The Interdependent Networked Community Resilience Modeling Environment (IN-CORE) of the NIST-funded Center for Risk-Based Community Resilience Planning

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toward a Multi-hazard Approach to Engineering

Resilience

Introduction: Motivation

- Community resilience depends on the performance of the built environment and on supporting social, economic, and public institutions that, individually and collectively, are essential for immediate response and long-term recovery of a community following a damaging hazard event
- The performance of the built environment, which is a key factor in community resilience, is largely determined by codes and standards, which are applicable to individual facilities and have the primary objective of preserving life safety under design-level hazard events
  - However, current codes do not address facility performance in the period of recovery following an event, and
  - The design of interdependent transportation systems, utilities (e.g., potable water, wastewater and electric power) and communication systems currently is based on criteria developed by independent professional organizations or industry sectors with different performance objectives and design hazard levels (i.e., independent designs of interdependent infrastructure)

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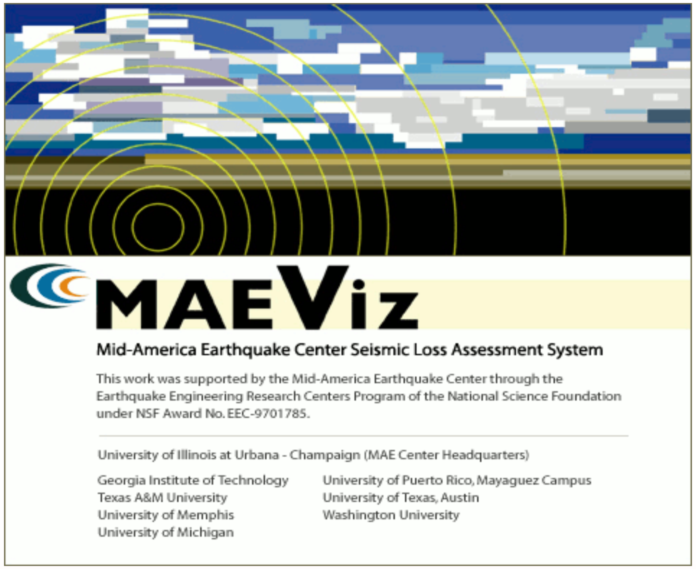
There is a need for (1) science-based measurement tools to evaluate performance and resilience at the community scale, (2) fully integrated supporting databases, and (3) a risk-informed decision framework to support optimal life-cycle technical and social policies

Introduction: CoE

- The National Institute of Standards and Technology (NIST) funded the multi-university five-year Center of Excellence for Risk-Based Community Resilience Planning (CoE) to develop the measurement science needed to support community resilience
- The developed measurement science is implemented in a computational environment with fully integrated supporting databases to
  - model the impact of natural hazards on communities including recovery,
  - evaluate the key attributes that make communities resilient, and
  - optimize resilience enhancement and planning strategies
- Such Interdependent Networked Community Resilience Modeling Environment (abbreviated as IN-CORE) is built upon the MAEViz software to leverage existing work in the modeling of physical, social, and economic systems

Background: MAEViz

- MAEviz has been developed by Mid-America Earthquake (MAE) Center (http://mae.cee.illinois.edu/) with initial funding from the National Science Foundation
- It is an advanced tool for loss assessment and risk management for buildings, bridges and other infrastructure, and for network level analysis



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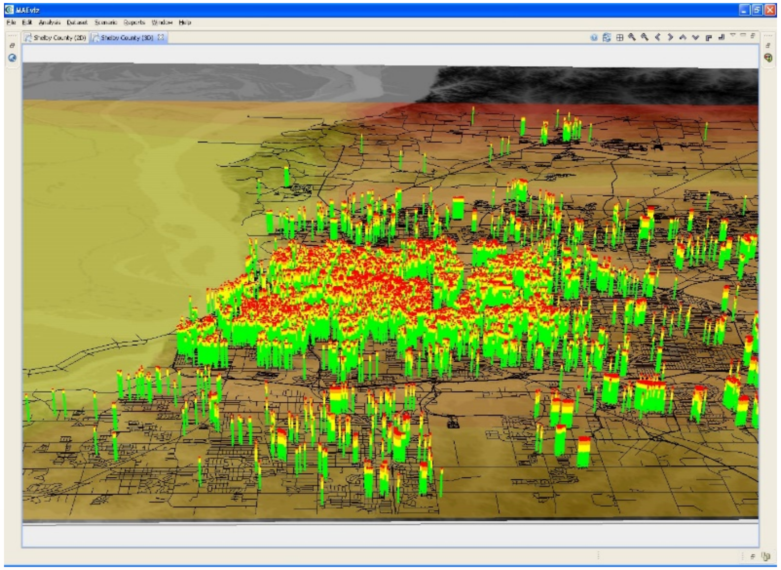
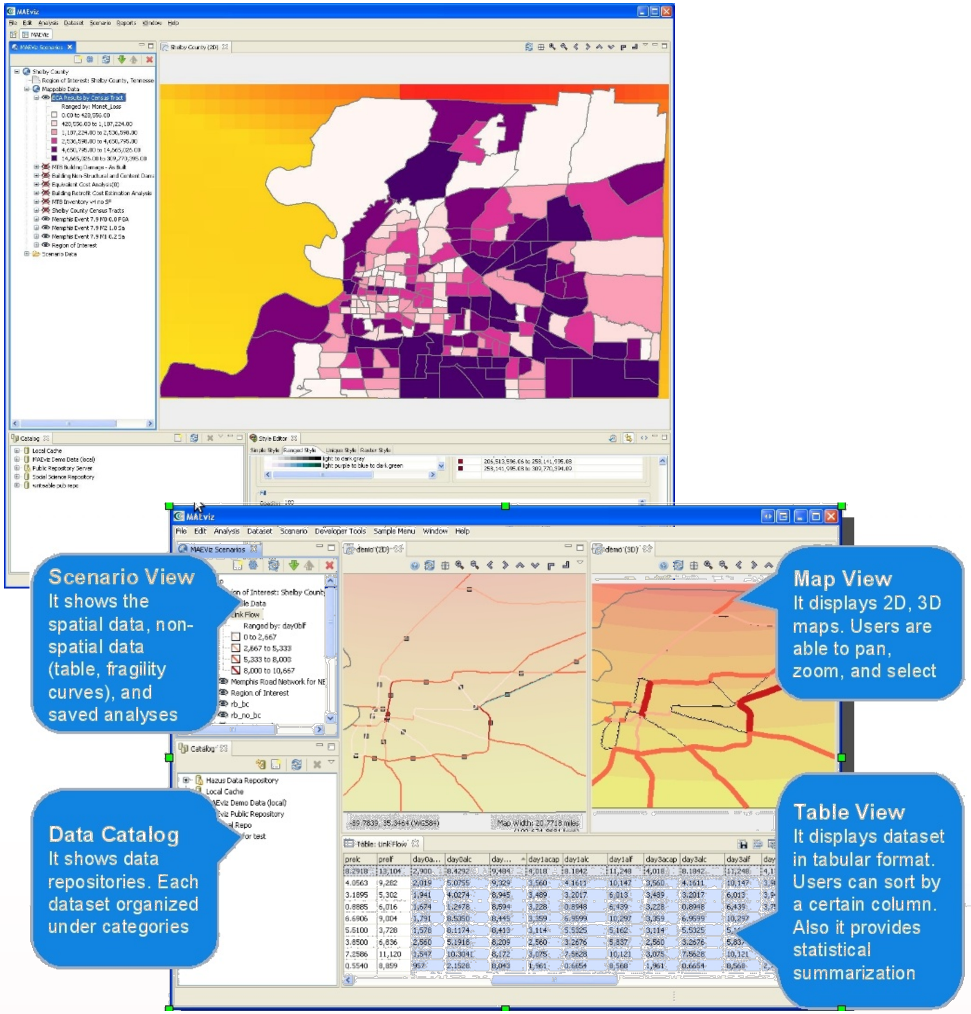


http://mae.cee.illinois.edu/

Background: MAEViz

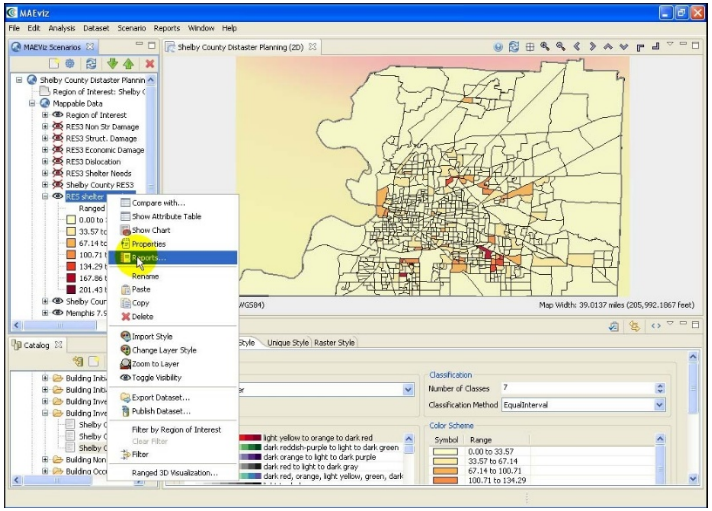
- MAEViz provides an extensible spatial analysis environment with a visually-based, menu-driven system
  - It generates damage estimates from scientific and engineering principles and data; tests multiple mitigation strategies; and estimates impacts of hazards on structures, infrastructure and social and economic systems
  - Fragility and repair rate functions are incorporated for infrastructure systems, such as transportation, power facilities, buried pipelines for water and gas, buildings, and bridges
  - There are capabilities for modeling interdependencies, such as the interdependency between the power network and water network



http://mae.cee.illinois.edu/

Background: MAEViz

- The socio-economic analyses include
  - estimating expected indoor deaths and injuries, business interruption loss, fiscal impact due to building damage, household/population dislocation, business content and inventory loss, short term shelter needs, shelter supply needs, and
  - optimizing the temporary housing allocation



http://mae.cee.illinois.edu/

- MAEviz was originally developed for seismic hazards and later extended to include inundation due to tsunami

- The World Bank (2014) conducted a comprehensive review of open access software packages for regional risk analysis and identified MAEViz as “the best software for scenario risk assessment and decision support”
  - As a result, to leverage the existing work beside the CoE, IN-CORE’s development started from the MAEViz software package

The World Bank – Global Facility For Disaster Reduction and Recovery (2014), “Understanding Risk: Review of Open Source and Open Access Software Packages Available to Quantify Risk from Natural Hazards” https://www.gfdrr.org/en/publication/understanding-risk-review-open-source-and-open-access-software-packages-available <01-29-19>

IN-CORE general features

- To better quantify community impacts and model recovery over time, IN-CORE is adding new capabilities to consider
  - multiple hazards and coupled threats
  - additional system interdependencies and cascading effects
  - the effects of aging and deterioration and
  - new models of social and economic systems

IN-CORE general features

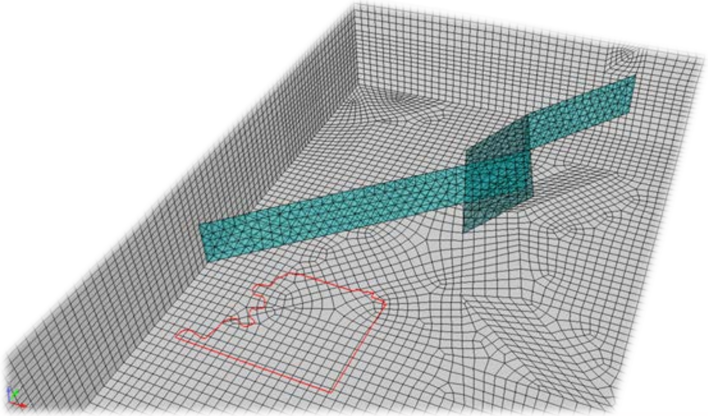
- IN-CORE will be released at the end of 2019 as an open-source environment to permit user-defined algorithms and databases to seamlessly interface with its advanced risk, loss, and recovery assessment capabilities
- IN-CORE builds upon previous research that has focused on the response of individual physical infrastructure systems to a single hazard to include multiple hazards and inter-dependent physical systems, which may exhibit significant cascading effects
- Nontechnical systems that are essential for the recovery and vitality of a community are integrated into the modeling environment narrowing the gap between engineering and social science aspects of resilience planning
- Finally, optimization strategies for enhancing community are developed based on performance metrics identified by the CoE

Hazard modeling

- IN-CORE considers both individual hazards and multiple hazards modeled as scenarios at the community scale to capture the spatial distribution of the demands
- Two levels of models will be available in IN-CORE, namely Tiers 1 and 2
  - Tier 1 hazard models will be executed completely within IN-CORE using libraries and plug-ins developed as part of the CoE research program, and will use standard natural hazard analysis technologies
  - Tier 2 hazard models will provide an option to import hazard data from analyses conducted outside of IN-CORE

Hazard modeling

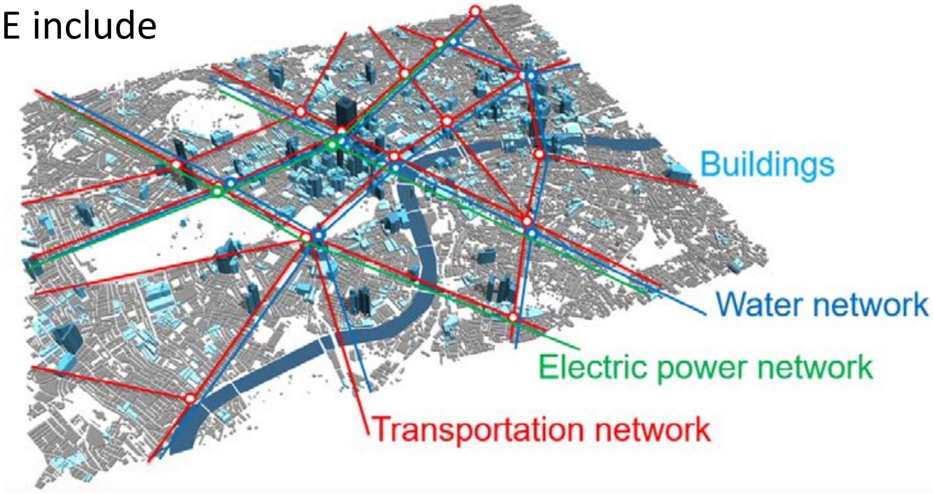
- For example, for earthquakes
  - The Tier 1 earthquake scenario will require the analyst to select an attenuation equation from the library available in IN-CORE and specify the relevant parameters (the option of weighting multiple GMP equations is also available)
  - The Tier 2 earthquake scenario will involve running an analysis externally, for example, running a high-resolution, 3-dimensional (3D), physics-based model for seismic wave propagation and importing the ground kinematics into IN-CORE



- Other hazards modeled with 1 or 2 tiers include windstorms, tornados, hurricanes, wildland-urban interface fires, tsunamis, and floods

Physical infrastructure and social and economic systems

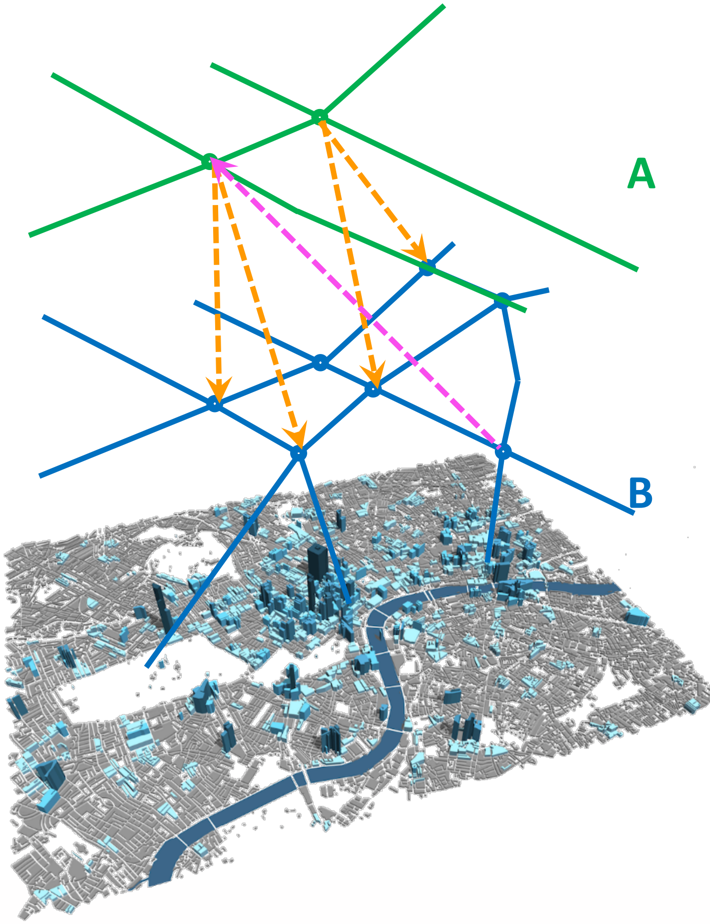
- **Physical infrastructure** modelled in IN-CORE include
  - Buildings
  - Transportation
  - Water and Wastewater
  - Energy
  - Telecommunications



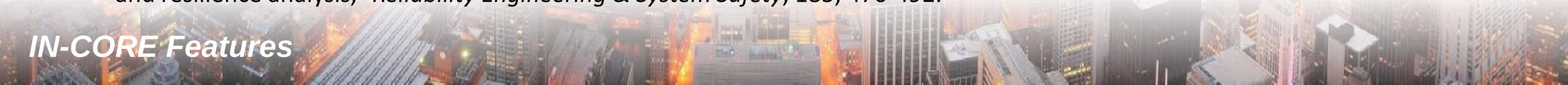
- Models of the **social systems** focus on population and employee dislocation, housing restoration and recovery, and business interruption and restoration
- Models of the **economic systems** focus on the prediction of economic damages, such as production, job, and wage losses in various local economic sectors and their subsequent impacts on residents, including health, income and migration

Interdependency and damage modeling

- IN-CORE models **interdependencies** within and between physical infrastructure systems, and social and economic systems (Guidotti et al. 2016)
  - Interdependencies can change over time, depending on the level of initial damage and the recovery process
    - For example, the water network analysis allows the user to include the dependency of the pumping stations on supporting power sub-stations
    - This dependency affects both the initial damage scenario, with a damaged pumping station or power substation, and the recovery process, where the recovery of the pumping station may be dependent on the recovery of the power substation
  - This modeling capability is being extended to the interdependencies between social and economic systems and physical infrastructure (Guidotti et al. 2019)

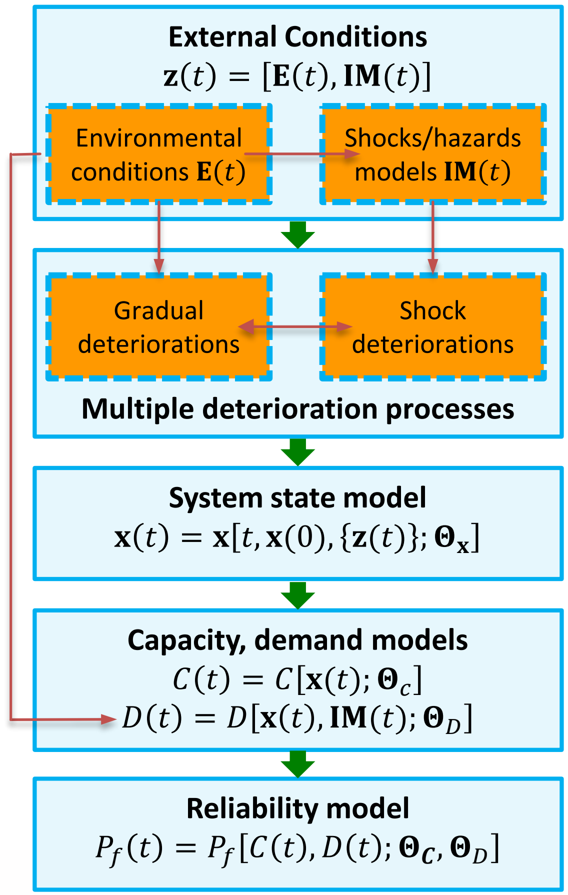


Guidotti, R., Chmielewski, H., Unnikrishnan, V., Gardoni, P., McAllister, T., and van de Lindt, J. (2016). "Modeling the resilience of critical infrastructure: the role of network dependencies," *Sustainable and Resilient Infrastructure*, 1(3-4), 153-168.
Guidotti, R., Gardoni, P., and Rosenheim, N. (2019) "Integration of physical infrastructure and social systems in communities' reliability and resilience analysis," *Reliability Engineering & System Safety*, 185, 476-492.



Aging and deterioration modeling

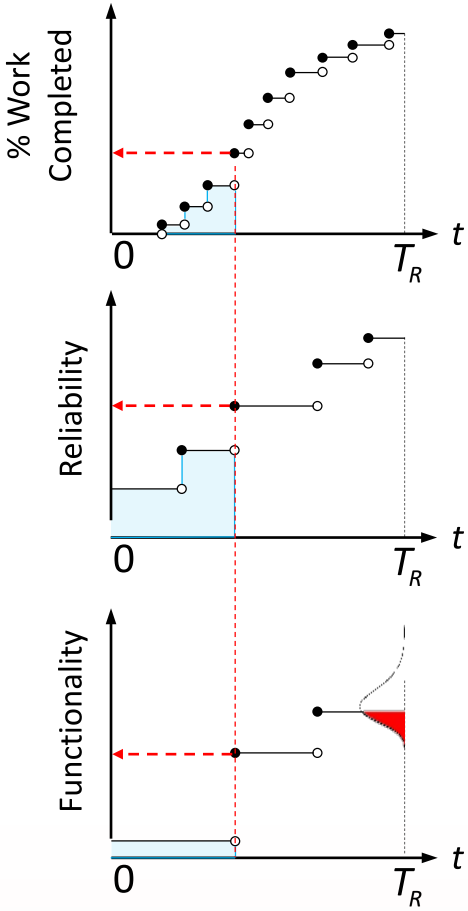
- IN-CORE will incorporate the effects of **aging and deterioration** on infrastructure components and the corresponding time-variant fragilities and repair rates
- A state-dependent formulation will allow us to model the deterioration accounting for the possible interactions among different deterioration processes (Jia and Gardoni 2018)
- The users will have the option to specify the input parameters that are needed in the relevant aging and deterioration models (e.g., age, environmental conditions, loading/hazard conditions, spatial variability for large infrastructure network)



Jia G. and Gardoni P. (2018). "State-dependent stochastic models: A general stochastic framework for modeling deteriorating engineering systems considering multiple deterioration processes and their interaction," *Structural Safety*, 72, 99-110.

Recovery modeling

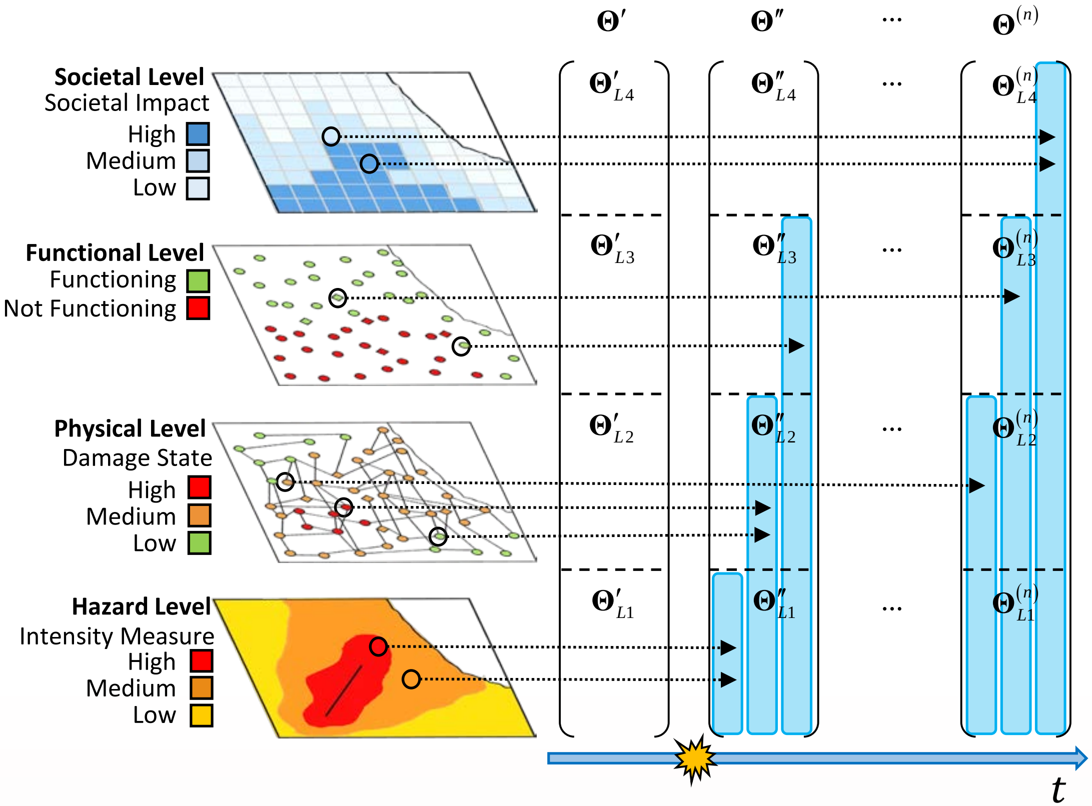
- IN-CORE will include the modeling of the recovery of the functionalities of (Sharma et al. 2018)
  - **Buildings**: Recovery of functionality for intended use
  - **Transportation**: Recovery of routes to critical facilities and critical infrastructure components
  - **Water/wastewater**: Recovery of services to buildings and infrastructure systems
  - **Energy**: Recovery of services to buildings and infrastructure systems
  - **Telecommunications**: Recovery of services to buildings and infrastructure systems
  - **Social Systems**: Recovery of services
  - **Economic Systems**: Recovery of services



Sharma, N., Tabandeh, A. and Gardoni, P. (2018) “Resilience analysis: a mathematical formulation to model resilience of engineering systems,” *Sustainable and Resilient Infrastructure*, 3(2), 49-67.

Model updating

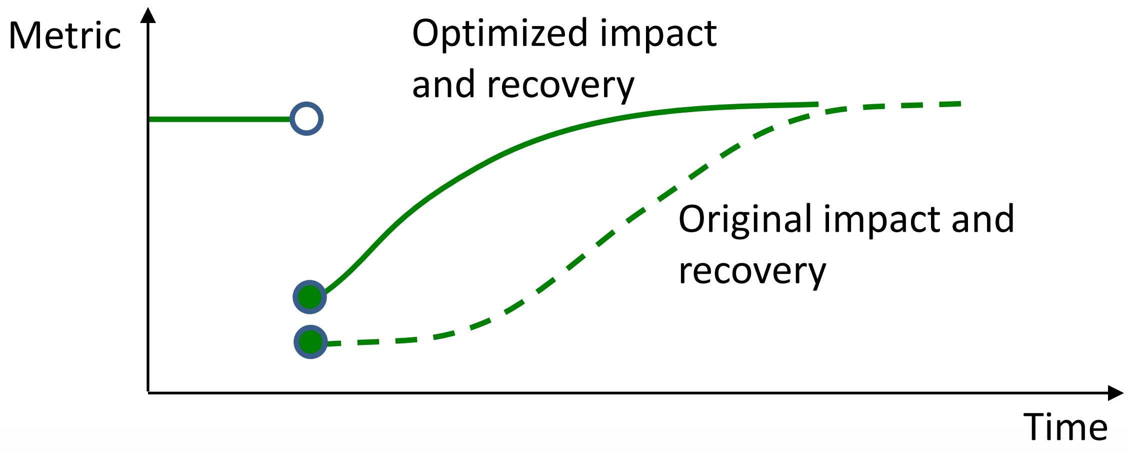
- IN-CORE will include recovery models with the ability to conduct spatial and temporal updates as field data become available
- We developed a Bayesian Updating for Probabilistic Multi-level Models of Interdependent Infrastructural Systems using Heterogeneous Field Data (Guidotti and Gardoni 2019)
- The methodology allows us to update the model parameters **Θ** in the lower level nested models considering different data types as they become available



Guidotti, R., and Gardoni, P. (2019). "Bayesian updating for probabilistic multi-level models of interdependent infrastructural systems using heterogeneous field data," *ASCE Journal of Structural Engineering* (in preparation).

Decision and optimization

- The characteristics of the physical infrastructure, and of the social and economic systems that can be used to modify the hazard impact are used in IN-CORE as levers in an optimization process (Sharma et al. 2019) targeted at
  - reducing the vulnerability of a community by prior planning
  - accelerating the community's recovery following a hazard event



Sharma, N., Tabandeh, A. and Gardoni, P. (2019) "Regional resilience analysis: A multi-scale approach to model the recovery of interdependent infrastructure," In Gardoni, P. (Ed.) *Routledge Handbook of Sustainable and Resilient Infrastructure*, Routledge.

IN-CORE architecture

IN-CORE 1.0

- IN-CORE 1.0 is an open source Java application with a plug-in based architecture called the Eclipse Rich Client Platform (RCP)
- This type of architecture allows researchers to extend IN-CORE's capabilities through the addition of new science/features by adding new plug-ins
- These features can be connected with the existing 40+ analyses in MAEViz/Ergo to produce new results
- The core technologies of the MAEViz platform include Eclipse RCP, Geotools, Visualization Toolkit, JFreeChart, KTable and Jasper reports (which are all open-source projects)

IN-CORE 2.0

- IN-CORE 2.0 is currently under development
- It will be a web-based application that includes the capabilities of IN-CORE 1.0 while adding extensive new capabilities
- Some of these new capabilities include a REST API, support for additional languages such as Python, support for spatio-temporal data, multi-variate fragilities, communicating with external tools such as OpenSees, overlaying data from web sources such as OpenStreetMap, NBI, NOAA, etc.

Testbeds and model validation using hindcasting

Testbeds

- During the development of IN-CORE, we developed four testbeds (Centerville, Seaside OR, Memphis Metropolitan Statistical Area, Houston/Galveston) to allow us to test and explore the developed algorithms related to community resilience
- These four testbeds will be included in IN-CORE for researchers to learn, expand upon, and validate their own algorithms as they expand IN-CORE

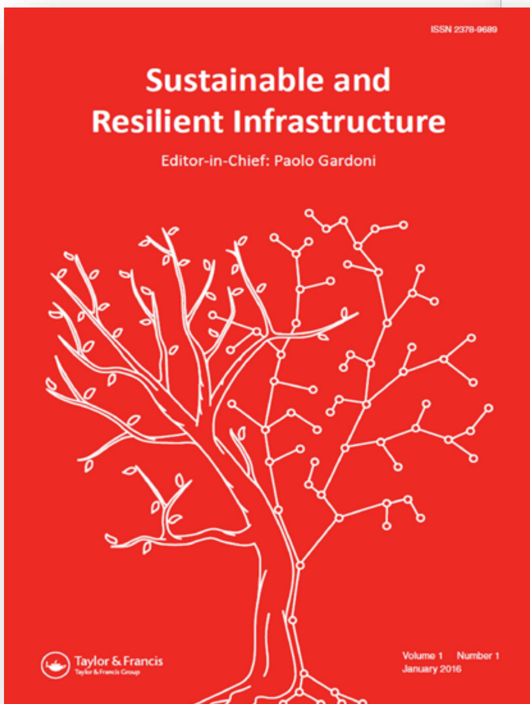
Hindcasting

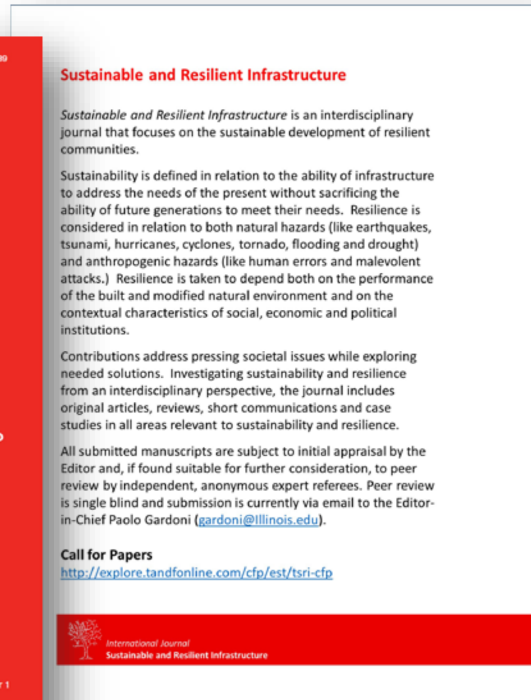
- Sector and community models are being validated by comparing modeling results to field data from selected past events and through sensitivity studies to examine parameters such as event sequence and interdependencies affecting the outcomes of community resilience

Closure

- The National Institute of Standards and Technology (NIST) funded the multi-university five-year Center of Excellence for Risk-Based Community Resilience Planning (CoE) to develop the measurement science to support community resilience assessment
- The developed measurement science is being implemented in a computational environment (IN-CORE) with fully integrated supporting databases to
  - model the impact of natural hazards on communities including recovery,
  - evaluate the key attributes that make communities resilient, and
  - optimize resilience enhancement and planning strategies
- This presentation described some of the key features and architecture of IN-CORE

There is a special issue on the modeling of the Centerville Virtual Community using IN-CORE 1.0





Sustainable and Resilient Infrastructure

Sustainable and Resilient Infrastructure is an interdisciplinary journal that focuses on the sustainable development of resilient communities.

Sustainability is defined in relation to the ability of infrastructure to address the needs of the present without sacrificing the ability of future generations to meet their needs. Resilience is considered in relation to both natural hazards (like earthquakes, tsunami, hurricanes, cyclones, tornado, flooding and drought) and anthropogenic hazards (like human errors and malevolent attacks.) Resilience is taken to depend both on the performance of the built and modified natural environment and on the contextual characteristics of social, economic and political institutions.

Contributions address pressing societal issues while exploring needed solutions. Investigating sustainability and resilience from an interdisciplinary perspective, the journal includes original articles, reviews, short communications and case studies in all areas relevant to sustainability and resilience.

All submitted manuscripts are subject to initial appraisal by the Editor and, if found suitable for further consideration, to peer review by independent, anonymous expert referees. Peer review is single blind and submission is currently via email to the Editor-in-Chief Paolo Gardoni (gardoni@Illinois.edu).

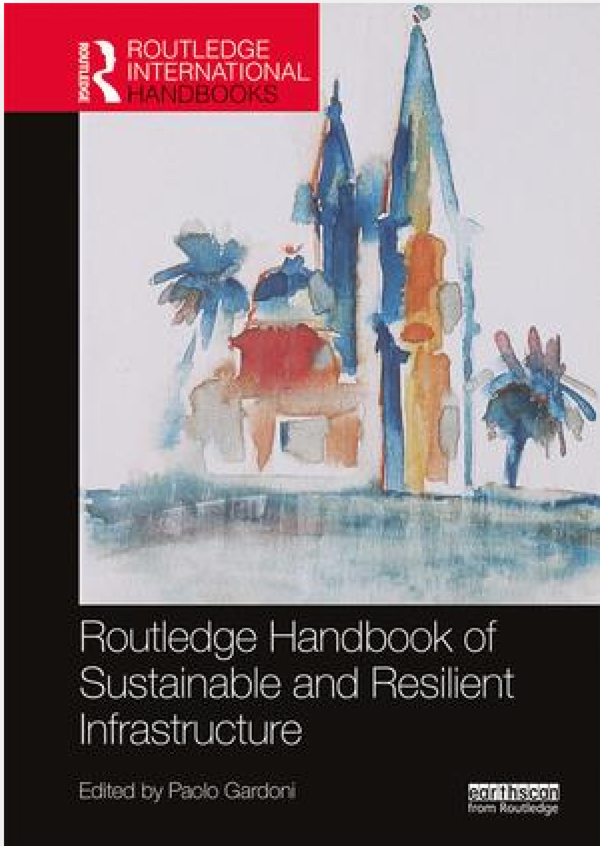
Call for Papers
http://explore.tandfonline.com/cfp/est/tsri-cfp

International Journal
Sustainable and Resilient Infrastructure

Sustainable and Resilient Infrastructure (SRI) is an interdisciplinary journal that focuses on the sustainable development of resilient communities.

Special Issue in *Sustainable and Resilient Infrastructure* (published by Taylor & Francis as Vol. 1, Issue 3-4, December, 2016)
http://www.tandfonline.com/loi/tsri

There is handbook on Sustainable and Resilient Infrastructure that includes Center's research



Routledge Handbook of Sustainable and Resilient Infrastructure

"This book collects articles by well-known experts on sustainability and resilience of infrastructure systems in the face of natural hazards, including climate change, and aging. It is a must read for anyone researching or practicing in this field."
— *Armen Der Kiureghian, President, American University of Armenia and Taisei Professor of Civil Engineering Emeritus, University of California, USA*

"This truly comprehensive compendium on theories and applications of resilience for the built environment is highly recommended for those seeking a comprehensive understanding of the issues […]."
— *Ross B. Corotis, Denver Business Challenge Professor of Engineering, University of Colorado, USA*

"Edited by one of the leading scholars in the field, the *Routledge Handbook of Sustainable and Resilient Infrastructure* provides an authoritative and comprehensive overview of the state-of-the-art. Essential reading for both professionals, students, and scholars working on the nexus between sustainability and resilience."
— *Neelke Doorn, Professor Ethics of Water Engineering, Delft University of Technology, The Netherlands*

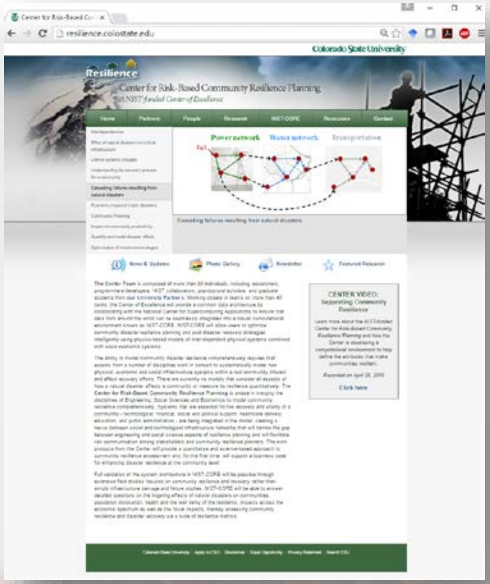
Gardoni, P. (Ed.) (2019) *Routledge Handbook of Sustainable and Resilient Infrastructure*, Routledge.

Other resources

The 2018 EMI Objective Resilience Lecture

"Promoting societal well-being by designing sustainable and resilient infrastructure: engineering tools and broader interdisciplinary considerations"

URL: https://www.asce.org/engineering-mechanics/objective-resilience-lecture/



CoE Website

URL: http://resilience.colostate.edu

Email: resilience@colostate.edu

Thank you!

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