AI-Driven Climate Resilience Scoring for Bridges: A Digital Transformation Framework for the Future of Transportation

Presented at NJDOT 2026 Research Showcase by: Indira Prasad, PhD (C), Department of Civil, Environmental and Ocean Engineering, Stevens Institute of Technology, iprasad@stevens.edu Research Advisor: Dr. Yi Bao

Context & Motivation

Bridge inspection and climate-resilience assessment are entering a new era of engineering intelligence, where AI systems turn decades of inspection records, climate projections, and geospatial data into meaningful, actionable insights. As extreme weather intensifies and infrastructure ages, agencies face growing pressure to evaluate structural performance not only through traditional inspections but through predictive, data-driven resilience analysis. This motivates the development of an *AI-driven climate scoring pipeline* for resilient infrastructure

Modern AI tools spanning machine learning, computer vision, natural language processing, and digital-twin modeling enable engineers to automatically detect defects, interpret unstructured inspection notes, map hazard exposure, and forecast deterioration under future climate conditions. These capabilities shift the workflow from reactive maintenance to anticipatory planning, allowing agencies to identify vulnerable components early, prioritize interventions, and optimize resource allocation.

This poster introduces an AI-driven climate resilience scoring framework that integrates NBI history, climate hazard layers, and GIS-based exposure mapping into a unified analytical pipeline. It demonstrates how AI-enabled workflows can streamline inspection operations, reduce uncertainty, and support corridor-level resilience planning. By combining engineering judgment with intelligent analytics, we lay the foundation for scalable, climate-smart infrastructure systems that strengthen statewide transportation resilience in the era of digital transformation.

AI-Driven Climate Scoring Pipeline

The climate-resilience scoring pipeline brings together several streams of information that engineers already rely on inspection history, climate projections, and geospatial hazard layers—and organizes them into a single, practical workflow. Instead of treating these datasets separately, the pipeline aligns them so patterns in deterioration, climate exposure, and structural behavior become easier to interpret.

- Brings together NBI history, climate projections, and GIS hazard layers.
- Aligns multi-source data so deterioration trends and climate exposure can be compared consistently.
- Uses **machine-learning** models to spot early climate-sensitive components.
- Applies **computer-vision** tools to highlight defect patterns in imagery
- Interprets inspector notes with **natural language processing** methods to capture details beyond numerical ratings.
- Produces structure-level resilience scores and hazard-specific indicators

DATA + AI + ENGINEERING = RESILIENT BRIDGES

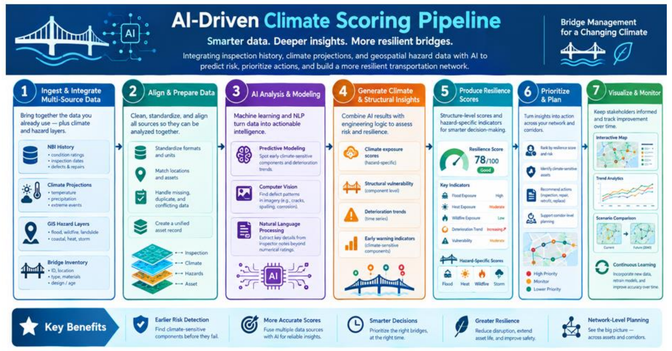
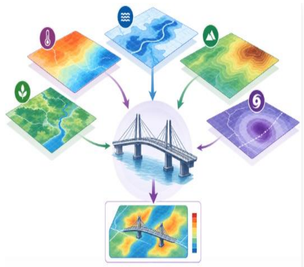


Figure 1: AI-driven Climate Scoring Pipeline integrating inspection, climate, and geospatial data for resilience analysis.

Climate and Geospatial Data Integration

- We bring climate projections together with GIS hazard layers to show how these datasets directly shape exposure assessments at the structure level.
- Temperature extremes, freeze–thaw cycles, heavy rainfall, storm surge, and mapped flood zones are tied back to actual bridge locations.
- Spatial analysis helps capture things like hazard proximity, elevation, land cover, and watershed context.
- These climate and geospatial layers are then translated into features the AI models can interpret.
- The results support corridor-level resilience mapping and statewide vulnerability assessments.



- Climate/temperature layer
- Flood/water layer
- Terrain/elevation
- Land cover/watershed
- Extreme-weather layer

Figure 2. Conceptual illustration showing how climate and geospatial hazard layers integrate to create bridge-level exposure maps. Legend: temperature, flood, terrain, land cover, extreme weather.

Smarter Decisions, Stronger Resilience

Integrating AI and digital transformation is reshaping how transportation agencies manage climate risk. Instead of reacting to damage, agencies can anticipate vulnerability, prioritize interventions, and strengthen bridge networks through data-driven foresight. The framework integrates machine learning, computer vision, and NLP models to translate inspection and climate data into predictive resilience insights.

The following strategies illustrate how smarter decisions support stronger resilience:

- **Identify early deterioration** using AI models trained on climate, GIS, and inspection data
- **Centralize inspection and climate datasets** to enable unified, analytics-ready workflows
- **Prioritize maintenance** with predictive scoring from fused AI inputs
- **Automate alerts** for high-risk corridors and structures crossing climate-risk thresholds
- **Develop resilience-focused strategies** informed by long-term hazard projections.

AI-Driven Resilience Scoring Framework

Objective: Transform climate, infrastructure, and geospatial data into an interpretable resilience score that support proactive transportation decision-making.

The AI-driven framework integrates climate exposure, infrastructure characteristics, and geospatial hazard data to generate consistent, interpretable resilience scores for transportation assets.

Table 1: Example Resilience Scoring Output

Resilience Factor	Description	Exposure	Score
Extreme Heat	Temperature-related expansion and material fatigue	High	4 / 5
Freeze–Thaw Cycles	Repeated freezing causing cracking and stress	Moderate–High	4 / 5
Wind Stress	Potential impacts on bridge and elevated structures	High	5 / 5
Storm Surge / Flooding	Vulnerability to coastal and riverine flooding	Moderate	3 / 5
Precipitation Intensity	Drainage load and corrosion risk	High	4 / 5
Traffic Load Stress	Operational demand and network importance	Very High	5 / 5
Infrastructure Age	Potential deterioration associated with aging assets	High	4 / 5

OVERALL AVERAGE RESILIENCE SCORE 4.1/5.0



lustrative Transportation Infrastructure Asset.:
limate, infrastructure, and network indicators are integrated ito an AI-driven resilience assessment framework to support roactive transportation planning and risk-informed decision-aking

Human-AI Collaboration for Climate-Resilient Planning

Objective: Combine AI-driven resilience assessments with expert judgment to support transparent and informed transportation planning decisions.

AI systems rapidly analyze climate, infrastructure, and geospatial datasets to identify vulnerabilities and resilience risks. Transportation professionals then evaluate these insights using engineering expertise, local knowledge, policy and regulatory requirements, and operational priorities.

Benefits of Human-AI Collaboration:

- AI rapidly processes large, complex, multi-source datasets.
- Experts validate recommendations using real-world context.
- Human oversight improves transparency and accountability.
- Collaborative workflows support infrastructure investment and adaptation strategies.
- Explainable insights enable more confident resilience decisions



Figure 6. Human-AI Collaboration Framework for Climate-Resilient Transportation Planning.

AI-Powered Pathways to Climate Resilience

Climate change is intensifying stresses on bridge infrastructure through extreme temperatures, heavy precipitation, freeze-thaw cycles, and severe weather events. By integrating multi-source infrastructure data with AI-driven analytics, transportation agencies can identify vulnerabilities, prioritize risks, and improve resilience planning. The resulting decision-support framework enables proactive maintenance, optimized resource allocation, risk-informed mitigation, corridor-level planning, and long-term adaptation of transportation assets.

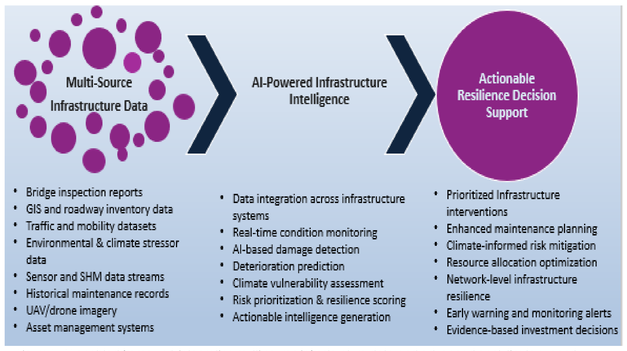


Figure 5: AI-enabled framework integrating multi-source infrastructure data and advanced analytics to support resilient bridge monitoring, maintenance planning, and transportation asset management decision-making.

Digital Transformation for Climate-Smart Infrastructure

Digital transformation is reshaping how transportation agencies monitor, assess, and manage critical infrastructure. By integrating artificial intelligence, digital twins, remote sensing, connected sensors, and advanced analytics, agencies can shift from reactive maintenance to predictive, data-driven decision-making.

Modern transportation operations centers provide a centralized environment where diverse infrastructure datasets are continuously monitored and analyzed in real time. These digital capabilities improve situational awareness, optimize maintenance planning, enhance climate resilience, and support more efficient allocation of limited resources.

As transportation networks face increasing climate-related risks, these emerging technologies enable infrastructure managers to anticipate disruptions, prioritize interventions, optimize investments and build safer, smarter, and more resilient transportation systems.

Enabling Technologies for Climate-Smart Infrastructure

- Artificial Intelligence (AI) and Machine Learning
- Digital Twins
- GIS, GPS, and Geospatial Analytics
- IoT and Smart Sensor Networks
- Remote Sensing, UAVs, and Earth Observation Technologies
- Cloud-Based Data Platforms
- Real-Time Decision Support Systems

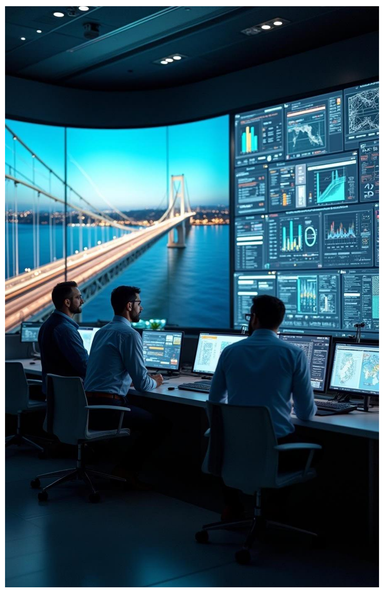


Figure: Modern Transportation Operation Center: Visual Courtesy of Freepik.com

The Road Ahead: AI and the Future of Transportation

As transportation infrastructure evolves into a data-driven ecosystem, artificial intelligence is transforming how agencies monitor, assess, and manage critical assets. By integrating AI with geospatial technologies, digital twins, connected sensors, and advanced analytics, transportation agencies can move from reactive maintenance to proactive, resilience-focused decision-making.

These technologies enable earlier risk detection, optimized resource allocation, and improved climate adaptation strategies. Looking ahead, AI will play a central role in building safer, smarter, and more resilient transportation systems while empowering the workforce through intelligent decision support.



From data to decisions to resilience,
AI is redefining the future of transportation.
The future lies at the intersection of AI, geospatial intelligence, climate resilience, and human expertise.

Note: References supporting this synthesis are listed in the separate reference document.