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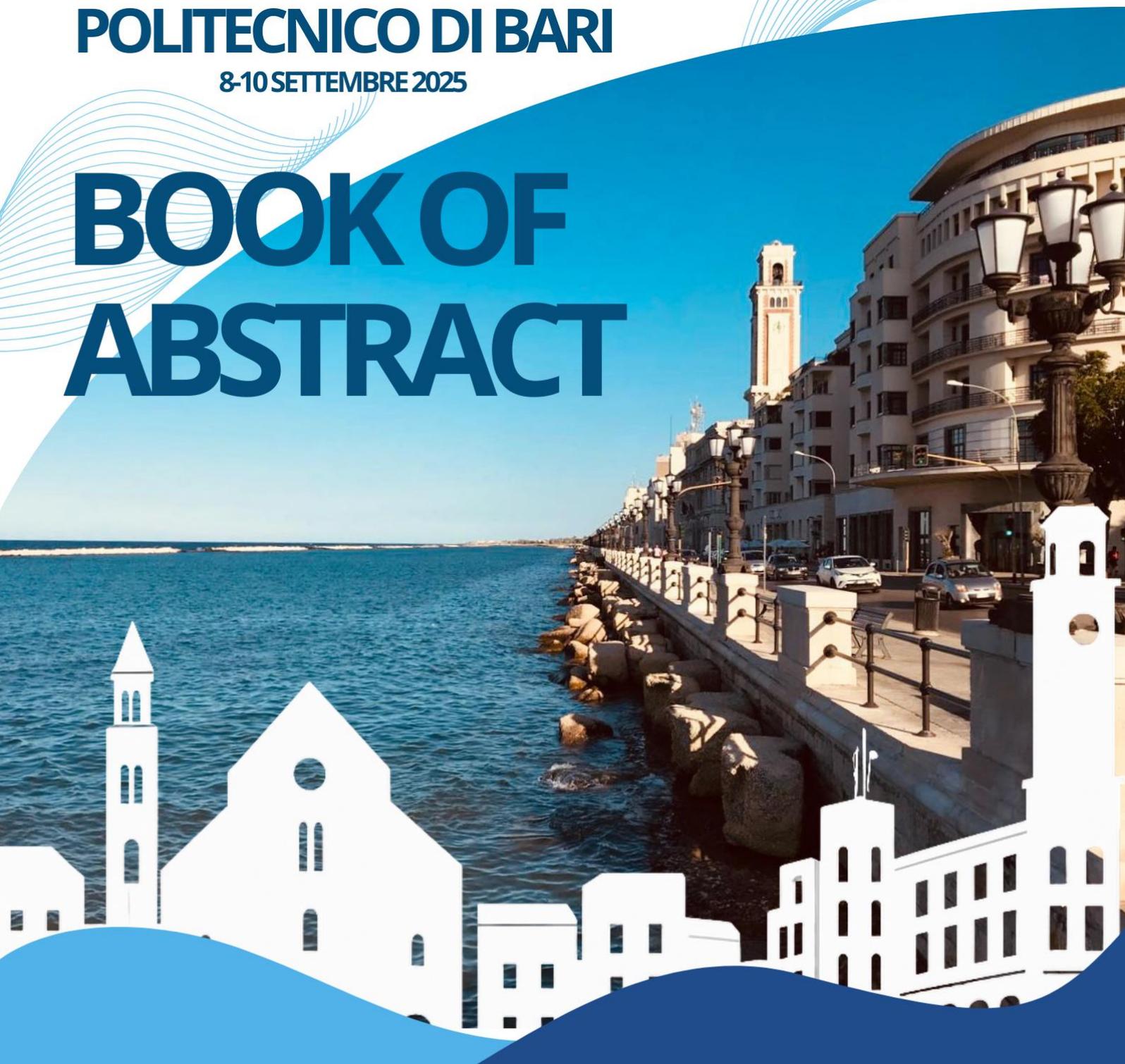
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BOOK OF ABSTRACT



Prioritizing bridges at flood risk: a large-scale index based on overtopping and traffic impact

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Abstract

Bridges are critical nodes in transportation networks, carrying high traffic volumes but offering few alternative detour options. Despite their strategic importance, they remain highly vulnerable to flood-related hazards. Among the various hydrological processes, this study focuses on the overtopping phenomenon, when rising water levels exceed the bridge deck elevation. Overtopping inundates the deck, leading to indirect impacts primarily related to traffic disruption, along with cascading effects such as interruptions to emergency services, economic losses, and increased smog emissions. Furthermore, the closure of a single bridge can trigger widespread network disruption. As such, overtopping should be considered a distinct failure mode with significant system-wide consequences (Pregolato et al., 2022).

This study focuses on the development and application of a large catchment-scale hydraulic risk (R) index for bridges that jointly considers: (i) overtopping propensity as the hazard (H) source; and (ii) the impact of bridge closure on the road network, corresponding to both exposure (E) and vulnerability (V).

The chain method for assessing flood risk to bridges is carried out on a large catchment-scale. For this purpose, the hazard source is the overtopping propensity, defined through a GIS-based screening approach (Amaddii et al., 2025), identifying bridge prone to overtopping based on their geometric-morphological characteristics. The approach integrates road and hydrographic networks with high-resolution LiDAR-derived DEMs of bare terrain (DTM) and surface (DSM). The method assumes that the more a crossing reduces the height of a watercourse section, the greater its overtopping potential, independent of hydrological forcing. Thus, when the height difference between the road level (DSM) and river thalweg (DTM) is lower than the corresponding riverbank height, the bridge has a high overtopping propensity. The main output is a simplified estimate of the overtopping propensity, namely a reasonable proxy for the minimum clearance, which is difficult to estimate on a large scale, requiring detailed hydrological-hydraulic modelling.

On the other hand, the macroscopic traffic simulation quantified the overall impact of bridge closure on the road network. This estimate corresponds to the remaining two components of risk: exposure and vulnerability. Here, exposure is defined by traffic volumes, while vulnerability is reflected in longer travel distances and the resulting time delays. In order to assess the overall significance of each bridge, independent of hydrological forcing or road type, the closure of each bridge was simulated, thereby evaluating its value. Two complementary indicators were evaluated for this task: (i) DWC_NoT (s), namely the product of weighted travel-cost difference and the number of trips between origin-destination (OD) pairs. This indicator reflects absolute disruption on high-traffic segments, and its maximum value also highlights the greatest potential delay imposed on the traffic network by the related road edge (bridge) closure. (ii) PDWC (%), which corresponds to the % change in weighted travel cost relative to the baseline, serving as a local risk indicator for low-volume links, capturing relative increases in travel cost between OD pairs even when only a few trips are affected. Since DWC_NoT captures large-scale delays on major corridors while PDWC reflects localized inconvenience, both indicators are considered, taking the maximum value for each bridge closure, and ensuring a comprehensive assessment of traffic impact.

The final product of the bridge flood risk assessment chain is the quantification of the risk, obtained through the combination of hazard, vulnerability, and exposure.

The method was applied to the Magra River Basin in northwestern Tuscany (Italy), a region prone to severe flooding, and at the same time, an area with critical links reaching Liguria and Emilia-Romagna regions.

By integrating GIS-based screening and macroscopic network-level traffic disruption analyses, the obtained risk index, although simplified, offers a reasonable starting point for prioritizing bridges at flood risk at a large-scale. The risk index guides attention toward bridges where overtopping hazard and traffic importance intersect most critically, thereby strengthening infrastructure resilience and optimizing flood risk management.

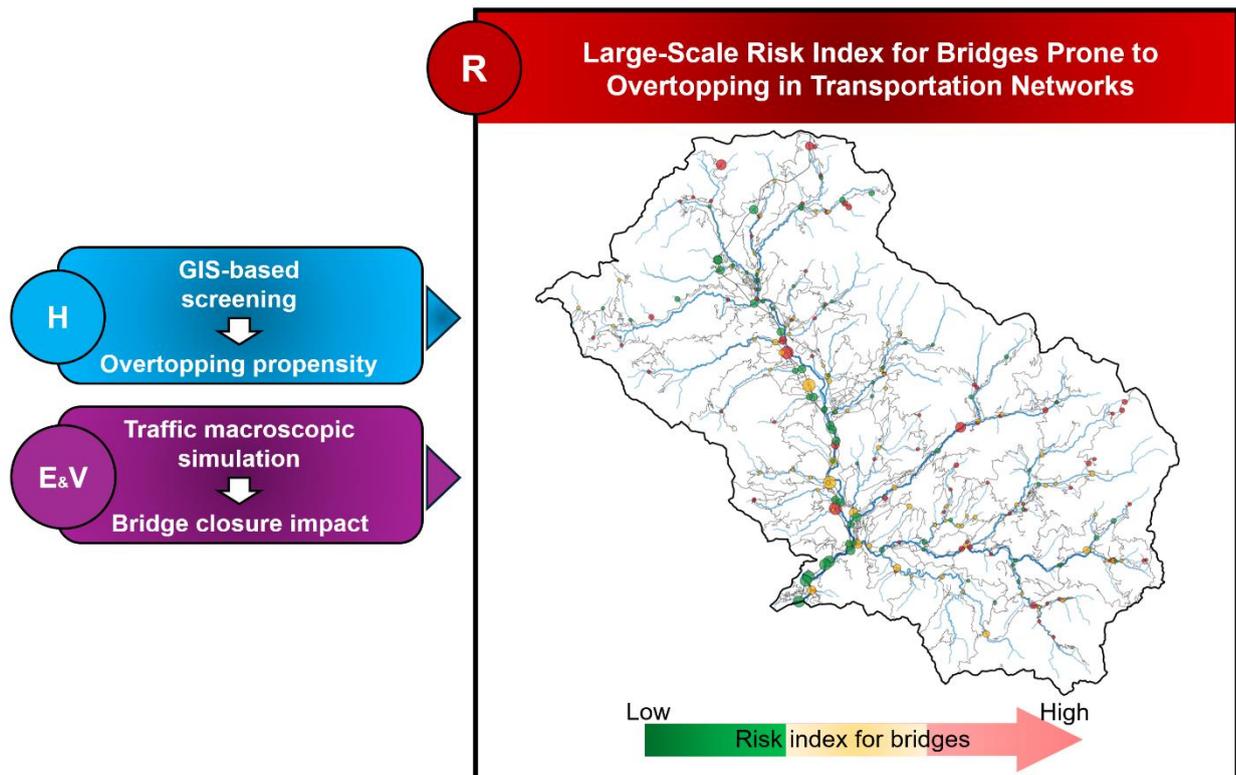


Figure 1. Workflow of the large-scale risk index assessment for bridges prone to overtopping in transportation networks.

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