



Introduction to Civil Information Systems

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Overview

1 Modern Civil Infrastructure Systems

- Industrial Revolution
- Transition to Information Era

2 Near-Term Challenges (2020-2060)

- Crisis in US Infrastructure Investment
- Urbanization and Sustainable Cities
- Infrastructure Protection and Recovery

3 Features of Modern Computing

4 Cyber-Physical and Digital Twin Systems

5 Urban and Global Applications

6 Summary (Connections to Scientific Computing)

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



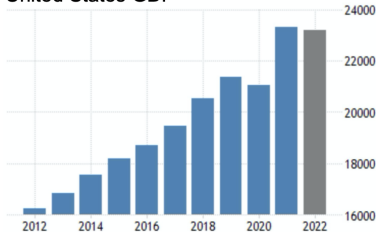
Bangkok, Thailand

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.

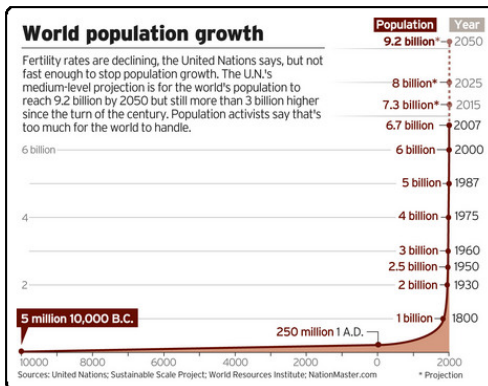
United States GDP



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:

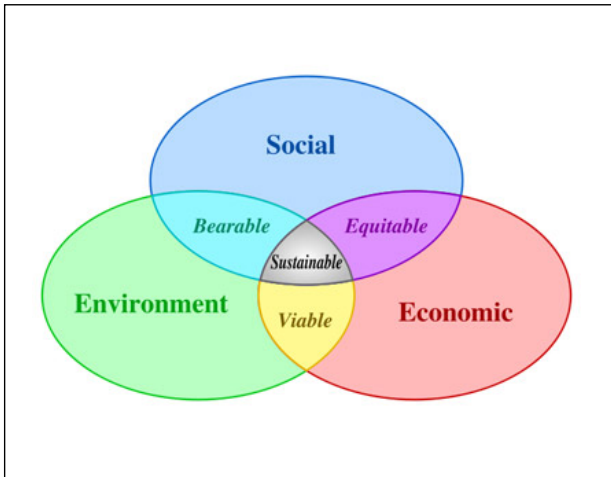
- Two thirds of the energy used,
- 60 percent of all water consumed, and
- 70 percent of all greenhouse gases produced worldwide.

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 \Leftrightarrow New York City Skyline).
- Cities **grow and flourish** 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**.

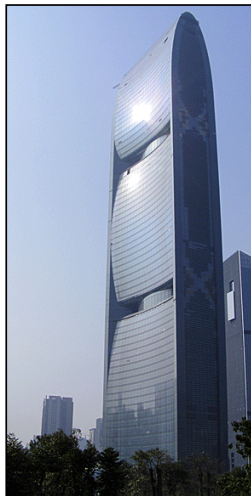
Cities are **system of systems**:

- 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**.

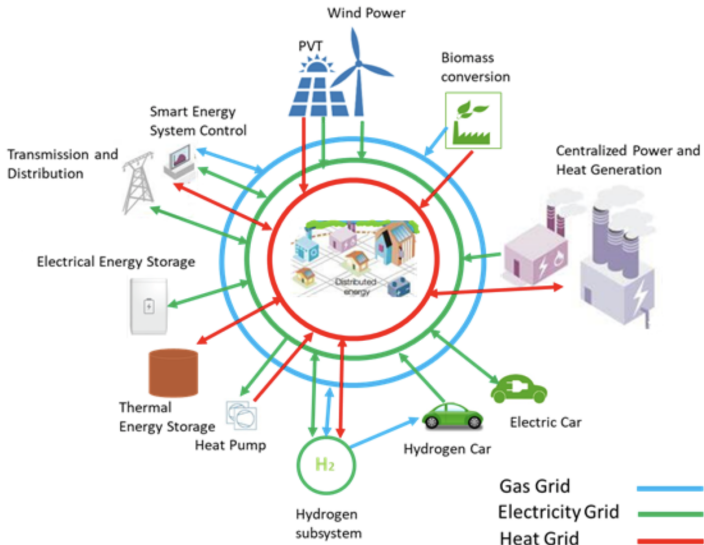
Integrated Energy Systems

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

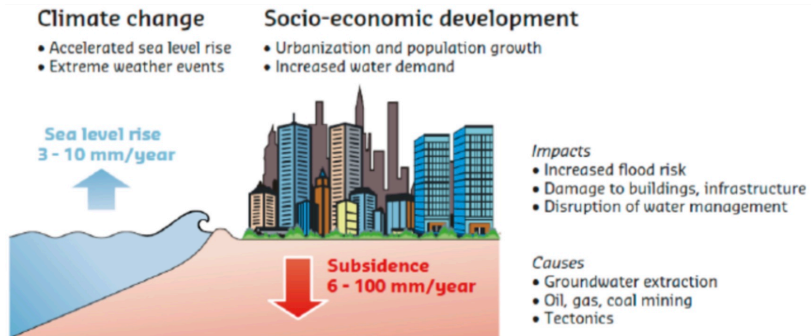
New Threats to Urban Infrastructure

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



New Threats to Urban Infrastructure

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

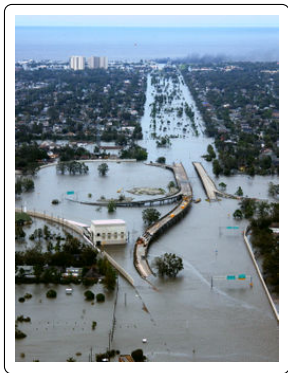


Statistics: New Orleans, 2 inches per year; Houston, 0.8 inches per year; Miami, 12 inches in the past 100 years. Virginia Beach, 12 inches in the past 50 years.

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.

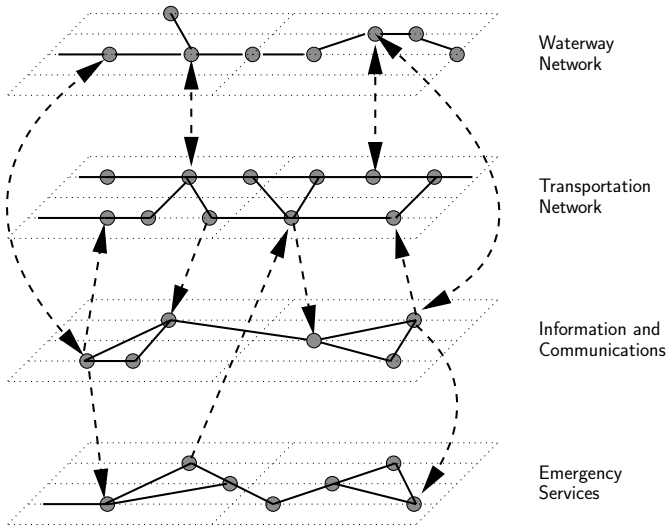


Resilience of Urban Infrastructure

Cascading Failures in Hurricane Katrina:

- **Waterway system failure.** The levees were insufficient 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.** Inhabitants 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

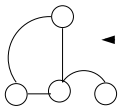
- What kinds of dependencies exist between the networks?
- How will a failure in one network impact other networks?
These are so-called **cascading failures**.
- What parts of a system are most vulnerable?

We need to look at **interactions between network models**.

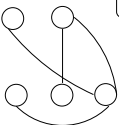
Near-Term View of Assessment & Planning for Recovery

Physical Infrastructure Domain

Utility Network



Power Network



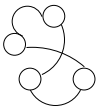
Flows of: information, goods, energy.

Infrastructure - Business Mediator

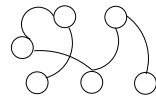
Flows of: information, goods, energy.

Business / Work Domain

Urban Business



Government Department



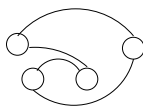
Flows of: information, goods, energy.

Business - Trans. Mediator

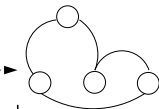
Flows of: information, goods, energy.

Mobility Domain

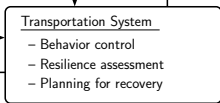
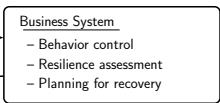
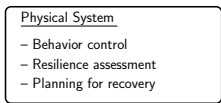
Bus Routes



Metro System Routes



Real-Time Network Control and Planning for Urban Operations



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**.

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