

Cost-Effective Prioritization of Road Networks for Post-Flood Recovery: A Network Robustness Framework

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Abstract

An increase in the occurrence and intensity of flooding events is posing significant damage to worldwide road infrastructure. Their consequences include reduced movement, loss of accessibility, and lower economic activity, which disrupt both community and regional transportation systems. For a swift post-flood recovery, it is important to decide the best repair actions for damaged roads and to keep the network strong, within the budget levels. The study introduces a new framework that helps choose the best repair options for flood-damaged roads by prioritizing the robustness of the network. It helps transportation agencies find the least-cost set of links to repair while maintaining a specified level of post-repair network robustness. The authors suggest a three-part approach for determining which sections of a road network should be recovered first. To start, various flood cases are defined by progressively dropping some road sections, symbolizing the extent of the flood. Second, network robustness is measured by computing the proportion of the Giant Connected Component (GCC) is with the whole population of nodes. It refers to the required level of network operations after repairs. A genetic algorithm (GA) is used to ensure the selection of the best links for repairing the network so that the target robustness can be achieved at the lowest overall cost. The optimization model aims to minimize the total reconstruction cost while ensuring the repaired network meets the robustness threshold. The approach forms the problem as a binary combinatorial optimization, where each road segment is assigned a bit (1 for reconstruction and 0 otherwise). The GA procedure starts by choosing a random initial population and then assesses fitness by summing reconstruction cost and network robustness, selects individuals based on a tournament process, performs crossover and mutation operations and finishes when the population converges or reaches the set number of generations. All road links are assumed to have uniform costs for reconstruction per kilometer. The model was used on artificial networks as well as actual road networks with differences in density and structure. In synthetic networks, reconstruction costs were shown to rise with both the extent of damage and the target's strength. Due to the less redundancy, sparse networks were more easily affected by disruptions and required more investment when damage was moderate. However, comparatively denser networks kept functioning strongly even when large parts were destroyed, so the reconstruction cost was lower. Despite the difference in value scale, actual road networks emerged with similar patterns against the damage levels and the target robustness levels. The model identified cost-effective repair strategies for both hypothetical and actual networks, validating its applicability to real-world infrastructure planning. Notably, the results revealed exponential cost growth with increasing damage levels, particularly at higher target robustness values, where small increments in damage led to disproportionately higher costs. This makes it clear that early improvements or upgrades can prevent large expenses in recovery after a disaster. This study aims to provide an effective approach for selecting cost-effective repair methods for roads

damaged by floods by analyzing the impacts of different kinds of damage on the road network. Using the model, transportation authorities can detect vulnerable parts of the system and calculate the minimal budget necessary to provide suitable repair strategies after a flood. Results reveal that proactive measures are important because the cost of reconstruction rises fast with each level of damage. Under fiscal constraints, authorities can select appropriate robustness targets that balance adequate functional restoration with available resources. The framework provides a systematic approach for developing scenario-based contingency plans, enabling more effective decision-making in post-flood road network recovery.

Keywords: *network robustness, genetic algorithm (GA), post-flood recovery, cost-effective repair strategies, prioritization modelling*

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