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Modeling Interdependent CI Systems for Seismic Resilience Evaluation and Design

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ETH Zürich

Institute of Structural Engineering
Structural Dynamics and Earthquake Engineering Group

Community:

Geographically bounded entity with shared history and future

Community Resilience

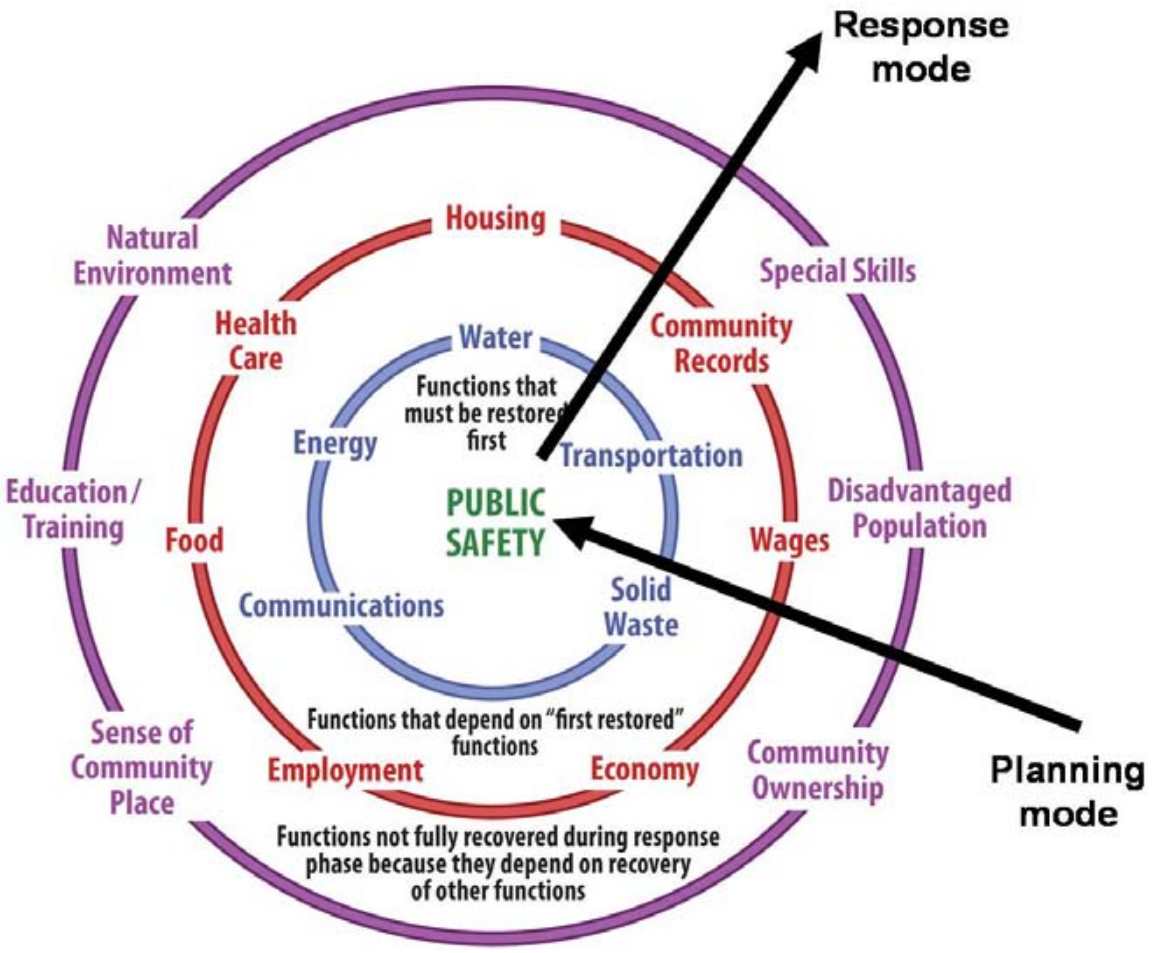
- Not giving up
  - Continuity of community existence thorough the survival of its inhabitants and the continuity of its social and economic functions

- Hypothesis: community resilience depends on the resilience of its built infrastructure

http://science.k12flash.com/naturalhazards.html

Community Functions and Its Civil Infrastructure Systems

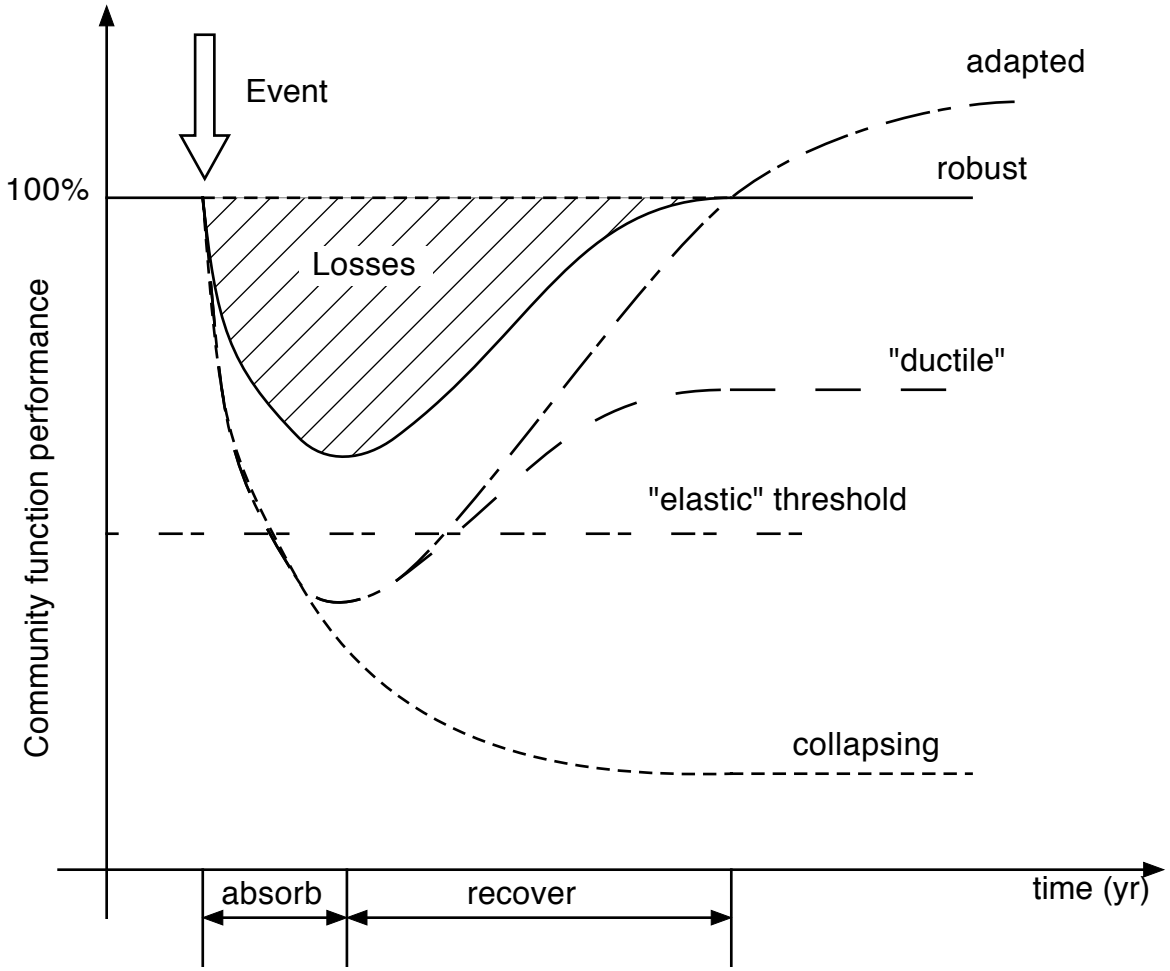
- Safety
- Physical infrastructure:
  - Energy
  - Water
  - Communication
  - Transportation
  - Waste
- Health and Economy
- Social:
  - Culture
  - Heritage
  - Education…



Raking of Important community functions
(SERRI and CARRI, 2009)

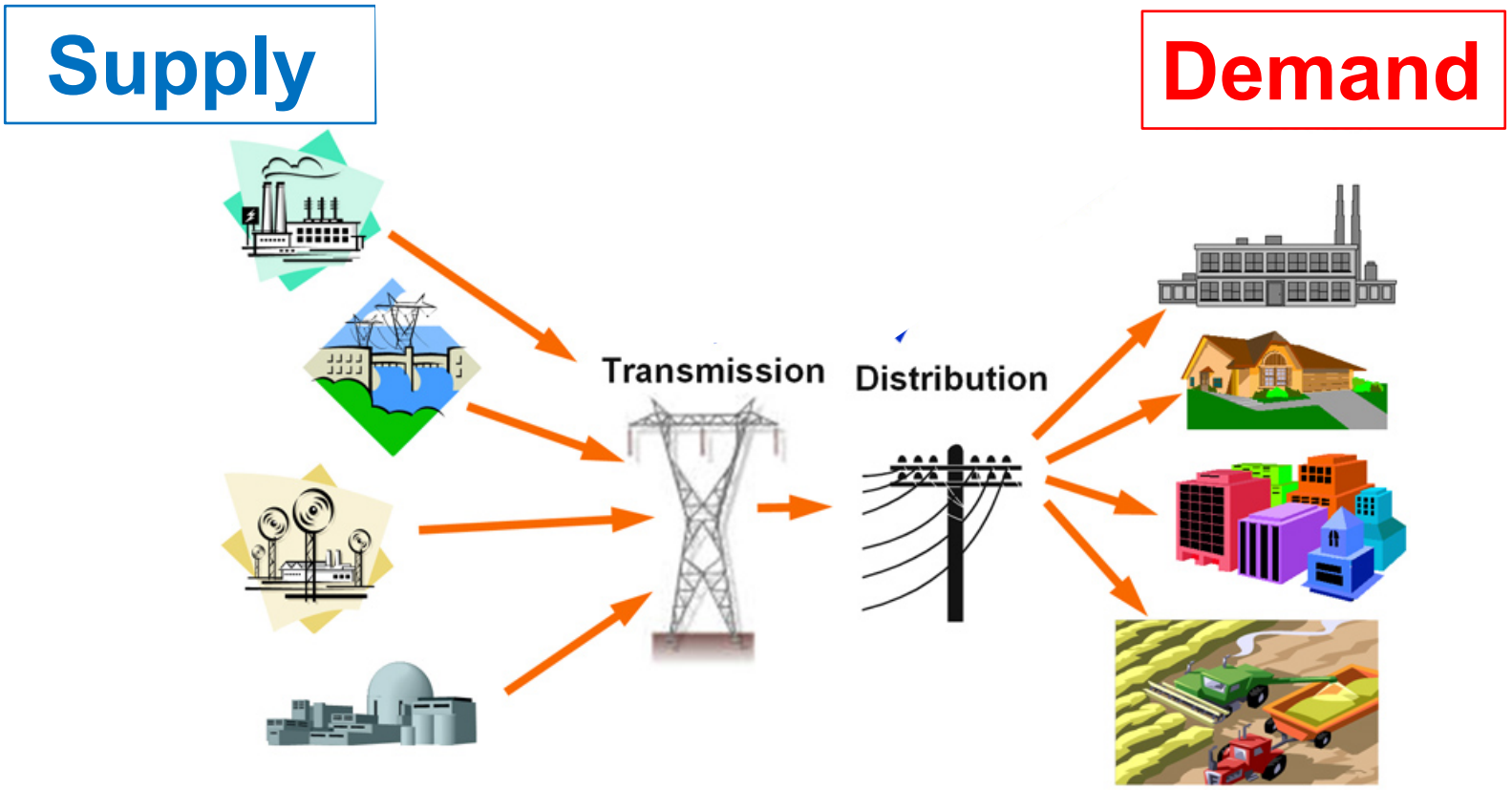
Quantification of Community Infrastructure System Resilience

- Measured in terms of loss of community function (MCEER'03)
  - Collapse:
    - Abandoned
  - Ductile:
    - Did not give up
  - Robust:
    - Same as before
  - Adapted:
    - Better than before



(after Brunearu, 2003, and Heinemann and Kröger, 2012)

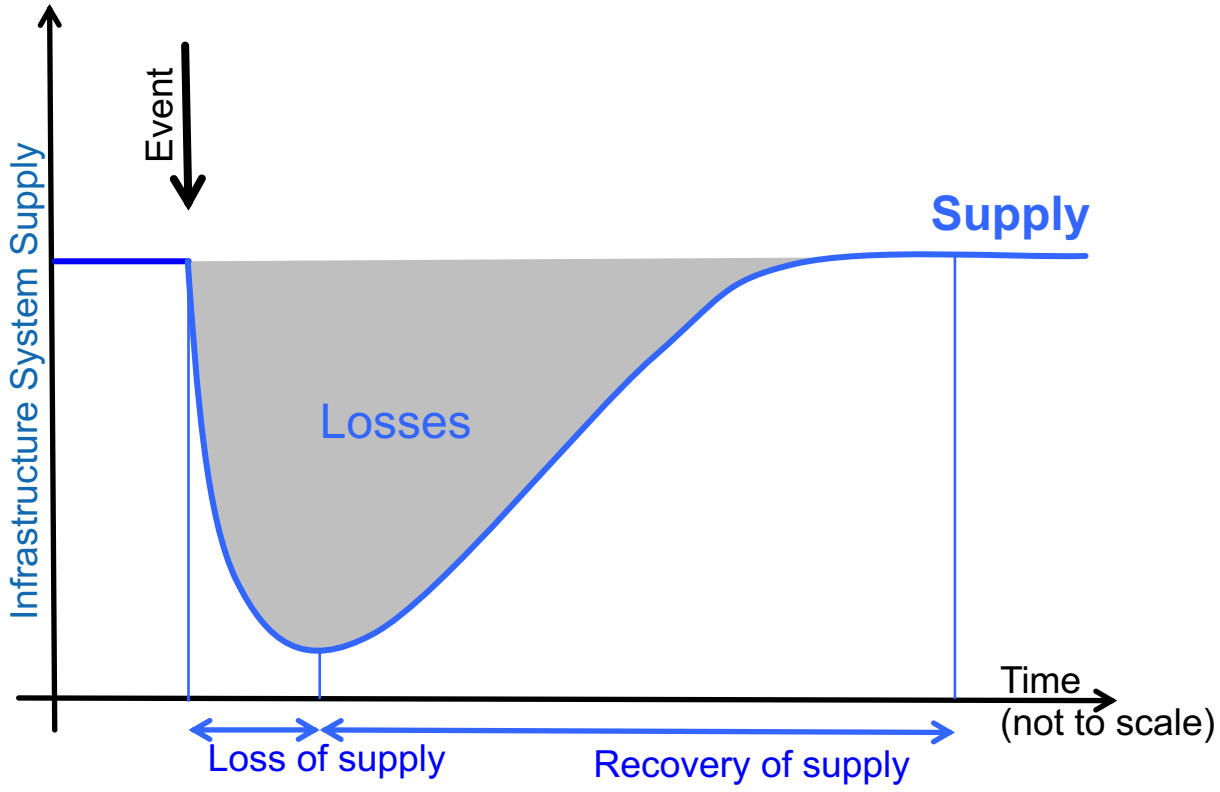
Quantification of Community Infrastructure System Resilience



http://ceeesa.es.anl.gov/images/ceeesa_ProjectsWECC_Climate_Power_Impacts_800.jpg

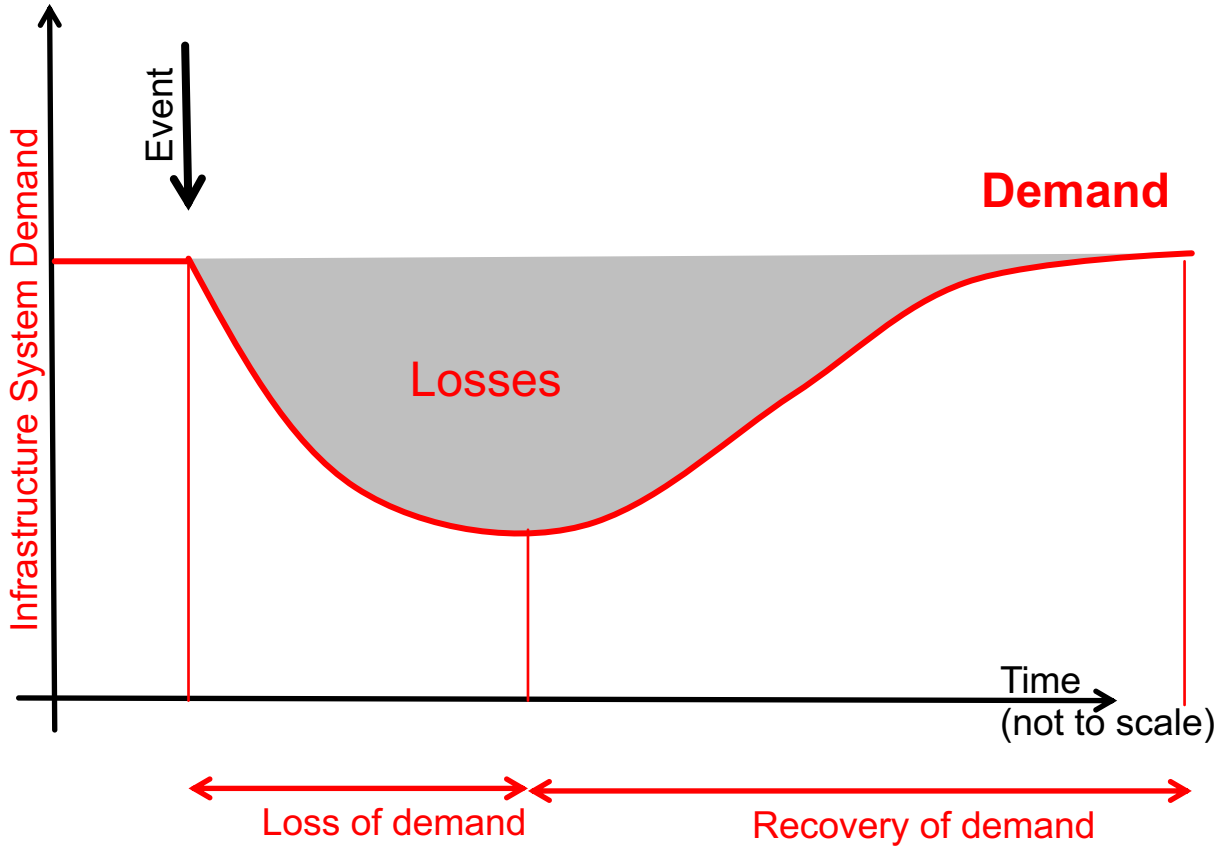
Quantification of Community Infrastructure System Resilience

- Infrastructure system supply:
  - Suffers an (instantaneous) drop when the event occurs
  - Recovers over time
  - Recovery depends on the vulnerability and recovery of elements of community infrastructure



Quantification of Community Infrastructure System Resilience

- Infrastructure system demand:
  - Suffers an (instantaneous) drop when the event occurs
  - Recovers over time
  - Recovery depends on the vulnerability and recovery of elements of community infrastructure

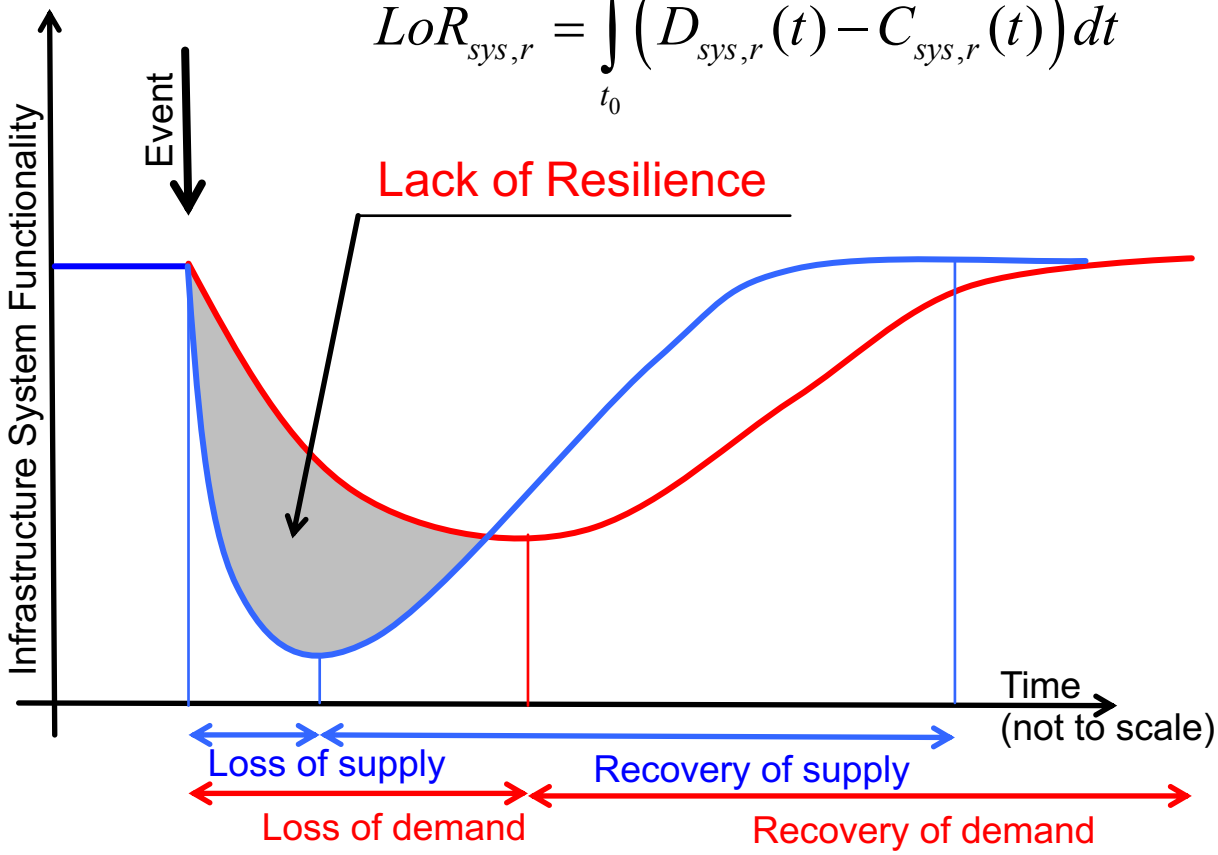


Supply/Demand Formulation to Quantify Community Infrastructure Resilience

- Lack of Resilience

  is the unmet demand of the community for the considered resource:
  - Power, water, communication…

$$LoR_{sys,r} = \int_{t_0}^{t_f} \left(D_{sys,r}(t) - C_{sys,r}(t) \right) dt$$



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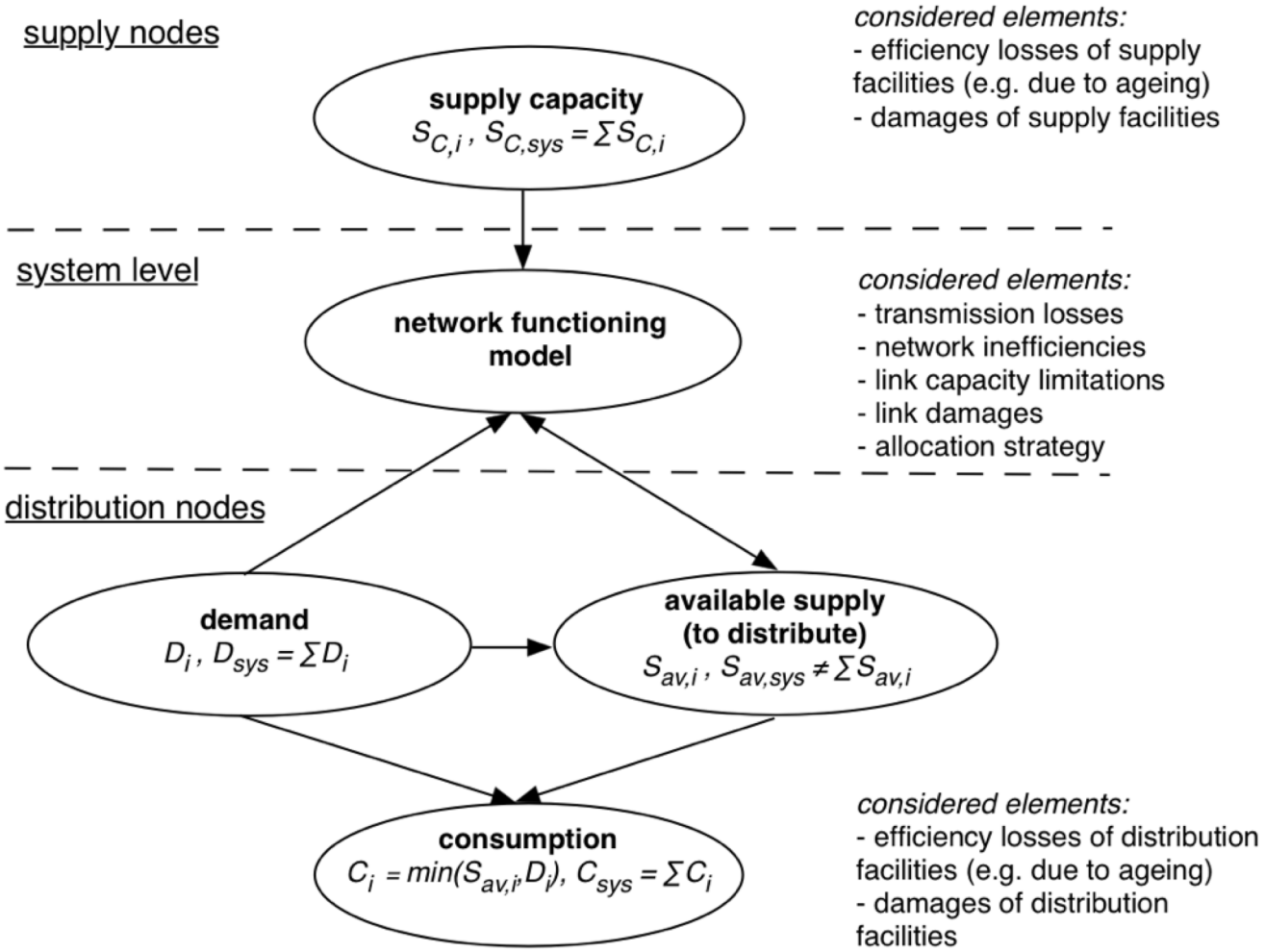
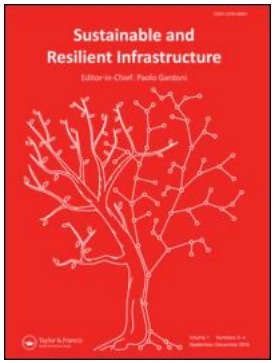
Didier M, Broccardo M, Esposito S, Stojadinovic B (2017). A Compositional Demand/Supply Framework to quantify the Resilience of Civil Infrastructure Systems (Re-CoDeS). *Sustainable and Resilient Infrastructure.*

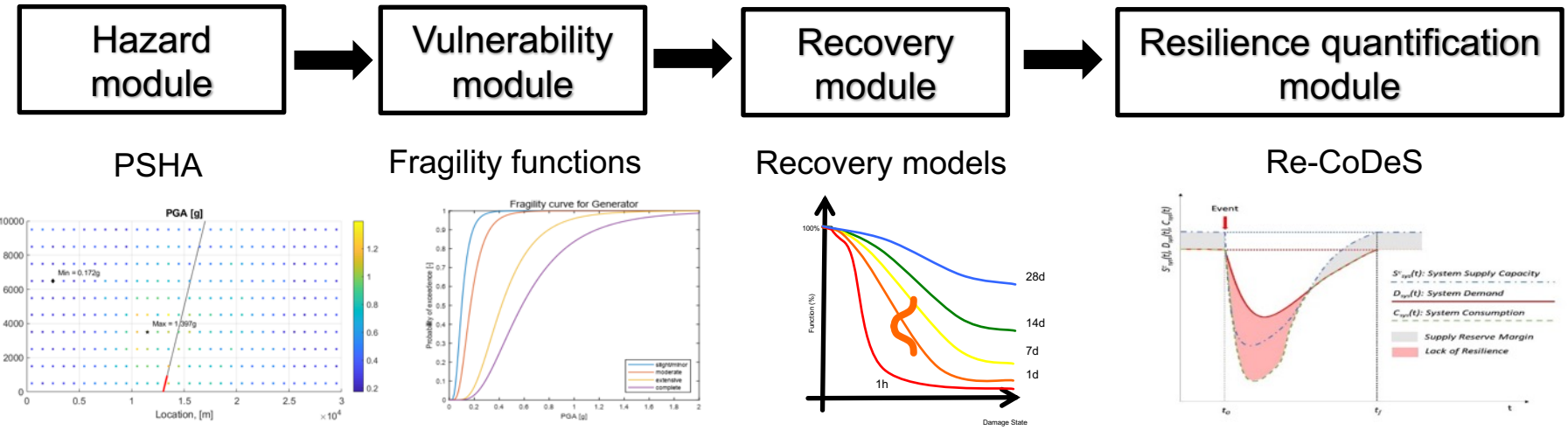
Re-CoDeS Framework





More details in:
https://doi.org/10.1080/23789689.2017.1364560

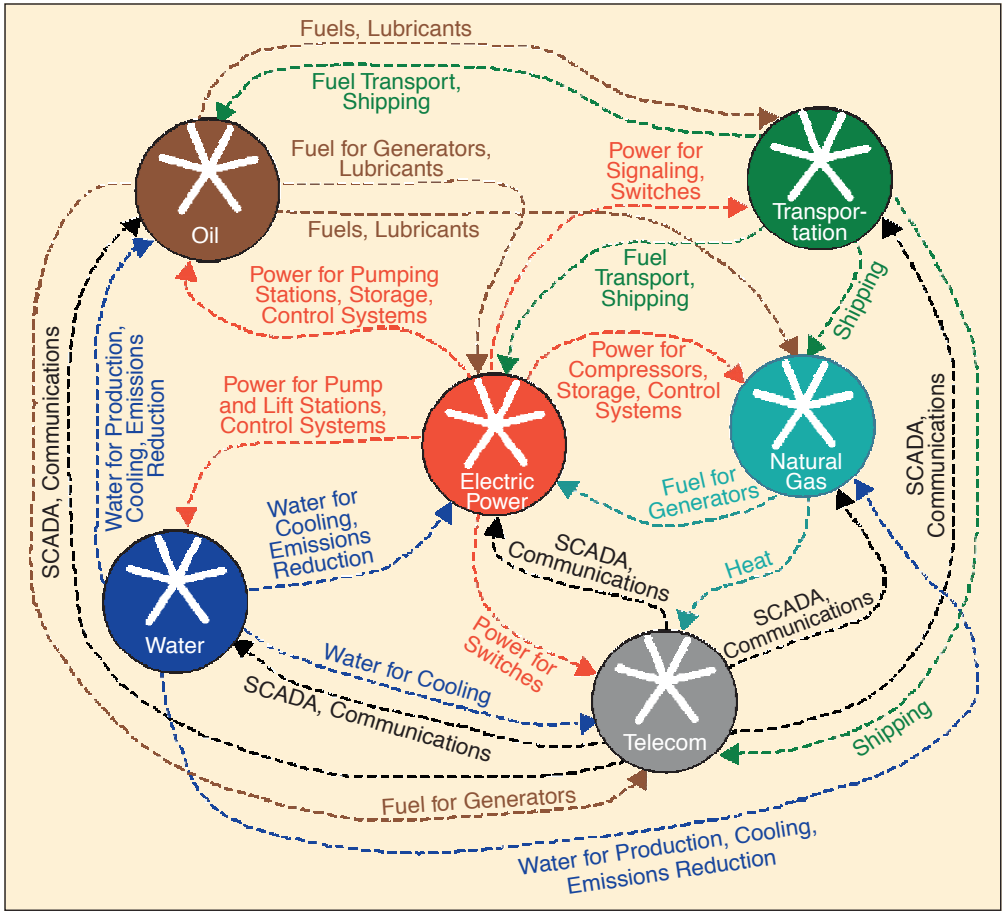
Re-CoDeS Framework: Formulation and Implementation



- Modeling the community on an component level:
  - Buildings, generators, pumps, cellular network base stations…
- Modular simulation platform architecture
- Physics-based (as much as possible)

Re-CoDeS Framework: Interdependence among Infrastructure Systems

- Lack of Resilience is the unmet demand of the community for the considered resource:
  - Power, water, communication…
- Interdependences among civil infrastructure system components play a significant role in community recovery

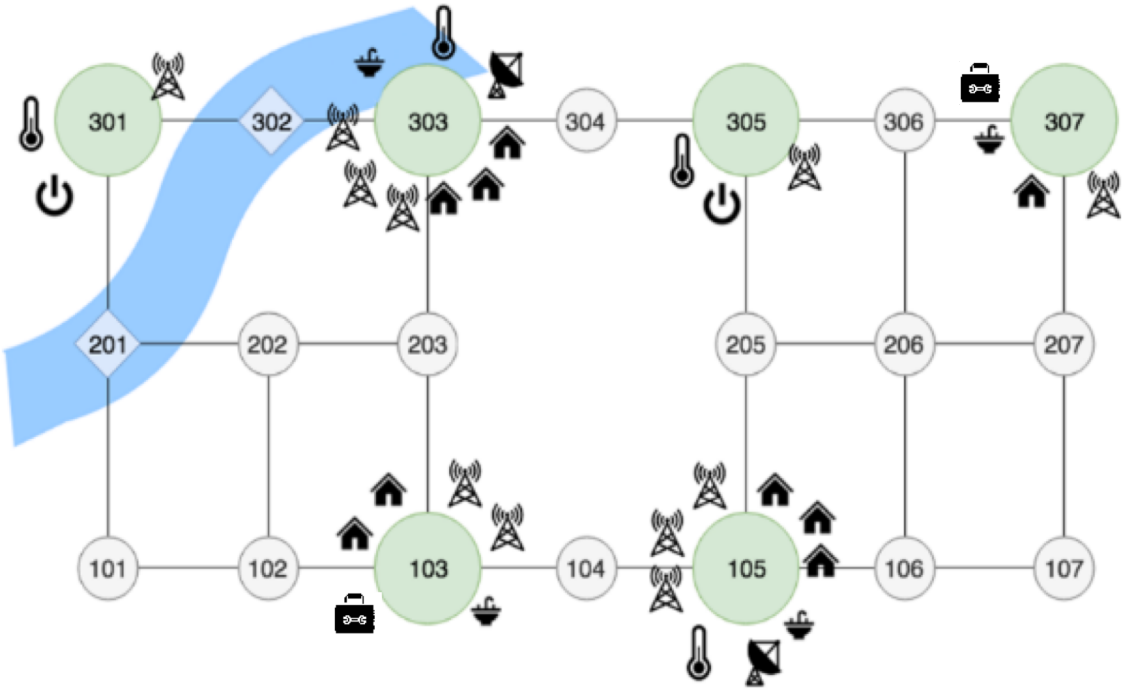


Rinaldi et al., 2001

A Virtual Community

- Area of 10 x 30 km
- 3600 inhabitants

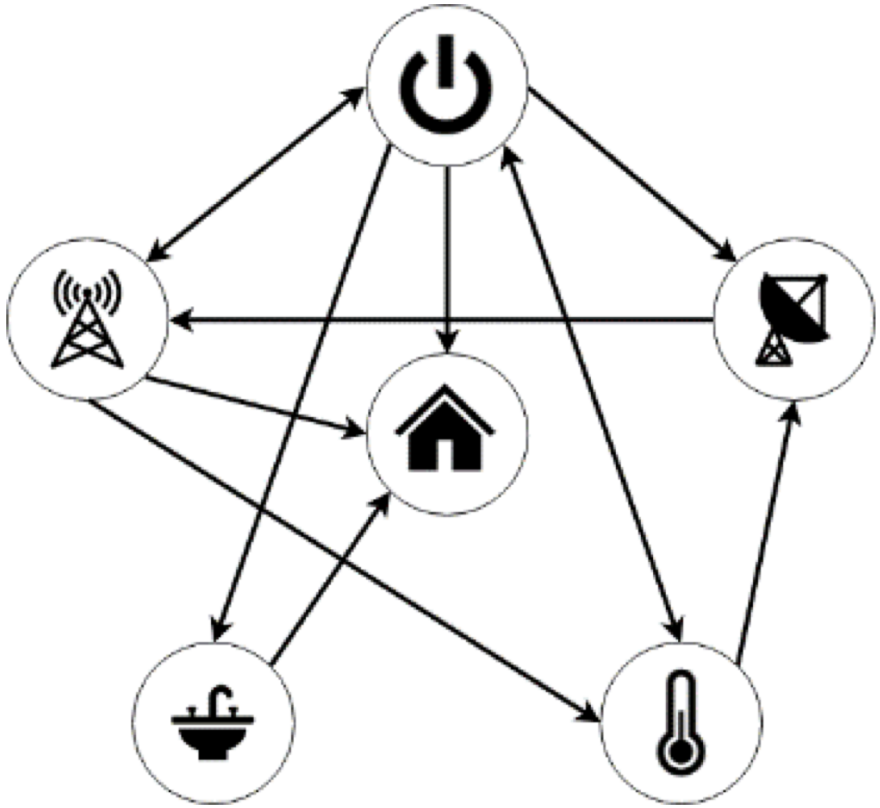
- Three infrastructure systems:
  - Electric Power Supply
  - Cellular Communication
  - Water Supply
- Three types of links:
  - Power lines
  - Water pipes
  - Roads (to transport repair crews, machinery and material)



A Virtual Community: Interdependence among Infrastructure Systems

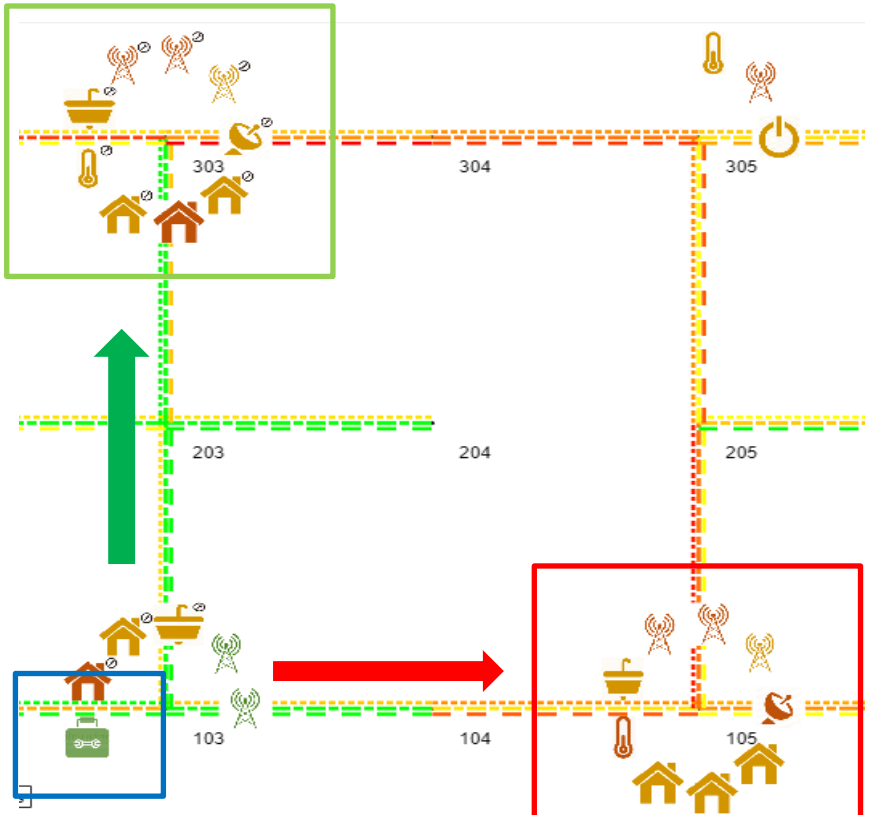
- Community components are dependent on each other for function

- Interdependencies among infrastructure systems are defined at the component level



A Virtual Community: Interdependence among Infrastructure Systems

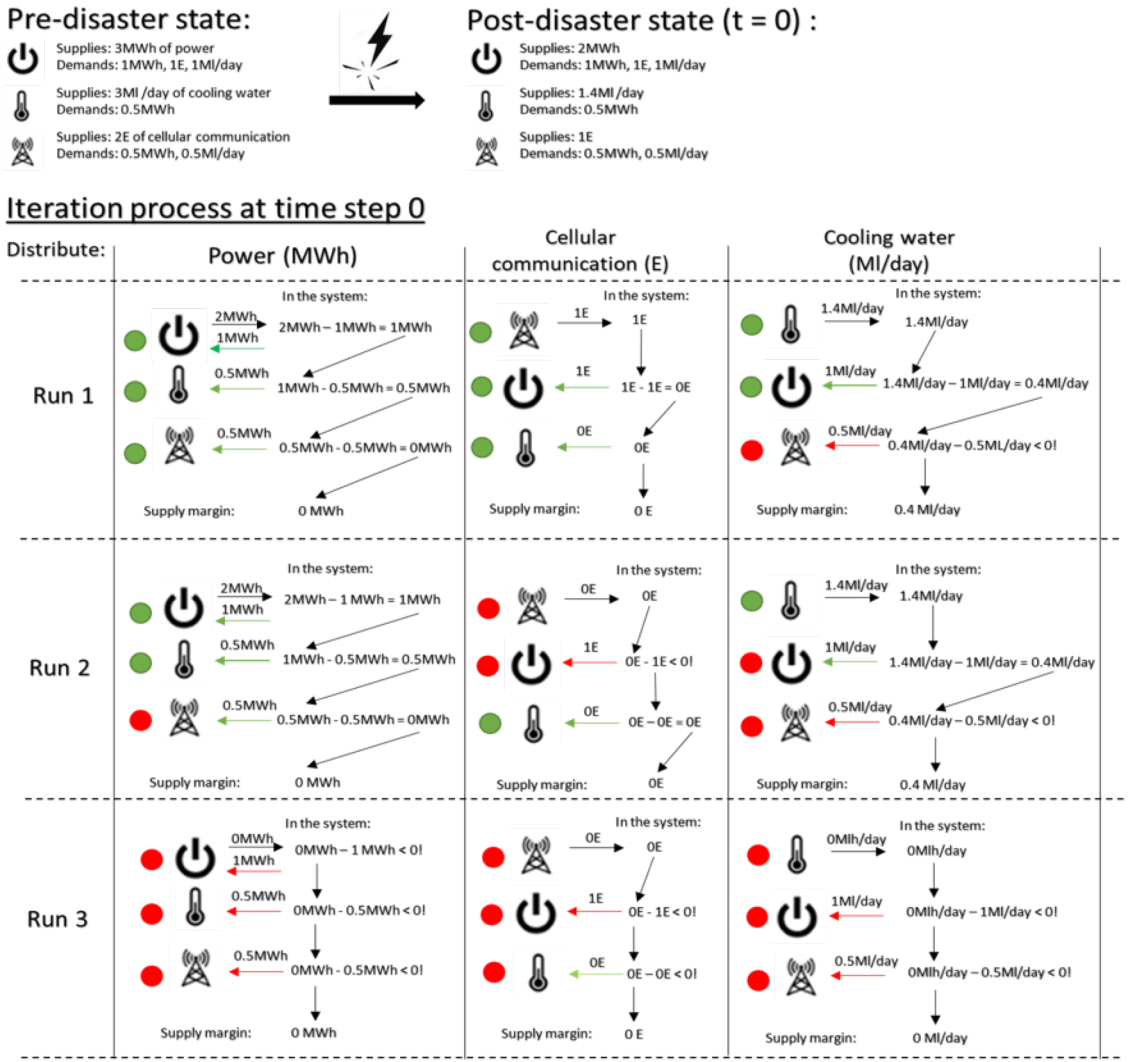
- Restoration of component function depends on:
  - Its damage
  - Resources needed for recovery
  - Start and rate of its recovery
  - Availability of resources it needs to function:
    - A generator needs cooling water and communication



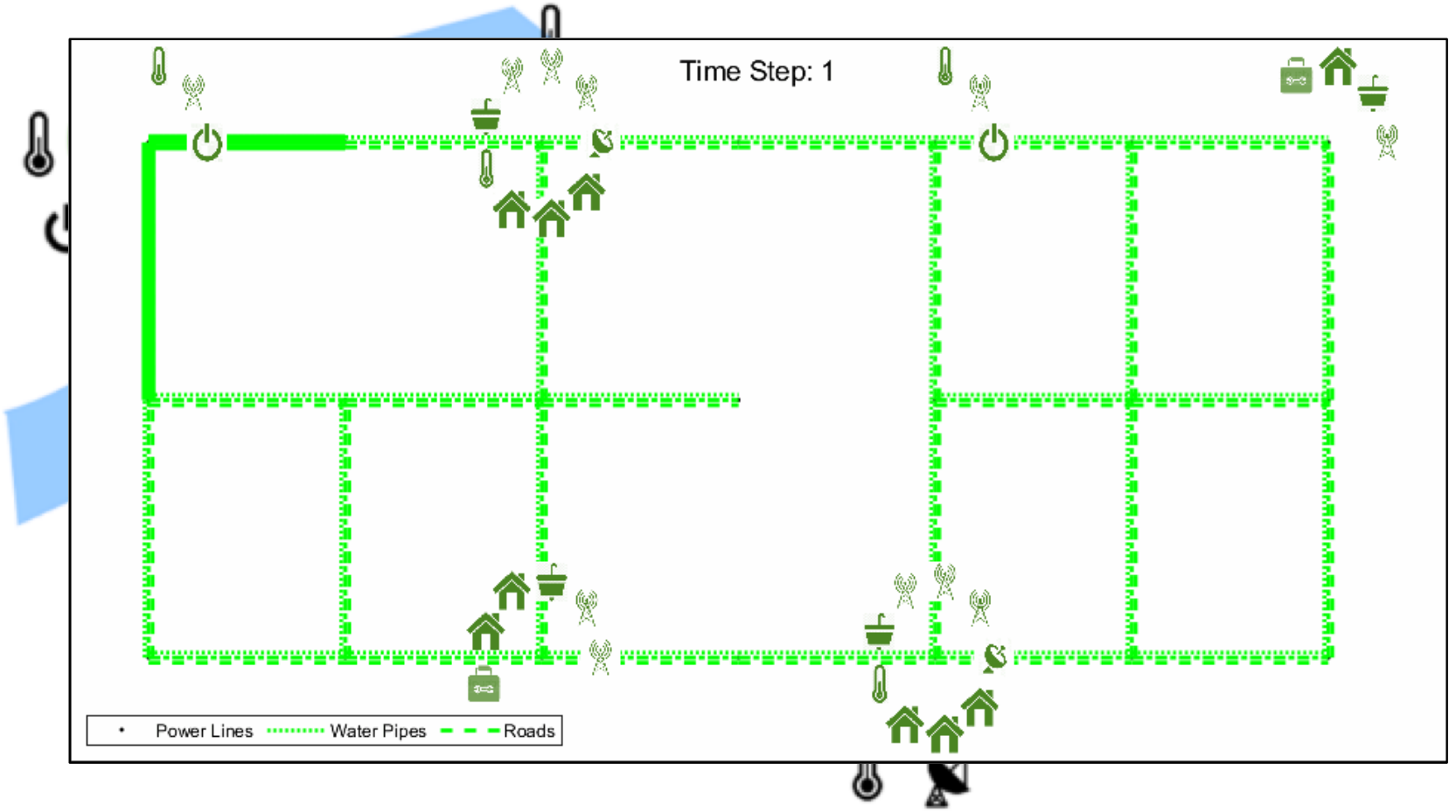
Emergency response center

A Virtual Community: Interdependence among Infrastructure Systems

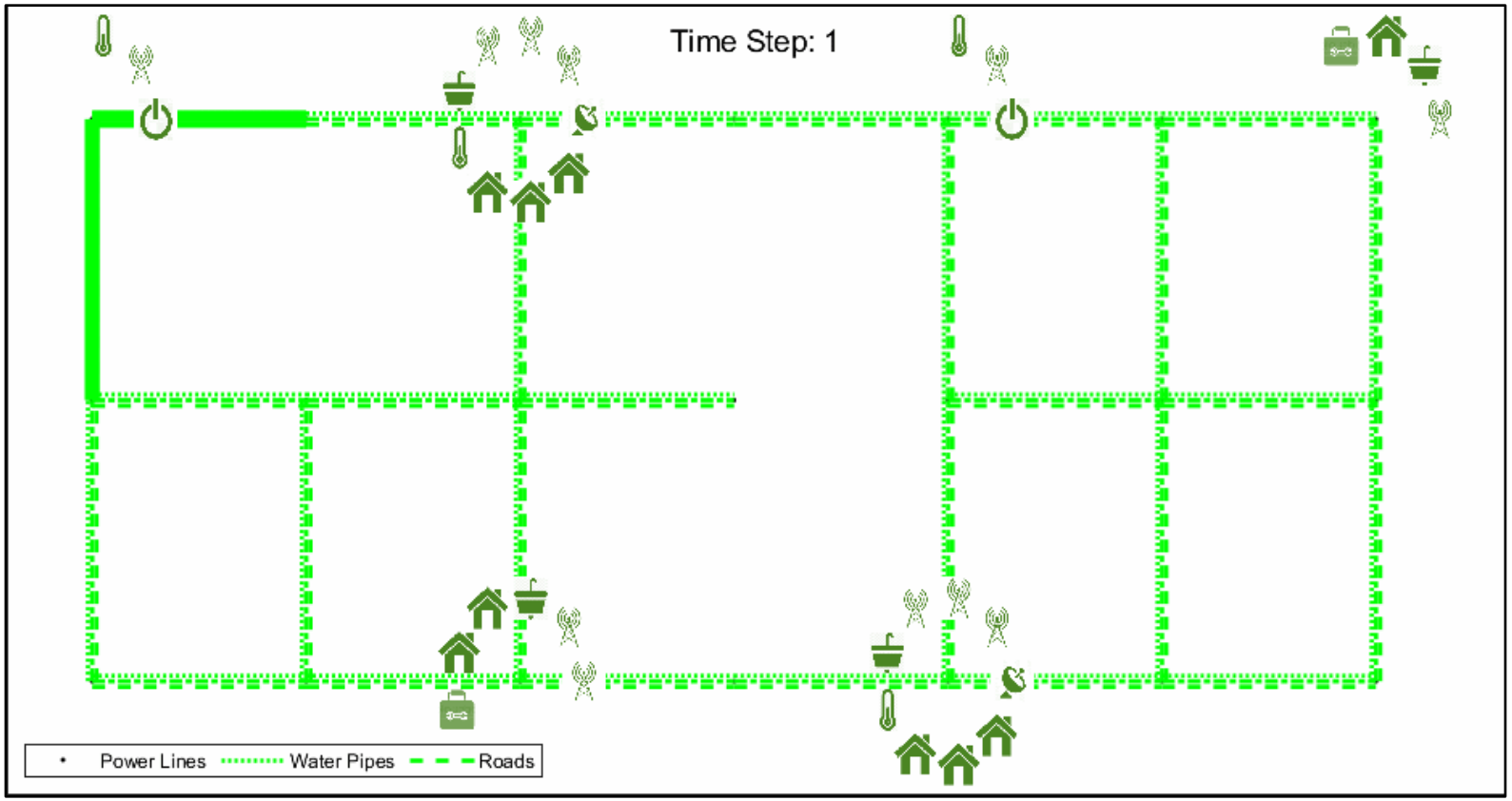
- At each recovery time step, functionality of each component is established in an iteration designed to detect feedback loops



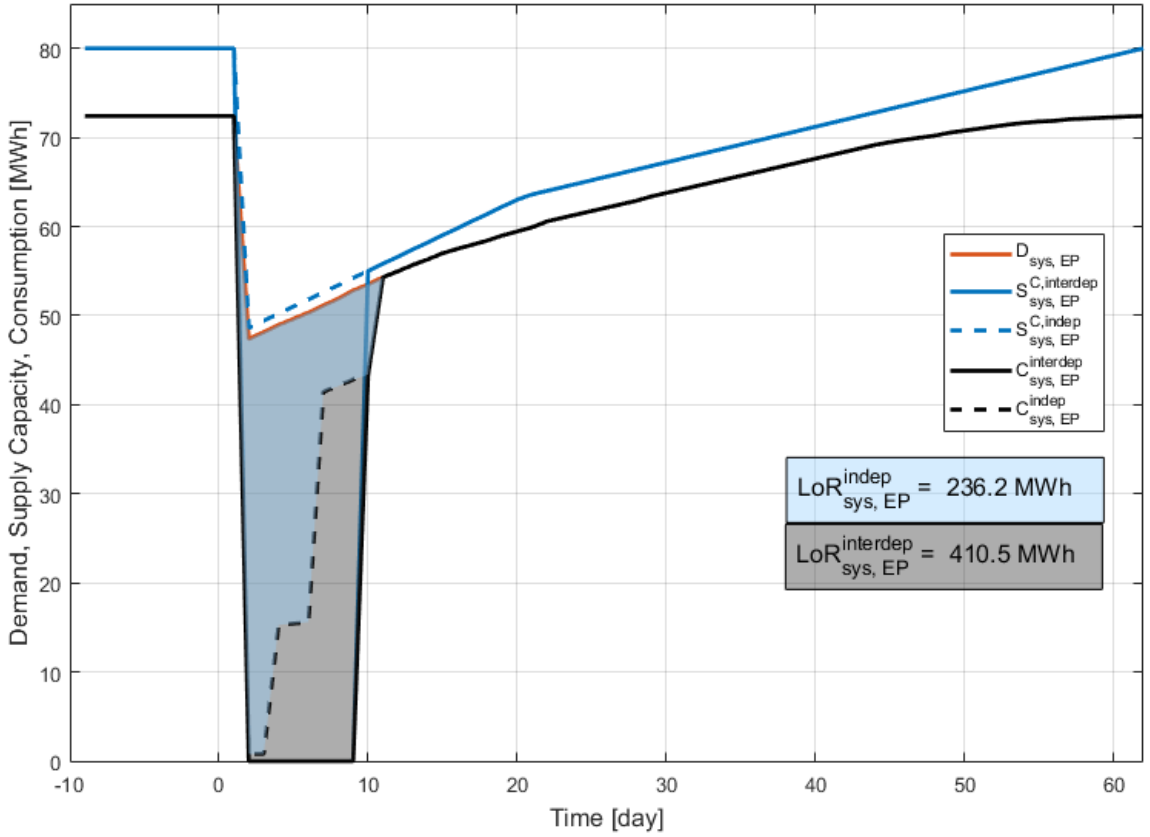
A Virtual Community:
Post-Earthquake Recovery Simulation



A Virtual Community: Post-Earthquake Recovery Simulation

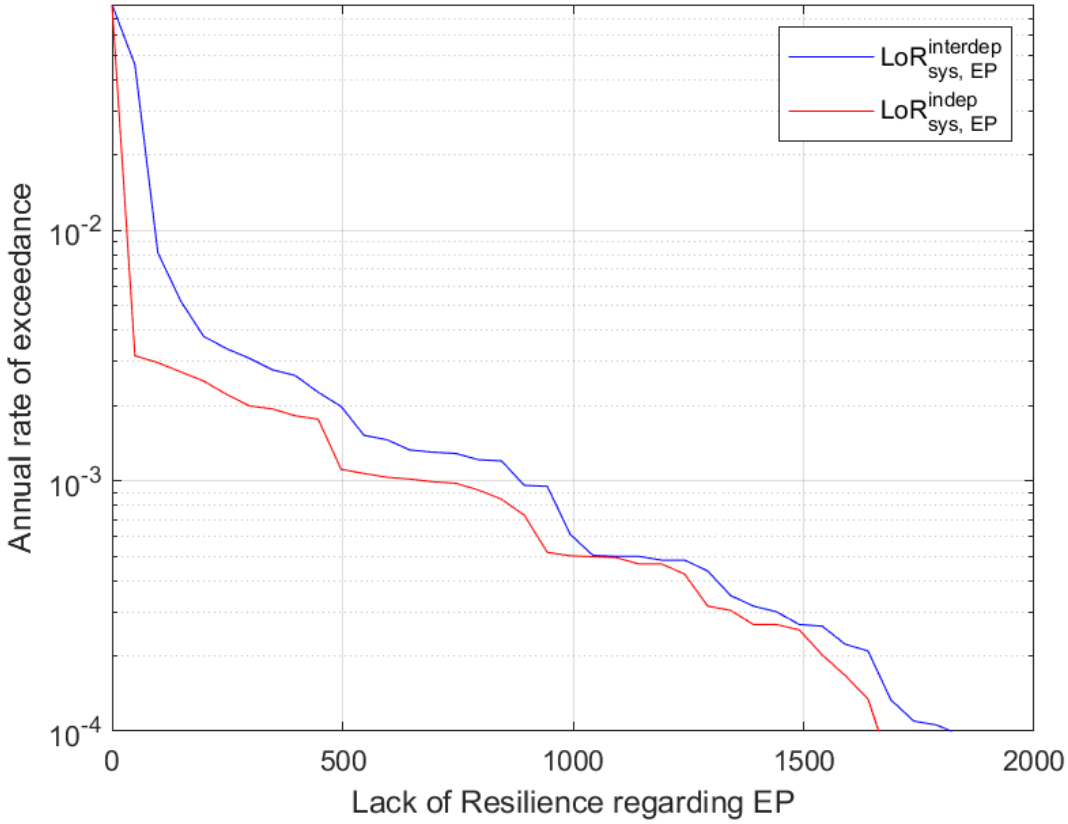


A Virtual Community: Effect of Interdependencies



Interdependencies increase LoR of EPS by 74%

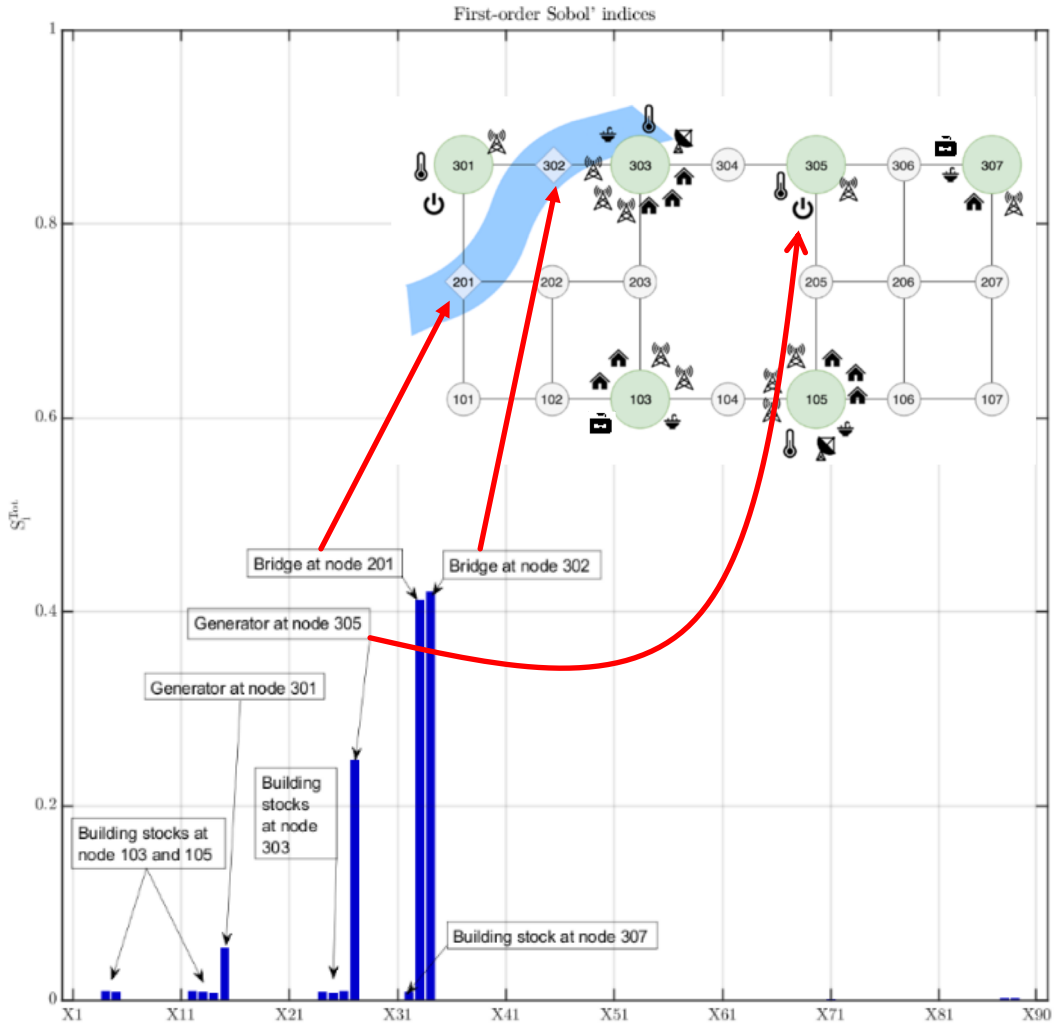
A Virtual Community: Effect of Interdependencies



Interdependency increases community disaster risk exposure

A Virtual Community: Investigation of Community Sensitivity

- Sensitivity analysis:
  - Sobol index approach
  - Find which community infrastructure elements contribute the most to changes in community disaster resilience (or lack thereof)



Challenge:
Make Communities more Resilient

- Community risk is increasing:
  - Population growth
  - Productivity
  - Innovation

- Engineering resilient communities is a key element of societal risk governance
  - Re-CoDeS framework can be used for community resilience evaluation and design

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https://www.nytimes.com/2019/07/16/opinion/smart-cities.html

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Objects
Decisions
Who
Confusion
Concepts
Nobody
Mark
Support
Exploration
Solution
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Strategy
Ideas
Lost
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and
Problems
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Help
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thank you
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teşekkür ederim
gracias
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спасибо
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Баярлалаа
faafetai lava
kiitos
dankie
nanni
nandri
dhanyavad
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