Introduction to Civil Information Systems

Mark A. Austin

University of Maryland

austin@umd.edu

ENCE 688R, Spring Semester 2023

January 27, 2023

Overview

Part 2

Near-Term Challenges

Civil Engineers need to create the infrastructure for citizens of the Information Era

Crisis in US Infrastructure Investment

Exemplars of Work from the 1800s and 1900s

From the 1800s	**From the 1900s**
Erie Canal (1825)	New York City Subway (1904)
Transcontinental Railroad (1869)	The Panama Canal (1914)
Brooklyn Bridge (1883)	Holland Tunnel (1927)
Washington Monument (1884)	Empire State Building (1931).
	Hoover Dam (1936).
	Golden Gate Bridge (1937)
	Interstate Highway System (1956)

Source: Celebrating the Greatest Profession, Magazine of the American Society of Civil Engineers, Vol. 72, No. 11, 2002.

Crisis in US Infrastructure Investment

Universal Observations:

- Aging infrastructure becomes expensive to maintain.
- New (replacement) infrastructure is very expensive.
- Politicians are eager to talk up Infrastructure Investment , but slow to deliver ….

Bottom line:

- Critical infrastructure is taken for granted and not a national priority (ASCE, IEEE).

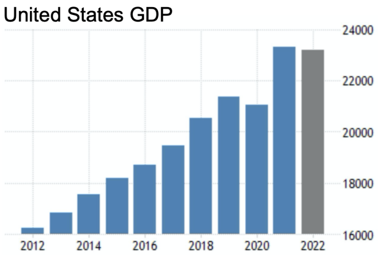
Delay, delay, delay ….

Bangkok, Thailand

Crisis in US Infrastructure Investment

Statistics:

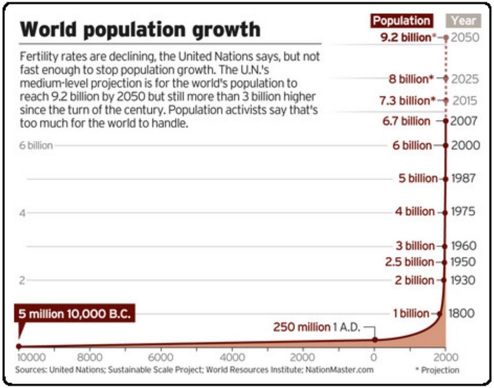
- US: Post World-War II (1950-1970): 3% of Gross Domestic Product (GDP)
- US: 1980-present: 2% of GDP.
- China: 5% GDP.
- India: 9% GDP.



Infrastructure Investment and Jobs Act (2021).

- Invest $1.2T over 10 years.
- Sounds like a lot – but is it too low, too high?
- Increases investment by 0.5% of GDP.

World Population Forecasts



Increasing Population → Increased Demand on Limited Resources
→ Increasing need for Improvements to System Efficiency.

Urbanization and Sustainable Cities

Urbanization in America:

- In 2010, 82 percent of Americans lived in cities.
- By 2050 it will be 90 percent.

Cities are responsible for:

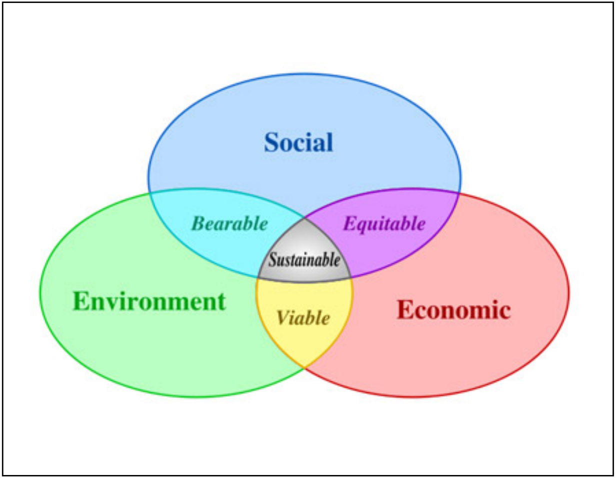
- Two thirds of the energy used,
- 60 percent of all water consumed, and
- 70 percent of all greenhouse gases produced worldwide.

Sustainable cities (SIEMENS, Sustainable Cities, USA):

- Environmentally friendly infrastructures;
- Improved quality of life for residents;
- Good economics.

Sustainable Urban Systems

Sustainability involves physical, organizational and social systems.



Sustainable Urban Systems

Urban systems are like plants in your garden:

- Cities are defined by their emergent properties (e.g., beautiful flower ⇔ New York City Skyline).
- Cities grow and fourish based on societal and economic stimulus, and fall into decay when stimulus is absent.

But sustainability is a tough problem:

- Many of the world's large urban areas – so-called mega-cities – are in poor economic shape.

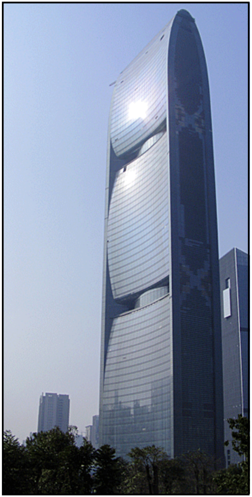
Cities are system of systems:

- Subsystems have a preference to operate as independently as possible from the other subsystems.
- Strategic collaborations needed to raise levels of attainable performance and limit cascading failures.

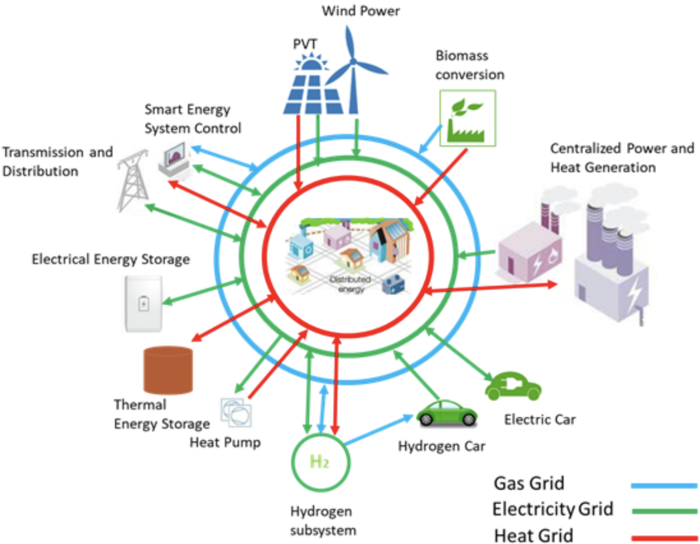
Integrated Energy Systems

Pearl River Tower (2010):

- High performance structure designed to produce as much energy as it consumes.
- Guides wind to a pair of openings at its mechanical floors.
- Wind drives turbines that generate energy for the heating, ventilation and air conditioning systems.
- Openings provide structural relief, by allowing wind to pass through the building.



Integrated Energy Systems (Proposed)



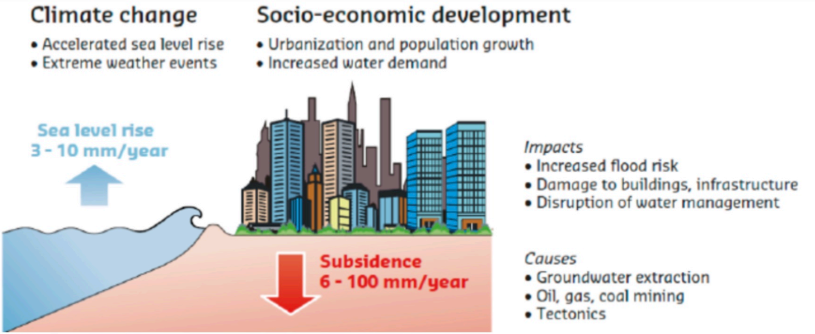
Infrastructure Protection and Recovery

New Threats to Urban Infrastructure

Coastal Cities are Sinking: (St. Mark's Square, Venice, Italy)

New Threats to Urban Infrastructure

Coastal Cities are Sinking: (within the US too ...)



Statistics: New Orleans, 2 inches per year; Houston, 0.8 inches per year; Miami, 12 inches in the past 100 years. Virginia Beach, 12 inches in the past 50 years.

Resilience of Urban Infrastructure

Example. Cascading Failures in Hurricane Katrina

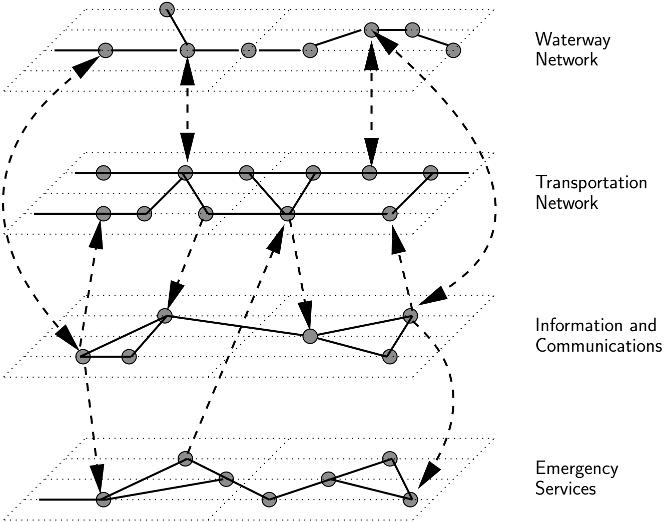
- Hurricane Katrina caused a storm surge which, in turn, resulted in the failure of levees around New Orleans.
- This is a failure in the waterway network.
- A more conservative (expensive) design might have prevented this failure.
- But the failure didn't stop there.

Resilience of Urban Infrastructure

Cascading Failures in Hurricane Katrina:

- **Waterway system failure.** The levees were insufficint to resist the storm surge.
- **Highway and electrical power system failures.** Flooding resulted in failure of the electrical power and highway systems.
- **Federal emergency failures.** Inhabits had to flee their homes, but few plans were in place for their orderly evacuation.
- **Social network failures.** After the inhabitants left their homes, looters stole property from evacuated properties.
- **Political system failures.** ...

Dependencies Among Urban Networks



Planning for Disaster Relief and Recovery

Lessons Learned

Cascading failures of this type indicate that:

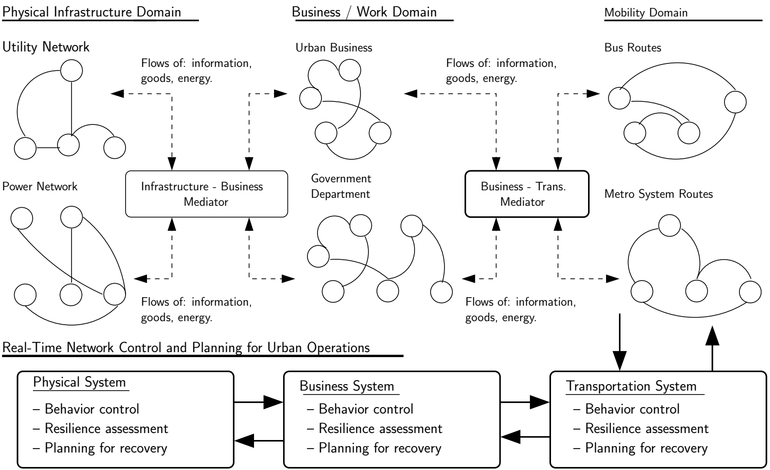
- There is a need to understand and manage interactions among infrastructure networks and organizational and societal factors.

Basic Questions

- What kinds of dependencies exist between the networks?
- How will a failure in one network impact other networks? These are so-called cascading failures.
- What parts of a system are most vulnerable?

We need to look at interactions between network models.

Near-Term View of Assessment & Planning for Recovery



Near-Term View of Assessment & Planning for Recovery

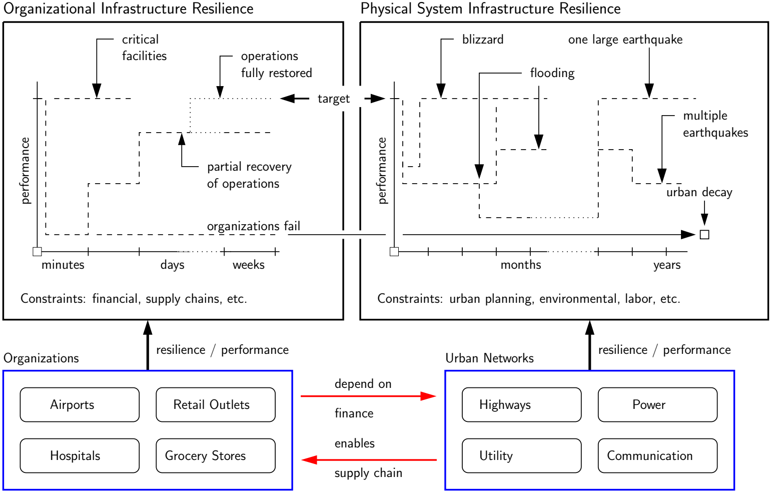
Key Characteristics

1. Networks are heterogeneous, interwoven, dynamic.
2. Disciplines want to operate independently in their domain.
3. Achieving target levels of performance and correctness of functionality requires that disciplines coordinate activities at key points in the system operation.
4. Disturbance in one system can impact other networks in ways that are unexpected.
5. Information exchange establishes common knowledge among the decision making agents. Better system management!

Key Challenge in Distributed System Control

1. How should decision makers cooperate to achieve system-wide performance and management objectives?

Longer-Term View of Infrastructure Resilience



Planning for Protection and Recovery

Critical Role of Sensing:

- Need situational awareness to understand what is actually happening (or about to happen) in a city.
- Sense the spatial, temporal, and intensity aspects of environmental phenomena (e.g., fires, flooding) and their impact on natural (e.g., air quality) and man-made systems (e.g., transportation networks, food chains).

Goal and Approach:

- Connect measurements and behavior modeling to planning of protection mechanisms and relief actions.
- Create warning systems that can look ahead and predict likely future states of the urban system.
- Use ML to identify events and cause-and-effect relationships. Use AI for distributed system behavior modeling.

References

- Array of Things: See https://arrayofthings.github.io
- Austin M.A., Delgoshaei P., Coelho M. and Heidarinejad M. , Architecting Smart City Digital Twins: Combined Semantic Model and Machine Learning Approach, Journal of Management in Engineering, ASCE, Volume 36, Issue 4, July, 2020.
- Bello J.P. et al., SONYC: A System for Monitoring, Analyzing, and Mitigating Urban Noise Pollution, Communications of the ACM, 62, 2, 2019, pp. 68-77.
- Coelho M., and Browning L.S., INL Digital Engineering: Model-Based Design, Digital Threads, Digital Twins, Artificial Intelligence, and Extended Reality for Complex Energy Systems, INL/CON-22-69247, Idaho National Laboratory, Idaho Falls, Idaho 83415, September, 2022.
- Leveson N.G., A New Approach to Software Systems Safety Engineering, System Safety Engineering: Back to the Future, MIT, 2006.
- Tien J.M., Toward a Decision Informatics Paradigm: A Real-Time Information-Based Approach, to Decision Making, IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews, Vol. 33, No. 1, February, 2003.