely useful.

Preparedness-Readiness (forecast and act)
Wherever measures are limited and ineffective, preparedness through efficient action plans [20] and readiness of emergency services (fire brigades, traffic police, snowplough equipment) and intervention patrols are mandatory. This is the case of wildfires and snowstorms (Figure 2), where the very low visibility completes the climatic phenomenon and creates desperate conditions.

Commitment and Financing
Policymakers and road operators must be committed to a climate adaptation strategy, although measures against climate threats do not pay back shortly. Financing is a serious issue and, usually, a major impediment.

Figure 2: Blizzard in Western Macedonia, Egnatia Motorway closed (2011): Low visibility and heavy snowstorm

Risk identification and assessment
Recently occurred climate disasters in Europe and elsewhere (2018-2020) reaffirmed the need for adaptation and protection of the road infrastructure against most climate events: wildfires in Sweden and Siberia, floods in Southern Europe, heavy snowfall in almost every European country. In Greece, the southern part of the Athens-Salonica Motorway gets closed every year, following severe snowstorm. Roads and motorways in Europe may undergo distress and closures due to every major climate event: heavy rainfall and rainstorms, wildfires, snowfall and blizzards. In fact, site and competent engineers must be capable of identifying road stretches where there is absolutely no risk from a specific weather event. For instance, roads in bare land do not risk from wildfires (Figure 3). Moreover, engineers must set in priority order measures to be taken against specific risks, following an empirical risk assessment based on their experience and scientific insight.

Figure 3: Stretch of Motorway E65 in Central Greece: low risk of wildfire

The adaptation measures and the need for vigilance

Dealing with existing roads, the road engineer, following the empirical risk assessment, will design engineering interventions of proactive character, in terms of preliminary, auxiliary, preventive and protective measures (Table 1).

Preventive and balance restoring Measures are necessary to re-establish the initial balance of the ecosystem and the contextual environment of a road: land use, rehabilitation of deactivated or backfilled streams, vegetation, capacity of watercourses, abandoned quarries, etc. Preventive measures are meant to prevent the hazard from aggressing and deteriorating the infrastructure. They are mostly engineering measures, applied, probably, in the broader environment of the road. They play the role of a shield barring the way of the climate threat to the road infrastructure (Figure 4).

Protective Measures are mostly reinforcing measures of engineering nature, designed to protect the infrastructure in case of a hazard event. They are meant to strengthen the road structure, to make it resistant to effects and shocks generated by climate hazards (Figure 4).

Auxiliary Measures are non-engineering measures. They are based on innovative technologies such as, telematics and digital technology. They are extremely useful in case of roads in dense forests but also wherever extreme weather events may occur. They may comprise elaboration of emergency plans, establishment of awareness and information channels, installation of monitoring equipment for hazard alert.

Figure 4: Preventive and protective measures against road inundation: **preventive** (a) watercourse diversion, (b) watercourse widening (c) additional vegetation uphill (d)intercepting pits and wells, **protective** (e) intercepting steel racks upstream (f) removable waterproof panels (g) slopes reinforced by geotextiles (h) removal of debris from culvert inlet.

All measures must be realistic and cost-effective. They must be adapted to the case study but also to the resources of the road operator. The present AUTH method comprises engineering measures, some of them trivial and well-known and other rather uncommon, most of them low-cost. They are applicable to all road categories and may constitute suitable solutions to fight against climate threats.

Table 1: The Preliminary actions-the Adaptation measures

CLIMATIC STRESSORS /HAZARDS	MEASURES			
	PRELIMINARY	AUXILIARY	PREVENTIVE	PROTECTIVE
a. High temperature/ Wildfires	-removal of flammable solid waste -fire protection zones -fire-resistant assets -access roads in forests	-emergency plan -evacuation plan -monitoring/early detection -ITS communication	-succulent plants on engineered slopes	-dense placement of fire water pumps
b. Rainstorm/ Plain flood, roadway inundation	-pipelines under roads on old water streams -divert streams to ample culverts -clear and widen riverbed	-emergency warning systems -ITS communication -emergency patrols	- additional vegetation uphill -debris removal from culverts - drill wells into impermeable rock substratum	-debris flow racks -riprap protection of slopes -lateral waterproof concrete barriers
c. Long and heavy rainfall/ Landslides-erosion	c. Long and heavy rainfall/ Landslides-erosion	-emergency warning systems -readiness of emergency patrols -geotechnical /water table monitoring	-drains on cut slopes -intercepting ditches -additional vegetation uphill	-soil nailing and rock anchoring -rock traps -vegetation on engineered slopes
d. Heavy snowfall/ Blizzards	-serviceability of the secondary network -operability of median crossovers	-ITS communication systems -readiness of emergency/ snowplow services	-snow fences on adjacent terrain -heat conduits to fight permafrost	-spread salt, $MgCl_2$ on roadway -activate heat storage systems

Conclusions and next steps

The method provides the planning and design of cost-effective measures. The method suggests an uncommon perspective in planning the protection of the infrastructure and of the road traffic. Measures restoring the original balance of the local ecosystem but also auxiliary measures of wireless communications and warning, in case of hazards, play a key role in this regard.

The hereby presented method, aims to assess risks associated with climatic hazards and to prescribe proactive measures of an alternative perspective. It claims to be simple, realistic and applicable to major and ordinary road links. A decisive criterion for establishing the main concept of the approach was the simplicity and the applicability of the proposed method, so as to provide Road Authorities the means to suitably adapt the existing infrastructure to future challenges and threats. It seems that, all over Europe, climatic hazards, such as floods, blizzards and wildfires, are becoming more frequent and more intense and affect all road infrastructure systems. Consequently, the need to react concerns not only motorway operators but also regional and local authorities managing road infrastructure, obliged to ensure smooth traffic flow by all means, and more specifically, by applying effective and realistic measures [20].

References

1. European Commission, Nemry F, Demirel H, "Impacts of Climate Change: A focus on road and rail transport infrastructures", JRC Scientific and Policy Reports 2012.
2. Federal Highway Administration (2015) "Climate change adaptation guide for transportation systems management, operations and maintenance", Technical Report hop 15026.
3. PIARC (2015) International Climate change adaptation framework for road infrastructure, Report R03EN.
4. Markoff S, Hoehne C, Fraser A, Chester M, (2018) "Transportation resilience to climate change and extreme weather events - Beyond risks and robustness", Transport Policy 74.
5. TRB, "Adapting Transportation to the impacts of climate change", State of the Practice 2011
6. Adesiyun A, Phillips S, Phillips L, Verhaeghe B, Wlaschin B (2011) Final Report of ERA-NET Road Programme "Road Owners Getting to Grips with climate change".
7. CEDR (2016) "Acting on Climate change", Report, Task Group I4.
8. PIARC (2015) "International Climate change adaptation framework for road infrastructure", Report R03EN.
9. World Bank (2017) "Integrating Climate Change in Road Asset Management, Report" No.114641.
10. PIARC (2019) "Adaptation methodologies and strategies to increase the resilience of roads to climate change-case study approach", Report R25EN.
11. International Union for Conservation of Nature (2006) Ecosystems, Livelihoods and Disasters: An integrated approach to disaster risk management.
12. European Environment Agency (2009) Flooding in England: A National Assessment of Flood Risk.
13. European Commission, Background to the PFRA European Overview, Assessment of Flood Hazard and Flood Risk Maps Member State Report: DK–Denmark 2015.
14. Ministry of Ecology, Sustainable Development and Energy, DGPR, The national strategy for flood risk management (SNGRI) 2014.
15. European Environment Agency, Green Infrastructure and Flood Management. Promoting cost-efficient flood risk reduction via green infrastructure solutions, EEA Report No14, 2017.
16. European Commission, Report from the Commission to the European Parliament and the Council on the implementation of the EU Strategy on adaptation to climate change 2018.
17. Moretti L, Loprincipe G (2018) Climate Change and Transport Infrastructures: State of the Art.
18. Chinowsky P (2011) "Climate Change: Comparative Impact on Developing and Developed Countries », Eng. Project Organisational Journal 1.
19. Ecologic Institute, Identification of the most appropriate measures that could address each threat, for implementation in the time frame 2013–2020,Climate Proofing" of key EU policies: report for task 2, 2011.
20. EU-DIRECTIVE 2007/60/EC of the European Parliament and of the council of 23 October 2007 on the assessment and management of flood risks. Official Journal of the European Union, L 288/27 (6/11/2007).