

Resilience: Defining and Measuring What Matters

Michel Bruneau

Director, MCEER

*Professor, Department of Civil, Structural, and
Environmental Engineering, University at
Buffalo*

Kathleen Tierney

Professor, Sociology

*Director, Natural Hazards Center
University of Colorado*



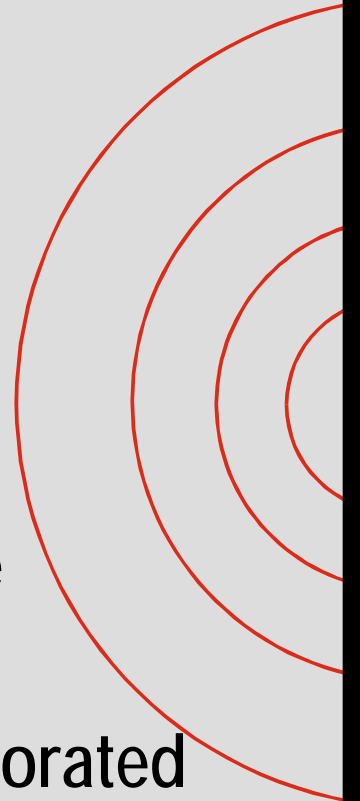
MCEER Vision

“The overall goal of MCEER is to enhance the disaster resilience of communities through improved engineering and management tools for critical infrastructure systems (water supply, electric power, and hospitals) and emergency management functions.”




Which Leads Logically to Questions Such As:

- How is Resilience Defined and Operationalized?
- How Can Resilience be Quantitatively Measured?
 - How Can Improvements in Resilience be Measured?
 - How Can Resilience Measures be Incorporated into Decision Support Systems?



MCEER's Strategy for Addressing These Questions

1. Define and Understand Resilience from Multiple Disciplinary Perspectives
 2. Identify Dimensions of Resilience
 3. Formulate Conceptual Models, Taxonomies
 4. Develop Measures
 5. Assemble Empirical Data on Measures
 6. Test and Analyze Resilience Models, with an Emphasis on Selected Critical Infrastructures
- 

Multidisciplinary Perspectives on Resilience

Integrating Knowledge on Resilience from:

- Ecology/Environmental Science
- Engineering
- Hazards Research
- Organizational Behavior & Performance
- Psychology, Social Psychology

Commonalities across Disciplines

Resilience Consists of:

- **Relatively Stable or Inherent Properties** That Protect Units of Analysis From Shock, Trauma & Disruption or Reduce Their Impacts (e.g., Biodiversity, Economic Diversification, Psychological Attributes, Social Support Networks)
- **Adaptive Properties** That Enable Units of Analysis to “Bounce Back” and Recover from Shock, Trauma, Disruption Without Experiencing Negative Effects Over a Long Period (e.g., Psychological Coping, Ability to Obtain External Resources, “Work-Arounds,” Organizational Innovation)

Dimensions, Components, or Properties of Resilience

- **Robustness:** Inherent Strength, Resistance
- **Redundancy:** System Properties That Allow for Alternative Options, Choices, Substitutions
- **Resourcefulness:** Capacity to Mobilize Needed Resources
- **Rapidity:** Speed With Which Disruption Can Be Overcome & Service, Income, etc., Restored



Lack of
Robustness:

**Bam Earthquake, 2003:
Adobe Construction**



**Hurricane Katrina:
Levee Breaks, 2005**



Lack of
Redundancy:

Hurricane Katrina, 2005:
Auto-Dependent Evacuation

World Trade Center Attack, 2001: No Alternate EOC



MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH



Lack of Resourcefulness:

**Pakistan Earthquake, 2005:
Disaster Far Exceeds Societal
Capacity**



**Indian Ocean Tsunami, 2004:
No Effective Warning
System**

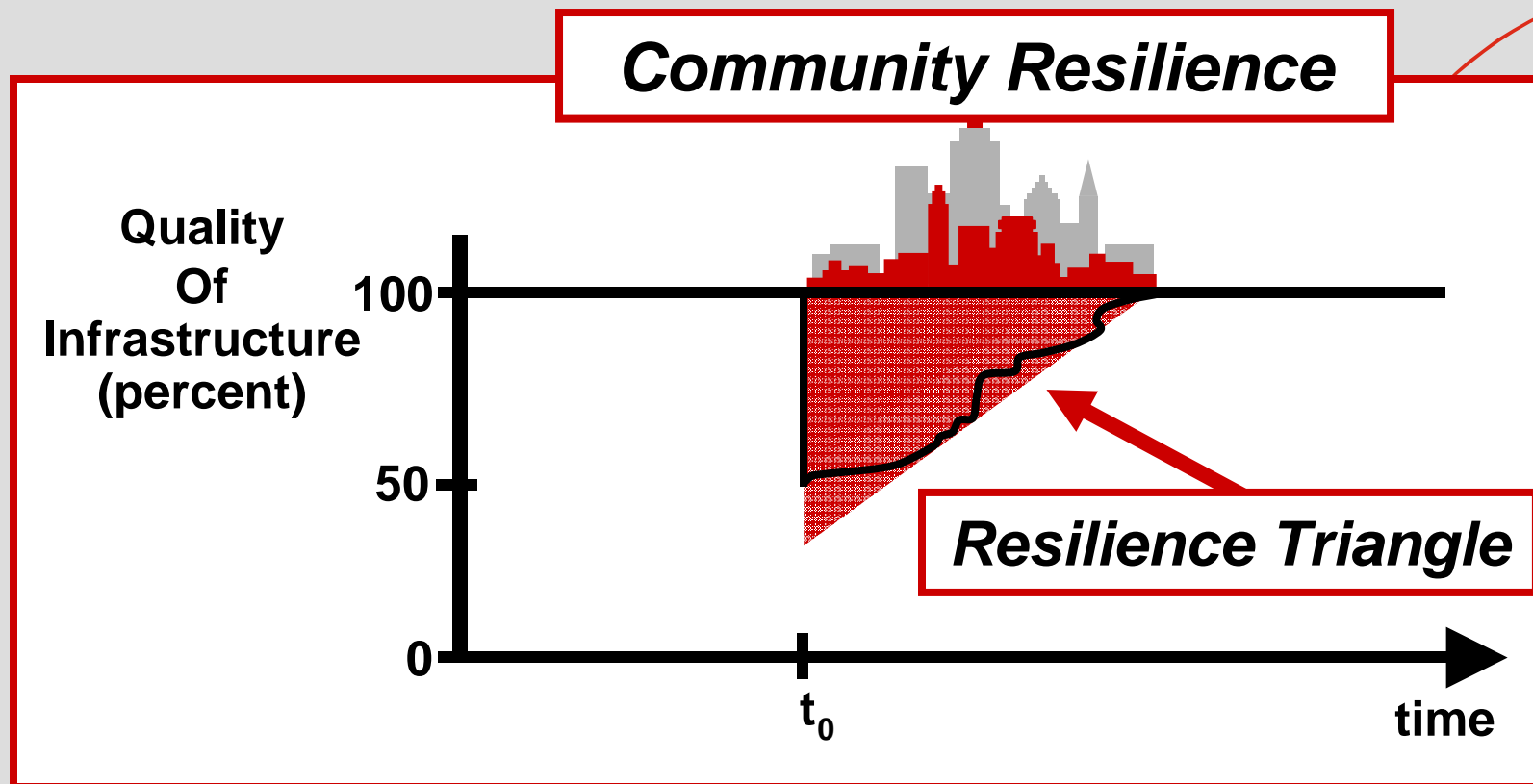


Lack of Rapidity:

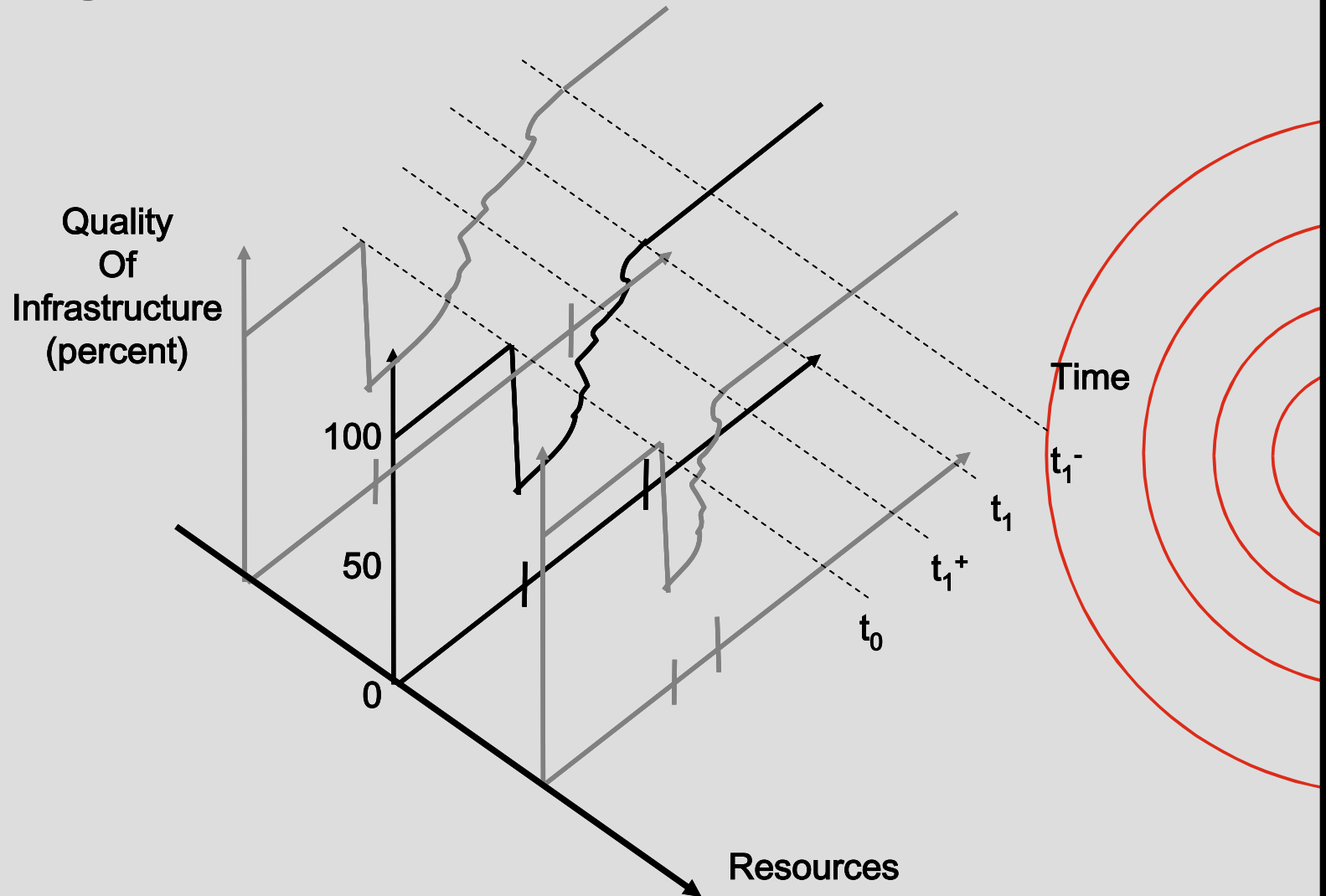
Katrina Victims
Await Help



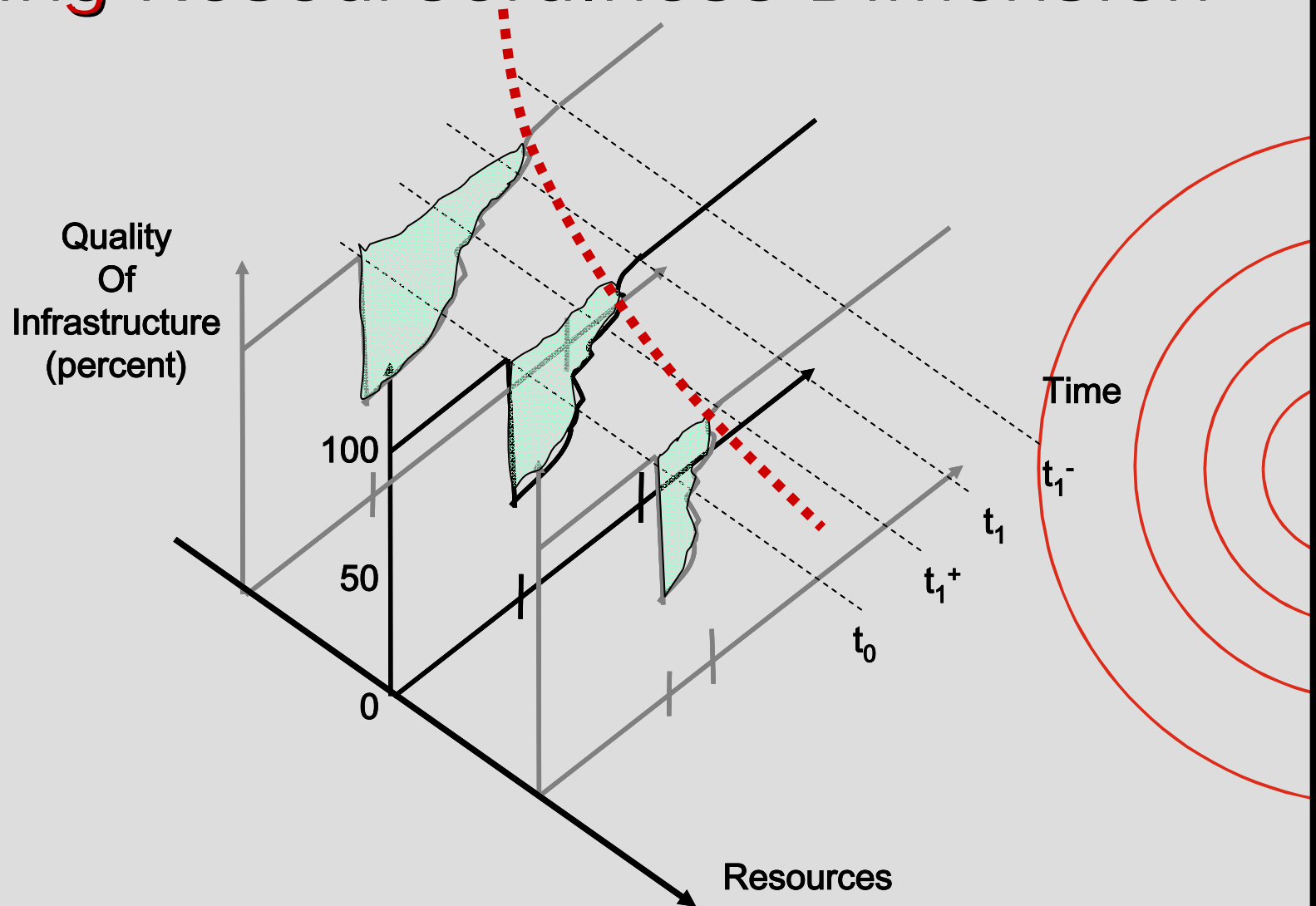
General Framework for Quantification: Extent of Disruption and Recovery Time



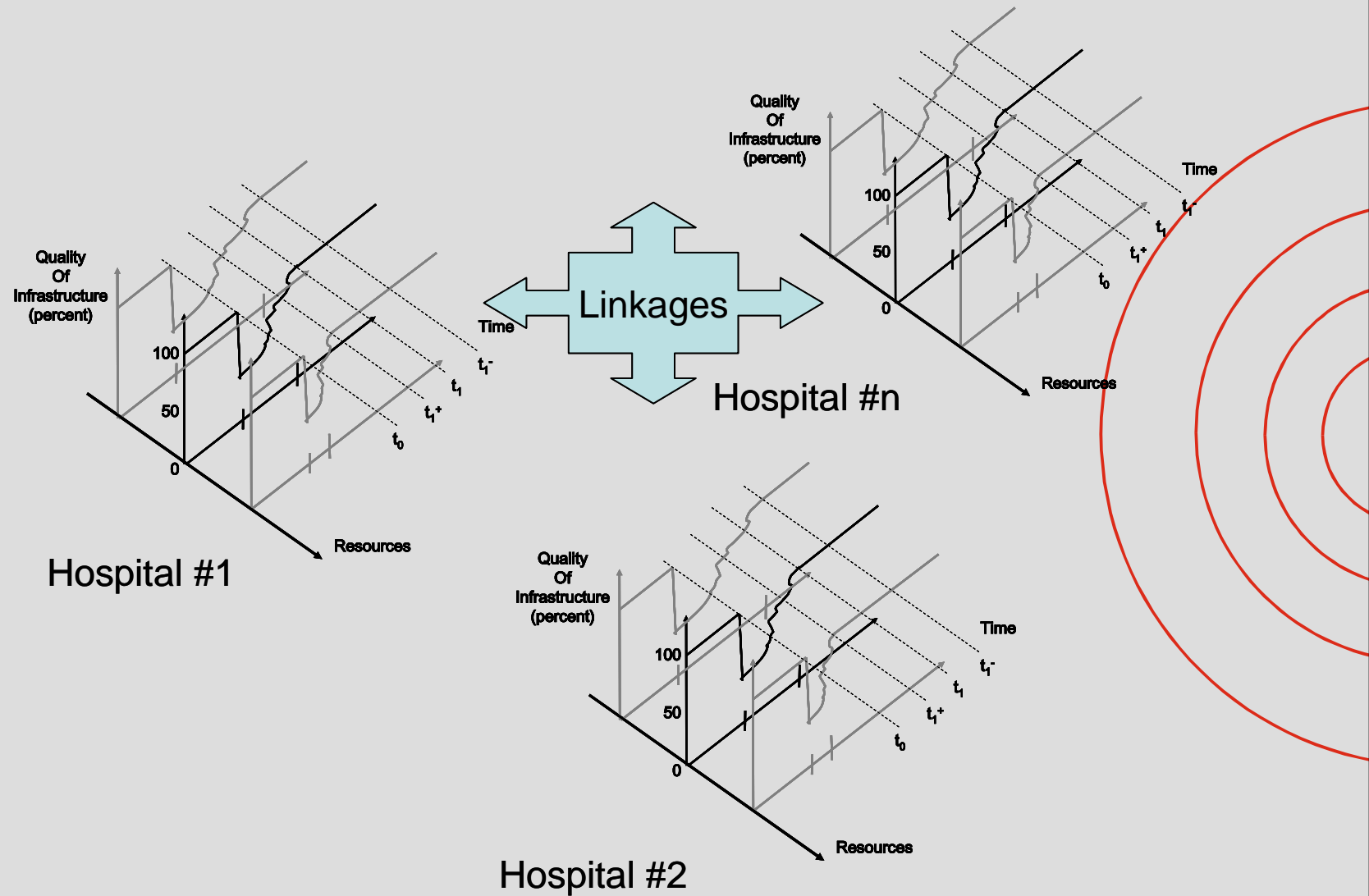
Adding Resourcefulness Dimension



Adding Resourcefulness Dimension



Adding Redundancy Dimension



Lifelines: Power Systems



MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Lifelines: Pipeline Systems (water supply)



Seismic Retrofit of Hospitals



MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Emergency Response and Recovery

Los Angeles City
Emergency Operations Center
1994 Northridge Earthquake



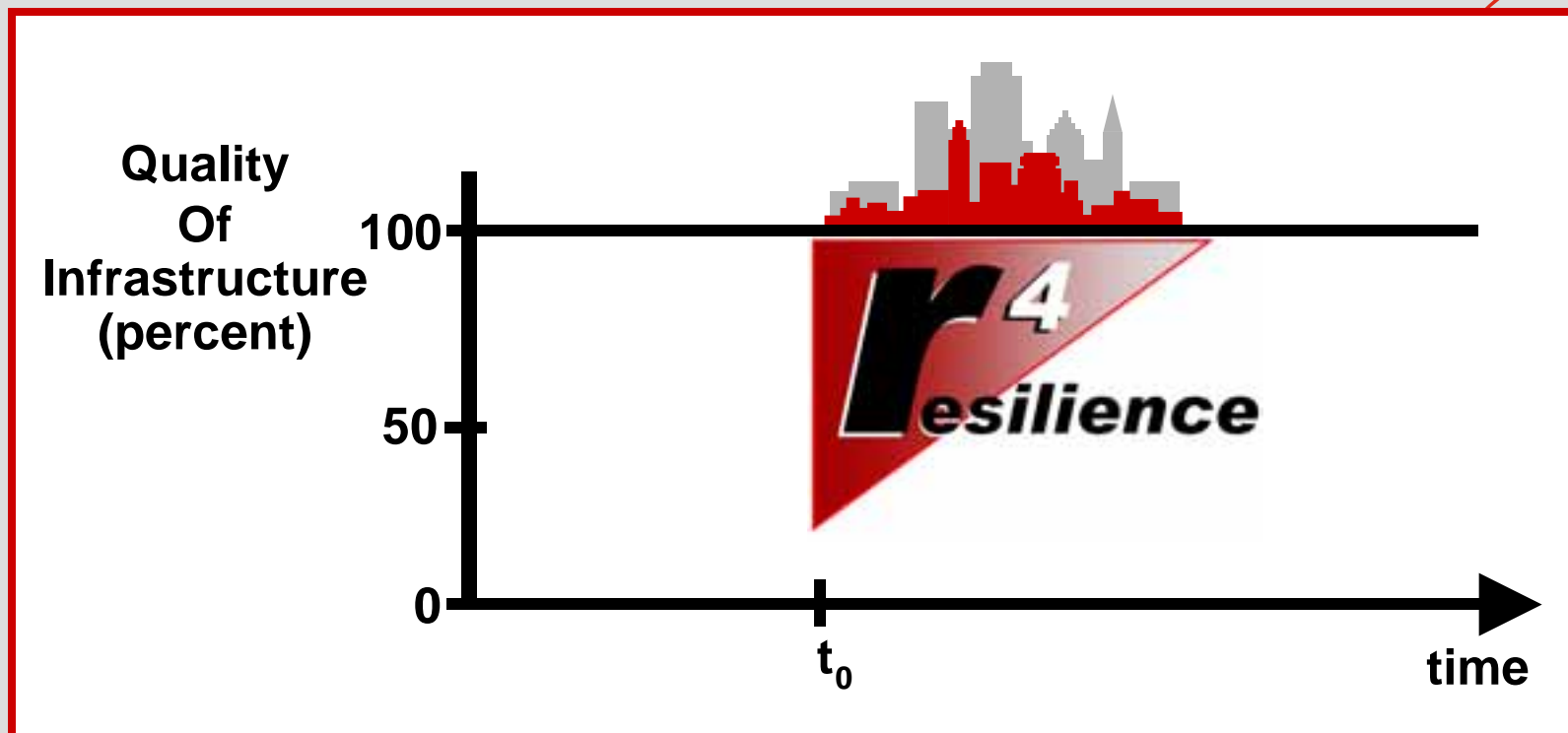
MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Highways

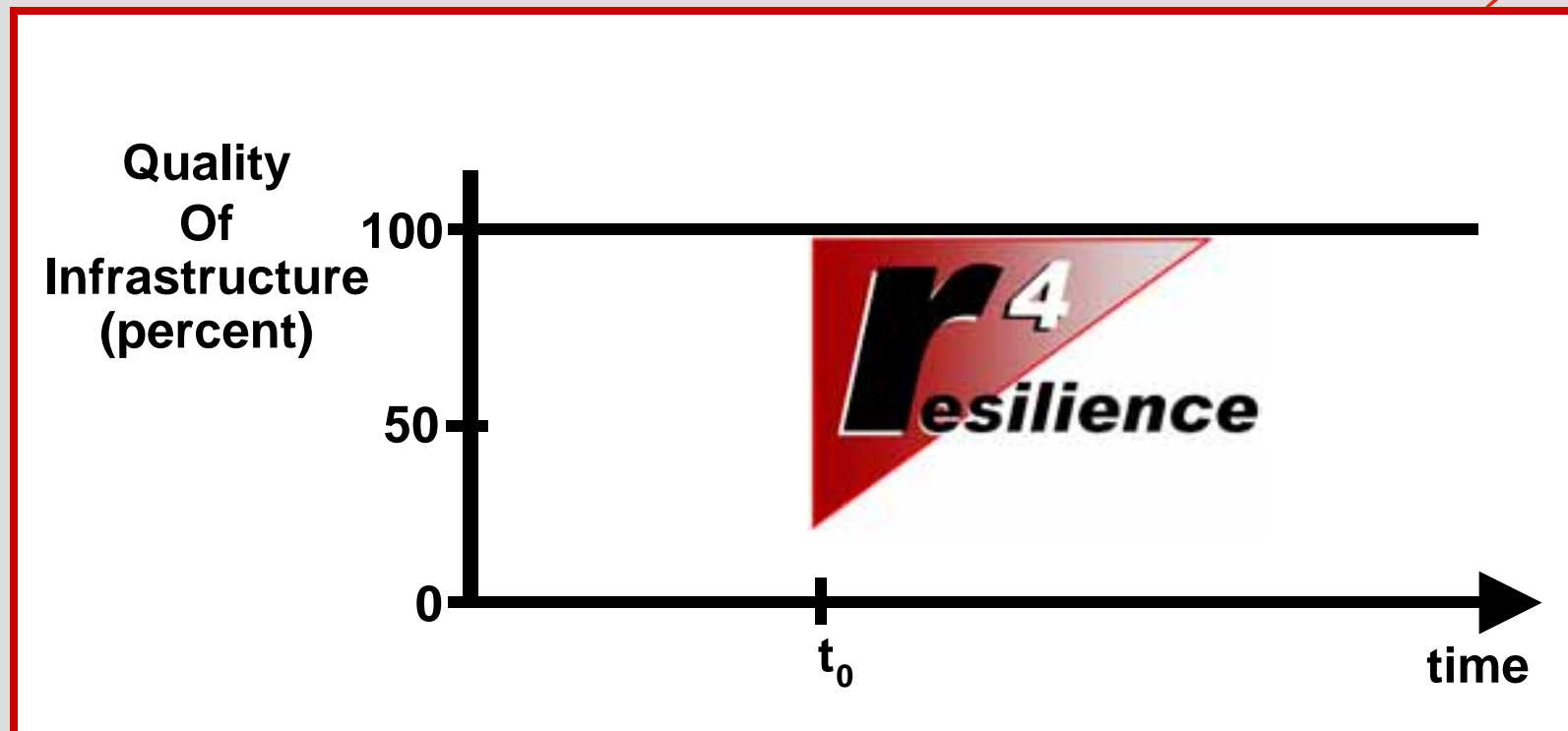


MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

General Framework for Quantification: Extent of Disruption and Recovery Time



General Framework for Quantification: Extent of Disruption and Recovery Time



THE CONCEPT OF

R⁴
esilience



MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

r⁴

*The Four Fundamental
Properties of Resilience*

*r*obustness

*r*edundancy

*r*esourcefulness

*r*apidity

Further Elaboration: Resilience Domains

- **Technical:** Physical Systems—Location-Based & Distributed Critical Facilities
- **Organizational:** Attributes, Dynamics of Organizations & Institutions
- **Social:** Attributes, Dynamics of Communities and Populations
- **Economic:** Attributes, Dynamics of Local and Regional Economies & Their Constituent Units (e.g. Businesses)

Resilience Property Space & Examples

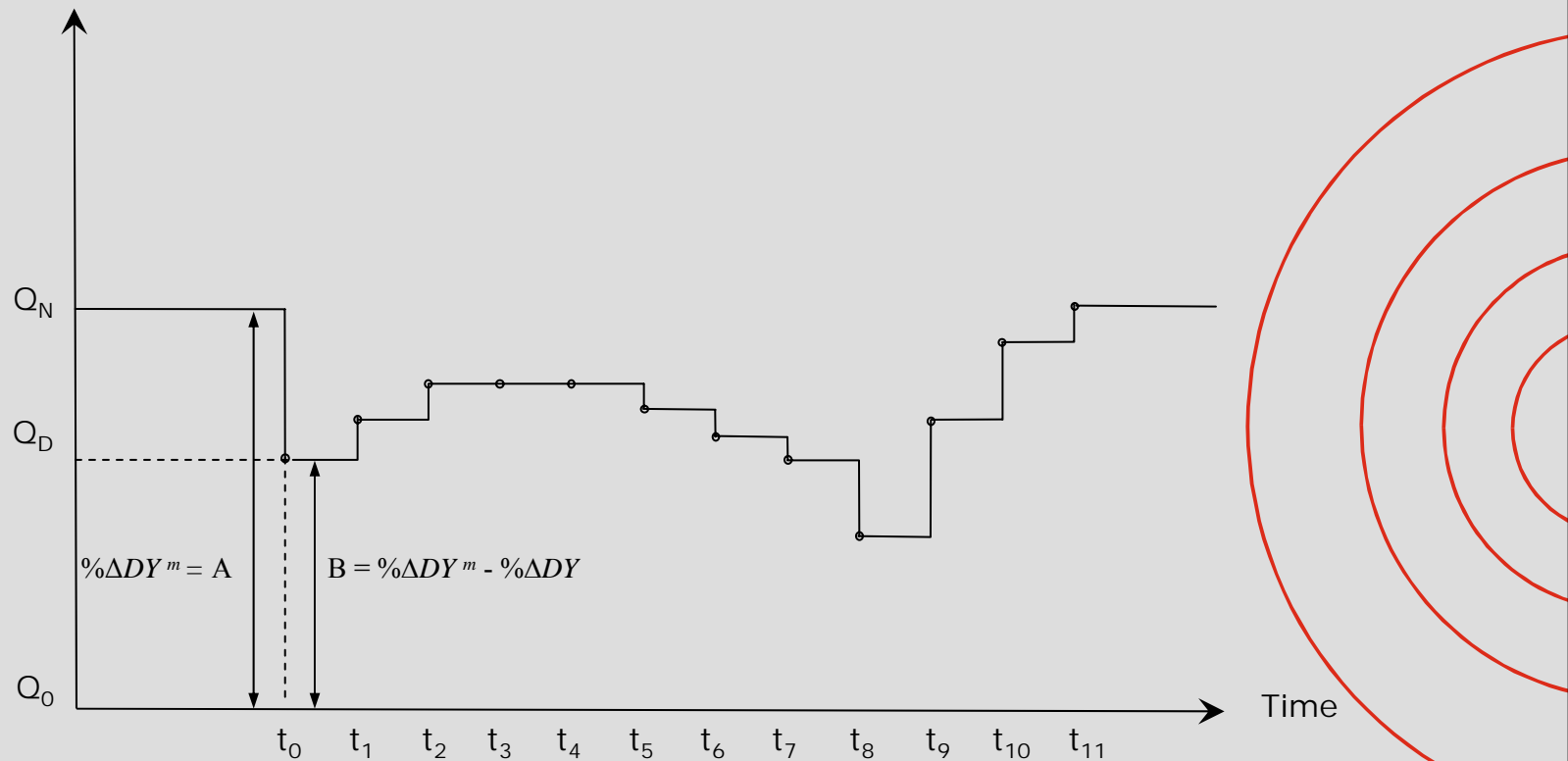
Dimension/ Domain	Technical	Organizational	Social	Economic
Robustness	Newer Structures, Built to Code	Extensiveness of Emergency Operations Planning	Social Vulnerability/ Resilience Indicators	Extent of Economic Diversification
Redundancy	Capacity for Technical Substitutions, "Work-Arounds"	Alternate Sites for Managing Disaster Operations	Availability of Housing Options for Disaster Victims	Ability to Substitute, Conserve Needed Inputs
Resourcefulness	Availability of Materials for Restoration, Repair	Capacity to Improvise, Innovate, Expand	Capacity to Address Hum- an Needs	Capacity to Improvise, Innovate
Rapidity	System Downtime, Restoration Time	Time Between Impact & Early Recovery	Time to Restore Life- line Services	Time to Regain Capacity, Lost Revenue

Resilience, Response, and Recovery

- Assessing How Resilience Dimensions Affect Response Times and Recovery Trajectories
 - For Lifelines
 - For Critical Facilities
 - For Social and Economic Units of Analysis (Households, Communities, Firms, Regional Economies)

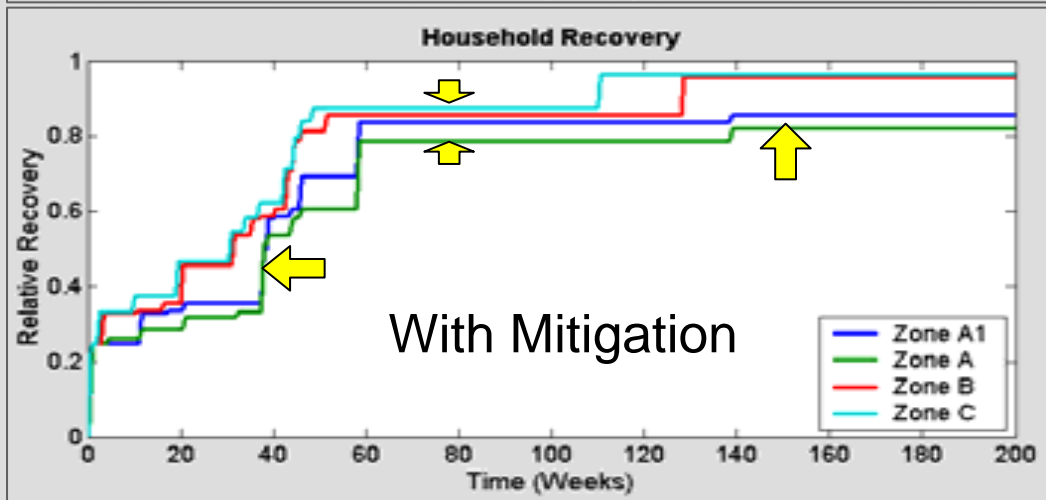
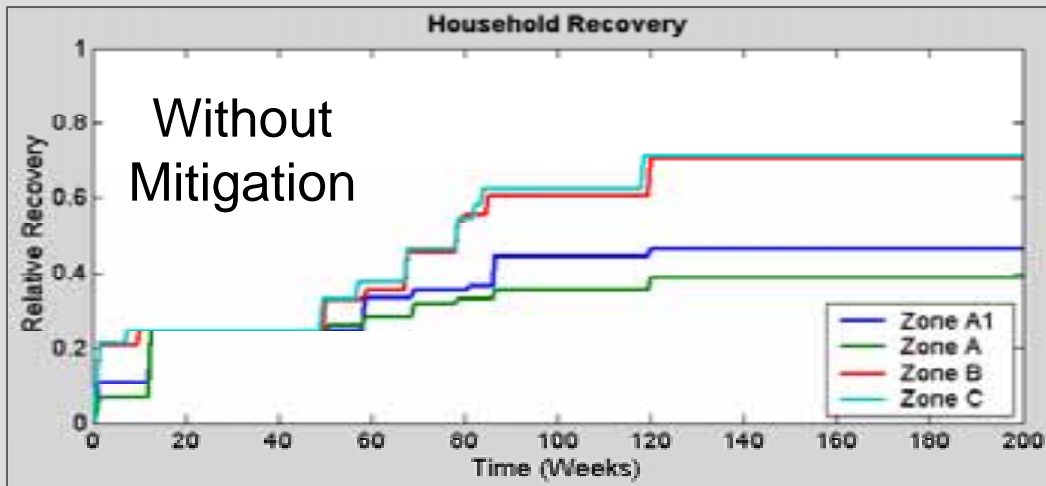
Organizational Resilience & Recovery From Business Interruption

Economic Output

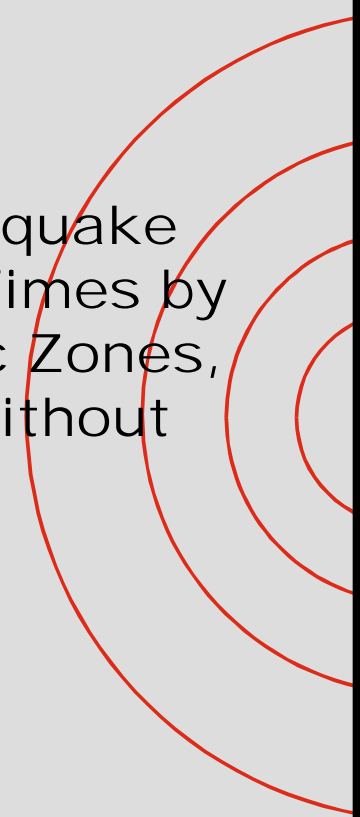


Recovery has two elements: **Repair/reconstruction** (capacity increases) and **Resilience** (productivity changes)

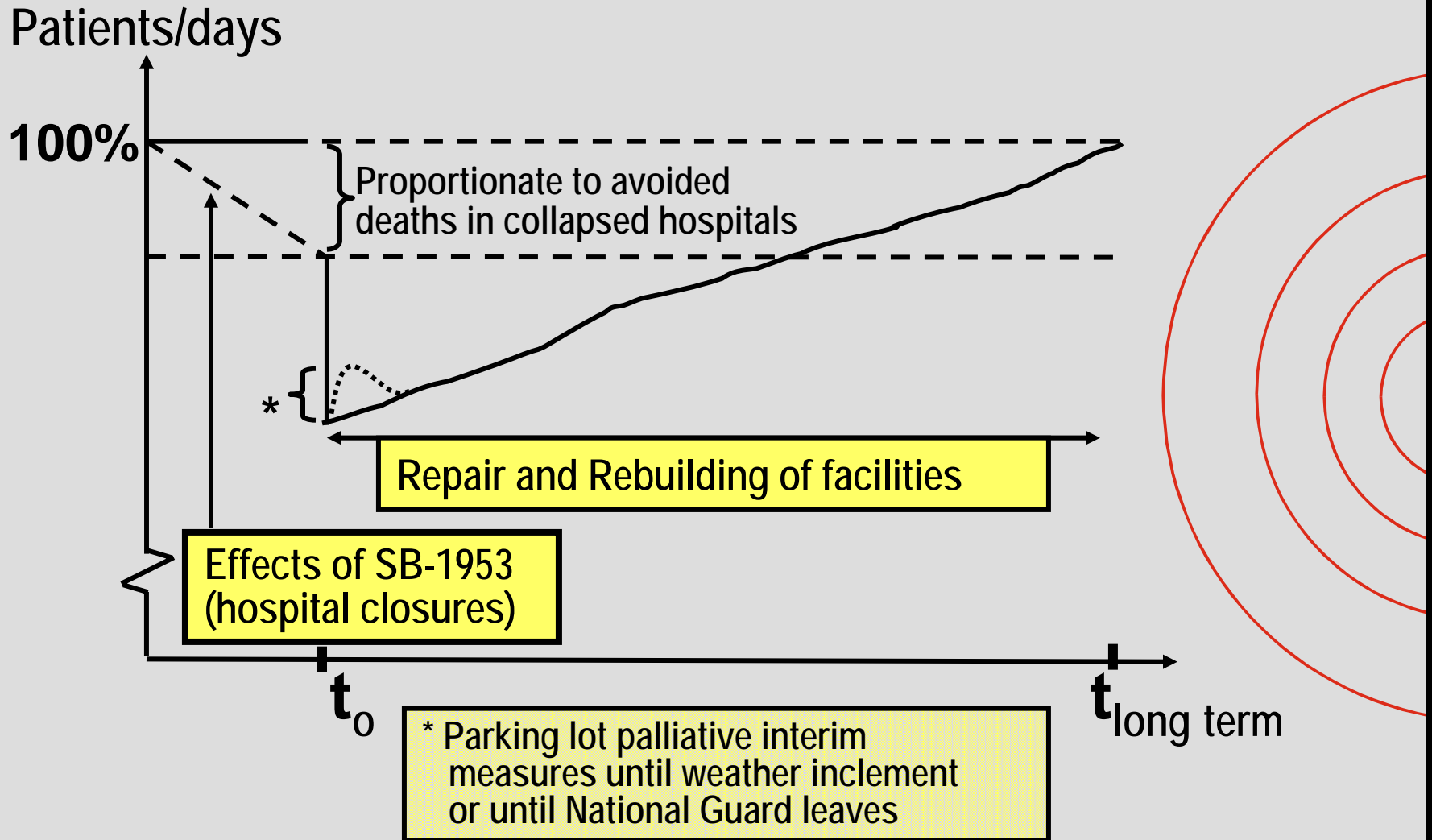
Improved Rapidity of Community Recovery Through Enhanced Robustness

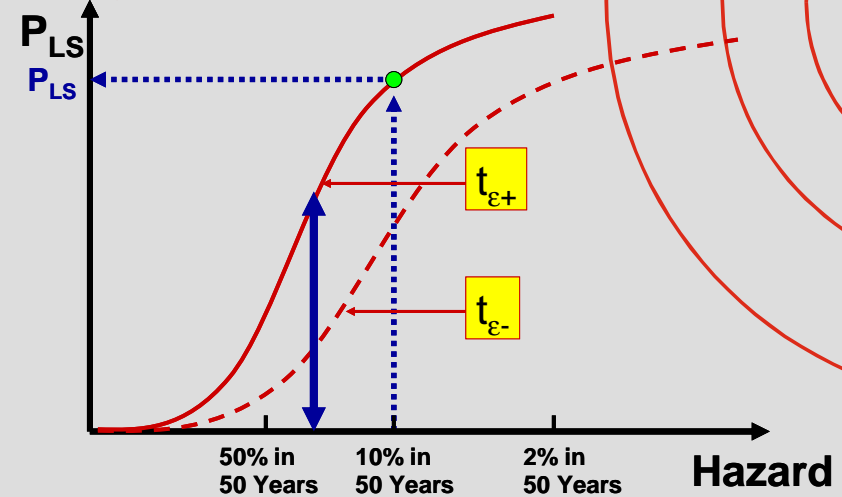
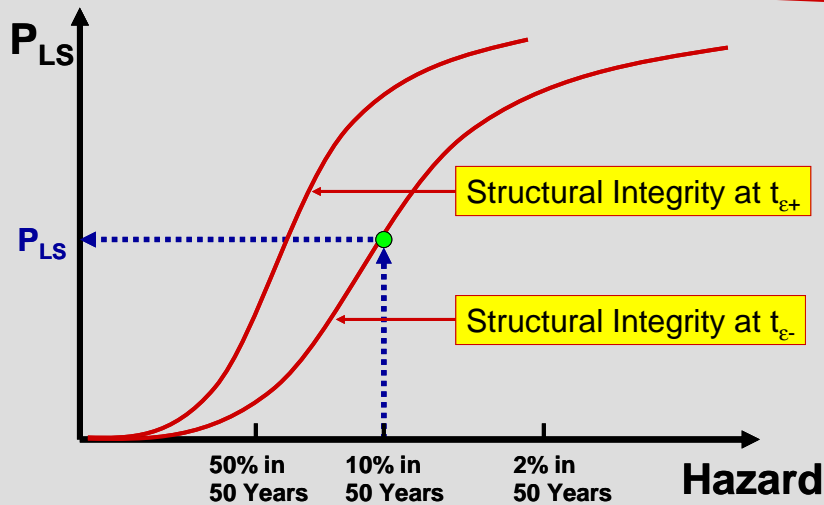
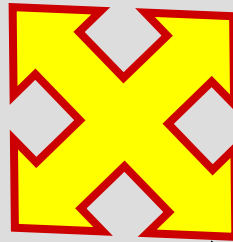
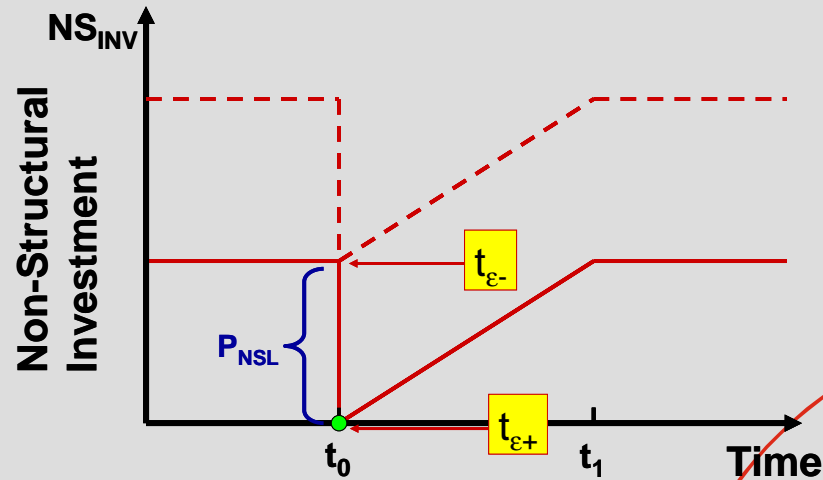
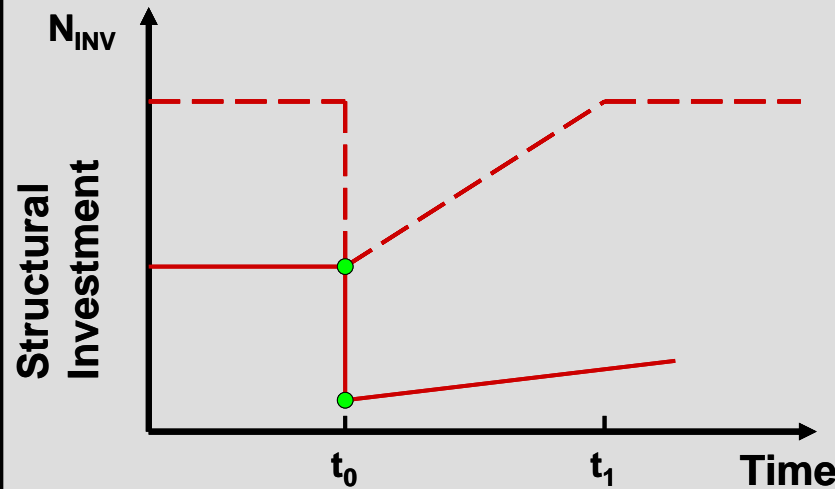


Kobe Earthquake Recovery Times by Geographic Zones, With and Without Mitigation

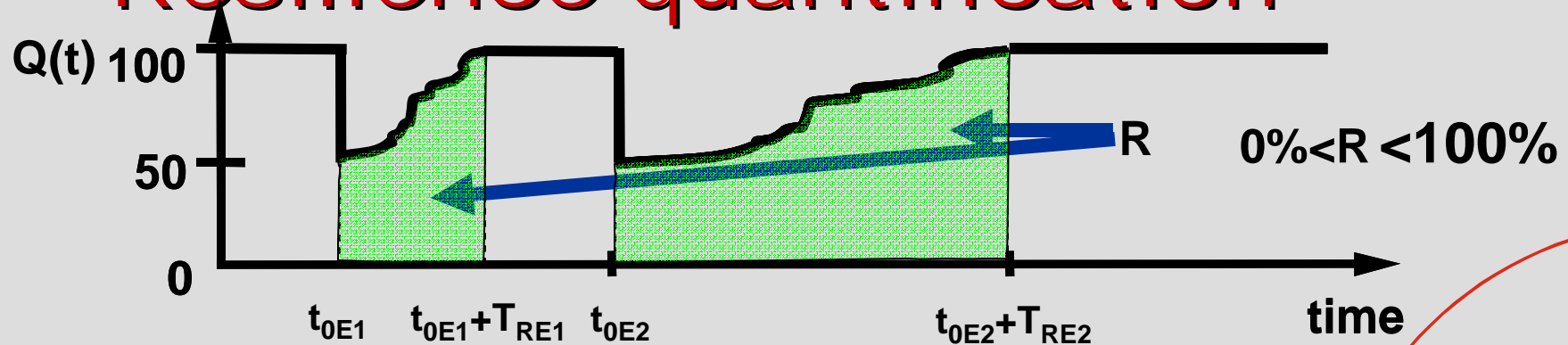


Treatment Capacity of Total Hospital Infrastructure





Resilience quantification



$$\bar{R} = \frac{1}{N_I} \sum_{I=1}^{N_I} \left\{ \frac{1}{N_E} \cdot \sum_{E=1}^{N_E} \frac{1}{T_{RE}} \cdot \int_{t_{0E}}^{t_{0E}+T_{RE}} \left\{ 1 - L(I, T_{RE}) \cdot [H(t_{0E}) - H(t_{0E} + T_{RE})] \cdot \alpha_R \cdot f_{Rec}(t, t_{0E}, T_{RE}) \right\} \cdot dt \cdot p_E(0, T_{LC}) \right\} \cdot P(I)$$

Where:

N_E Number extreme events expected during the lifespan (or control period) T_{LC} of the system

N_I Number of different extreme events intensities expected during the lifespan (or control period) expected during the T_{LC} of the system

T_{RE} Recovery time from event E

t_{0E} Time of occurrence of event E

$f_{rec}(t, t_{0E}, T_{RE})$ Recovery function

$H(t_{0E})$ is a step function (=0 for $t < t_{0E}$; =1 otherwise)

α_R Recovery factor =1 for full recovery

$L_I(I, T_{RE})$ Normalized loss function

$P(I)$ Probability that an event of given intensities happens in a given time interval T_{LC}

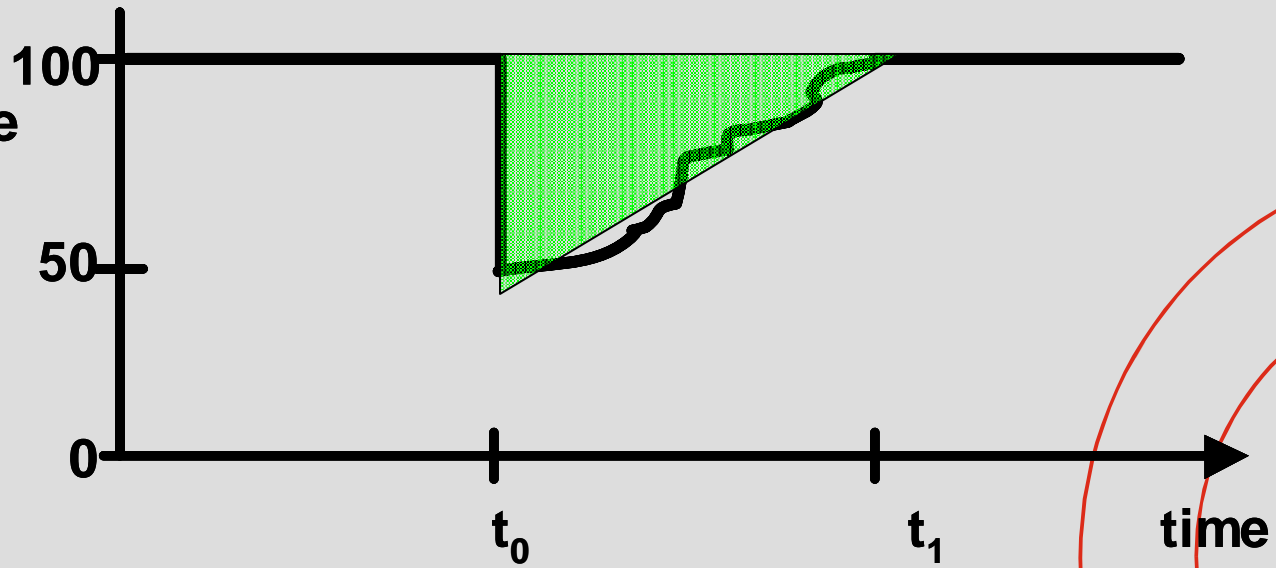
$p_E(0, T_{LC})$ probability that an event happens E times in a given time interval T_{LC}

Key Role of Mitigation

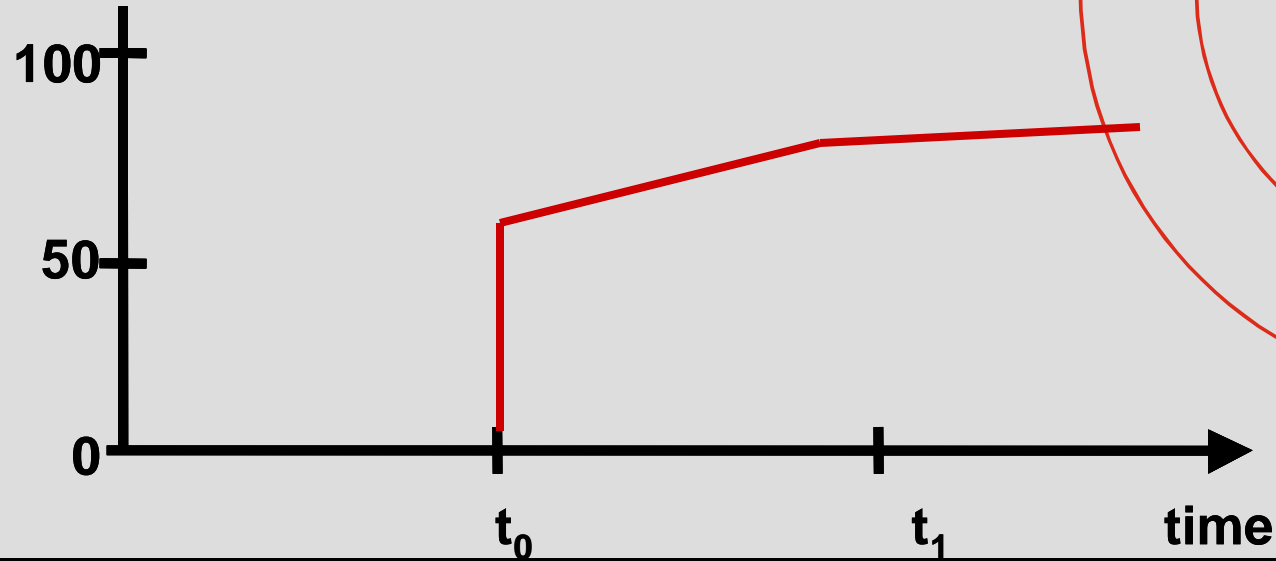
- (Complementary to improvements in response/recovery) Enhancing the Nation's disaster resilience requires mitigating the disaster vulnerability of critical facilities and lifelines
- A perfect response and recovery plan will not eliminate the massive initial losses
- Mitigation needed to break cycle of destruction-reconstruction-destruction-...
- Public expects critical facilities and lifelines to be operational following a disaster

Mitigation and Response

Quality
Of
Infrastructure
(percent)

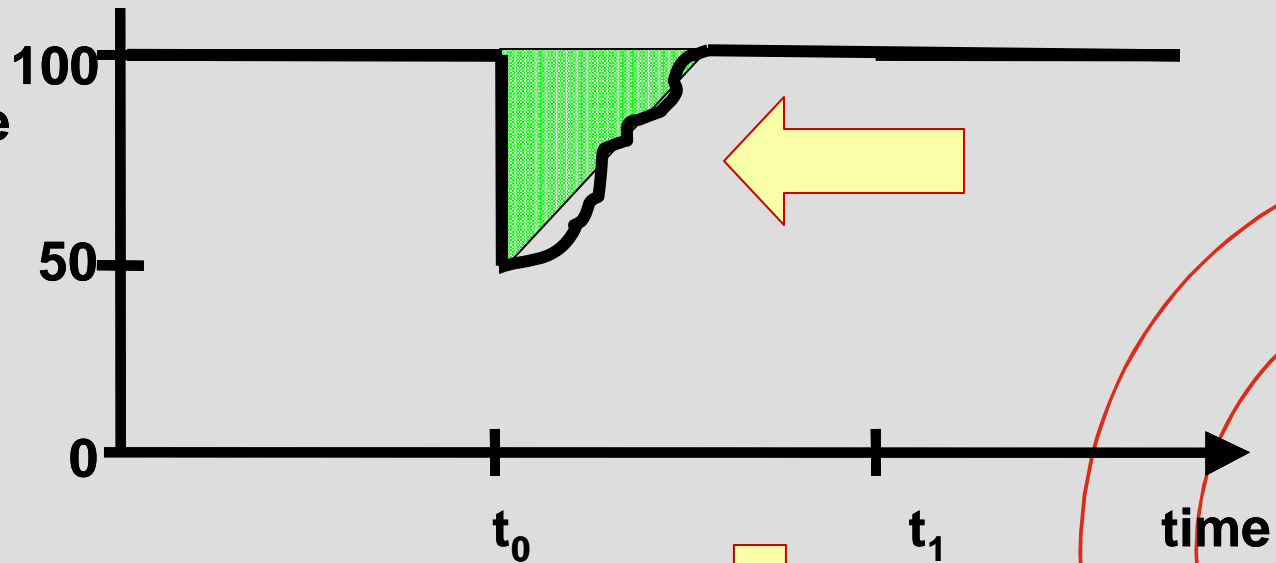


Losses
(Human)
(Direct)
(Indirect)

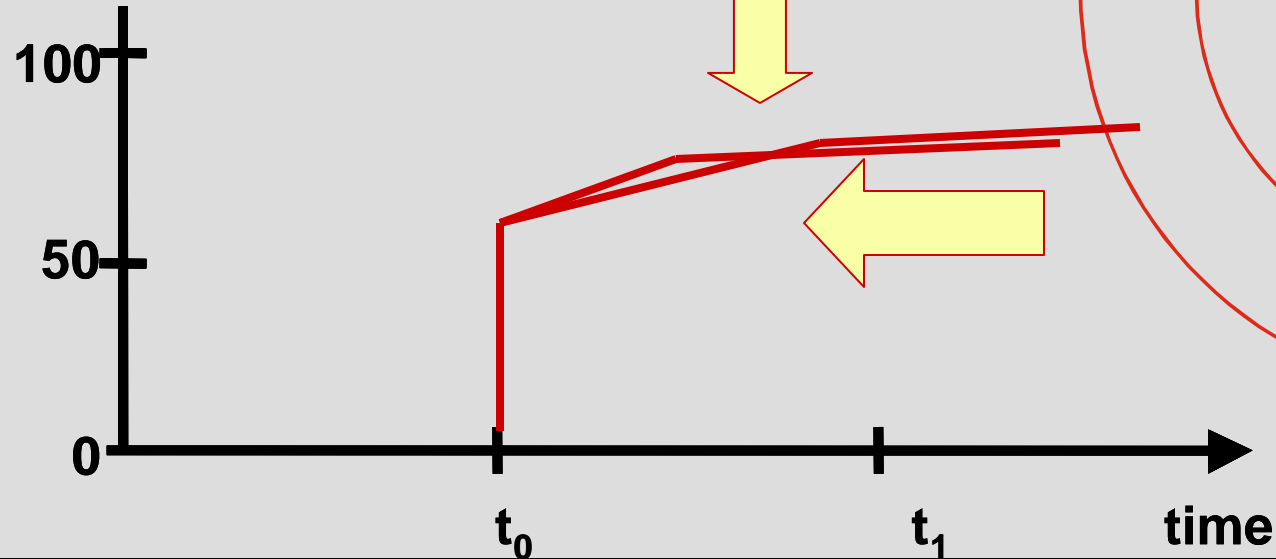


Mitigation and Response

Quality
Of
Infrastructure
(percent)

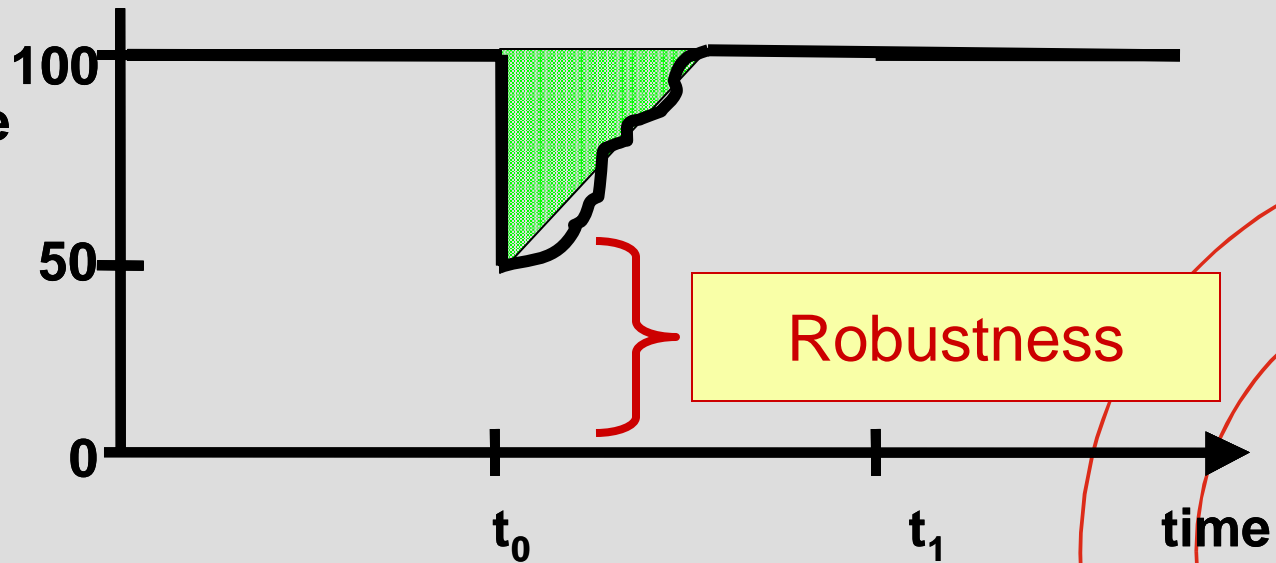


Losses
(Human)
(Direct)
(Indirect)

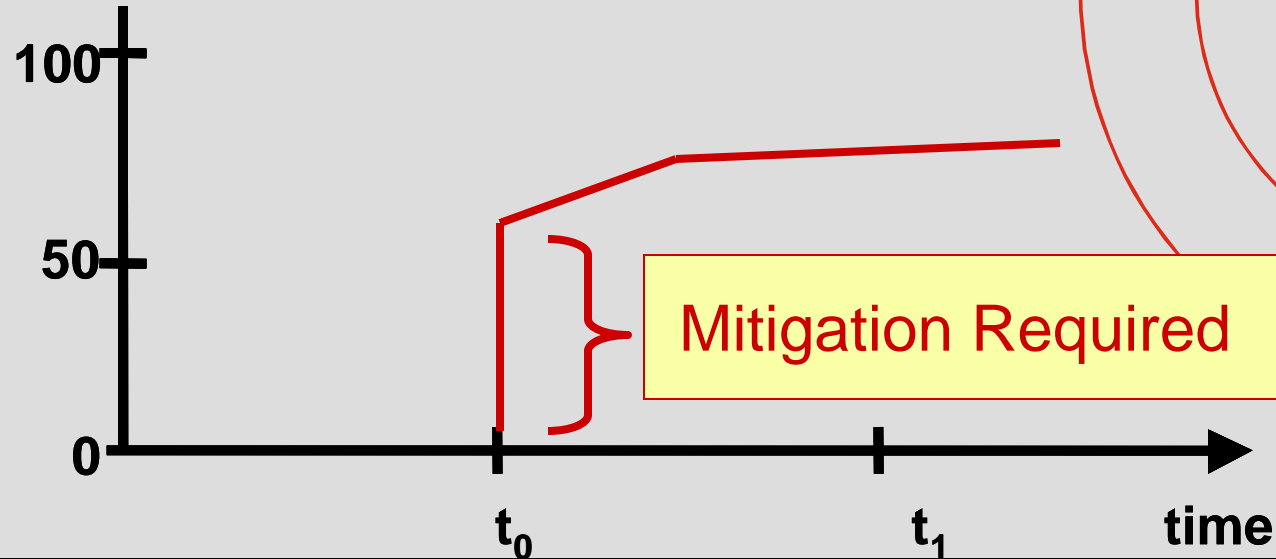


Mitigation and Response

Quality
Of
Infrastructure
(percent)



Losses
(Human)
(Direct)
(Indirect)



“Natural Hazard Mitigation Saves” Report

- National Institute of Building Sciences
- 5 Year Study
- Federal funding for mitigation is cost effective
 - \$1 of mitigation = \$4 of saved losses



NATURAL HAZARD MITIGATION SAVES: An Independent Study to Assess the Future Savings from Mitigation Activities

Volume 1 – Findings, Conclusions, and Recommendations

Conclusions

- MCEER has developed a methodology to frame and quantify disaster resilience
- A “meta-concept” applicable to all hazards and critical infrastructure types
- MCEER has operationalized and measured resilience in real-world settings (MCEER Test-Beds)
- New MCEER Vision: Resilience in **all extreme events**– Operationalized in presentations that follow

Thank you!

Questions?