# A Sociotechnical Framework for Infrastructure Analysis: Capturing Scale and Complexity

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# Orientation

- This talk presents a very broad conceptual framework for understanding infrastructure in terms of scale and/or complexity
- Work in progress
  - Loose ends, inconsistencies haven't fully been worked out
  - Looking for all kinds of input, suggestions, criticisms, connections
    - Ideas for links to ethnographic/historical work
    - Ideas for stronger connections into STS theory

# Background

- Interest in synthesizing STS work on infrastructure
  - Including my own work on seismic retrofitting (thesis) and Hurricane Katrina (Disrupted Cities chapter)
- New problems suggested by my involvement with infrastructure protection and modeling communities
  - Broad definitions of infrastructure
  - Need for better conceptual frameworks
  - Need to identify/quantify social relevance of infrastructure
- Interest in understanding infrastructure in terms of its relevance to social worlds and social order generally
  - Beyond context of innovation and system building

# National Infrastructure Protection Plan

Covers these "critical infrastructure" sectors:

- Defense Industrial Base
- National Monuments and Icons
- Chemical
- Commercial Facilities
- Critical Manufacturing
- Dams
- Nuclear Reactors, Materials, & Waste
- Government Facilities
- Energy
- Water
- Information Technology
- Communications
- Transportation Systems
- Postal and Shipping
- Agriculture and Food
- Healthcare and Public Health
- Banking and Finance
- Emergency Services

# National Infrastructure Protection Plan

These are widely-distributed assets but do not directly connect dispersed sites (i.e. they are not networks):

- Defense Industrial Base
- National Monuments and Icons
- Chemical
- Commercial Facilities
- Critical Manufacturing
- Dams
- Nuclear Reactors, Materials, & Waste
- Government Facilities
- Energy
- Water
- Information Technology
- Communications
- Transportation Systems
- Postal and Shipping
- Agriculture and Food
- Healthcare and Public Health
- Banking and Finance
- Emergency Services

# National Infrastructure Protection Plan

These are classic infrastructure networks:

- Defense Industrial Base
- National Monuments and Icons
- Chemical
- Commercial Facilities
- Critical Manufacturing
- Dams
- Nuclear Reactors, Materials, & Waste
- Government Facilities
- Energy
- Water
- Information Technology
- Communications
- Transportation Systems
- Postal and Shipping
- Agriculture and Food
- Healthcare and Public Health
- Banking and Finance
- Emergency Services

# National Infrastructure Protection Plan

These are something more complex than a network:

- Defense Industrial Base
- National Monuments and Icons
- Chemical
- Commercial Facilities
- Critical Manufacturing
- Dams
- Nuclear Reactors, Materials, & Waste
- Government Facilities
- Energy
- Water
- Information Technology
- Communications
- Transportation Systems
- Postal and Shipping
- Agriculture and Food
- Healthcare and Public Health
- Banking and Finance
- Emergency Services

# National Infrastructure Protection Plan

Q: Are all of these things even infrastructure?

A: Yes, I think

- Distributed, standardized, tie together places and practices

Q: How can such diverse entities all be defined as infrastructure?

A: Scale

- Defense Industrial Base
- National Monuments and Icons
- Chemical
- Commercial Facilities
- Critical Manufacturing
- Dams
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# Defining Infrastructure

- Infrastructure is:
  - Embedded:
    - “Infrastructure is sunk into, inside of, other structures, social arrangements, and technologies” (Star and Ruhleder)
  - Distributed:
    - “Infrastructure has reach beyond a single event or one-site practice” (Star and Ruhleder)
    - Infrastructure is also integrated across events and sites; it connects events and sites
  - Standardized:
    - Standardized sociotechnical components
    - Standardized interfaces: “Infrastructure takes on transparency by plugging into other infrastructures and tools in standardized fashion” (Star and Ruhleder)
    - Standardized interactions with users
- As a result, infrastructure has a universal quality

# The Importance of Scale

- Paul N. Edwards (2003): The significance of infrastructure is that it cuts across scales
  - “By linking macro, meso, and micro scales of time, space, and social organization, [infrastructures] form the stable foundation of modern social worlds” (Edwards)
- At a macro scale, function is more important than specific technologies and practices
- Larger-scale (spatially, socially) aspects of infrastructure tend to be more stable, while specific technologies and components may change more frequently

# Scale and Infrastructure Evolution

| | Systems | Infrastructures | |
|---|---|---|---|
| | | ***Networks*** | ***Internetworks or Webs*** |
| **Key actors** | System builders<br>Users (adjustment roles) | Gateway builders<br>Standards bodies<br>Corporations & governments<br>Users (transformative roles) | Gateway builders<br>Standards bodies<br>Corporations & governments<br>Users (foundational roles) |
| **Elements** | Heterogeneous components and subsystems | Heterogeneous systems | Heterogeneous networks |
| **Gateways and standards** | Dedicated or improvised | Generic or meta-generic | Generic or meta-generic |
| **Control vs. coordination** | Control<br>Central, strong | Control and coordination<br>Partially distributed, moderate strength | Coordination<br>Widely distributed, weak<br>Reliant on other infrastructures |
| **Boundaries** | Closed, stable | Open, reconfigurable | Open, reconfigurable<br>Virtual or second-order large technical systems |
| **Examples** | Local electric power company<br>Enterprise computing (e.g. banks, insurance companies) | Railroad; electric power grids<br>Grid computing<br>NEES, GEON<br>National weather services | Intermodal freight<br>Global telephone system (fixed + mobile + VOIP)<br>Internet and WWW<br>World Weather Watch |

Source: Edwards, Jackson, Bowker and Knobel (2007)

# Scale and the Social Worlds of Infrastructure

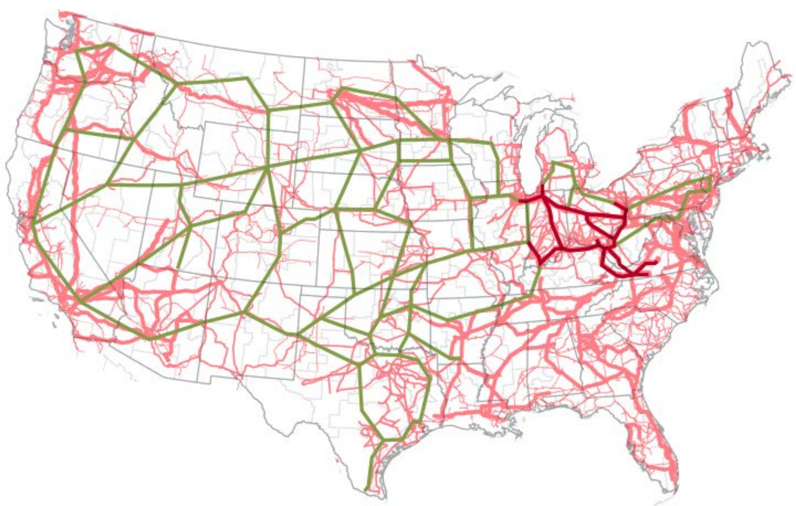
- Extend this categorization in several ways
  - Talk about coexistence of different scales of infrastructure, rather than changes of scale over time of individual infrastructures
  - Capture scales of infrastructure integration below and above networks (NIPP list)
  - Capture relevance of infrastructure to social worlds with both insider and outsider connections to technology
- Three proposed levels of infrastructure
  - Boundary systems
  - Networks
  - Functional sectors

# Levels of Infrastructure

- Boundary Systems
  - Sociotechnical entities that have standardized roles/meanings across locations but do not themselves tightly couple locations
  - Some infrastructure is primarily composed of these entities:
    - Chemical production
    - Manufacturing
- These entities can also be components of infrastructure networks
  - Power plants

# Levels of Infrastructure

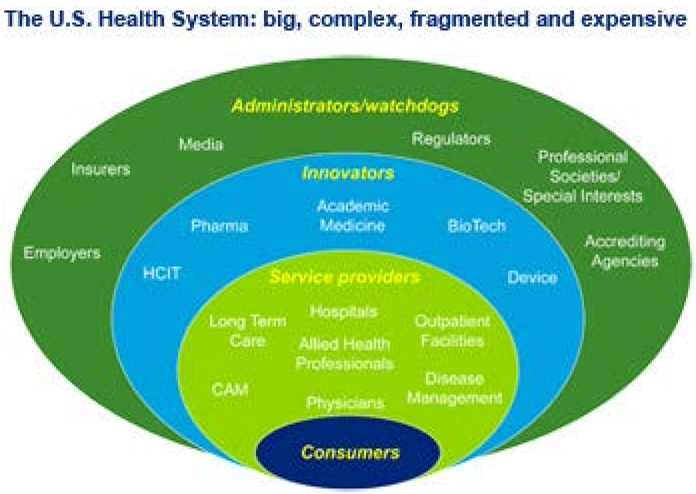
- Networks
  - Distributed collections of standardized entities that tightly couple dispersed locations to form a network
  - Examples:
    - Electrical grid
    - Road network
    - Internet



  - Encompass boundary systems (interchanges, connectors)

# Levels of Infrastructure

- Functional Sectors
  - Distributed collections of standardized entities and practices that tightly couple dispersed locations at multiple levels of practice and technological integration
  - Examples:
    - Health care
    - Banking and finance
    - World Wide Web
  - Encompass and depend on multiple networks
  - Create continuous cultural forms across locations



# Scales of Integration

| | Boundary Systems | Networks | Functional Sectors |
|---|---|---|---|
| **Spatial** | • Micro scale<br>• Strong interdependencies at local scale<br>• Weak interdependencies globally, may be handled by other infrastructures | • Meso scale<br>• Moderate interdependencies at local and global scales | • Macro scale<br>• Strong interdependencies at local and global scales<br>• Interdependencies are denser, broader, and via multiple modes of interaction |
| **Temporal** | • Changes typically take place in years-decades | • Changes typically take place in decades | • Changes typically take place in decades-centuries |
| **Production** | • Resources → Commodities | • Commodities → Services | • Services → Packages |

# Definitional Characteristics

| | Boundary Systems | Networks | Functional Sectors |
|---|---|---|---|
| **Embedding** | • Embedded in local practices and sites<br>• Embedded in infrastructure networks and functional sectors | • Embedded in local practices at numerous sites and in generic global practices<br>• Embedded in functional sectors | • Embedded in dominant cultural frames and social structures at numerous sites |
| **Distribution** | • Sites have common relationship to networks and forms of practice | • Same as at left, plus tight sociotechnical coupling between sites | • Multiple dimensions of sociotechnical and cultural continuity between sites |
| **Standardization** | • Standardized equipment and practices<br>• Standardized outputs | • Standardized connectors, gateways, interfaces, and protocols | • Standardized cultural frames, gateways and roles |

# Social Worlds

| | Boundary Systems | Networks | Functional Sectors |
|---|---|---|---|
| **Characteristic actors** | • Skilled workers<br>• Engineers<br>• Line managers | • Field technicians<br>• System analysts<br>• System managers<br>• Customer service representatives | • Service workers<br>• Human resource managers<br>• Client-oriented professionals |
| **Types of work** | • Invisible/"dirty" work<br>• Low status<br>• Low cultural relevance | • Mix of visible/invisible, clean/dirty<br>• Moderate status<br>• Moderate cultural relevance | • Some work is highly visible and "clean"<br>• Some work is high status<br>• High cultural relevance |
| **Internal ways of knowing** | • Time and motion studies<br>• System models | • Systems analysis<br>• Network dynamics models | • Policy/econ analysis<br>• Sociotechnical simulations (?) |
| **Connection to external social worlds** | • Indirect, via higher levels of infrastructure | • Provide services directly to users<br>• Limited interaction with users | • Provide complex, interactive services to users in shared social settings |

# STS Analysis Approaches

| | Boundary Systems | Networks | Functional Sectors |
|---|---|---|---|
| **Key theoretical perspectives** | • Theories of interaction and construction of meaning in practice | • Organizational theory, ANT approaches | • Structural/economic theories (Marx, Durkheim) |
| **Potential methodologies** | • Ethnographic studies, one or several sites | • Multi-site ethnographic studies<br>• Historical studies<br>• User studies | • Multi-site/multi-mode ethnographic studies<br>• Cultural studies<br>• Political/economic studies |
| **Useful levels of access** | • Work sites<br>• System design and engineering<br>• Local management decision making | • Workers in the field<br>• System/network analysis and planning<br>• Standard-setting bodies<br>• Central management decision making | • Internal-external interaction sites<br>• Policy analysis and planning<br>• Regulatory bodies<br>• Professional associations<br>• Government agencies |

# Conclusion: Advantages of this perspective

- Ties together existing STS literature on infrastructure
  - Definitional characteristics, scale, system building
- Encompasses infrastructure connections to both builder/worker and user social worlds
- Provides guidelines for appropriate methodologies for studying infrastructure at different scales
  - Implications for STS analysis, infrastructure simulation, policy and planning
- Sensitive to issues that might predict social impact of infrastructure disruption
  - Spatial and temporal scales of dependencies
  - Nature of user interfaces/dependencies

# Discussion

- Questions?
- Loose ends, inconsistencies?
- Ideas for links to ethnographic/historical case studies
- Ideas for stronger connections into STS theory (ANT, SCOT, etc.?)