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AI-Based Multi-Criteria Risk Assessment for Civil Infrastructure under Extreme Environmental Hazards

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Abstract

This study proposes an **AI-based multi-criteria risk assessment framework** to address the inherent subjectivity and limitations of traditional infrastructure evaluation methods under extreme environmental hazards. The proposed methodology integrates **Artificial Intelligence (AI)**, **Fuzzy Logic**, and the **Analytic Hierarchy Process (AHP)** into a unified quantitative decision-support tool. Five major risk dimensions are systematically incorporated: **structural performance**, **environmental exposure**, **functional importance**, **emergency response capacity**, and **maintenance condition**. Quantitative indicators are processed using min-max normalization, while qualitative variables are transformed via fuzzy membership functions.

A key innovation of this research is the introduction of **AI-assisted weight calibration**, which utilizes historical failure data and gradient-based optimization to refine AHP weights. This mechanism effectively reduces subjective bias and improved weight stability by **18–25%** compared to conventional expert-only weighting methods. To validate the framework, a representative case study of a reinforced concrete bridge was conducted. The results yielded a **Comprehensive Risk Index (CRI) of 0.71**, indicating a **moderate-to-high risk level**. Structural performance and environmental exposure were identified as the dominant risk contributors, highlighting the coupled impact of aging assets and intensifying climate-related stressors.

Sensitivity analysis further demonstrated the framework's robustness against weight fluctuations, confirming its reliability for practical engineering applications. By providing a transparent and quantitative index, this research supports the implementation of **SDG 9** (Industry, Innovation, and Infrastructure) and **SDG 13** (Climate Action). The framework offers a practical foundation for infrastructure maintenance prioritization, disaster risk reduction, and long-term resilience enhancement in the face of global climate uncertainty.