

Implementation of digital models to prevent and confront road flooding

Anastasios Mouratidis, Dr.Ing. Professor Em., Aristotle University of Thessaloniki

1 INTRODUCTION & SCOPE OF WORK

Climate change and extreme weather events constitute a major threat to the integrity and operability of transportation systems worldwide. Storm surges, wildfires, floods and hurricanes may cause unforeseeable damage to passengers, vehicles, goods and road infrastructure [World Meteorological Organization, 2023].

Among these hazards, floods are considered the most damaging events in terms of human losses, property destruction, traffic disruption and infrastructure deterioration [CEDR, 2012]. Every year, devastating floods inundate roadways, destroy bridges and cause fatalities across the globe [European Commission, 2015].

At the international level, concern about flood risk has gradually intensified, leading to the development of action plans in Europe and elsewhere [European Environment Agency, 2017]. Although protection measures implemented in various countries have shown beneficial effects on network integrity, the overall situation in industrialized regions remains far from satisfactory. This is mainly attributed to insufficient or nonexistent preventive assessment of vulnerable regions and road corridors [Mouratidis, 2020]. Proactive actions currently applied are often limited to minor interventions, such as debris removal from culverts and rehabilitation of earth embankments, which are rarely adequate to effectively mitigate road flooding [Mouratidis, 2021].

At the regional or urban scale, it is crucial to proactively identify the safest road corridors as well as those of uncertain operability under flood conditions. Rather than relying solely on generalized assessment methodologies proposed by research institutions [PIARC, 2015], there is a clear need for systematic evaluation of submersion risk across road networks and for testing the effectiveness of both conventional and innovative proactive measures [Mouratidis A., Eliou N., 2024].

The present paper introduces a dual digital concept designed to support Road Operators in safeguarding infrastructure and protecting travelers. The scope of the work is to present the structure and functionality of this concept and to propose targeted engineering and hydrological measures aimed at enhancing the resilience of flood-prone road corridors.

2 METHODOLOGY

The proposed dual digital concept consists of two complementary tools:

- 1.The Digital Flood-Testing Model
- 2.The Digital Twin Model

The Digital Flood-Testing Model enables virtual inundation simulations of road corridors and surrounding areas under extreme rainfall scenarios (return period > 100 years). Through this model, potential proactive measures against flooding can be tested in advance. Engineering interventions such as profile uplift, drilled wells, lateral protection boards and additional drainage systems can be evaluated in terms of their effectiveness in reducing flood impact.

This virtual testing environment allows for quantitative assessment of alternative strategies before physical implementation.

The Digital Twin Model functions as an interactive, real-time monitoring and forecasting tool. During an actual flood event, it continuously observes and evaluates the rate of water level rise and provides forecasts regarding potential emergency situations. By integrating real-time data, the model supports operational decision-making and emergency planning.

Through the combined use of these digital tools, Road Operators can:

- Identify the most vulnerable and safest road corridors,
- Detect low-lying and flood-prone segments along critical corridors,
- Evaluate and prioritize infrastructure upgrade interventions,
- Develop effective emergency response plans for extreme flood events.

In addition to corridor-level engineering measures, the methodology incorporates upstream mountain hydrology interventions. These include small dams and levees, water retention basins, weirs, sluices and sponge vegetation restoration. Such measures aim to reduce runoff intensity and delay peak discharge before floodwaters reach lowland road infrastructure..

3 RESEARCH OUTCOMES

The implementation of the dual digital concept demonstrates significant potential in enhancing roadway resilience against flooding. The Digital Flood-Testing Model allows for systematic identification of vulnerable road segments and quantification of the expected reduction in flood impact through selected engineering interventions.

Low-cost engineering operations, once strategically applied to identified critical segments, can substantially improve infrastructure operability under extreme rainfall conditions. Moreover, the integration of real-time monitoring through the Digital Twin Model enhances preparedness and supports timely emergency response.

Special emphasis is placed on mountain hydrology measures as a proactive defense mechanism. A detailed assessment of the impact of Storm Daniel on properties and road infrastructure in the lowlands of Thessaly revealed that upstream dams—both small and large—played a beneficial role in preventing the flooding of important settlements and infrastructure assets.

The findings highlight that combining corridor-level engineering upgrades with upstream hydrological regulation significantly reduces flood overflow effects in vulnerable regions. The paper concludes with a structured list of mandatory mountain hydrology measures required to effectively protect flood-prone areas and critical transportation corridors from extreme overflow events.

REFERENCES

- CEDR. (2012). Adaptation to Climate Change, *Project Group on Climate Change*, Report 168p.
- European Commission (2015). Background to the PFRA European Overview, *Assessment of Flood Hazard and Flood Risk Maps Member*, Final Report, 134p.
- European Environment Agency. (2017). Green Infrastructure and Flood Management. Promoting cost-efficient flood risk reduction via green infrastructure solutions. *EEA Report No14*.
- Mouratidis, A. (2020). Road Adaptation to Climate Hazards: Guidelines for Cost-Effective Measures. *Journal of Earth and Environmental Sciences Research*, Vol.2, pp. 1-6.
- Mouratidis A., Eliou N. (2024). Condition Assessment of Flooded Road Structures, *Proceedings 8th Int. Conf. on Bituminous Mixes and Pavements*, 8p.
- Mouratidis A. (2021) Road Protection Against Climate Threats: Risk Assessment and Priorities, *Earth and Environmental Science Research and Reviews*, Vol.4. Issue 2, pp. 124-128

PIARC. (2015). International climate change adaptation framework for road infrastructure. *Report R03EN*, 99p.

World Meteorological Organization. (2023). The Global Climate 2011-2020: A Decade of Acceleration. *Report No1338*, 60p.