ASCE Geo-Institute February 2018

Infrastructure Lifelines Systems: Risk and Reliability

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CAL POLY

Civil and Environmental Engineering

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DHS

CalOES

NavFac

Components implemented in:

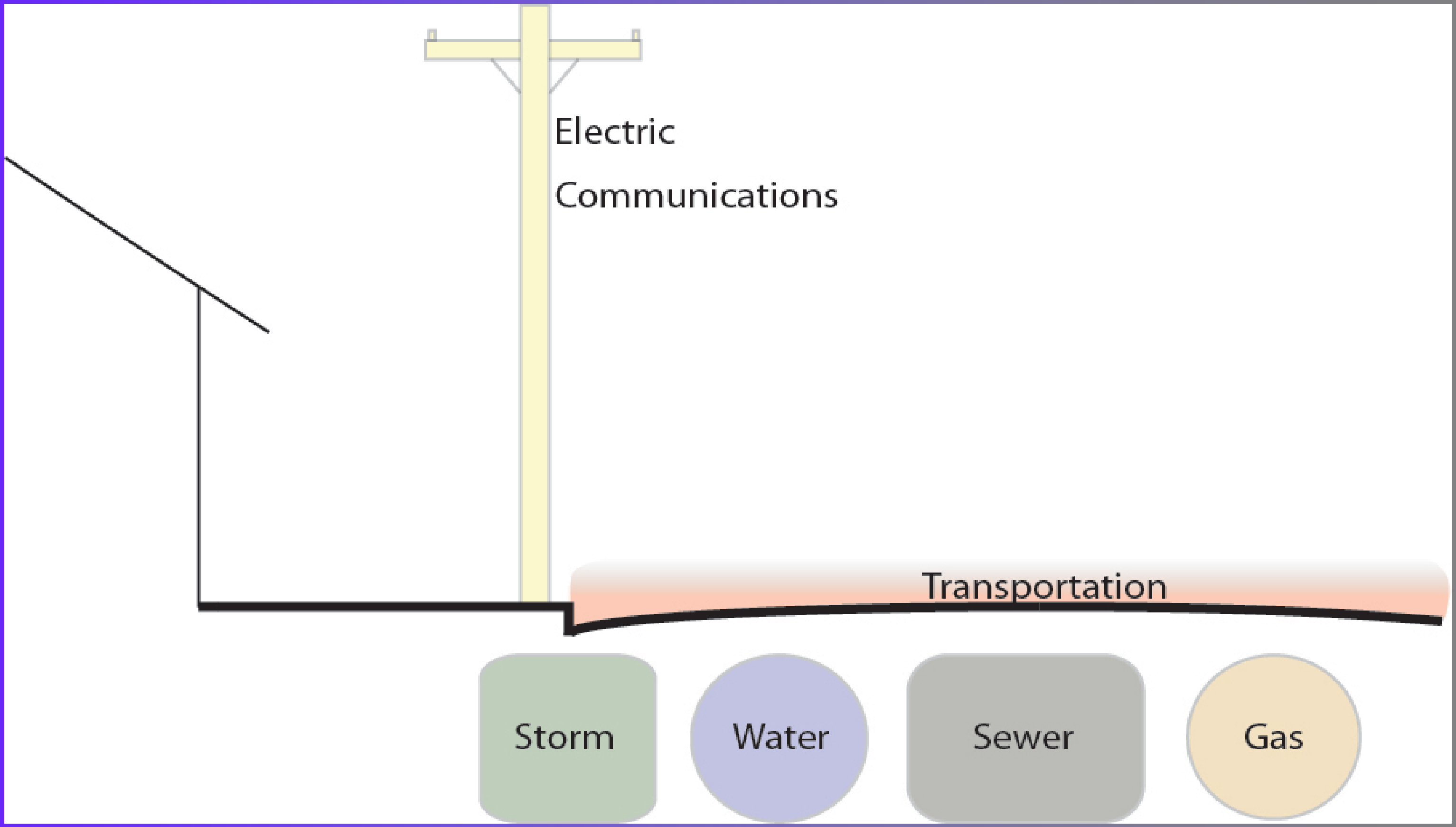
- CA SHMP (2013, 2018)
- Moss 2013
- Moss & Hollenback 2015

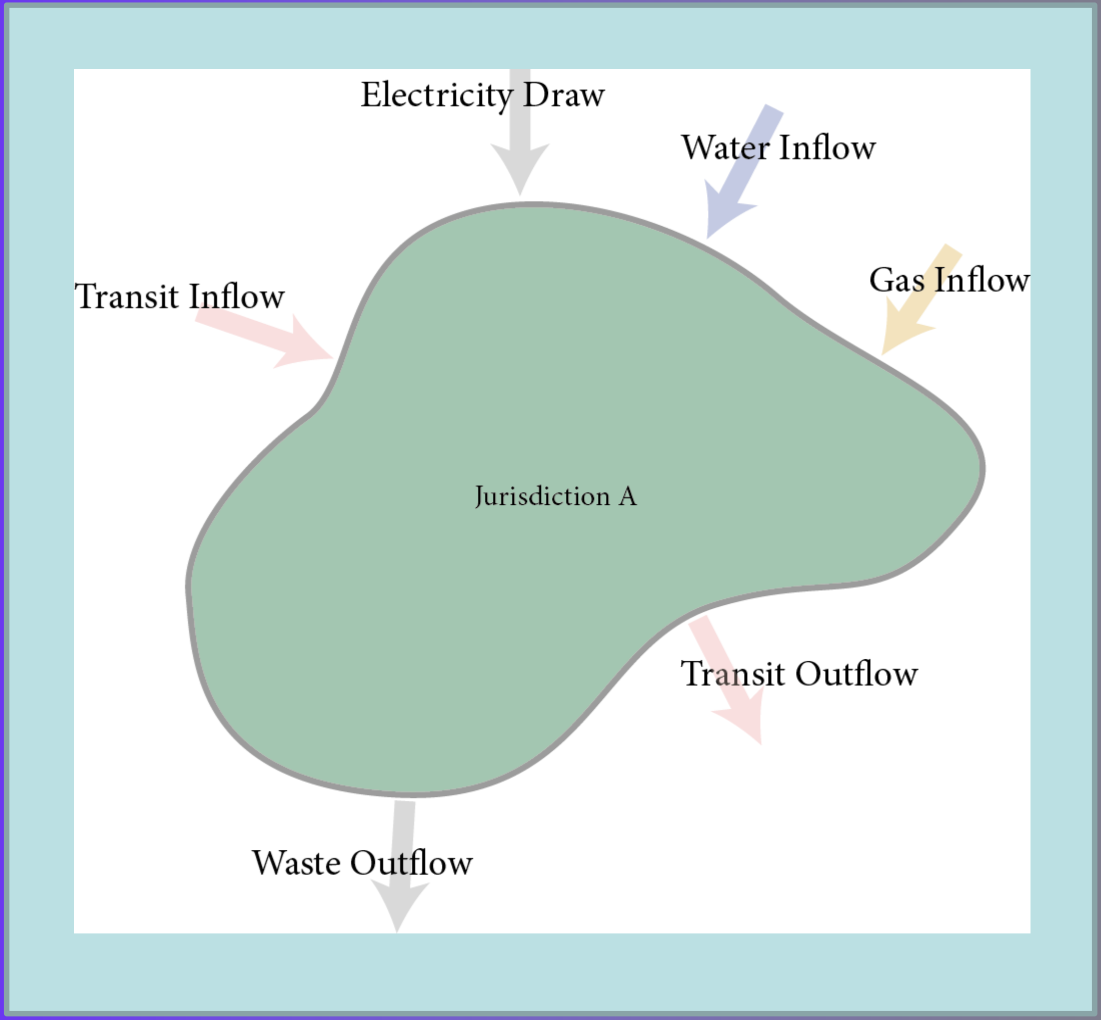
Thanks to former students:

Justin Hollenback, PhD

Michael Germeraad, MS

Lifelines


Electric
Communications
Transportation
Storm
Water
Sewer
Gas

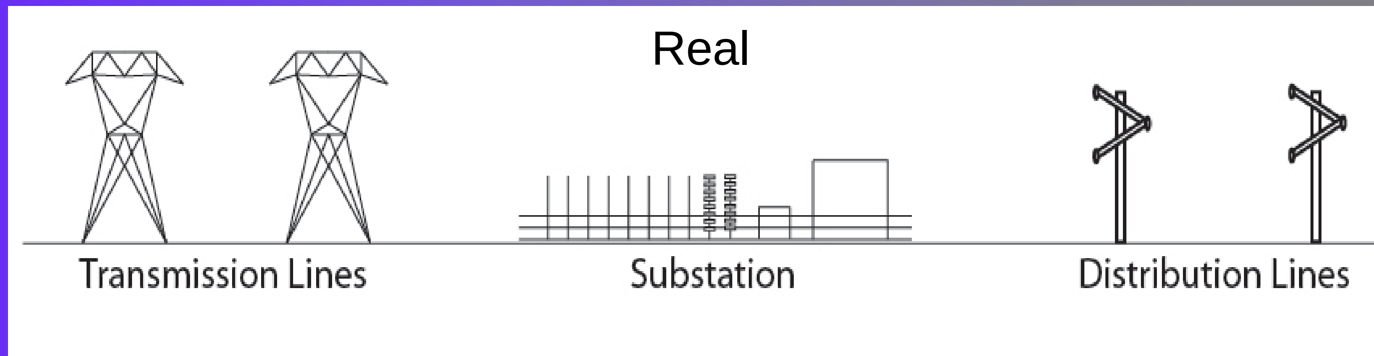

Electricity Draw
Water Inflow
Gas Inflow
Transit Inflow
Jurisdiction A
Transit Outflow
Waste Outflow

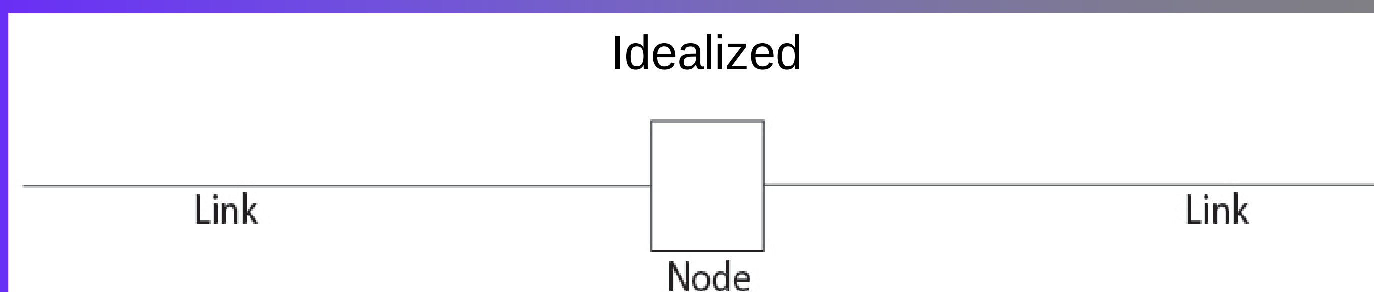
Background

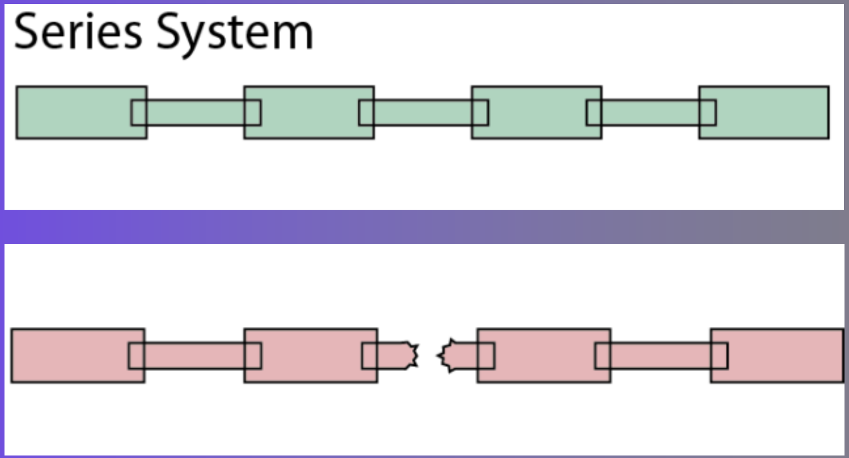
Case Histories

Concepts

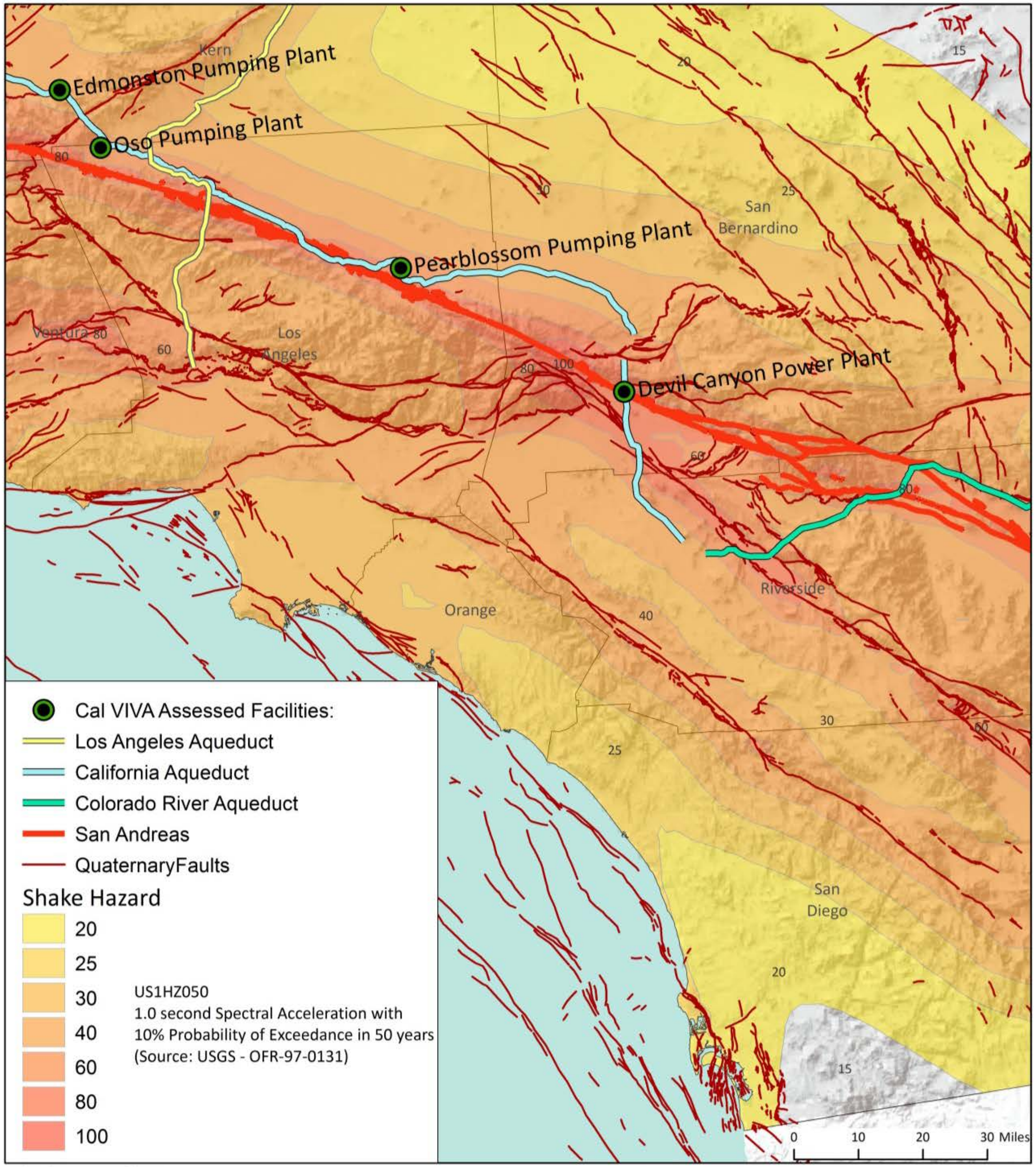
Summary







- Interconnected/Interdependent Systems
- Spatially Correlated (load and resistance)
- Redundancy vs Capacity | Active vs Passive
- Ageing and Maintenance and Retirement



Cal Poly, San Luis Obispo
City and Regional Planning
June 2013

Sources: USGS, CA Natural Resources Agency, CA DWR

Created by: C. Schuldt (Annex 3--SoCal Water EQ Vuln.mxd)

Why a Geo(Institute) Issue?

Geotech's are often the lead on Hazards that control the design:

- **Ground shaking**
- **Fault rupture**
- **Slope Instability**
- **Ground deformations**
- **etc**

Loma Prieta 1989

Hazards = Ground Shaking + Liquefaction + Fire

"Seismically Resistant" Axillary Water System Failed

Fire Suppression succe

ts

Backup Systems / Redundancy / Load Correlation

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La Conchita 2005 (Montecito 2018)

Rainfall Induced Landslide/Deb

Hwy 101 and Rail Corridor bloc

Limited/Difficult Transportation Alternatives

Lifeline Outage & Repair Cost

New Orleans Levee Failure 2005

Uniform Loading vs Non-

Levee Breach due to Inadequate Engineering

Component Failure = System Failure

Series System / Weak Link

Chile 2010 Earthquake

Ground Shaking damage

Power loss disrupted Communication and Water

Ground failures along Hwys hindered Rescue/Repair

Interdependence / Redundancy

Japan 2011 Earthquake/Tsunami

Tsunami damaged Power Grid and Backup Power

Nuclear facility required Power to Shutdown

Redundancy / Active vs Passive

Oroville Dam 20

Half a century of adequate performance

Excessive Erosion of Main and Emergency Spillway

Ageing / Redundancy

Montecito Debris Flows 2018

Water distribution syste

Fire disabled control-inl

Storm-caused power ou
other SCADA controls

Debris flows sheared pipelines at several locations

Uncontrolled reservoir release, during ongoing drought

Multi-hazard / Spatial Correlation

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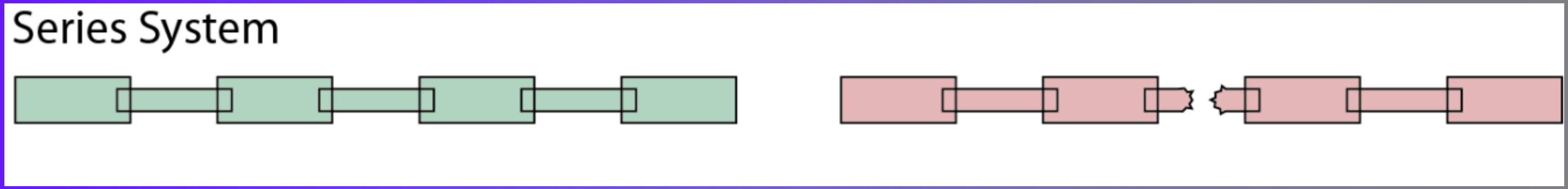
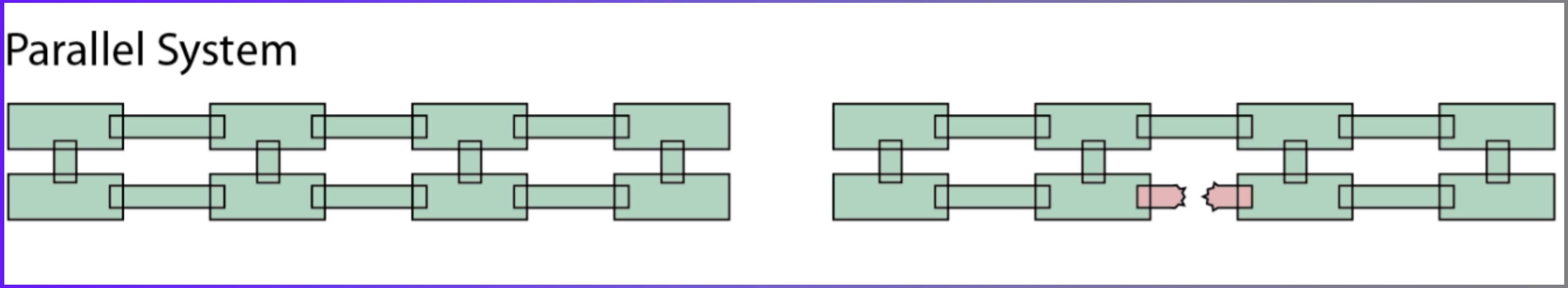
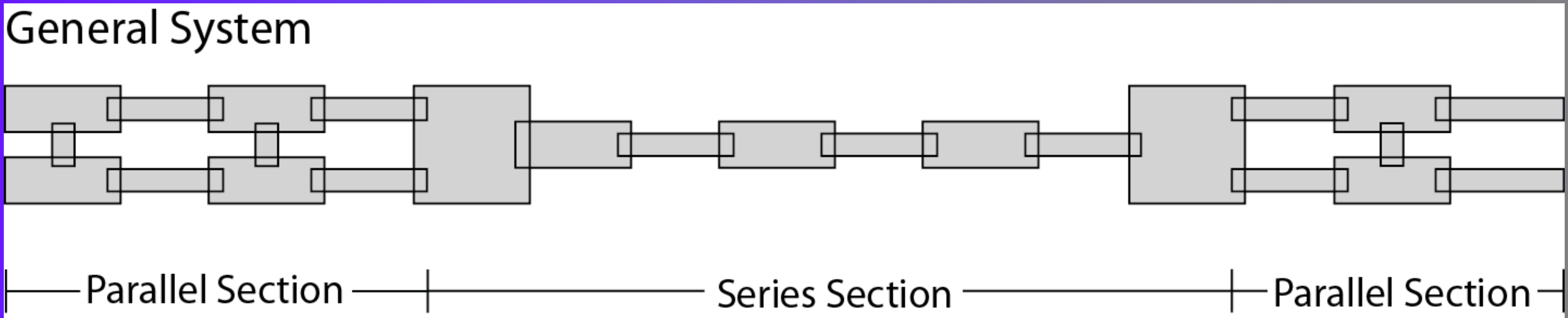
Conceptual Arrangement of Components (Links and Nodes)



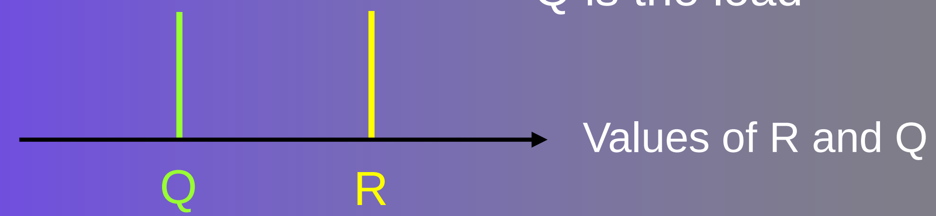




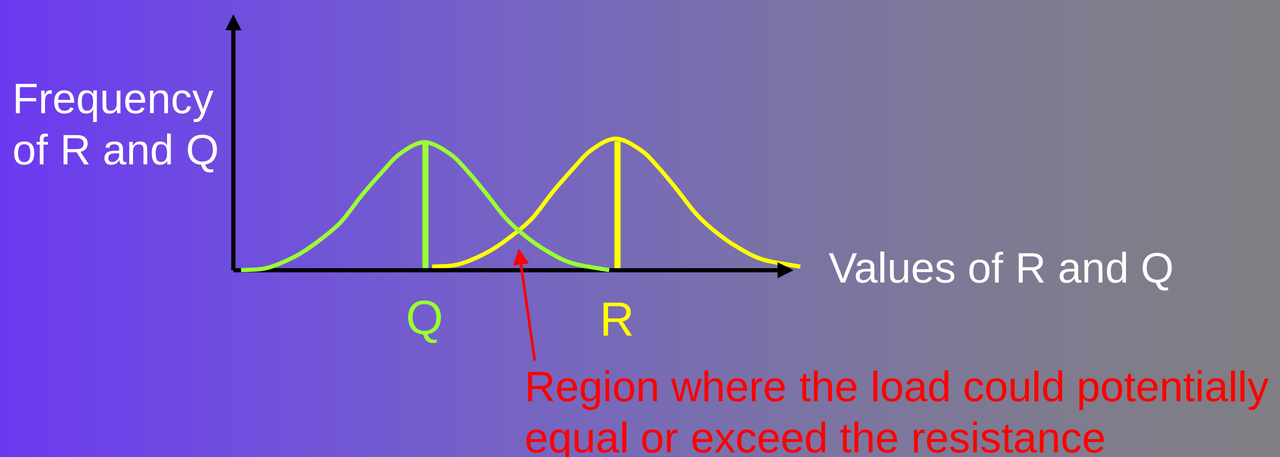
Reliability = Load vs Resistance

Deterministic View

R is the resistance
Q is the load



Probabilistic View (includes uncertainty in load and resistance)



Component Reliability

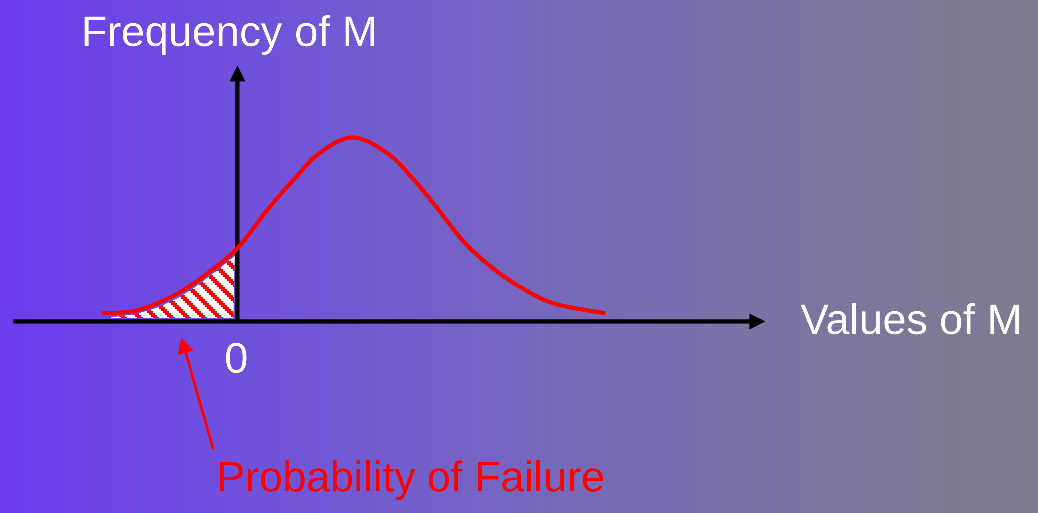
Components (Nodes or Links)

<u>Margin of Safety (or Limit State) Formulation</u>

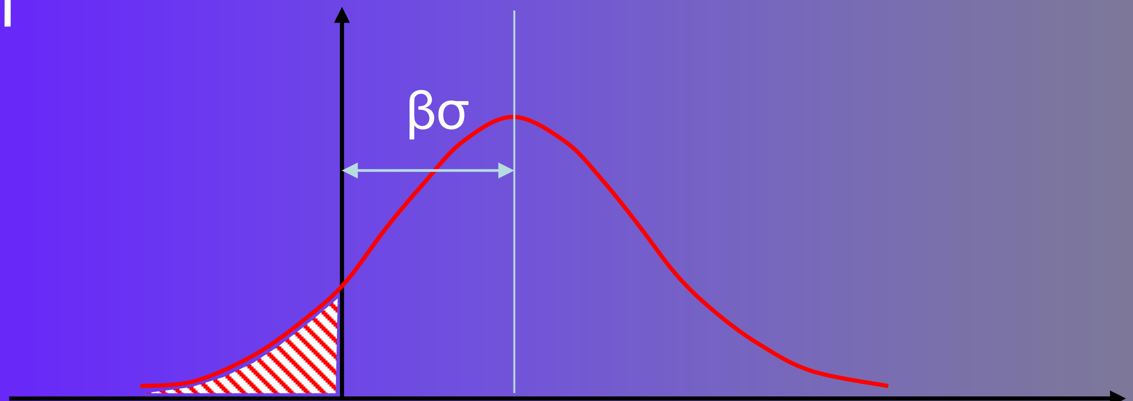
M = R - Q where R and Q are uncertain

f(M) = f(R) – f(Q) propagate uncertainty

if M ≤ 0, then failure / unsatisfactory performance



Component Reliability



Code requires reliability index (β) of at least 2.0, and up to 3.0 for critical facilities, which means 2 to 3 standard deviations away from failure

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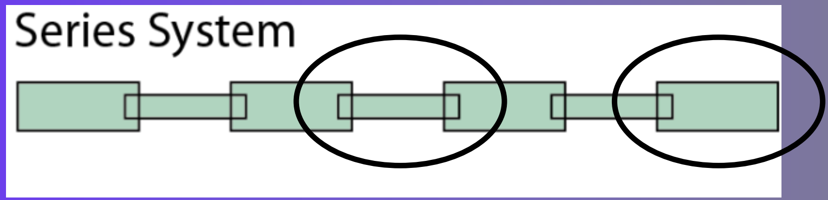
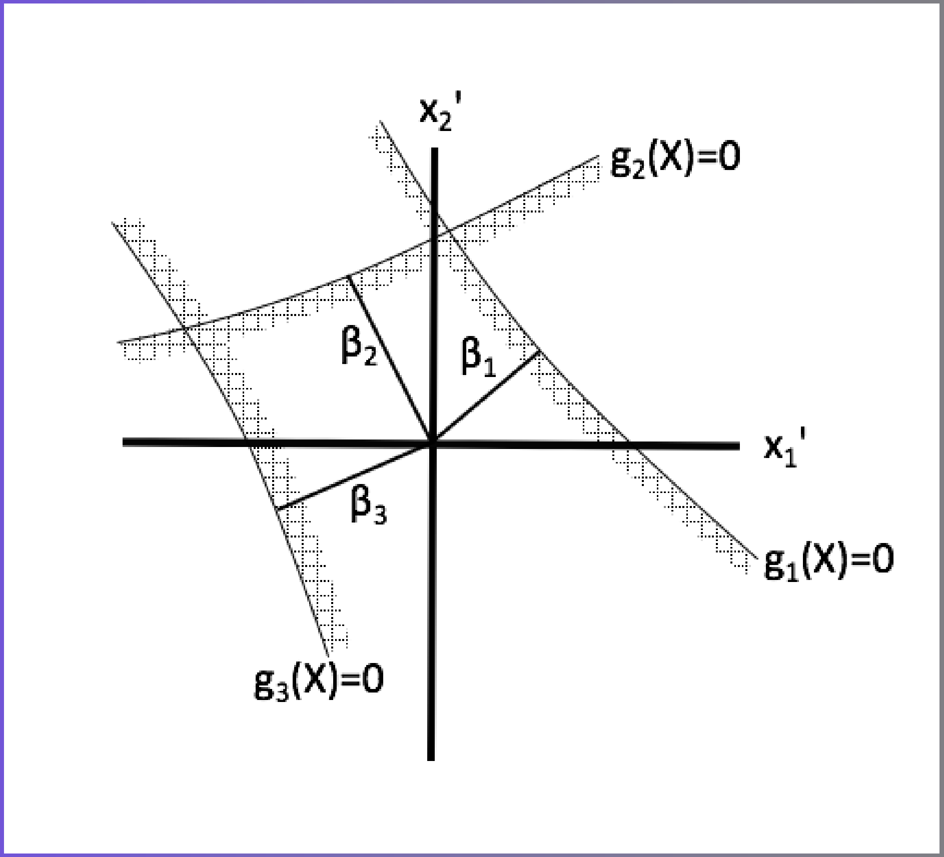
Component vs System Reliability



Multiple components (links & nodes)

Multiple failure modes

Multiple hazards



System Unimodal Bounds

Positively Correlated Series

(Ang & Tang, 1984)

$$p_F = p(E_s) \text{ where } E_s = E_1 \cup E_2 \cup \ldots \cup E_n$$

$$[\max_i p_{Fi}] \leq p_F \leq [1 - \prod_{i=1}^{n}(1 - p_{Fi})]$$

$$[1 - \prod_{i=1}^{n}(1 - p_{Fi})] \approx \sum_{i=1}^{n} p_{Fi}$$

Statistically Independent

Perfectly Correlated

Positively Correlated Series (Examples)

- Levee Systems
- Gas/Water/Sewer Pipelines
- Transportation Corridors
- Transmission Lines
- Water Canals
- most spatially contiguous civil infrastructure…

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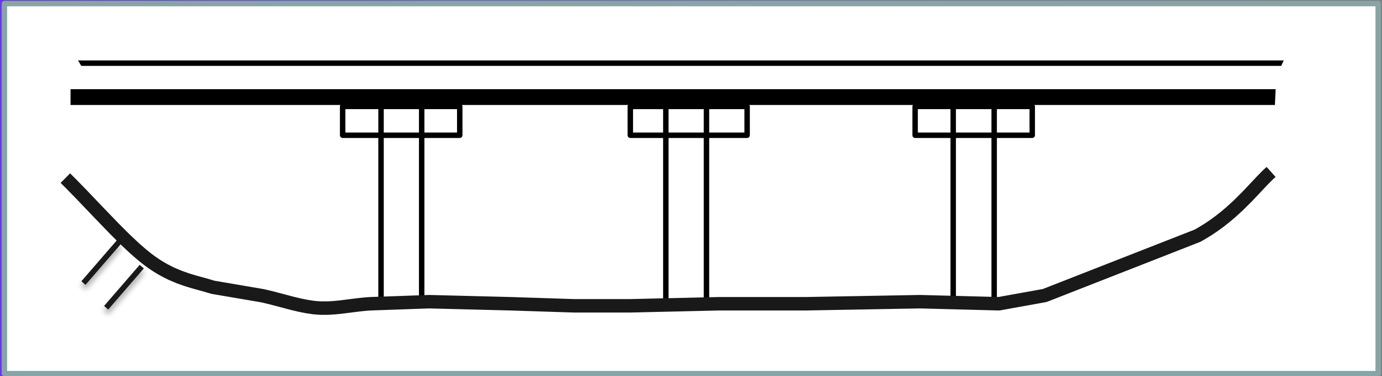
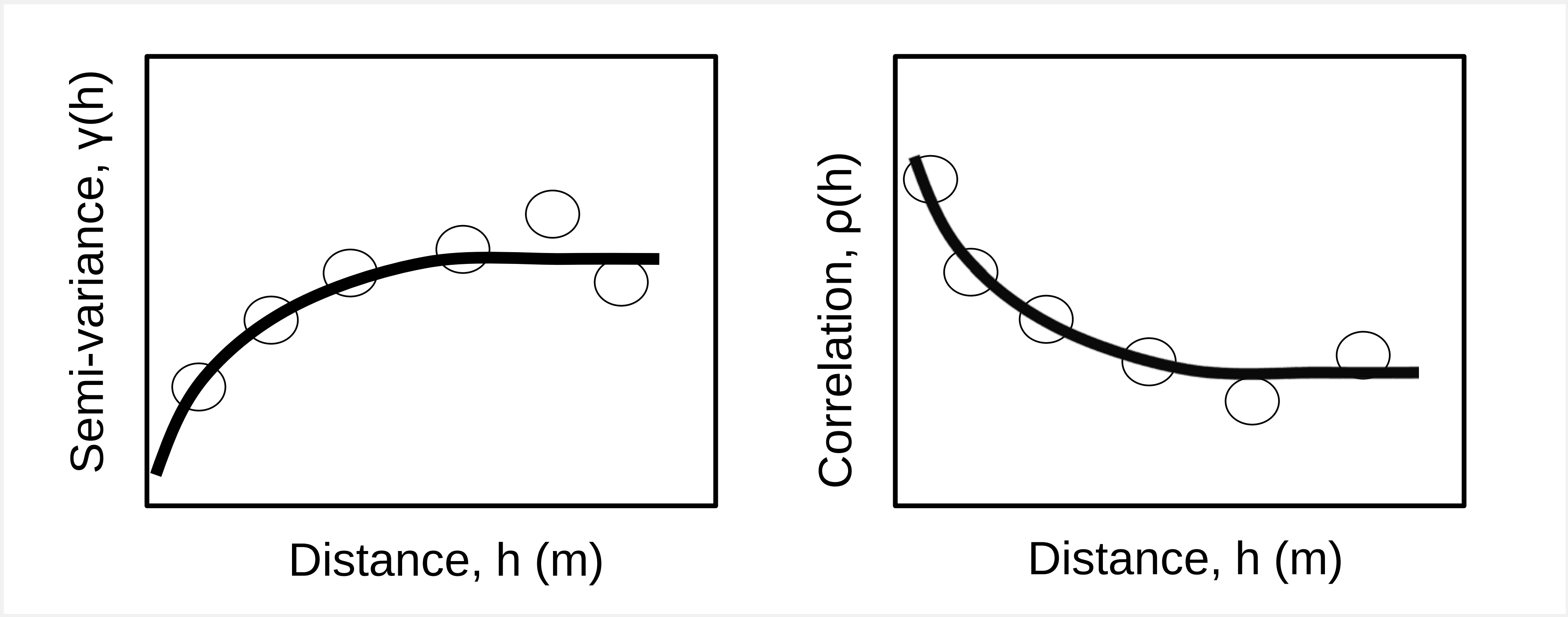
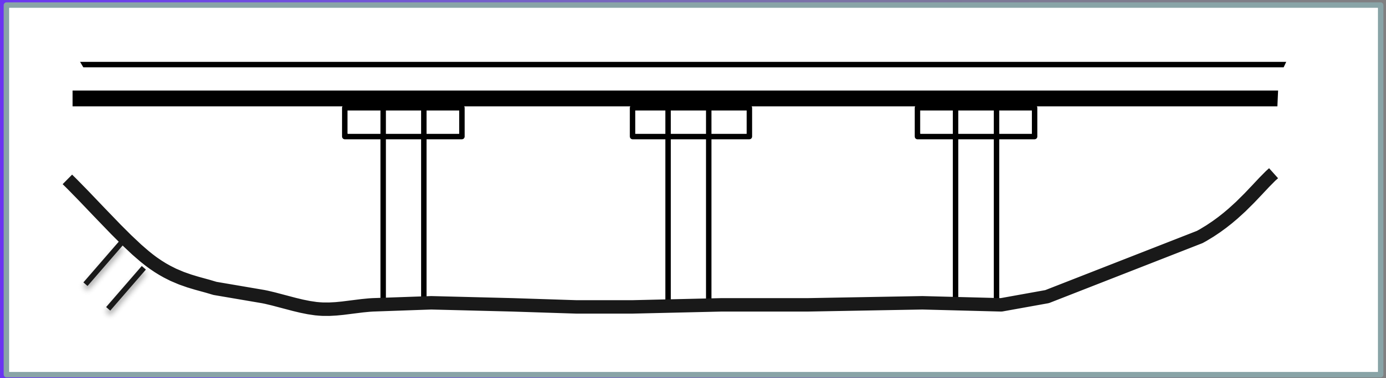
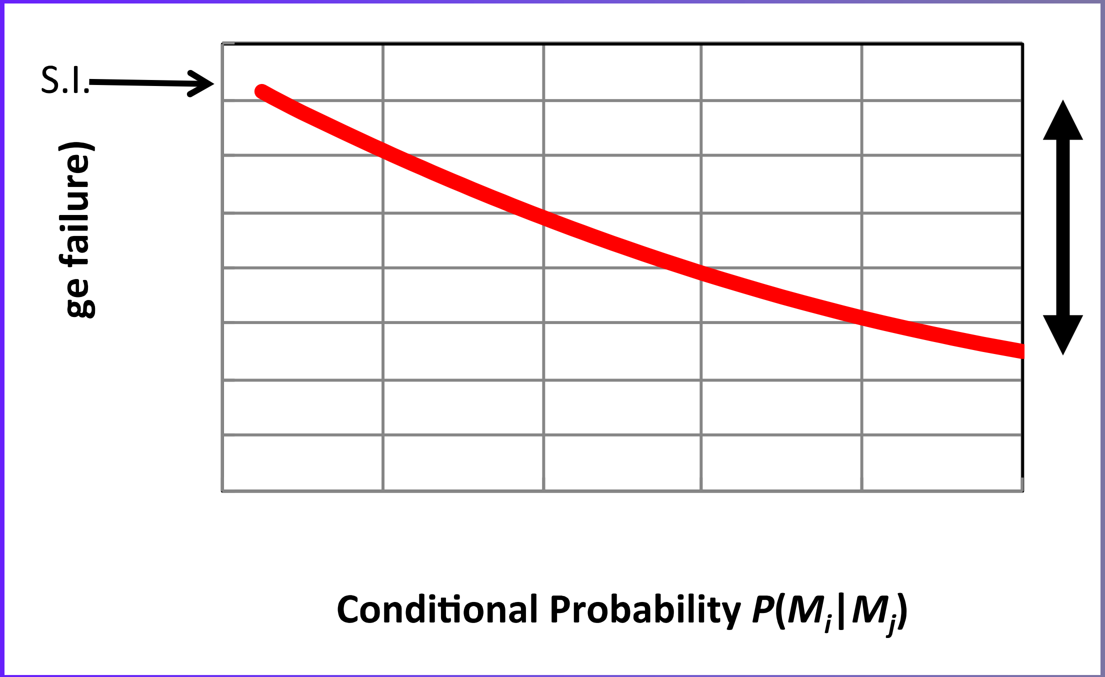
Spatial Correlation





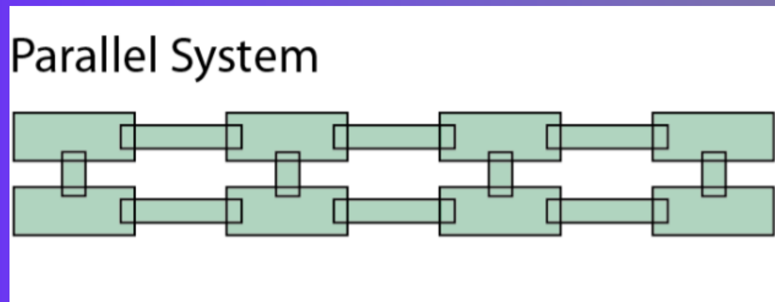
Spatial Correlation





Unimodal Bounds

Redundancy



Active = situational backup

Passive = always available

Correlation (load & resistance)

Components and Correlation

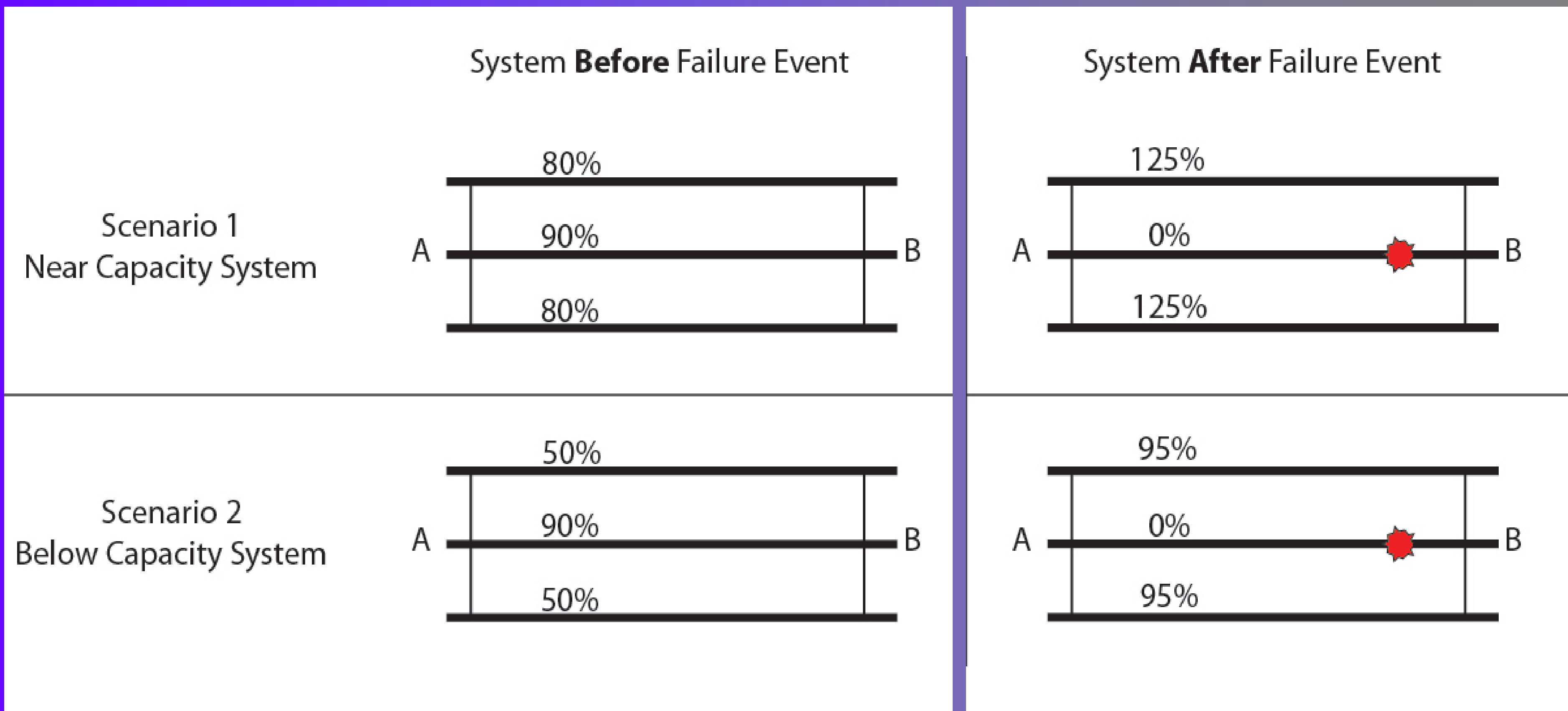
Increase
+ρ

Series System	Decreased p_f
Parallel System	Increased p_f

Increase #
Components

Series System	Increased p_f
Parallel System	Decreased p_f

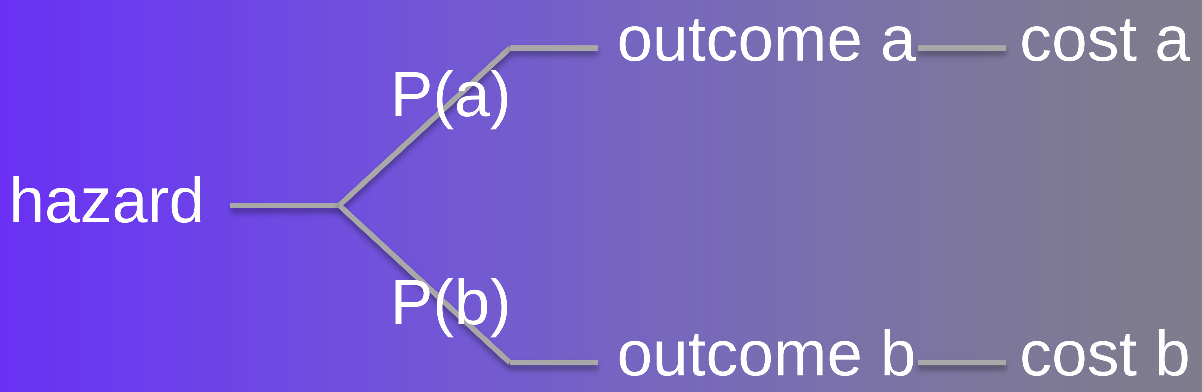
Redundancy vs Capacity



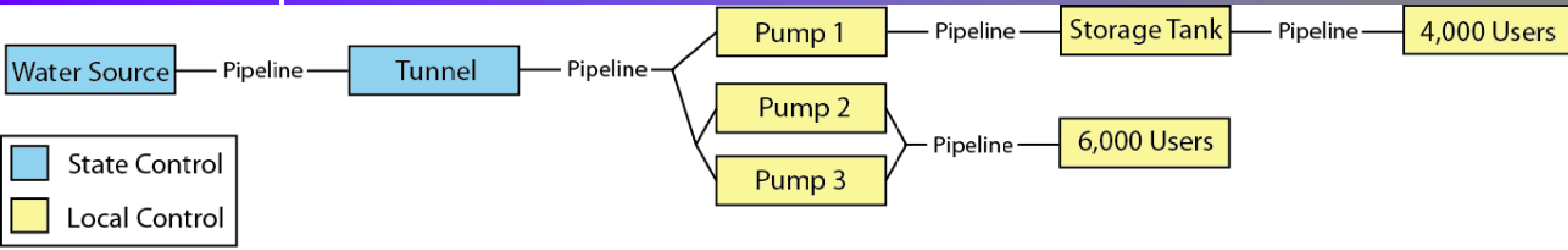
Risk Analysis

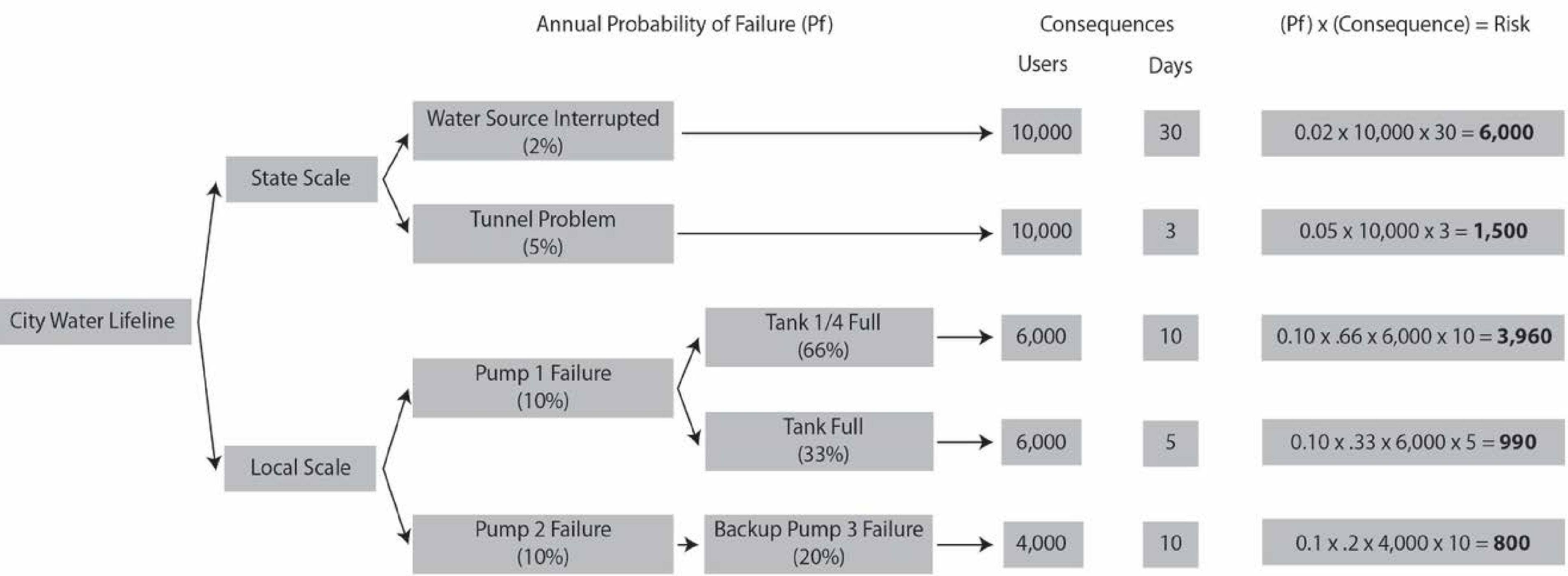
= prob of failure x consequences

Decision Tree

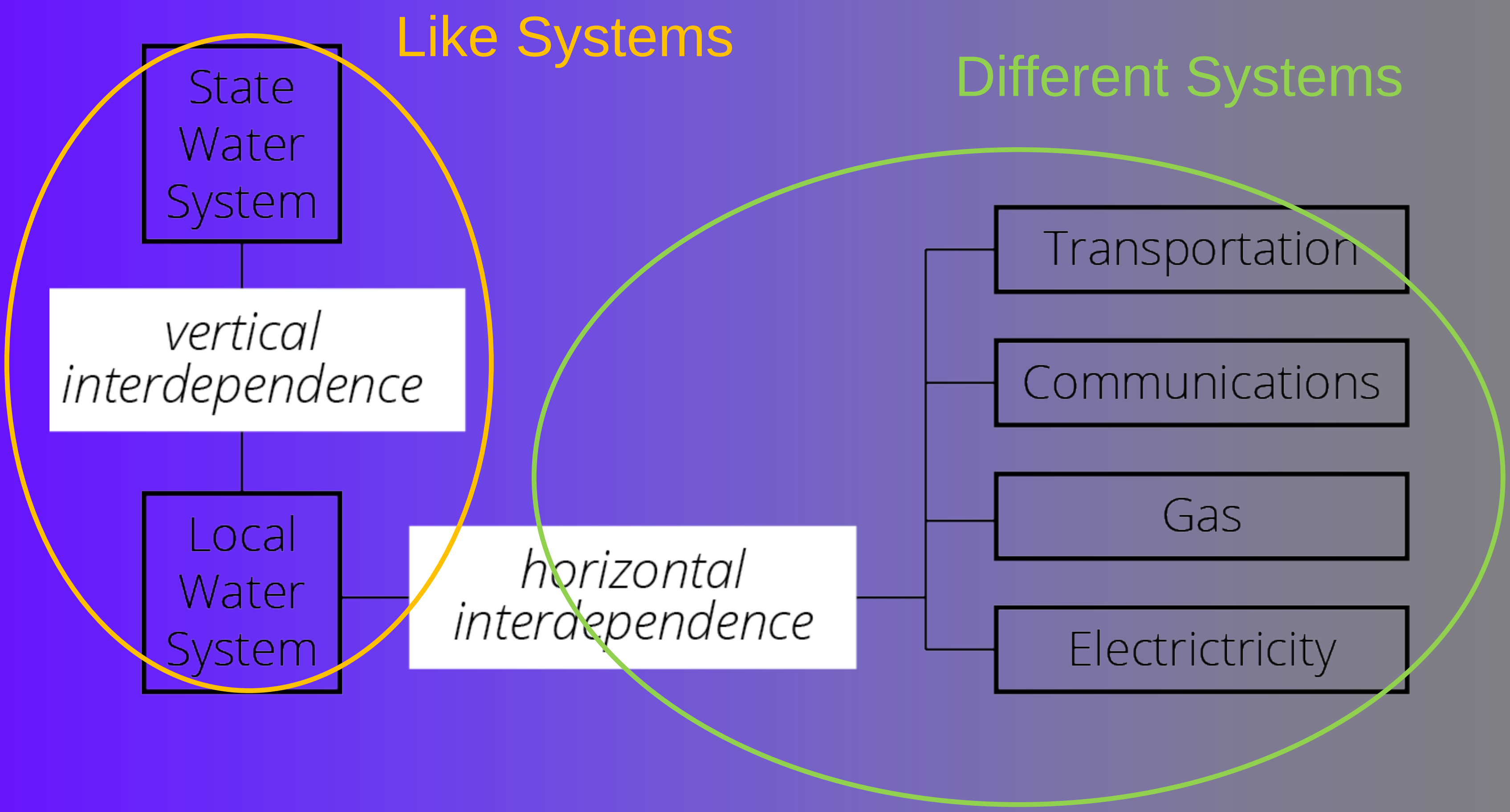


Risk Analysis



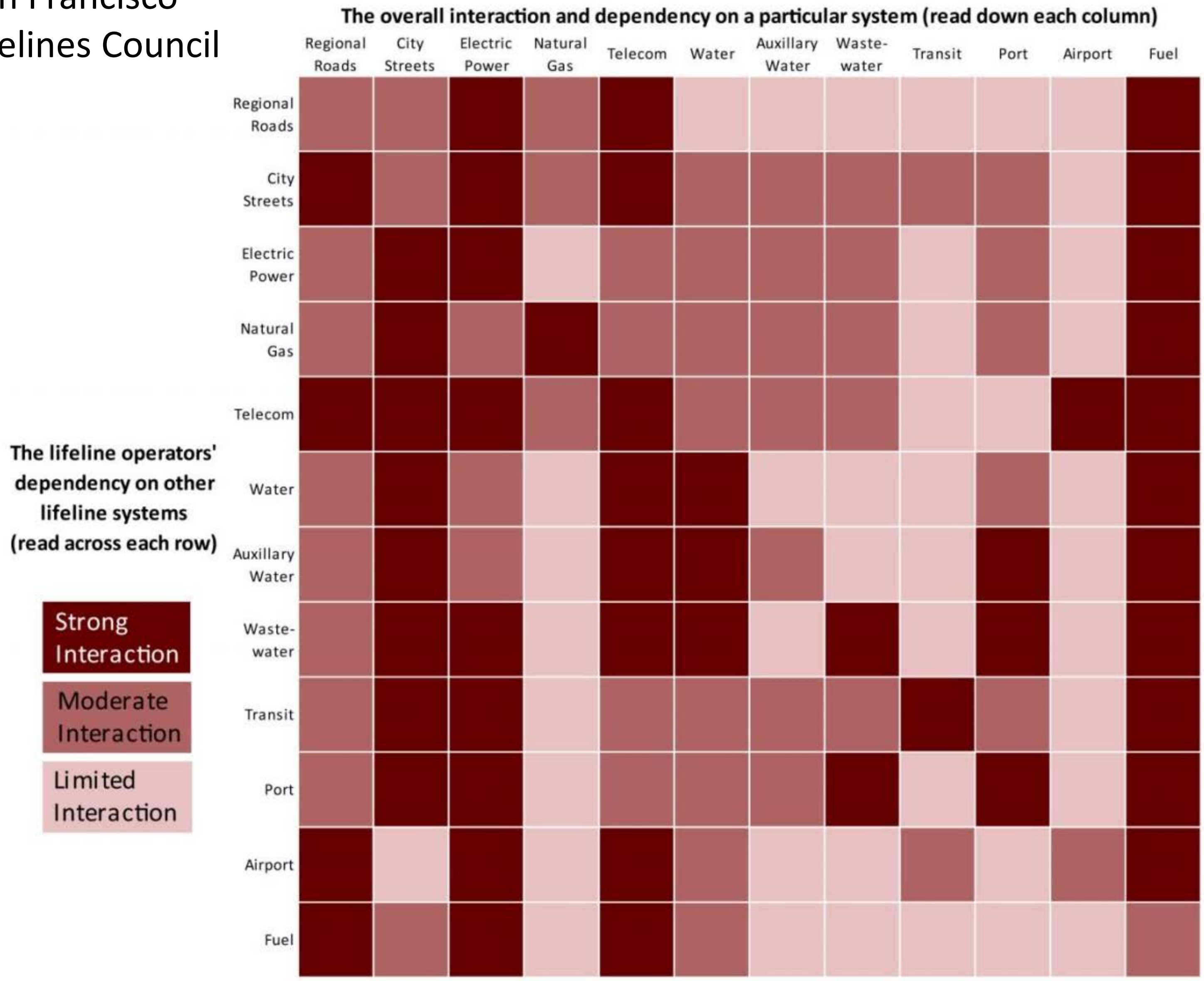


Interdependence

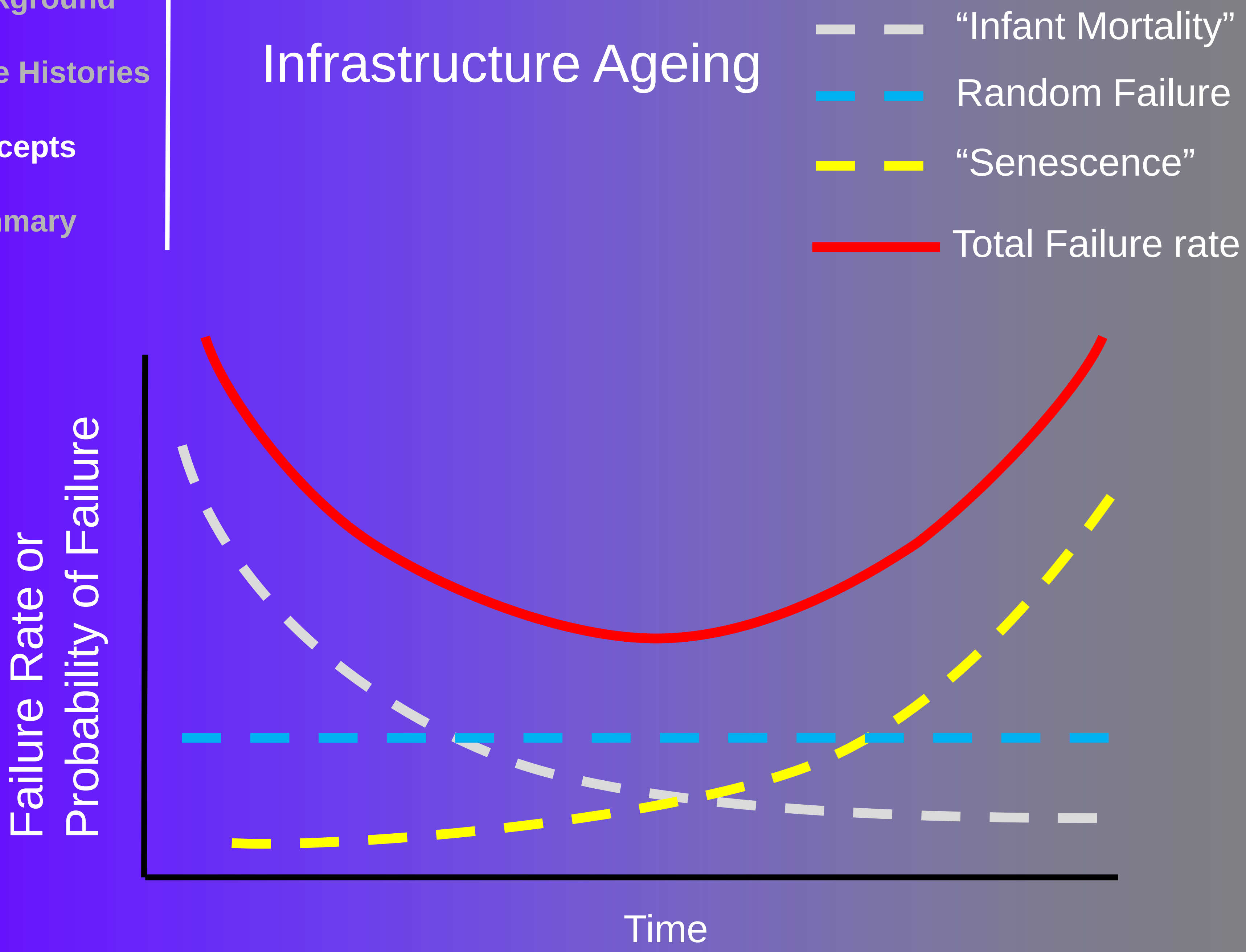


Interdependence

San Francisco Lifelines Council



Infrastructure Ageing



Lifelines Resilience

Improving the user's ability to function without lifeline services;

Improving the lifeline provider's ability to restore services by making the system:

- Robust (retrofit and construct lifeline systems to a higher level to resist hazard forces, thereby decreasing the likelihood of failure), or
- Repairable (accept that damage may occur but have quick repair strategies or temporary elements to provide limited services quickly after a disaster);
- Redundant (construct or develop a secondary system that can provide full or partial service while repairs to damaged components are made)

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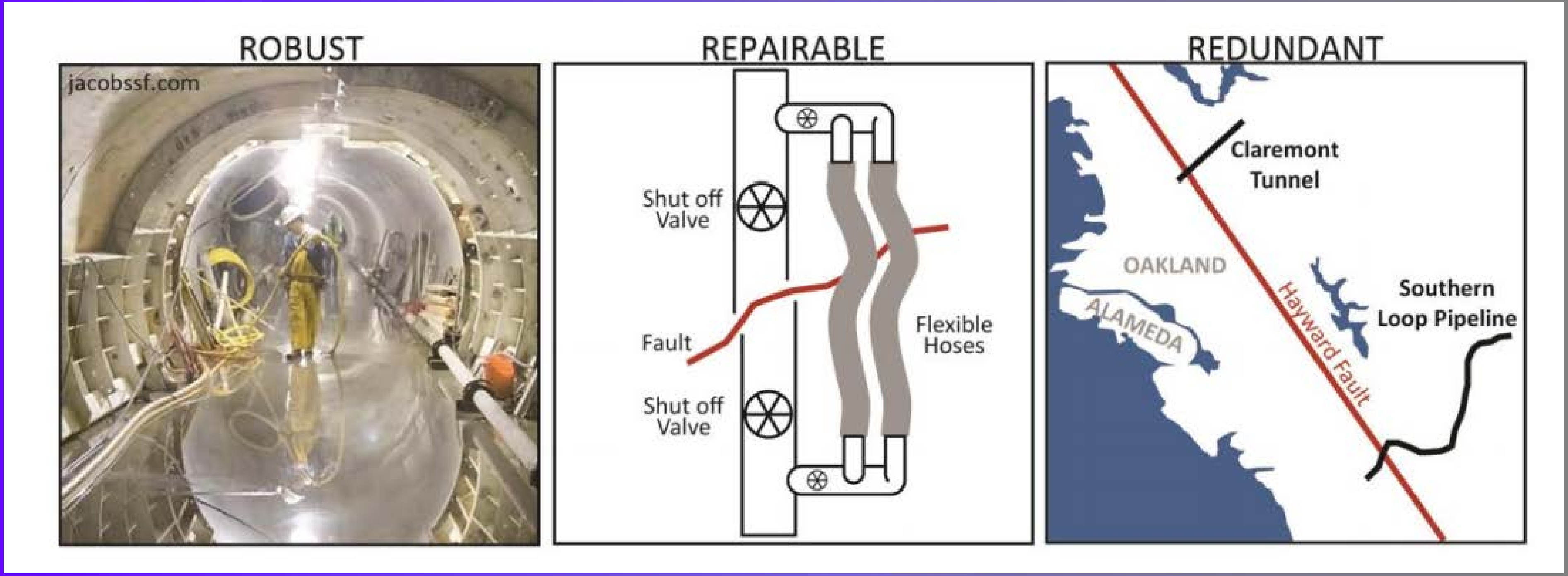
Lifelines Resilience

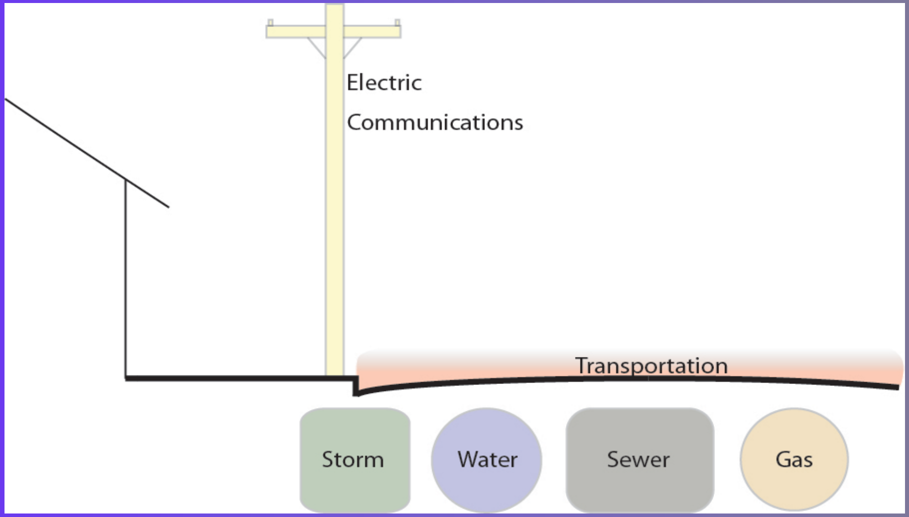


EBMUD - Fault Crossing

Lifelines Resilience

Lifeline service following a disaster measured on four scales that are often interdependent:

- Outage time
- Quantity of lifeline service
- Quality of lifeline service
- Distance to service



Summary of Presented:

- Examples of lifeline failures in the form of previous failure case examples
- Simplified concepts of lifeline organization and properties of engineered systems
- Path forward in assessing risk and reliability of interdependent systems

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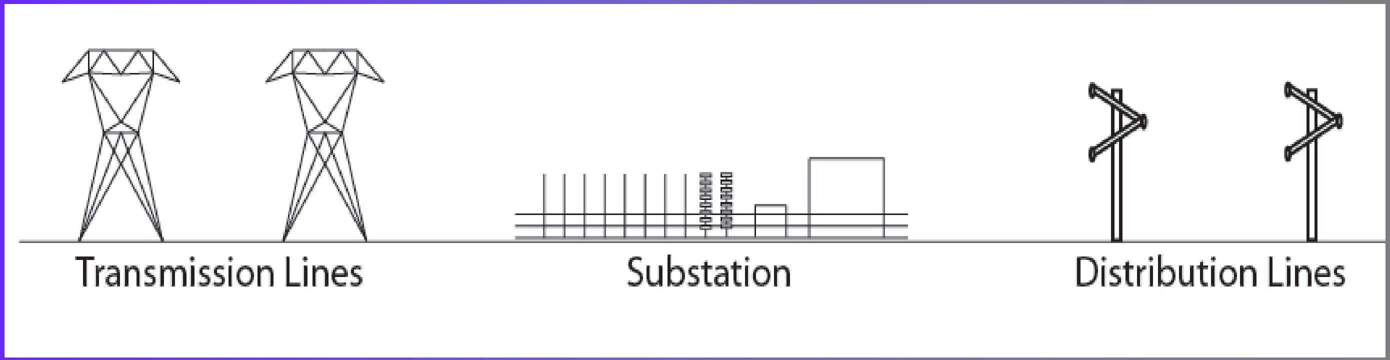

Lifelines Systems Approach:

- Evaluating the multi-scale aspects of lifelines
- Considering correlation among system components (nodes,links)
- Identifying interconnectedness / interdependence of lifelines
- Overlaying multiple hazards on lifelines
- Identifying real versus perceived redundancy within a system
- Assessing existing system capacity prior to disaster
- Considering ageing, rehabilitation, and retirement of infrastructure
- Resiliant=Robust+Repairable+Redundant

References

- Ang, A. H-S., and Tang, W. H. (1984). Probability Concepts in Engineering Planning and Design: Volume II-Decision, Risk, and Reliability. Author published.

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- Moss, R.E.S. & Hollenback, J.C. (2015) “The Influence of Spatial Variability on Lifelines Probability of Failure.” 15th Pan-American Conference on Soil Mechanics and Geotechnical Engineering, Buenos Aires, Argentina, Nov.

THANK YOU