



National Science Foundation  
WHERE DISCOVERIES BEGIN

# Infrastructure Systems and Asset Management

Istanbul Technical University  
Istanbul, July 6-9, 2008

Franklin Moon, A. Emin Aktan, Patrick L. Gurian,  
and Franco Montalto

Drexel University

Drexel Intelligent Infrastructure Institute

Addressing infrastructure challenges from a multi-domain perspective

# Presentation outline

Definitions

Motivations

Challenges

Opportunities

Role of workshop



## U.S. Transportation system (TRB 2002)

- 600,000 bridges
- 3.9 million miles of road
- 4.1 trillion passenger-miles/yr
- Carries \$8 trillion/yr in goods
- Demand for travel increased by 50% between 1977-1995

# Infrastructures...

- have high fixed costs, high public investment and long economic lives
- form the underpinnings of the **nation's defense, economy (1980s), health and safety, and national morale (post 9-11)**

	National Defense	Economic Security	Public Health and Safety	National Morale
Telecommunications	Red	Green	Grey	Grey
Energy	Red	Green	Grey	Grey
Banking/finance	Grey	Green	Grey	Grey
Transportation	Red	Green	Grey	Grey
Water	Grey	Grey	Blue	Grey
Food/agriculture	Grey	Grey	Blue	Grey
Law enforcement	Grey	Grey	Blue	Grey
Chemical	Grey	Grey	Blue	Grey
Postal/shipping	Grey	Grey	Blue	Grey
National monuments	Grey	Grey	Grey	Purple

John Moteff, Claudia Copeland, and John Fischer (2003) "Critical Infrastructures: What Makes an Infrastructure Critical?," Report to Congress, Congressional Research Service, The Library of Congress.

# Asset Management is...

a systematic process of maintaining, upgrading, and operating physical assets cost-effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making.



US Department of Transportation, "Asset management primer," Office of Asset Management, *US DOT*, Washington, D.C. 1999.

Motivations: Societal Impact

# Things that make the papers

The New York Times

## Design Shortcomings Seen in New Orleans Flood Walls

By CHRISTOPHER DREW and [ANDREW C. REVKIN](#)  
Published: September 21, 2005



The New York Times

By JAMES BARRON  
Published: August 15, 2003

**THE BLACKOUT OF 2003: The Overview; POWER SURGE BLACKS OUT NORTHEAST, HITTING CITIES IN 8 STATES AND CANADA; MIDDAY SHUTDOWNS DISRUPT MILLIONS**

The New York Times

## Bridge Collapse in Minneapolis Kills at Least 7

By LIBBY SANDER and SUSAN SAULNY  
Published: August 2, 2007



## Motivations: Societal Impact

# Things that don't make the papers

## Transportation Safety

- 43,443 people died in highway crashes in 2005
- Fatality rate increased in 2005 for the first time since 1986.
- Each roadway fatality costs approximately \$977,000 or \$231 billion a year, or \$820 for every person living in the United States.

NTSB Annual Report to Congress (2006)



## Congestion

THE SECRETARY OF TRANSPORTATION  
WASHINGTON, D.C. 20590

Congestion is one of the single largest threats to our economic prosperity and way of life. Whether it takes the form of trucks stalled in traffic, cargo stuck at overwhelmed seaports, or airplanes circling over crowded airports, congestion is costing America an estimated \$200 billion a year.

Sincerely,



Norman Y. Mineta  
U.S. Secretary of Transportation  
May, 2006

Motivations - Funding

# Accountability, transparency

**The New York Times**

By TIMOTHY EGAN  
Published: April 10, 2004

## Built With Steel, Perhaps, but Greased With Pork



**The New York Times**

## Congress Is Still Pursuing Earmarks

By CARL HULSE  
Published: December 20, 2007

2008 spending bills include more than  
11,700 earmarks, totaling \$16.9 billion.

White House Office of Management and Budget



**The New York Times**

By MARK MAZZETTI  
Published: October 18, 2006

## Report Spells Out Abuses by Former Congressman

[www.wikipedia.org](http://www.wikipedia.org)

## Motivations - Funding

# Budget shortfalls

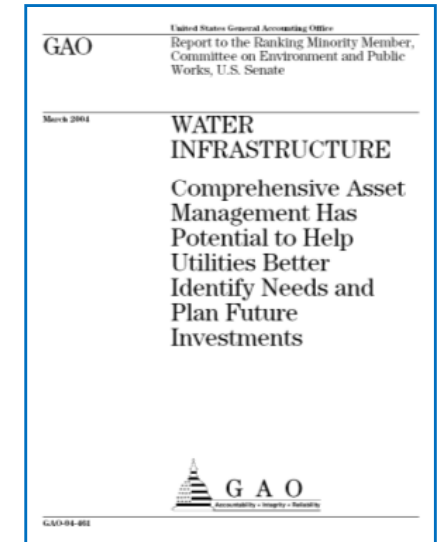
According to ASCE:

- To infrastructure needs over the next five years is \$1.6 trillion
- Currently allocated funds ~\$1.1 trillion
- **Funding gap of \$500 billion over the next 5 years**



According to the U.S. General Accounting Office:

- 29 % of the drinking water utilities and 41 % of the wastewater utilities do not generate enough revenue to cover their full cost of service
- 1/3 of water utilities **deferred maintenance because of insufficient funding**



According to PennDOT (Hoffman 2004):

- Six Year Needs for bridge and pavements \$ 21.3 billion
- Six Year Available Funds \$ 15 billion
- **Funding gap of \$6.3 billion over the next 6 years**





# Potential influx of funding

*The New York Times*

Bloomberg Creates a Task Force to Advocate for U.S. Infrastructure Needs

## ➤ **National-level**

### **Non-partisan Infrastructure Coalition**

Goal: Make infrastructure funding a national priority.

PA Gov. Ed Rendell, CA Gov. Arnold Schwarzenegger, NYC Mayor Michael Bloomberg

Backed by the Rockefeller Foundation

## ➤ **State-level (e.g. Pennsylvania)**

### **Governor Rendell's Bridge Plan** (Philadelphia Inquirer, 2008)

Borrow \$600 million over 3 years to address 1,145 of 6,000 structurally deficient bridges

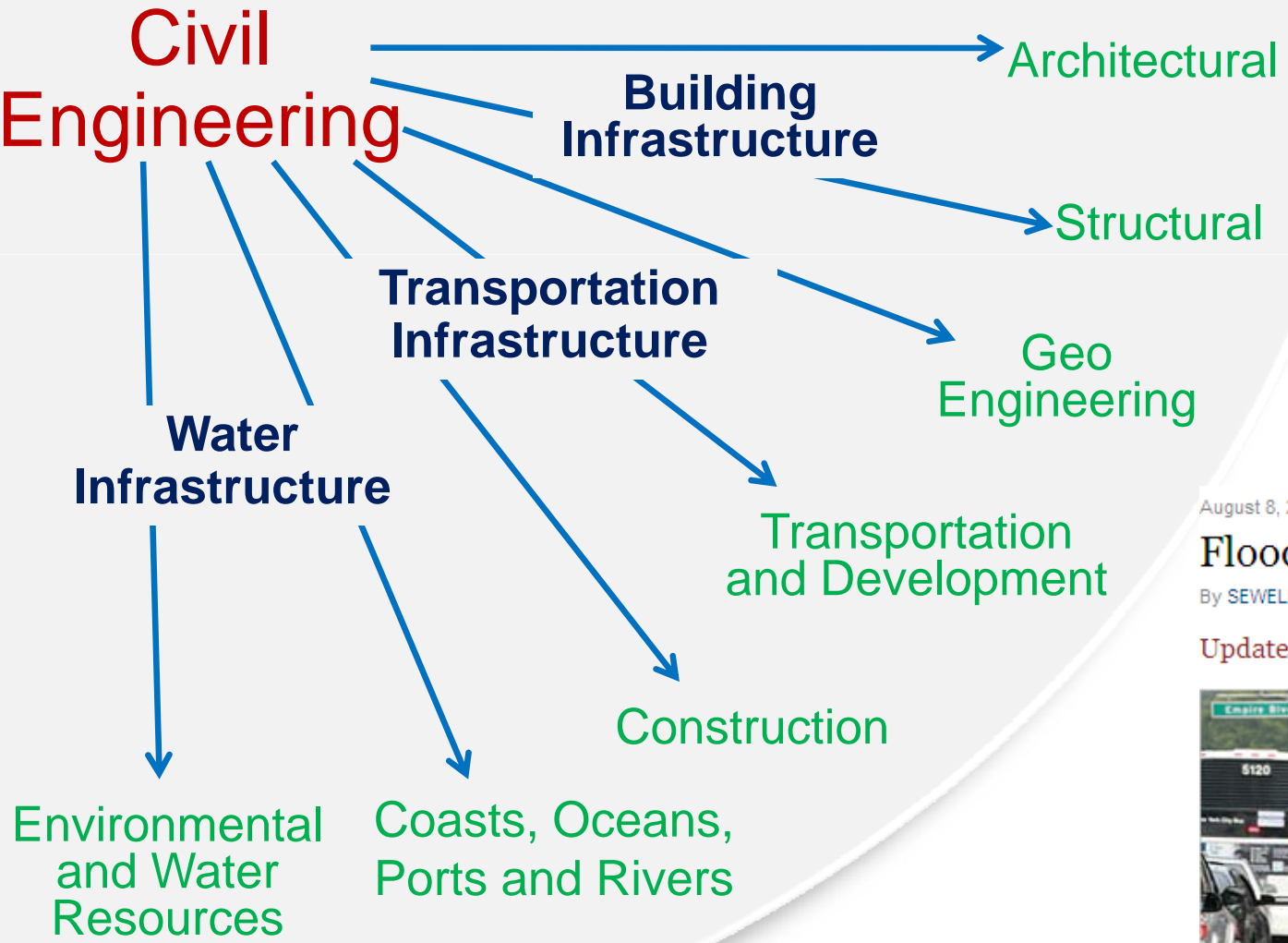
### **Abertis Infra. and Citi Infra.** (Wall Street Journal, 2008)

75-year lease of PA Turnpike; \$12.8 Billion to PA, \$5.5 Billion to rebuilding turnpike

### **Act 44** (Central Penn Business Journal, 2007)

PA Turnpike to toll and operate I-80; \$83.5 Billion to PennDOT over 50 years

# Across Infrastructure Classes



**Leads to different languages, cultures and unforeseen interactions...**

August 8, 2007, 8:49 am

## Flooding Cripples Subway System

By SEWELL CHAN

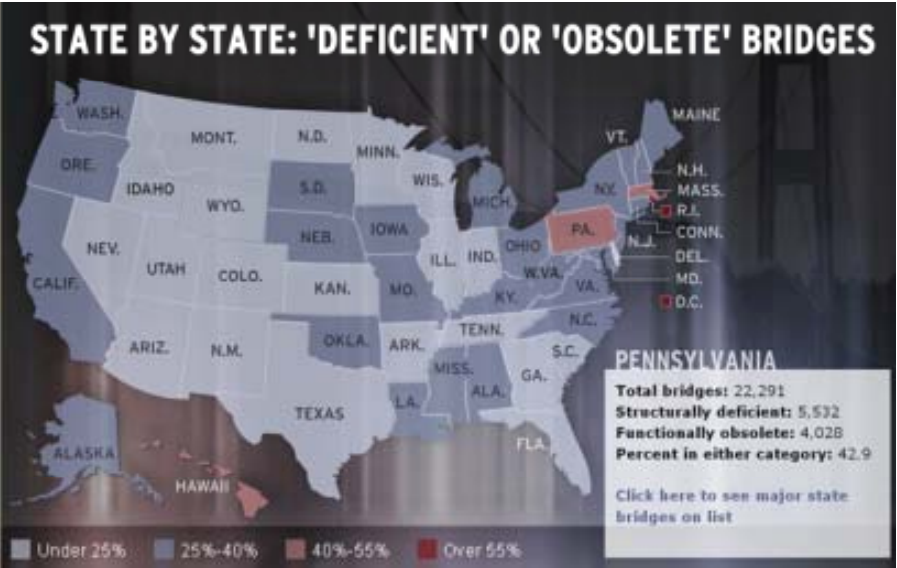
Updated, 4:10 p.m.



(ASCE Institutes, 2006)

# Challenges

# Disconnect with asset reality



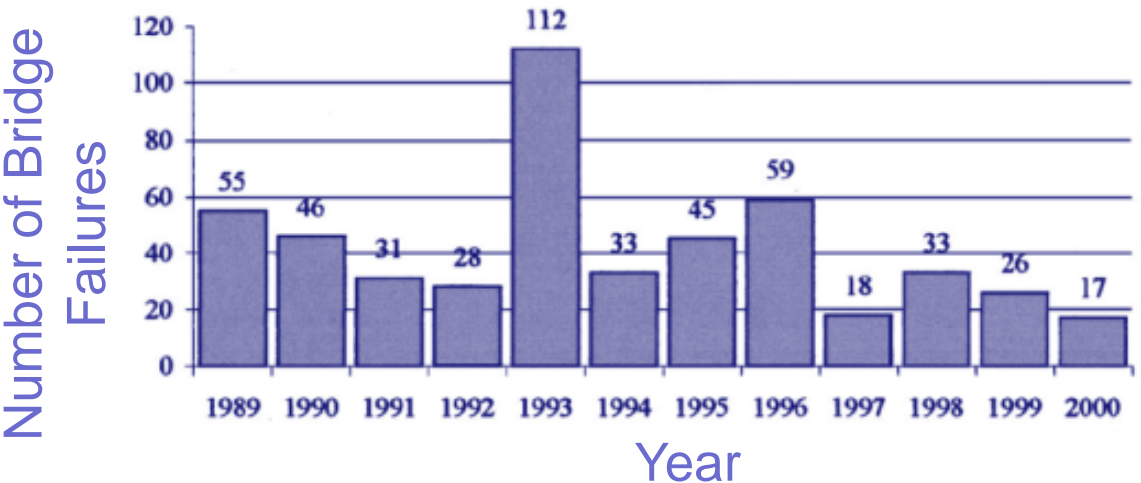
According to the U.S. Federal Highway Administration, in 2006 there were 73,764 bridges classified as **structurally deficient**

Perception?

MSNBC.com



Reality?



Wardhana & Hadipriono (2003) "Analysis of recent bridge failures in the United States," ASCE Journal of Performance of Constructed Facilities, Vol. 17, No. 3

# Political incentives

## **Lifespan of infrastructure...**

- Water pipe:
- Landmark bridge: > 100 yr
- Bridge: 75-100 yr
- Flexible pavement: 20 yr
- Rigid pavement: 40 yr

## **Terms of elected officials...**

- U.S. President – 4 yr
- U.S. Senator – 6 yr
- U.S. Representative – 2 yr
- State Governor – 4 yr
- City Mayor – 4 yr

“The bottom line is that routine but important things like maintenance always get shortchanged because it’s nice for somebody to cut a ribbon for a new structure.”

- Charles Schumer (Senator, NY)

# Process-based mindset

Product-based Approach

(Edmunds.com)



## 2007 Hyundai Accent

Price: \$12,565 (MSRP)

### Performance Metrics:

Horsepower: 110 hp; Max Horsepower: 6000 rpm;  
Torque: 106 ft-lbs; Max Torque: 4500 rpm; Turning  
Circle: 33.1 ft.; EPA Mileage Estimates: 32 mpg / 35  
mpg; Range in Miles: 380.8 mi. / 416.5 mi; etc...

### Warranty:

Bumper-to-Bumper: 5 yr. / 60,000 mi.  
Drivetrain: 10 yr. / 100,000 mi.  
Rust: 7 yr. / Unlimited mi.

Process-based Approach



## Hamilton Co., OH Bridge (1997)

- Over 24 subcontractors
- Many Bureaus of ODOT District 6

Price: \$1,000,000-2,000,000

### Performance Metrics:

???

### Warranty:

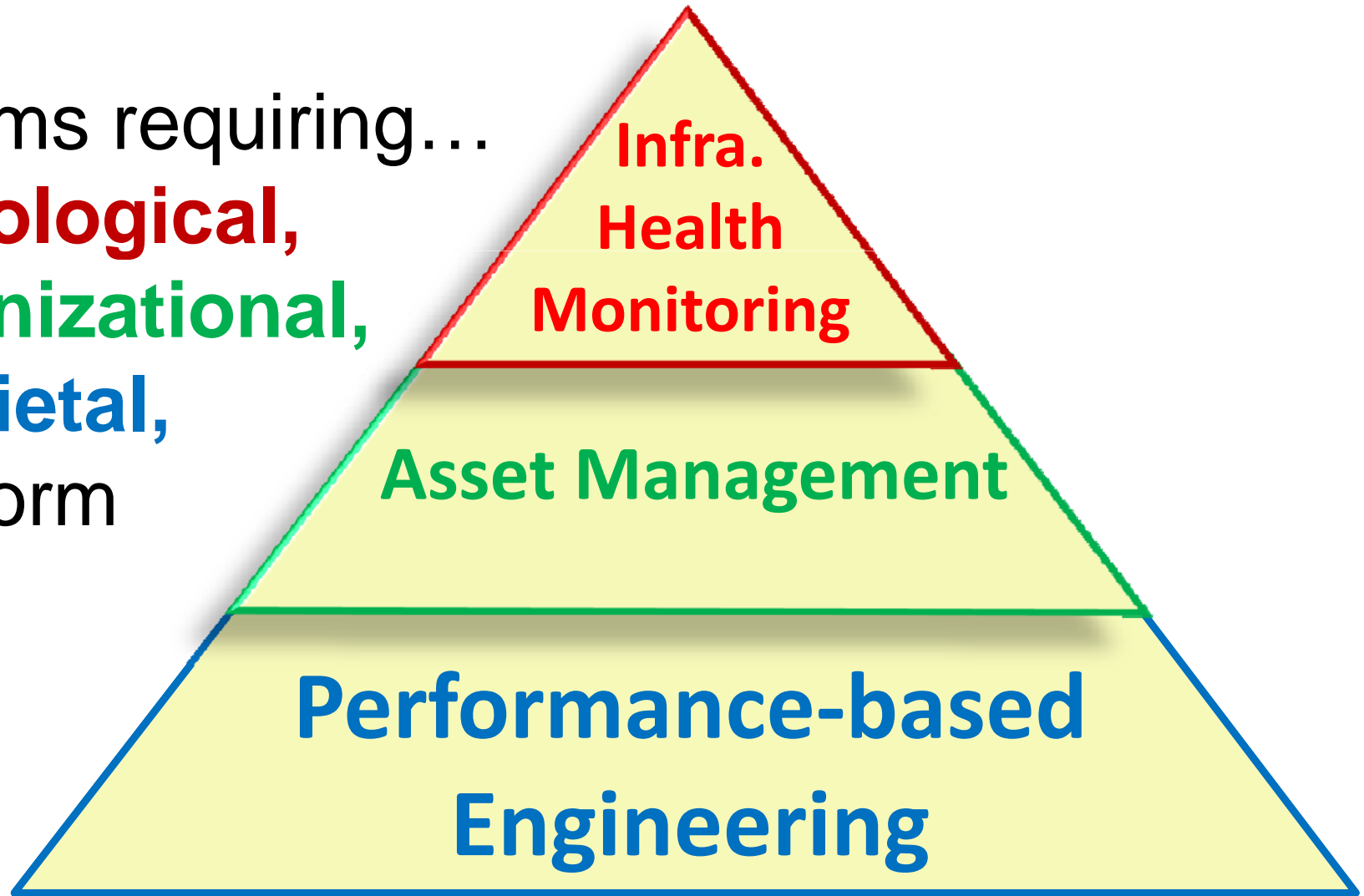
None

Aktan, A.E. and F.L. Moon, (2005) "Transition Towards Performance-Based Civil Engineering," 11th Transportation Engineering and Safety Conference, State College, PA

# Enabling Asset Management

Paradigms requiring...

**Technological,**  
**Organizational,**  
**Societal,**  
reform

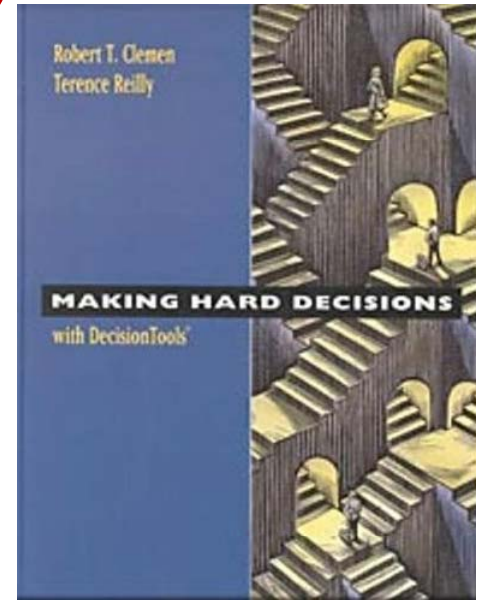


# Is Asset Management Benefit Cost Analysis?

**Benefit Cost Analysis** considers both monetary and non-monetary impacts of the project to identify net value of the project relative to its alternatives

**Utility theory** considers benefits and costs under uncertainty.

**Multi-criteria decision making** considers tradeoffs among different attributes.



## How can we...

- Assess Costs?
- Assess Benefits?
- Implement? (identifying trade-offs, interactions, etc.)

Related paradigms – Assessing Costs

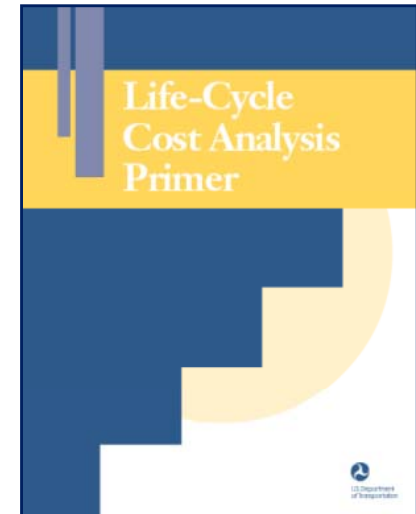
# Life Cycle Analysis and Life Cycle Cost Analysis

“**Life cycle analysis** is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- compiling an inventory of relevant energy and material inputs and environmental releases;
- evaluating the potential environmental impacts associated with identified inputs and releases;
- interpreting the results to help you make a more informed decision.”

“**Life-cycle cost analysis** is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs...over the life of the project segment.”

*Transportation Equity Act for the 21st Century*



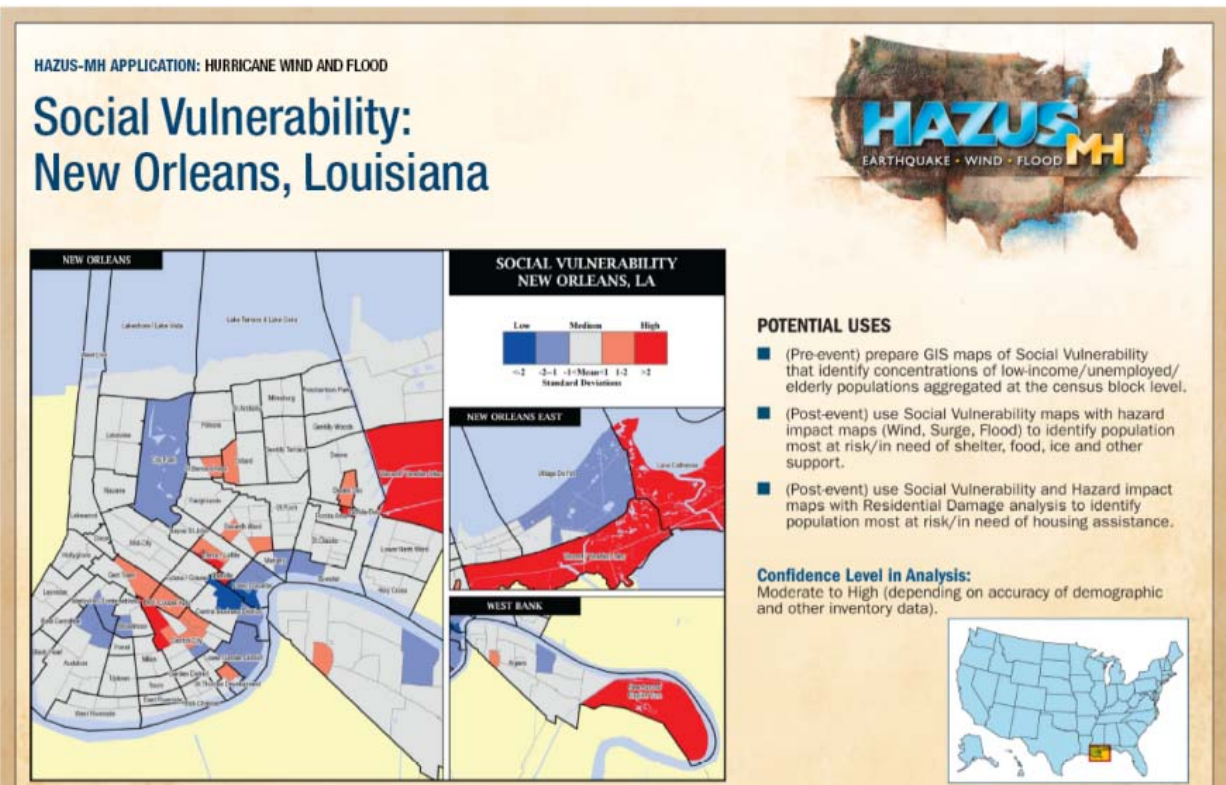


# Related paradigms – Assessing Costs

# Multi-Hazard Risk Assessment

The HAZUS-MH framework includes six interdependent modules:

- Potential Earth Science Hazard
- Inventory
- Direct Damage
- Induced Damage
- Direct Economic/Social Losses
- Indirect Losses



## MULTI HAZARD

*Identification and Risk Assessment*

*A Cornerstone of the National Mitigation Strategy*

Prepared in support of the International Decade for Natural Disaster Reduction

FEMA 1997

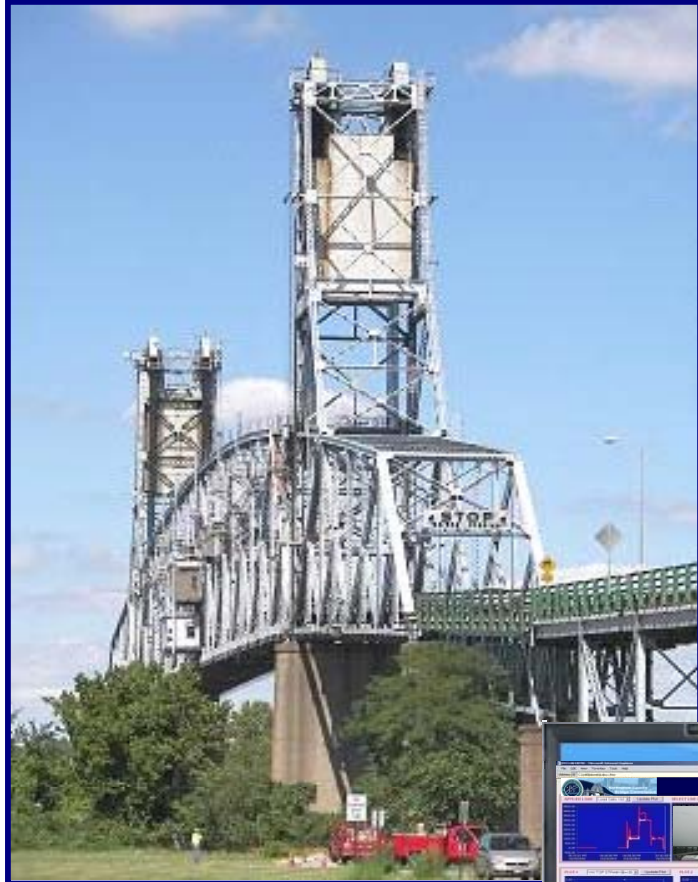
# Performance-based Engineering

	<b>Domain</b>		
<b>Limit State</b>	<b>Engineered</b>	<b>Societal</b>	<b>Natural</b>
<b>Operational and Utility</b>	Safety Security Efficiency	Transparency Organizational Effectiveness Fiscal Prudence	Sustainability Minimal impact Hazards risks management
<b>Engineering</b>	Serviceability Durability Safety Stability of failure	Inspectable Maintainable Adaptable Renewable	Recyclable Carbon FP Unobtrusive
<b>Societal Goals</b>	Long-term economic sustainability Preserve culture	Healthy and Just Society Promote good governance	Respecting the environment Rely on sound science

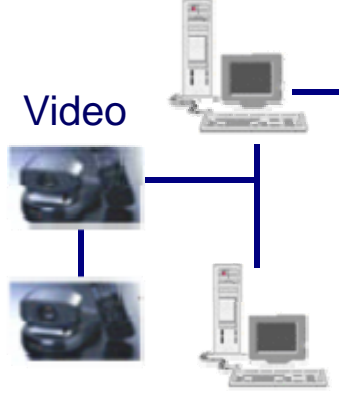
Related paradigms – Assessing Benefits

# Infrastructure Health Performance

## Monitoring

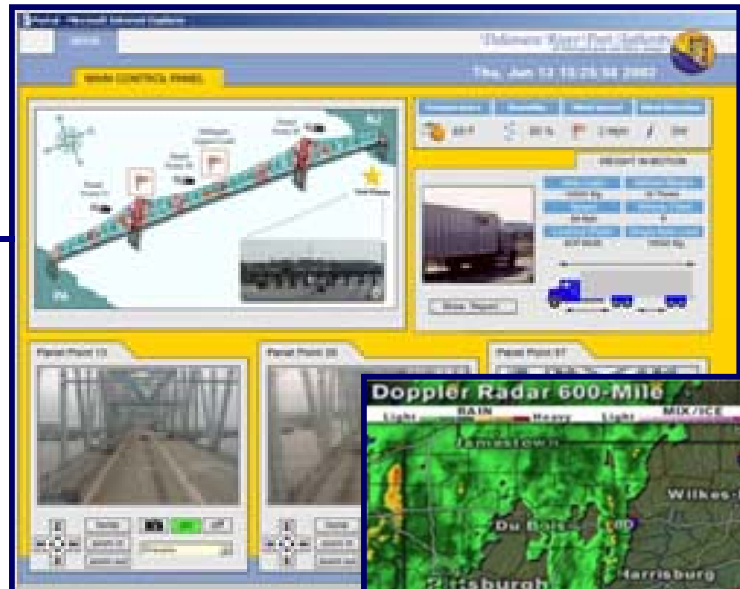


DI<sup>3</sup> Servers



data acquisition

remote data processing



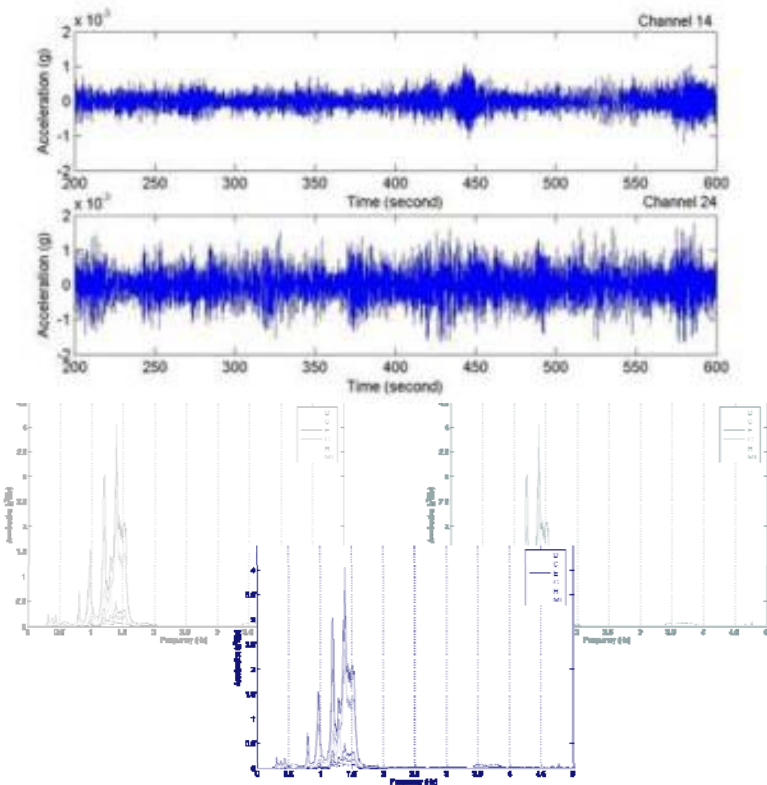
weather.com



# Related paradigms – Assessing Benefits

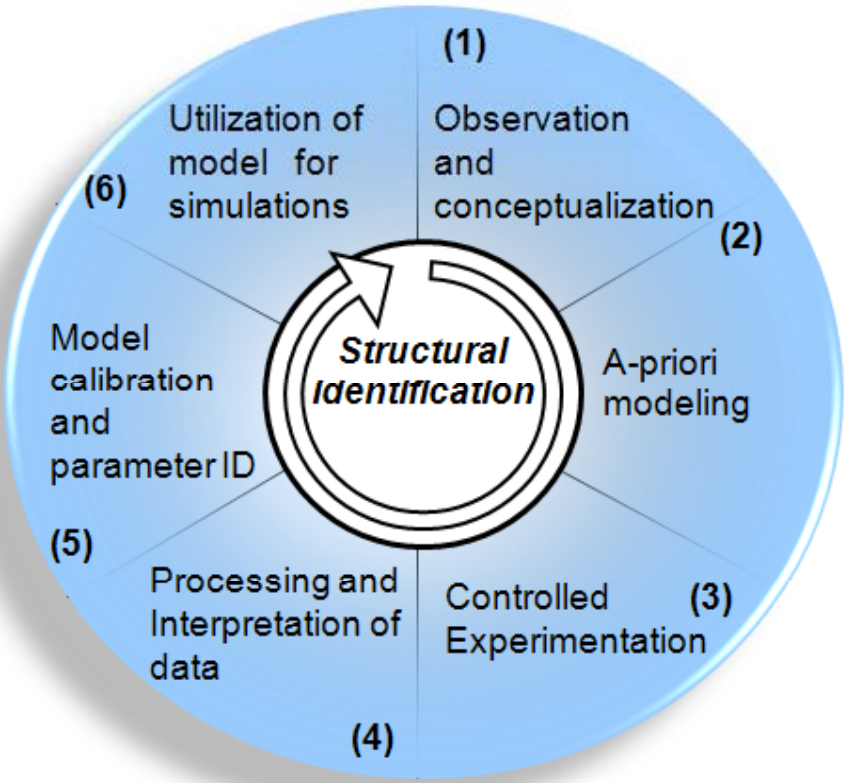
# Structural Identification

## Sensing



Leads to mountains of data that defy honest interpretation and cannot support decisions

## Structural Identification



Leads to an honest view of structure performance capable of supporting rational decisions

# Systems Engineering involves...

- **definition of systems**, including identification of user requirements and technological specifications;
- **development of systems**, including conceptual architectures, tradeoff of design concepts, configuration management during system development, integration of new systems with legacy systems, and integrated product and process development
- **deployment of systems**, including operational test and evaluation, maintenance over an extended lifecycle, and reengineering.

Journal of Systems Engineering

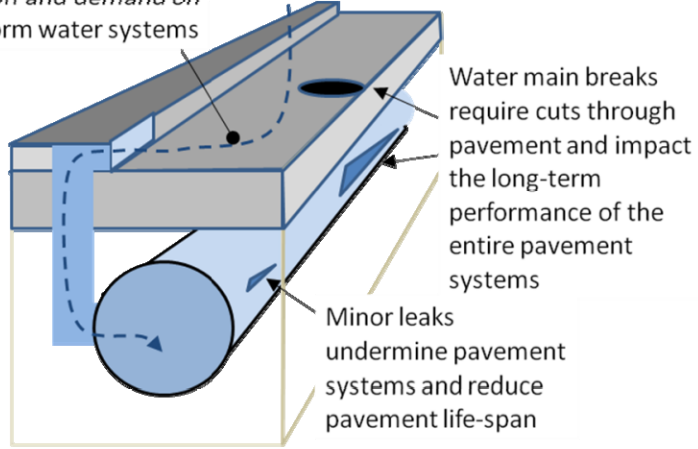


# Related paradigms - Implementation

# Systems Engineering



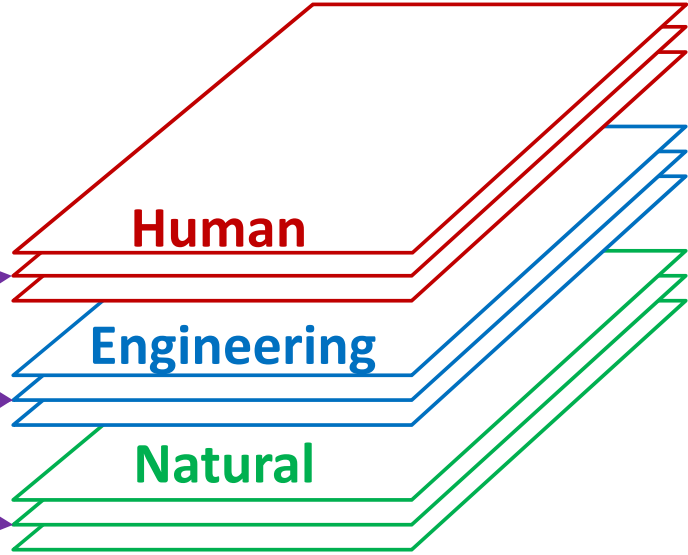
Impervious ground cover increases run-off and demand on storm water systems



Input to Policy, Revenue Generation, Allocation

Look Measure Model

Applied Systems Analysis



Identify interactions interconnections

# Asset Management Research

## What will it look like?

### Disciplines

- Basic Sciences
- Civil Engineering
- Economics
- Environmental Science
- History
- Information Science
- Public Policy
- Political Science
- Urban Planning
- Others

### Methods

- Interviews/surveys
- Pilot Implementation
- Analytical Modeling
- Field Research
- Laboratory Studies
- Others

### Paradigms

- Cost Benefit
- Utility Theory
- Multi-Criteria Decisions
- Life Cycle Analysis
- Life Cycle Cost Analysis
- Risk Assessment
- Structural Identification
- Systems Engineering
- Others

**Performance-based  
Engineering**

**Asset  
Management**

**Health  
Performance  
Monitoring**

**Investigators  
Government  
Academe  
Industry**

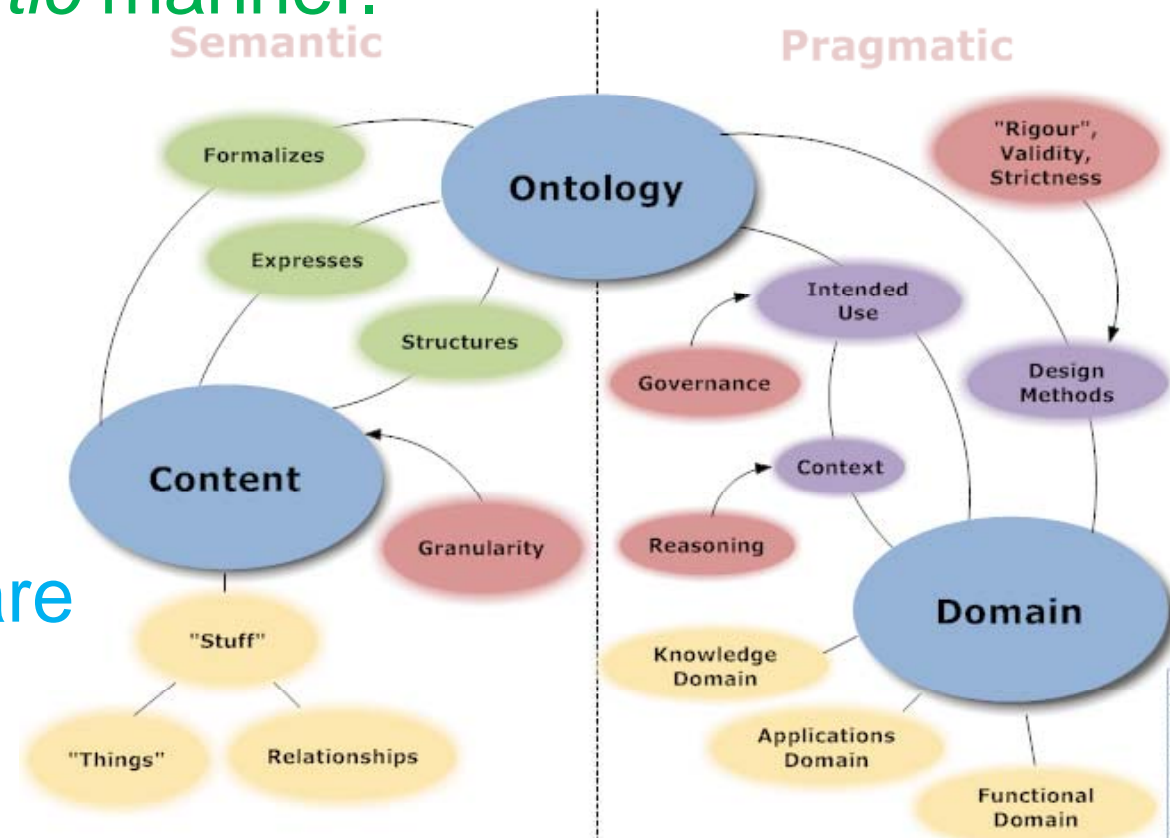


## Goal of the Workshop

# To construct an ontology that...

- is “a formal and explicit specification of a shared conceptualization” of Asset Management.
- represents Asset Management concepts, objects, interdependencies, data, and other elements in both a *semantic* and *pragmatic* manner.

- is equally readable and understandable, easily shared, and practically reused across diverse groups, platforms, applications, and software tools.





# To develop a research agenda

## Sample Initial Survey Results:

### Asset Management Research priorities are...

- assessment of system performance across infrastructure asset classes (~1.7)
- engineering studies of asset performance (~1.7)
- real-world case studies (~1.8)
- social science studies of organizational management (~2.2)

### Asset Management Research priorities are not...

- development of sensor systems (~3.1)
- development of theoretical assessment approaches (~2.9)

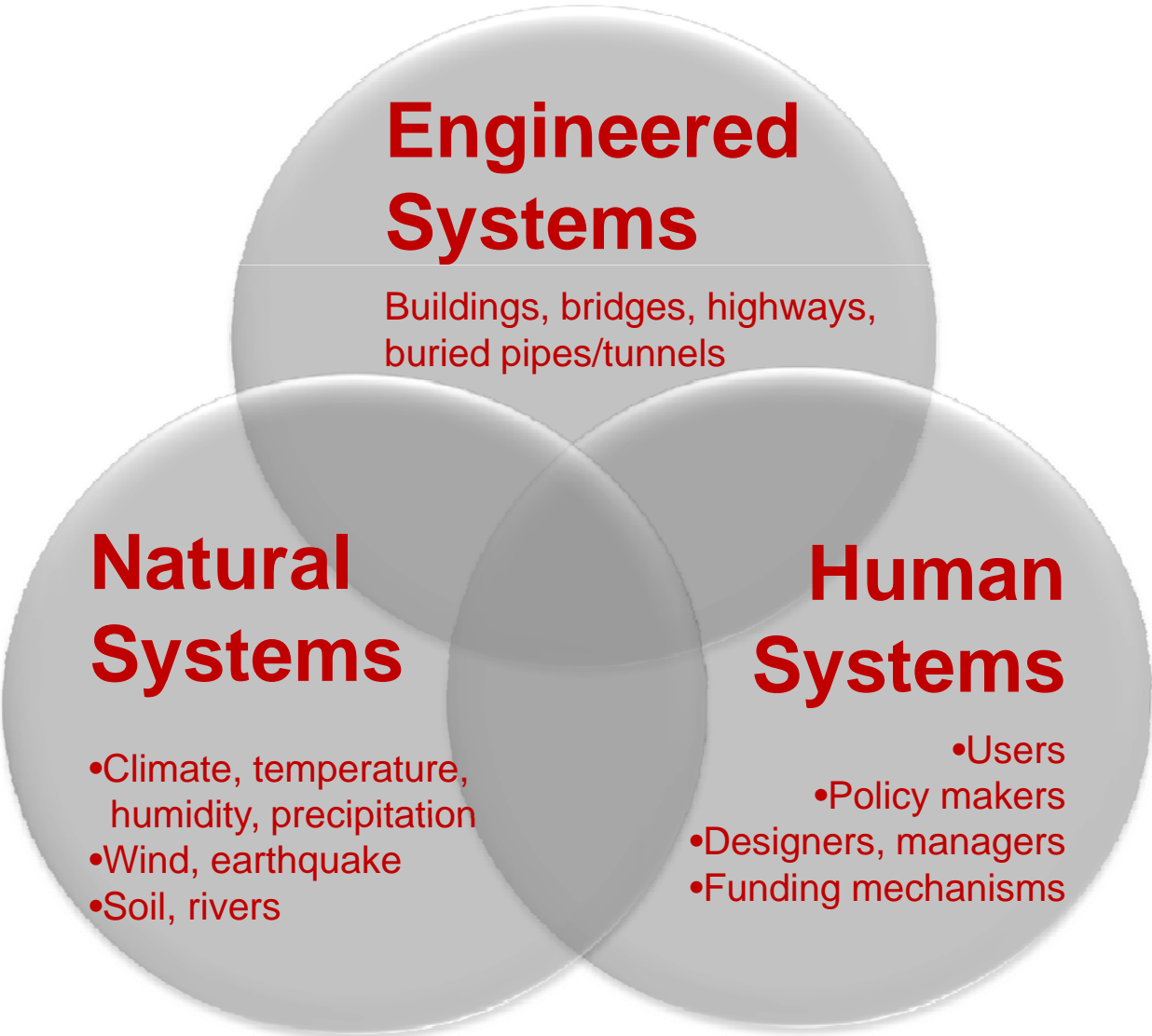
# Questions, comments, discussion?

## U.S. Transportation system (TRB 2002)

- 600,000 bridges
- 3.9 million miles of road
- 4.1 trillion passenger-miles/yr
- Carries \$8 trillion/yr in goods
- Demand for travel increased by 50% between 1977-1995



# Infrastructures are made of...

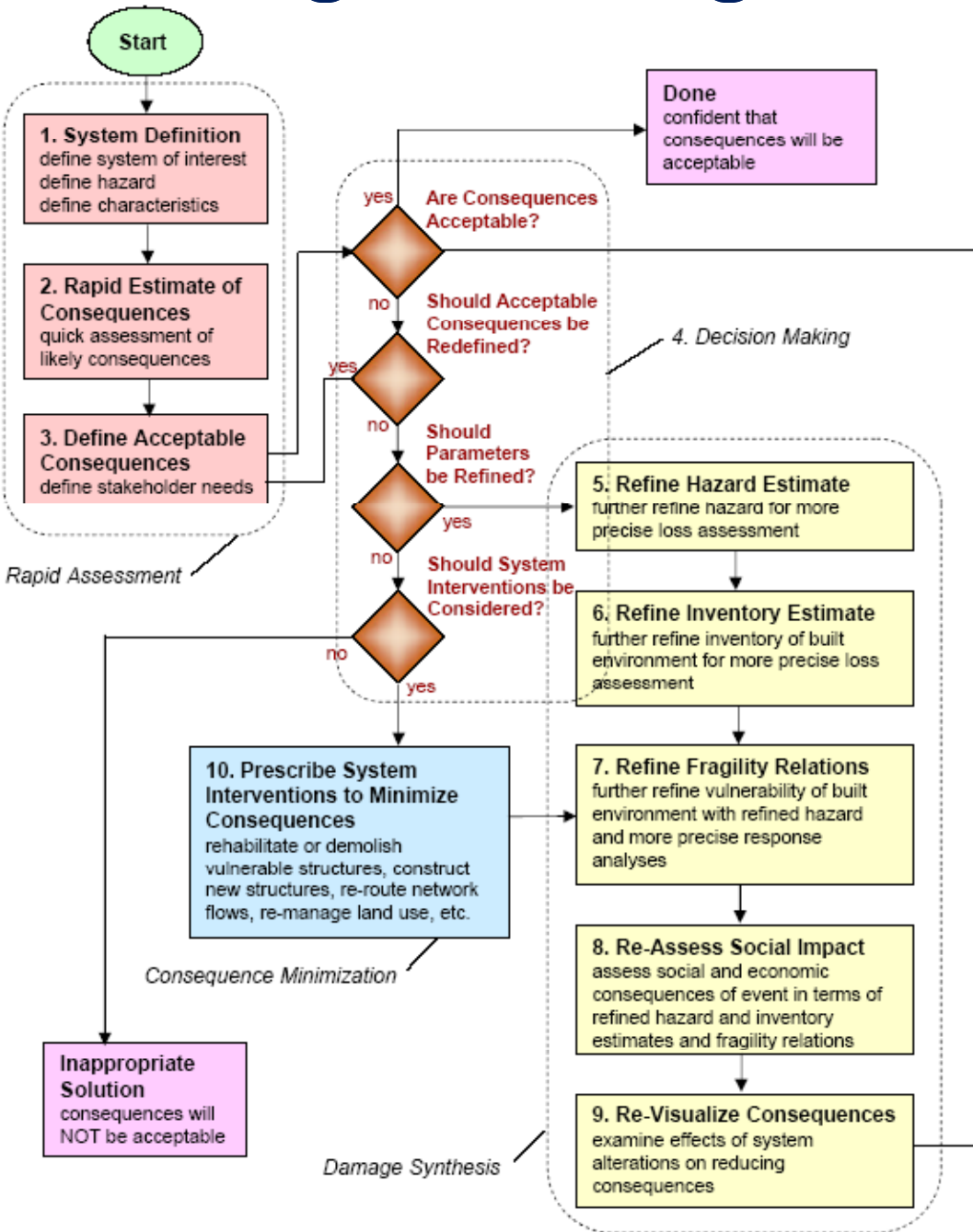


# Related paradigms – Assessing Costs

# Consequence-based Engineering...

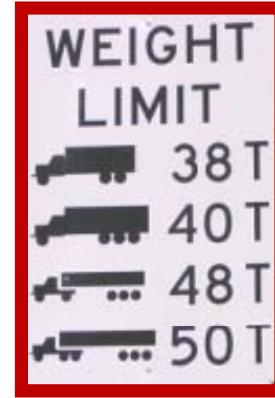
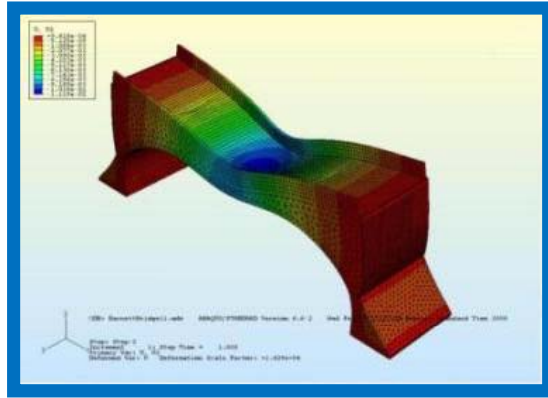
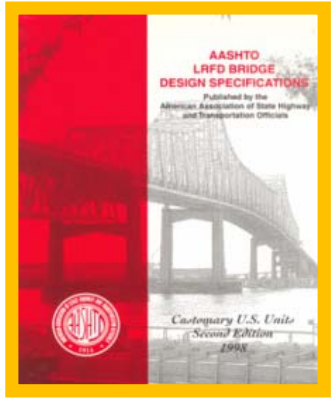
*is a new paradigm for seismic risk reduction across regions...that incorporates identification of uncertainty in all components of seismic risk modeling and quantifies the risk to societal systems and subsystems...to develop risk reduction strategies...*

D.P. Abrams, A.S. Elnashai and J.E. Beavers (2002) "A New Engineering Paradigm: Consequence-Based Engineering," EERI



## Challenges – Fragmentation

# Along the Life-Cycle of Assets



*Politics - Policy - Planning - Financing - Preliminary /Conceptual Design - Feasibility -Social and Environmental Impacts - Detail Design - Bidding - Contracting - Redesign - Refinance for Construction - Procure Materials - Fabricate - Construct - Commission - Operate - Inspect - Manage - Maintain - Repair - Rehabilitate -Change/modify - Reuse - Hazard - Retrofit - Renew - Decommission - Recycle .....*

# Asset Management is...

- **Policy-Driven.**
- **Performance-Based**
- **Capable of Analyzing Options and Trade-offs**
- **Based on Quality, Objective Information**
- **Monitored to Provide Accountability and Feedback**



United States General Accounting Office  
Report to the Ranking Minority Member, Committee on  
Environment and Public Works, U.S. Senate (March 2004)