Infrastructure Systems and Asset Management

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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)

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Definitions

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.

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**

**Bridge Collapse in Minneapolis Kills at Least 7**

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

**The New York Times**

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

Published: August 15, 2003
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

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
Acknowledgments, transparency

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

White House Office of Management and Budget
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
Motivations - Funding

Potential influx of funding

- **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
Challenges – Fragmentation

Across Infrastructure Classes

- Civil Engineering
- Building Infrastructure
  - Architectural
  - Structural
- Transportation Infrastructure
  - Geo Engineering
- Water Infrastructure
- Construction
- Transportation and Development
- Environmental and Water Resources
- Coasts, Oceans, Ports and Rivers

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

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

**Perception?**

**Reality?**

[MSNBC.com]

Pittsburgh, PA - Collapse of I-70 overpass under its own weight, 27 December 2005

Number of Bridge Failures per Year:

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<td>59</td>
<td>18</td>
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Challenges – Culture

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)
Challenges – Culture

Process-based mindset

(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.

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

Enabling Asset Management

Paradigms requiring...

Technological, Organizational, Societal, reform

Performance-based Engineering

Asset Management

Infra. Health Monitoring
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
The HAZUS-MH framework includes six interdependent modules:

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

www.fema.gov/plan/prevent/hazus/
# Performance-based Engineering

<table>
<thead>
<tr>
<th>Domain</th>
<th>Limit State</th>
<th>Operational and Utility</th>
<th>Engineering</th>
<th>Societal Goals</th>
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<tr>
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<td>Safety</td>
<td>Serviceability</td>
<td>Long-term economic sustainability</td>
<td>Healthy and Just Society</td>
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<tr>
<td>Societal</td>
<td>Security</td>
<td>Durability</td>
<td>economic sustainability</td>
<td>Promote good governance</td>
</tr>
<tr>
<td>Natural</td>
<td>Efficiency</td>
<td>Safety</td>
<td>Long-term economic sustainabilty</td>
<td>Rely on sound science</td>
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</tbody>
</table>

- Limit State: Safety, Security, Efficiency
- Operational and Utility: Serviceability, Durability, Safety, Stability of failure
- Engineering: Long-term economic sustainability, Preserve culture
- Societal Goals: Respecting the environment
Related paradigms – Assessing Benefits

Infrastructure  Health  Performance

Monitoring

remote data processing

DI³ Servers

Video

data acquisition

weather.com
Related paradigms – Assessing Benefits

**Structural Identification**

Sensing

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

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

**Structural Identification**

1. Observation and conceptualization
2. A-priori modeling
3. Controlled Experimentation
4. Processing and Interpretation of data
5. Model calibration and parameter ID
6. Utilization of model for simulations

Structural Identification
Related paradigms - Implementation

**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

Input to Policy, Revenue Generation, Allocation

Look Measure Model

Applied Systems Analysis

Human

Engineering

Natural

Identify interactions interconnections

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

Water main breaks require cuts through pavement and impact the long-term performance of the entire pavement systems

Minor leaks undermine pavement systems and reduce pavement life-span
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.
Role of the Workshop

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)

1=Strongly agree, 2=Agree, 3=On the fence, 4=Disagree, 5=Strongly disagree
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
Definitions

Infrastructures are made of...

- **Engineered Systems**: Buildings, bridges, highways, buried pipes/tunnels
- **Natural Systems**: Climate, temperature, humidity, precipitation, wind, earthquake, soil, rivers
- **Human Systems**: Users, policy makers, designers, managers, funding mechanisms
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...

Challenges – Fragmentation

Along the Life-Cycle of Assets

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)