System Performance Under Multihazards

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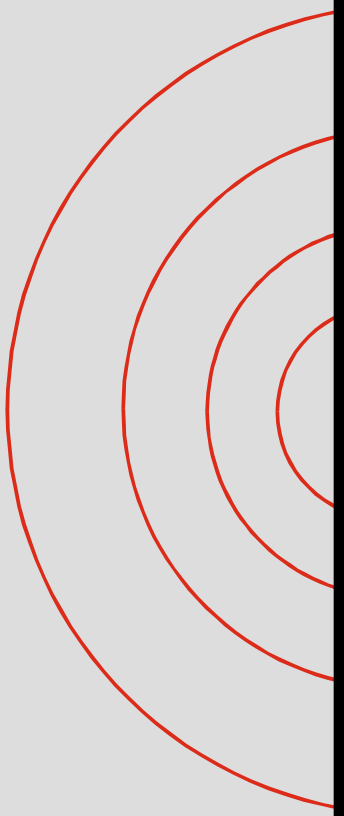


MCEER 2006 Annual Meeting

"*Enhancing Resilience Against Multiple Hazards*"

June 29, 2006

The Four Fundamental Properties of Resilience

robustness

redundancy

resourcefulness

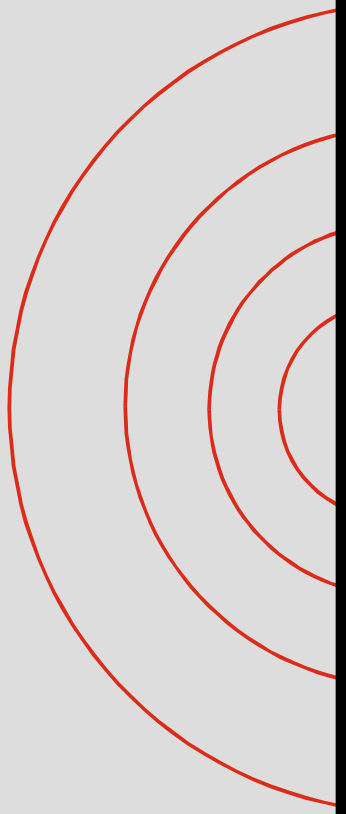
rapidity

System Performance Under Multihazards

- Objectives:
  - Maximize robustness, *i.e.*, facility availability, and
  - Maximize rapidity, *i.e.*, minimize restoration time for damaged facilities
- Means of achieving these objectives:
  - Increase system redundancy
    - components connected in parallel
    - replacement components in inventories
  - Increase resourcefulness; *i.e.*, reduce system fragility

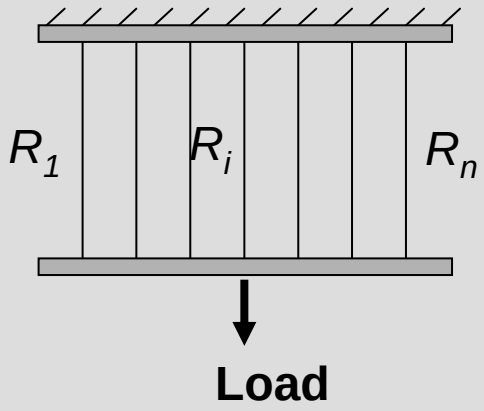
Analysis and Design Under Multihazards

- Computational model:
  - Temporal/spatial discretization
  - Response level
- System fragility:
  - System topology
  - Hazard level
- Multihazards:
  - Consequences / safety levels
  - Hazards concurrence

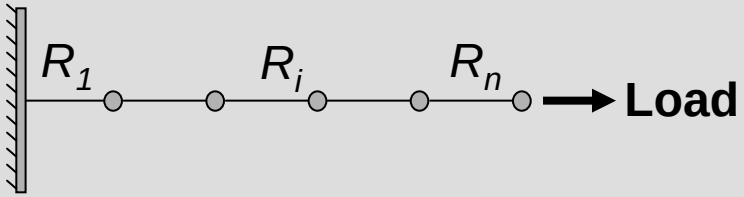


- **System fragility** (topology / hazard level):
  - System with *n* components of capacity R_i

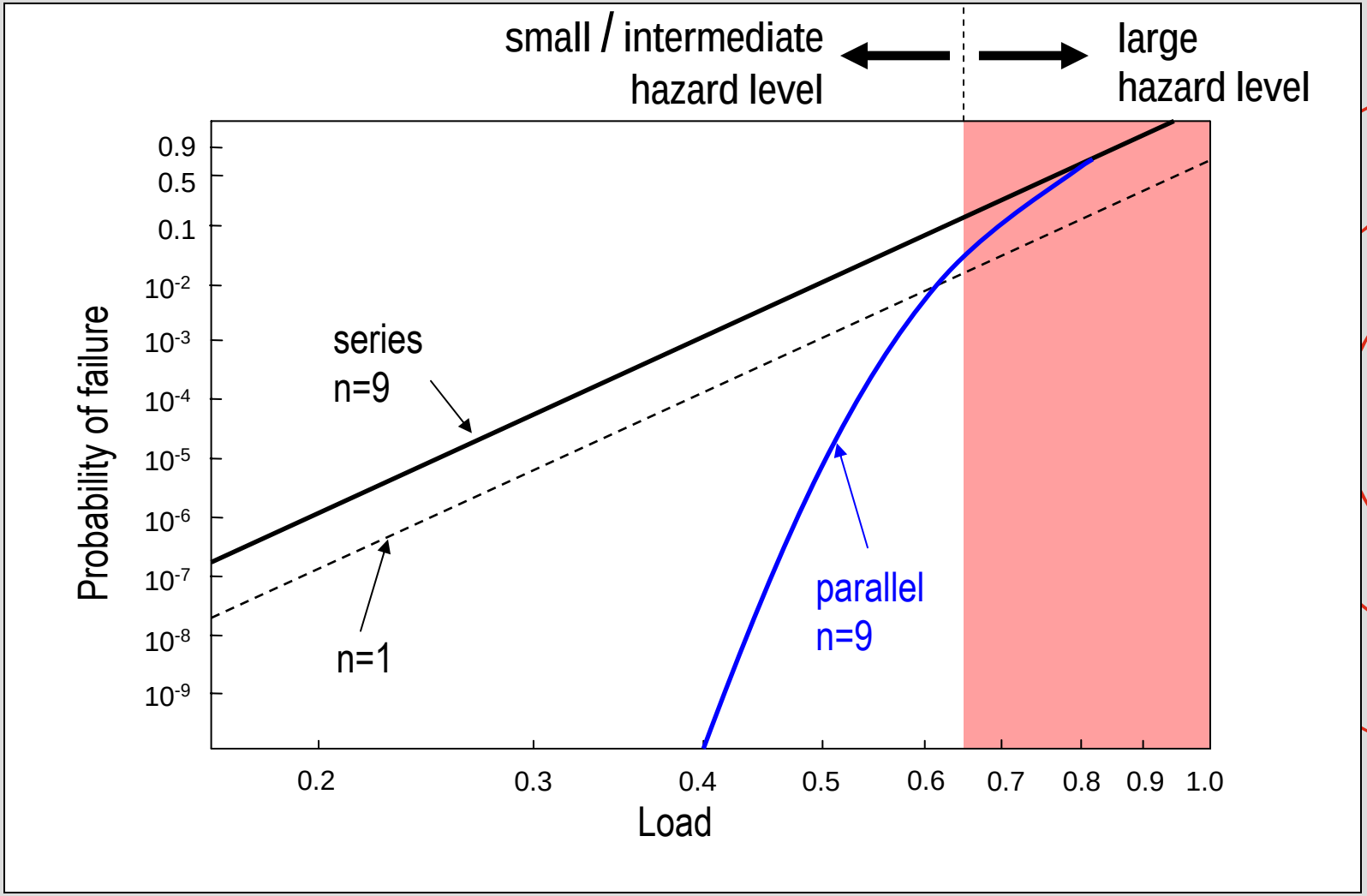
Brittle parallel system



Series system

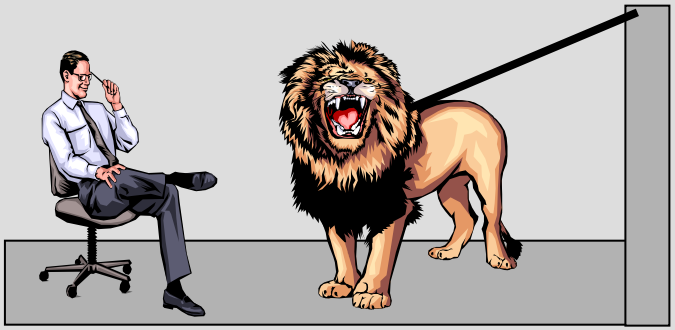


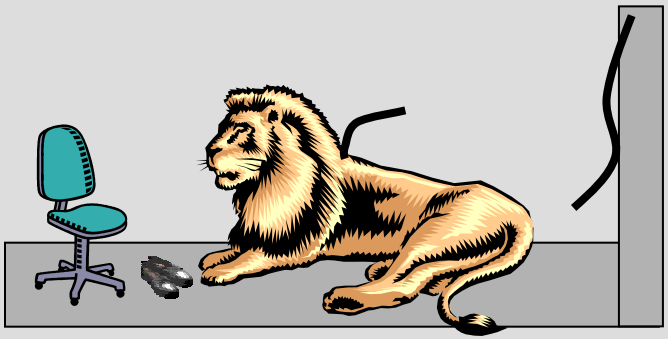
- System fragility (R_i ~ i.i.d. Weibull (ρ =10) random variables)



- **Multihazards** (consequences / safety levels):

Severe consequences



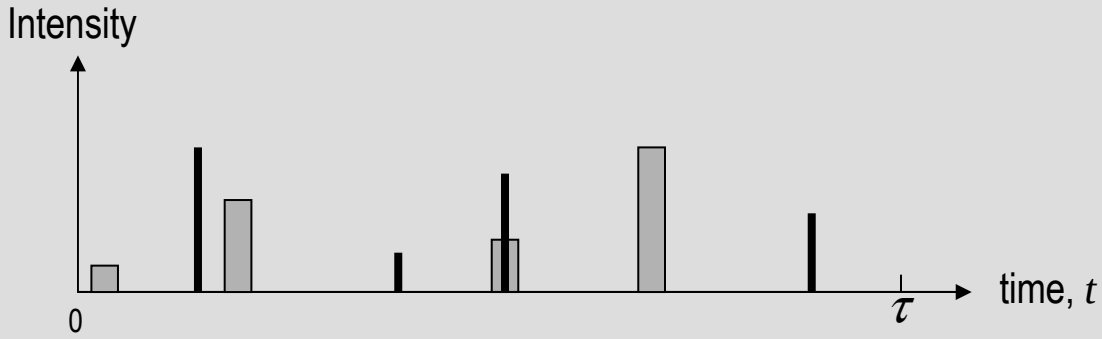


very large safety levels

Mild consequences

moderate safety levels

- **Multihazards** (hazards concurrence):
  - System under multihazards
    (*e.g.* extraordinary live loads, tornadoes, earthquakes, blasts)



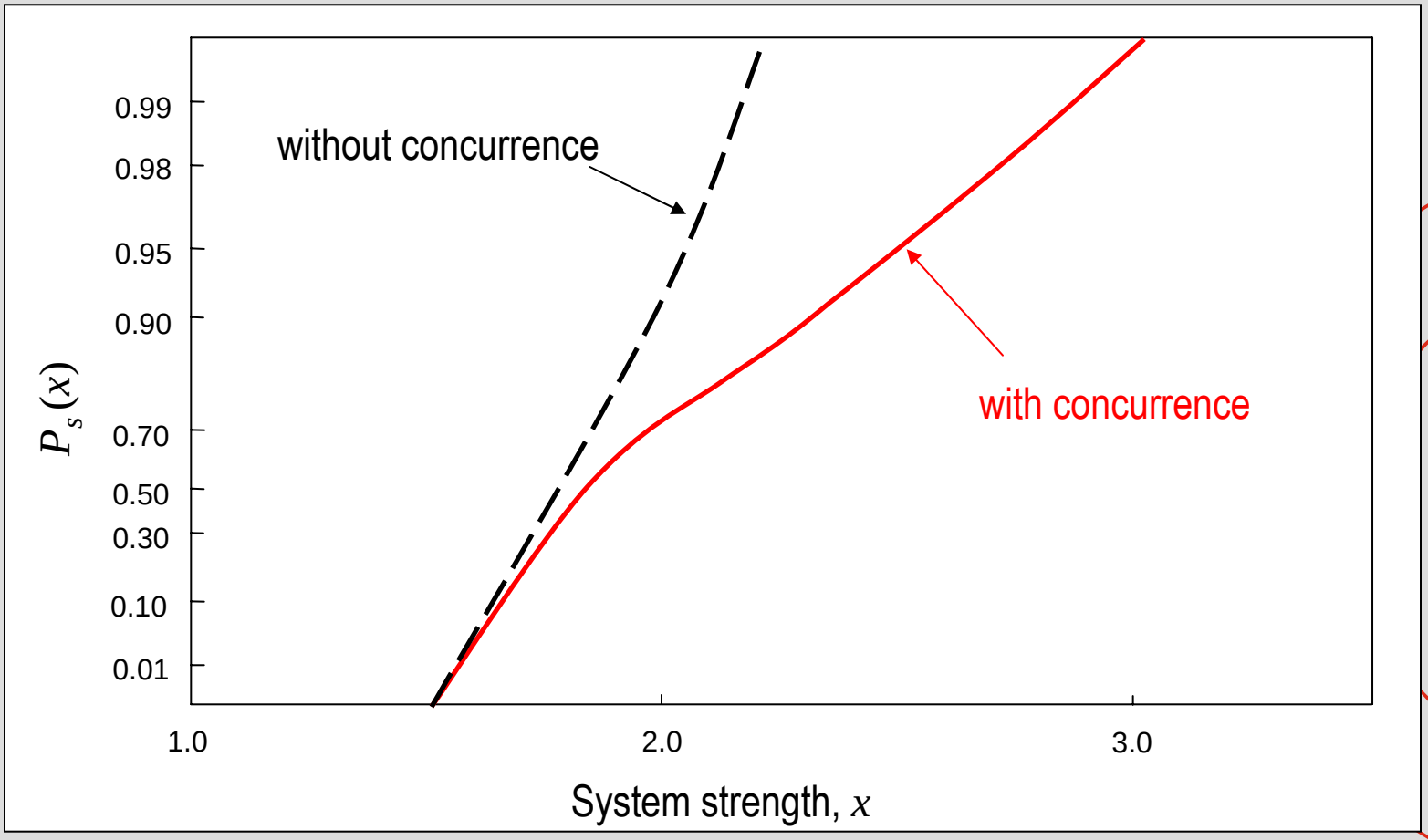
  - System reliability under 2 hazards in $(0, \tau)$

$$P_s(x) = \exp\left[-\upsilon_1\tau(1-F_1(x)) - \upsilon_2\tau(1-F_2(x)) - \upsilon_1\upsilon_2(\mu_1+\mu_2)\tau(1-F_{12}(x))\right]$$

υ_k = mean arrival rate of hazard k $\quad F_k$ = cdf of hazard k intensity

μ_k = average duration of hazard k $\quad F_{12}$ = cdf of combined hazard intensity

- System reliability $\left(\upsilon_1 = \upsilon_2 = 2/\text{yr},\ \mu_1 = \mu_2 = 10^{-3}\,\text{yr},\ \tau = 50\ \text{yr},\ F_1 = F_2 = N(1, 0.09)\right)$



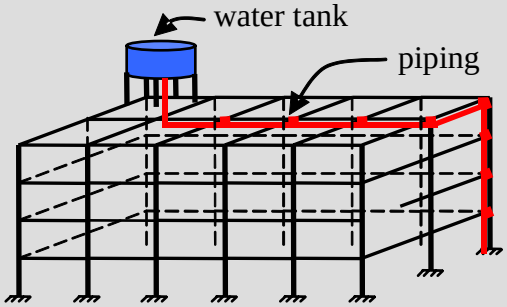
Note: $1\text{-}P_s(x)$ = system fragility under multihazards

Benchmark Problem (seismic hazard)

- Structural/nonstructural systems:
  - MCEER West Coast Demonstration Hospital
  - Nonstructural systems
    - heating, ventilating, air-conditioning
    - partition walls
    - piping
- Objective: Develop a method for estimating life cycle capacity/cost for the MCEER Demonstration Hospital

Methodology:

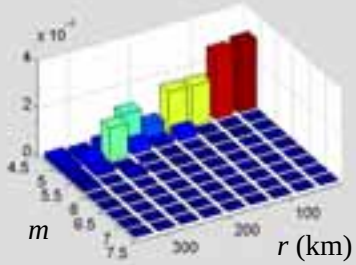
Structural/nonstructural system definition



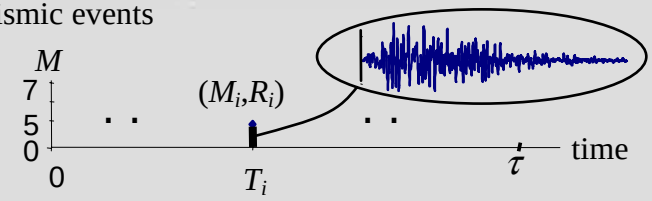
Seismic hazard

- USGS → seismic activity matrix

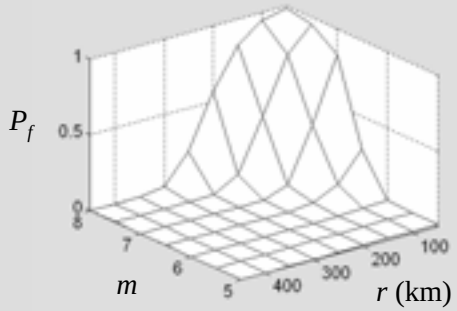
mean annual rate



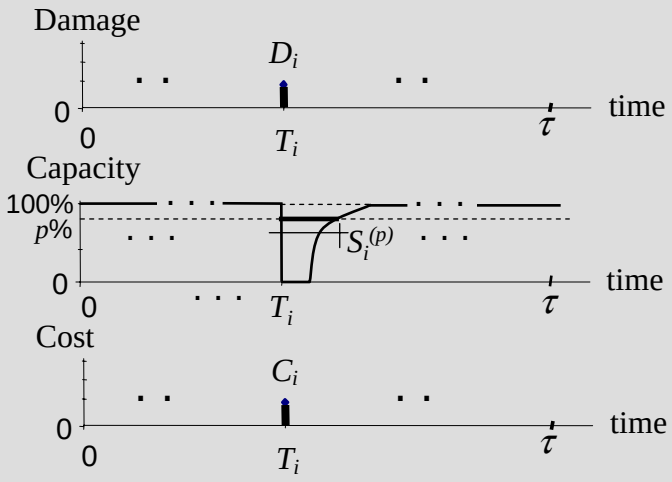
- Seismic events



Fragility surfaces
(for specified limit states)



Life cycle capacity/cost estimates



Life cycle capacity/cost estimates:

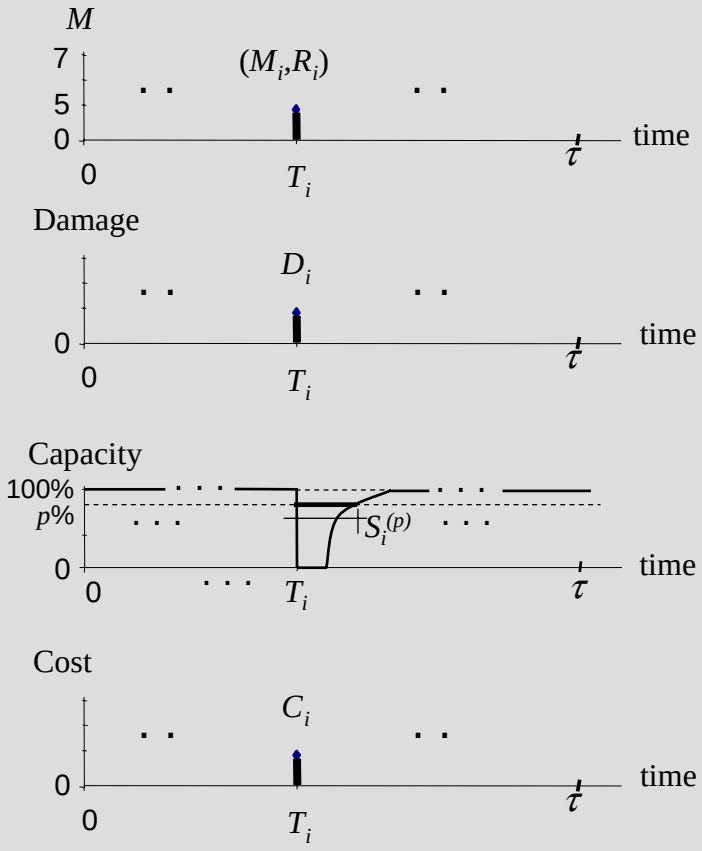
- Capacity estimate during time τ

$$S_p(\tau) = \sum_{i=1}^{N(\tau)} S_i^{(p)}$$

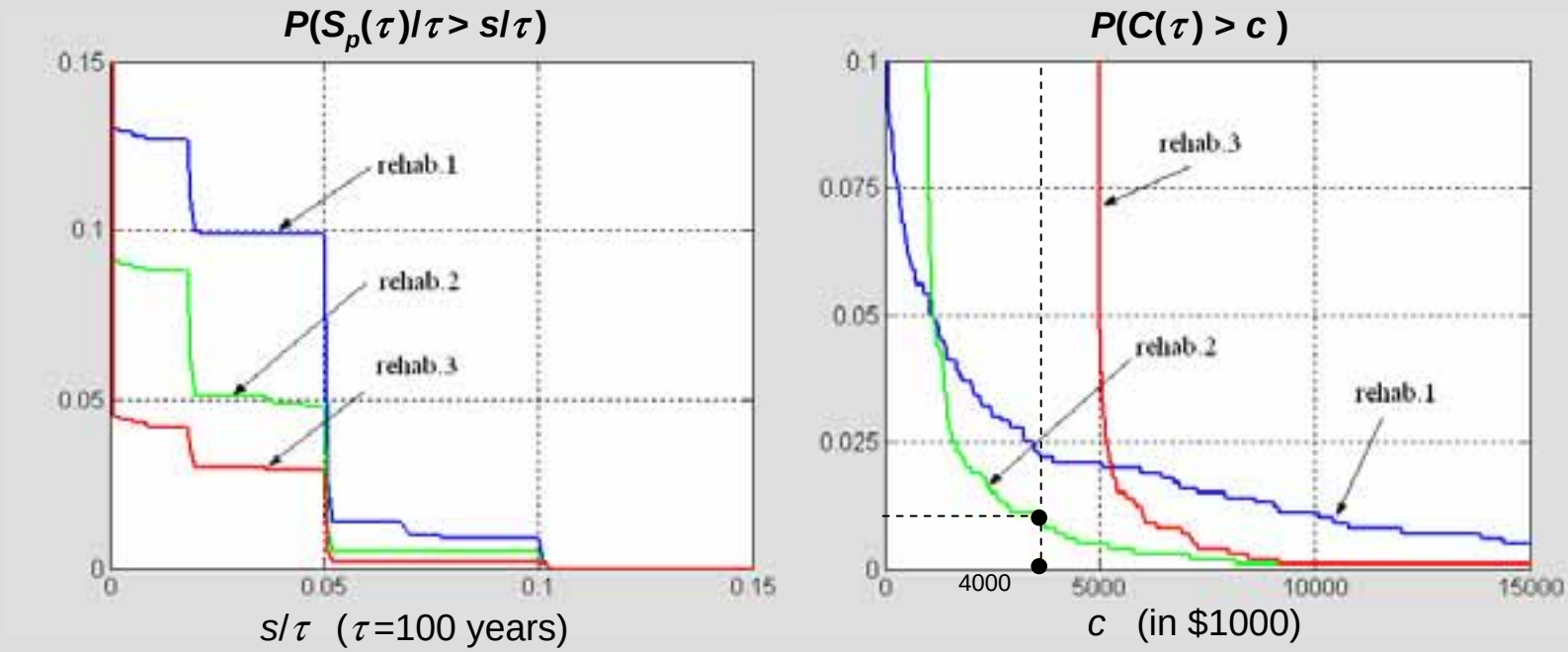
- Cost estimate at time τ

$$C(\tau) = \underset{(\nearrow)}{\text{rehabilitation cost}} + \sum_{i=1}^{N(\tau)} \underset{(\searrow)}{C_i/(1+dr)^{T_i}}$$

$\Rightarrow$ Optimal rehabilitation strategy



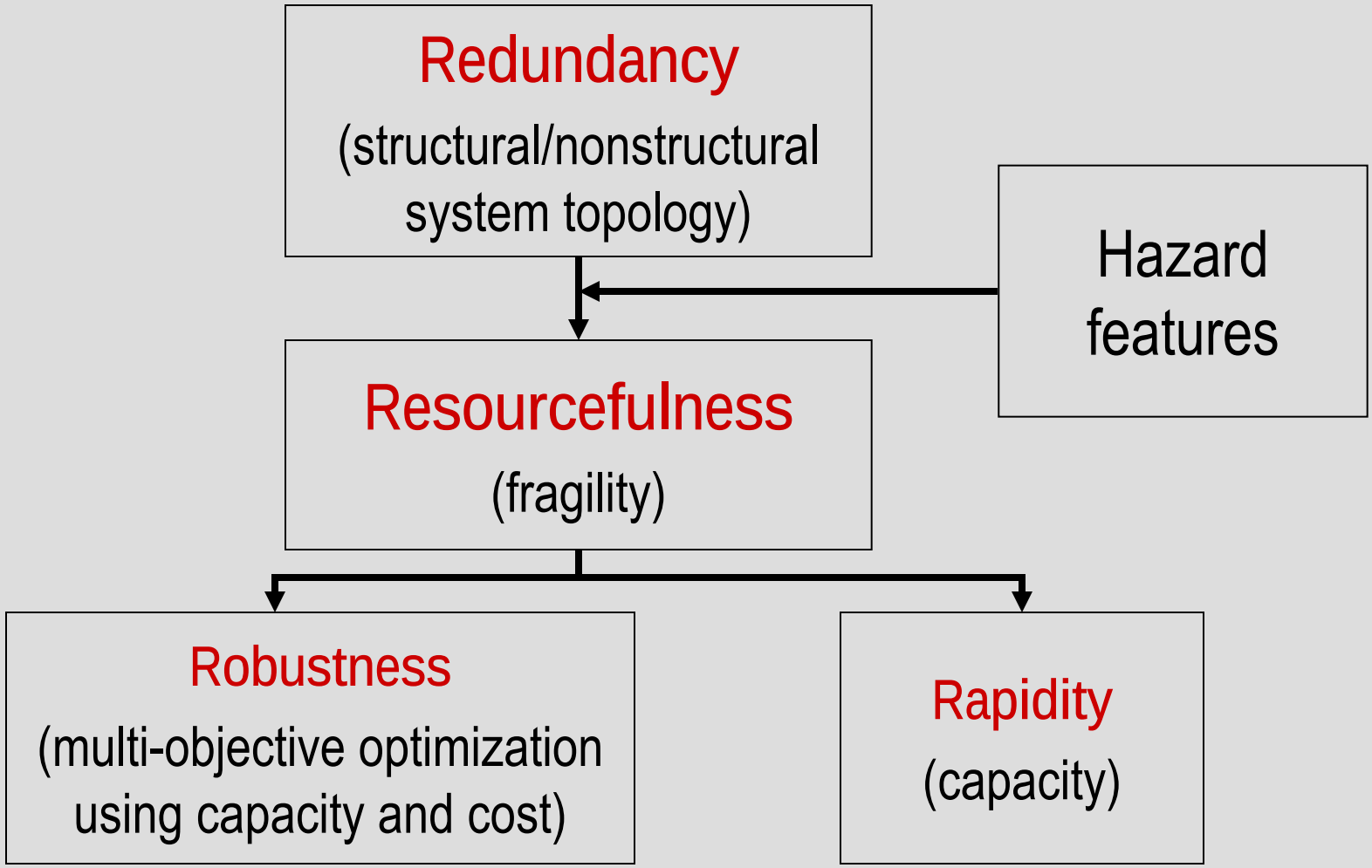
- Performance measures (compare 3 rehabilitation alternatives)



- Example of optimal rehabilitation strategy: minimize $P(C(\tau)>4000)$

  $\Rightarrow$ rehabilitation strategy 2

r^4 Performance Measures (technical)



- Performance criteria and measures under multihazards

Performance measures

Performance criteria	Robustness	Redundancy	Resourcefulness	Rapidity
Technical	Damage avoidance and continued service provision	Backup/duplicate systems, equipment and supplies	Diagnostic and damage detection technologies and methodologies	Optimizing time to return to pre-event functional levels
Organizational	Continued ability to carry out designated functions	Backup resources to sustain operations	Plans and resources to cope with damage and disruption	Minimize time needed to restore services and perform key response tasks
Social	Avoidance of casualties and disruption in the community	Alternative means of providing for community needs	Plans and resources to meet community needs.	Optimizing time to return to pre-event functional levels
Economic	Avoidance of direct and indirect economic losses	Untapped or excess economic capacity	Stabilizing measures	Optimizing time to return to pre-event functional levels