28. Assessing Railway Vulnerability to Flooding via Flow- Based Temporal Betweenness Centrality: Evidence from the Italian Network

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This study proposes a GIS-based, flow-aware and time-sensitive framework for identifying flood exposed elements of systemic importance in the Italian railway network, integrating the national timetable, the infrastructure model and the ISPRA high-probability flood-hazard map. Scheduled train movements are represented as a temporal graph, and node importance is measured through a Flow-Based Temporal Betweenness Centrality. Earliest-arrival paths capture timetable feasibility, while each origin-destination relation is weighted by the number of daily direct services connecting its endpoints. Centrality is estimated at national scale through importance sampling with Horvitz-Thompson correction, computed on the intact network and subsequently intersected with flood exposure. The results show a geographically concentrated hierarchy of systemically important nodes, whereas exposed high-centrality nodes form a distinct spatial pattern. The network-wide ranking is strongly stable between a weekday and a non-working day. The spatial analysis further shows that 1,114.66 km, corresponding to 6.01% of the analysed network, intersect the P3 hazard layer, while most exposed sections are affected along less than one quarter of their length. A preliminary damage scenario, removing the 2.3% of track sections with at least half of their length exposed to flooding, leaves the top of the ranking intact but removes most critical nodes from the functional network, shifting the rerouted demand onto adjacent corridors. The framework provides an ex-ante indicator of flood-exposed systemic criticality and supports the prioritisation of detailed asset assessment and resilience interventions.