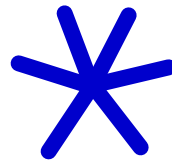


# Infrastructure Interdependencies



Terrence K. (Terry) Kelly, Ph.D.

Senior National Security Officer

White House Office of Science and Technology Policy

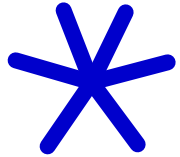
based in part on an article to appear in IEEE Control (December 2001)

by

Steve Rinaldi, Air Force Quadrennial Defense Review

Jim Peerenboom, Argonne National Laboratory

Terry Kelly, Office of Science and Technology Policy



## **Infrastructure Interdependencies**

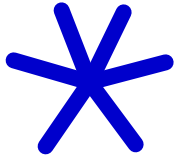
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**Our nation's infrastructures have become increasingly interconnected and interdependent**

**... this creates an increased possibility that a rather minor and routine disturbance can cascade into a regional outage**

**... it also creates new assurance challenges that can only be met by a partnership between owners and operators and government at all levels.”**

*President's Commission on  
Critical Infrastructure Protection 1997*



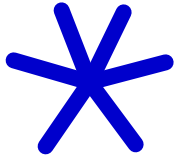
## Critical Infrastructures

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**... the framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, the smooth functioning of governments at all levels, and society as a whole.**

*Critical Infrastructure Assurance Office*

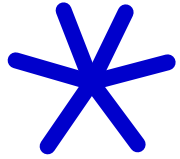
*[www.ciao.gov](http://www.ciao.gov)*



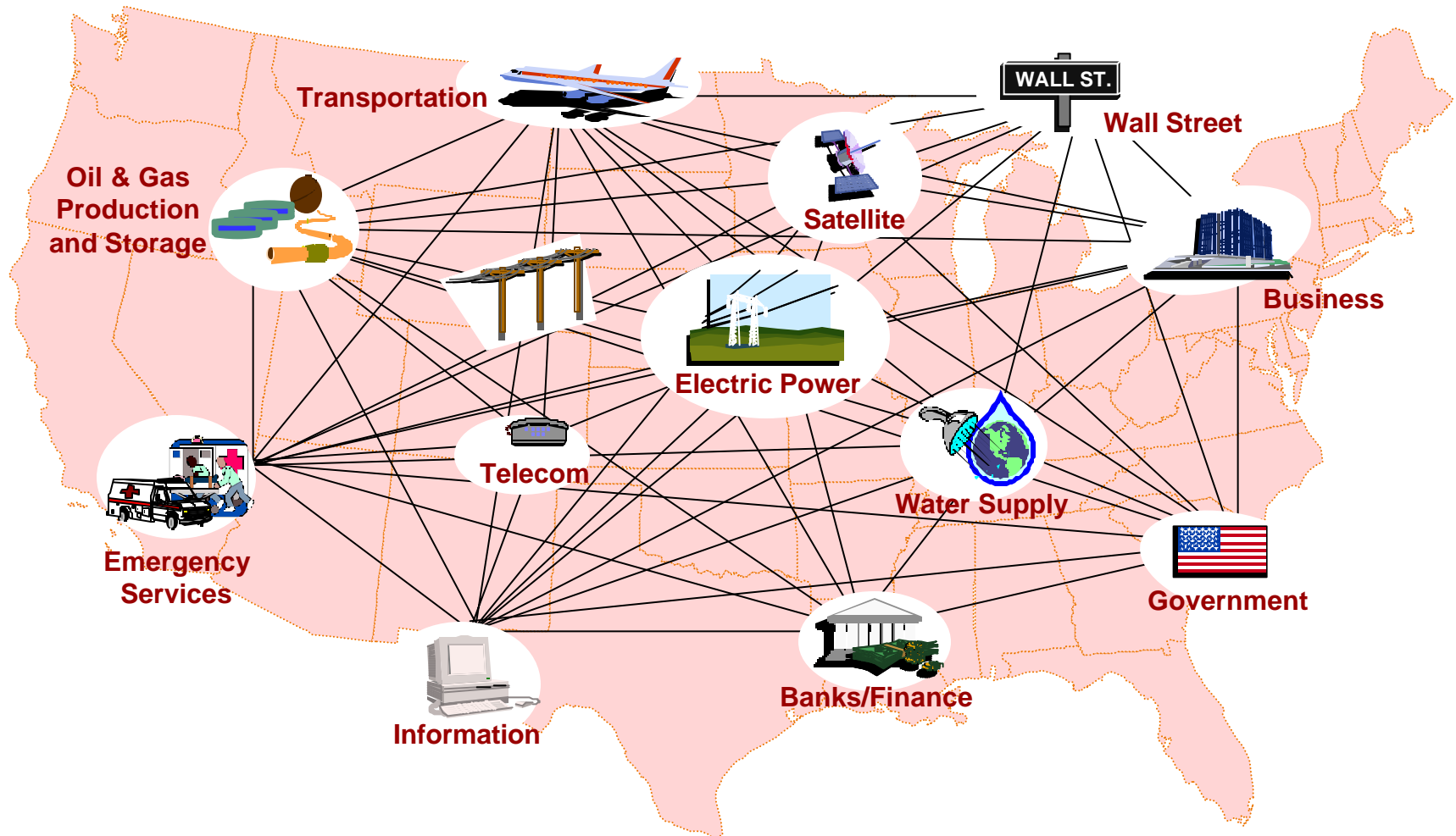
## Examples of Critical Infrastructures

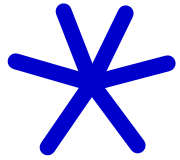
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- **Energy (electric power, oil, natural gas)**
- **Telecommunications**
- **Transportation**
- **Water systems**
- **Banking and finance**
- **Emergency services**
- **Government services**
- **Agriculture**
- **Others**



# Interdependencies Are Intuitive, but not Well Understood

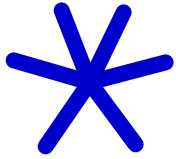




# Infrastructures as Complex Adaptive Systems (CAS)

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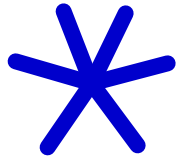
- **Framework for our analysis**
- **Guiding principles:**
  - Any analysis of infrastructures must account for their CAS nature
  - Infrastructures will exhibit emergent behaviors - which cannot be predicted *a priori*
  - Infrastructures are adaptable - whether through human intervention or the nature of the physical system itself
  - Interdependencies greatly increase infrastructure complexity
  - CAS nature requires that analyses are holistic - not reductionist - and that these analyses consider multiple “dimensions”



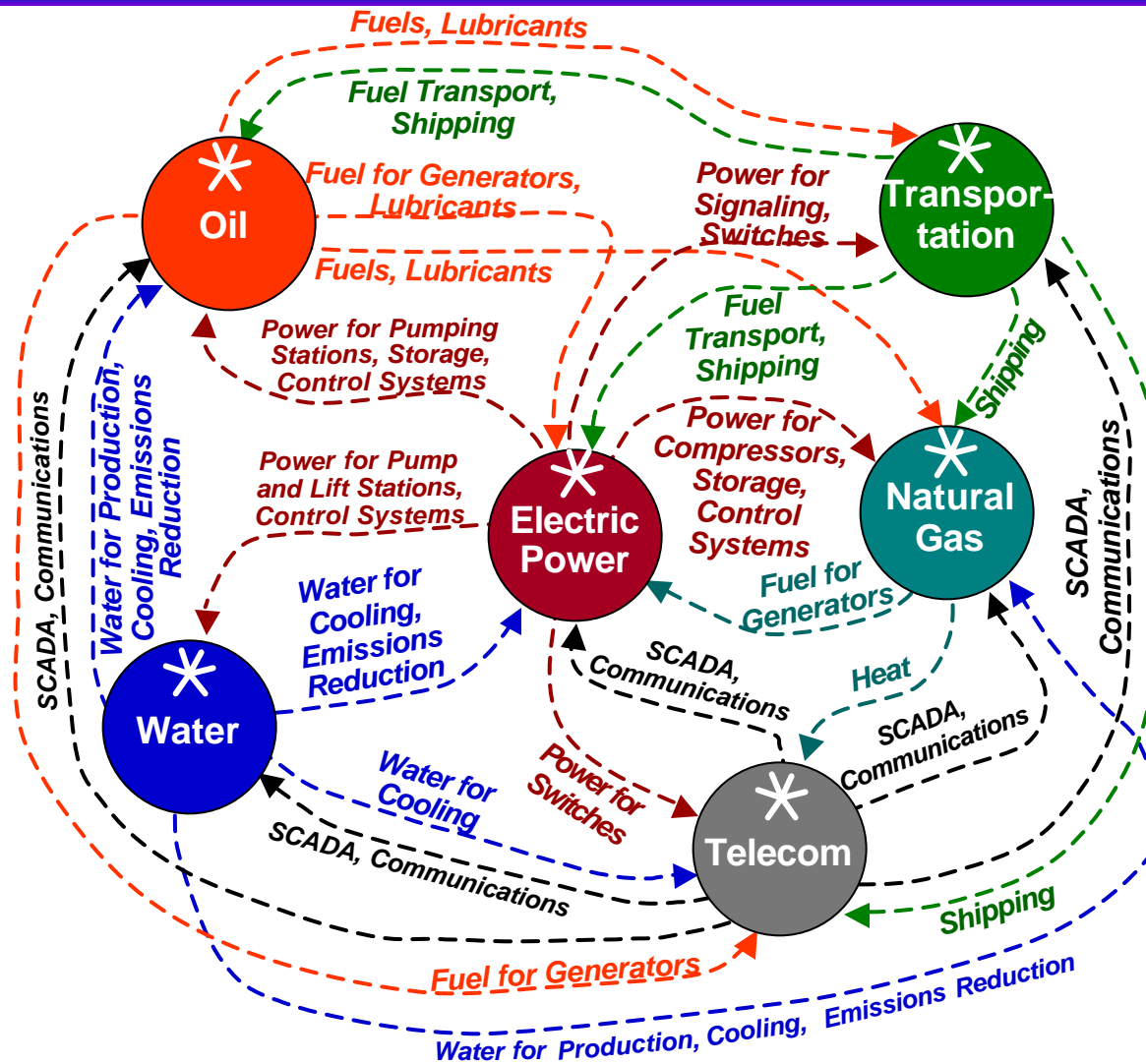
## Definitions

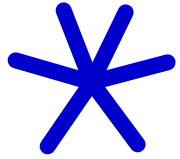
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- **Dependency:** A linkage or connection between two infrastructures, through which the state of one infrastructure influences or is correlated to the state of the other
- **Interdependency:** A bidirectional relationship between two infrastructures, through which the state of each infrastructure influences or is correlated to the state of the other infrastructure. More generally, two infrastructures are interdependent when each is dependent on the other



# Examples of Infrastructure Interdependencies

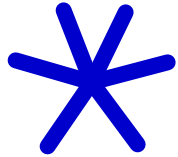




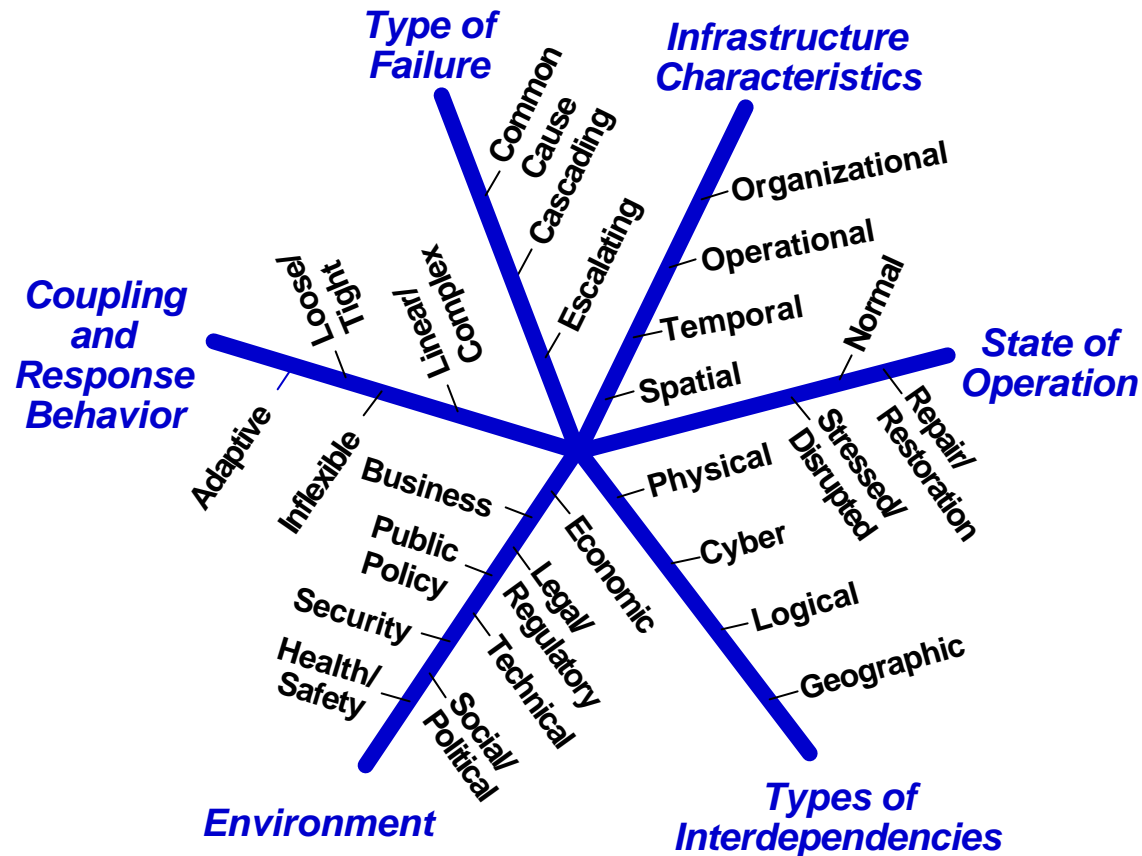
## **Interdependencies Considerations**

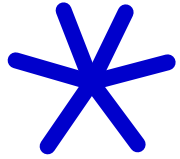
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- **Increasing reliance on information technology and telecommunications has increased interdependencies**
- **Interdependencies transcend individual public and private-sector companies**
- **Infrastructure linkages vary significantly in scale and complexity — local, regional, national, international**
- **Gaps exist in capability to analyze multiple contingency events involving interdependent infrastructures**
- **Understanding interdependencies requires examining multiple dimensions**



# Dimensions for Describing Infrastructure Interdependencies

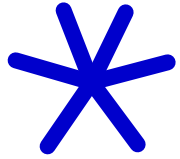




## Types of Interdependencies

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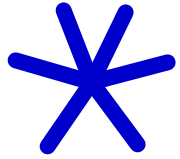
- **Physical:** Two infrastructures are physically interdependent if the state of each is dependent on the material output(s) of the other
- **Cyber:** An infrastructure has a cyber interdependency if its state depends upon information transmitted through the information infrastructure
- **Geographic:** Infrastructures are geographically interdependent if a local environmental event can create state changes in all of them
- **Logical:** Two infrastructures are logically interdependent if the state of each depends on the state of the other via a mechanism that is not a physical, cyber, or geographic connection



# Infrastructure Environment

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- Economic
- Business
- Public policy
- Legal and regulatory
- Technical
- Security
- Social/political
- Health/safety



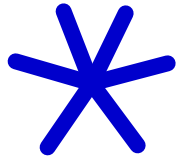
# Coupling and Response Behavior

- Degree of coupling
  - Loose
  - Tight
- Type of interaction
  - Linear
  - Complex
- Response behavior
  - Inflexible
  - Adaptive

Interactions

		Interactions	
		Linear	Complex
Coupling	Tight	<i>Dams</i> <i>Power Grids</i> <i>Airways</i>	<i>Nuclear Plant</i> <i>Space Missions</i>
	Loose	<i>Manufacturing</i>	<i>R&amp;D Firms</i> <i>Universities</i>

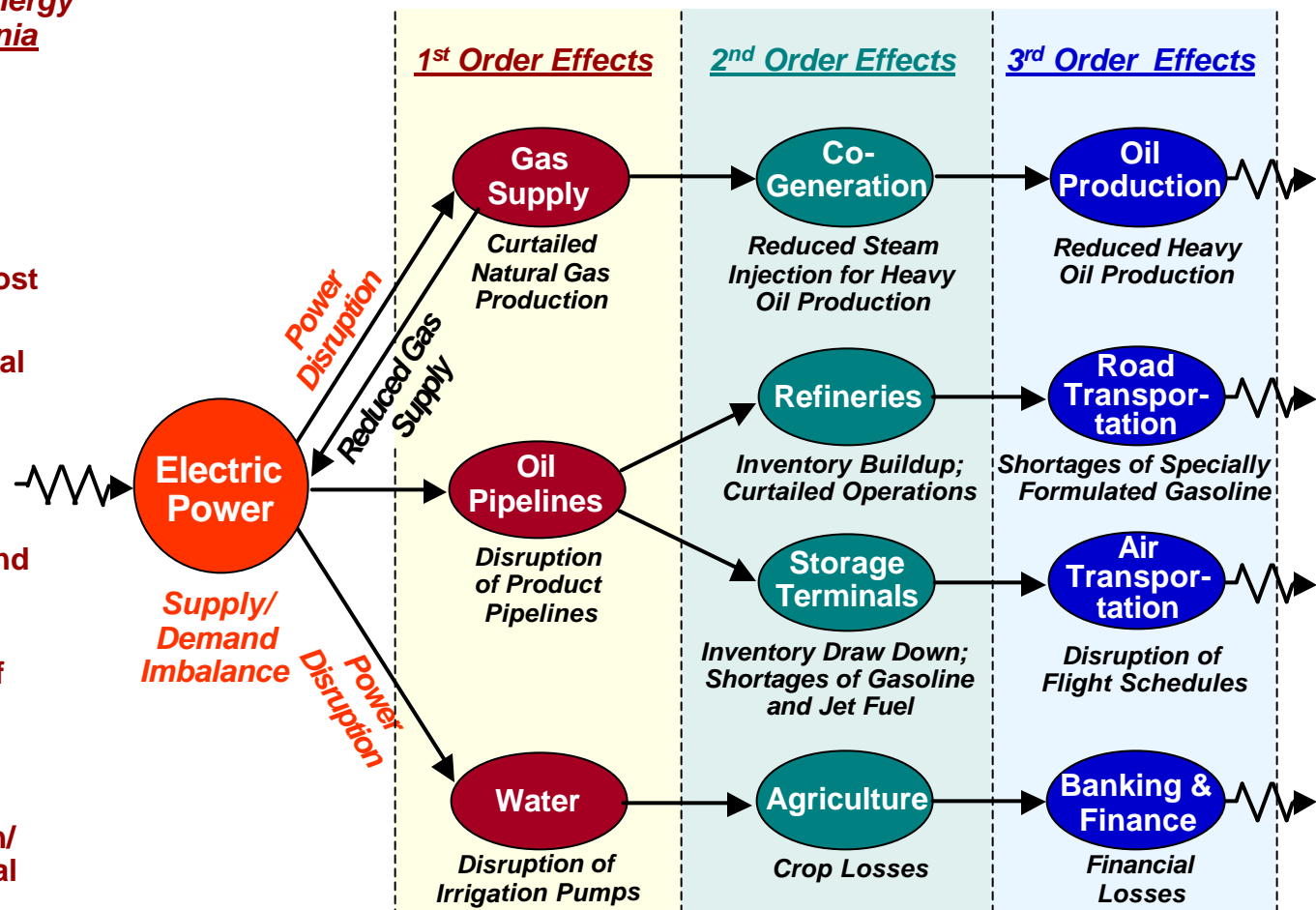
*from Perrow: Normal Accidents*

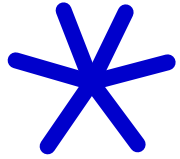


# Examples of Recent Interdependencies Effects in California

## Factors/Forces Contributing to Energy Crisis in California

- Deregulation policies
- New energy marketplace dynamics
- Tight, high-cost gas supplies
- Utility financial crisis
- Substantial load growth
- Lack of new generating and transmission capacity
- Aging fleet of power plants
- Low hydro conditions
- Transmission/environmental constraints

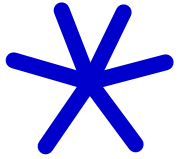




# Infrastructure Characteristics

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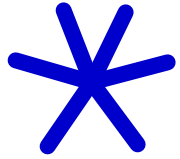
- **Organizational**
- **Operational (how the infrastructure reacts when stressed or perturbed)**
- **Temporal**
  - Infrastructure time constants
  - Time scales of interest
- **Spatial**
  - Components (part, unit, subsystem, system, infrastructure, interdependent infrastructures)
  - Geographic scale (cities, regions, national, international)



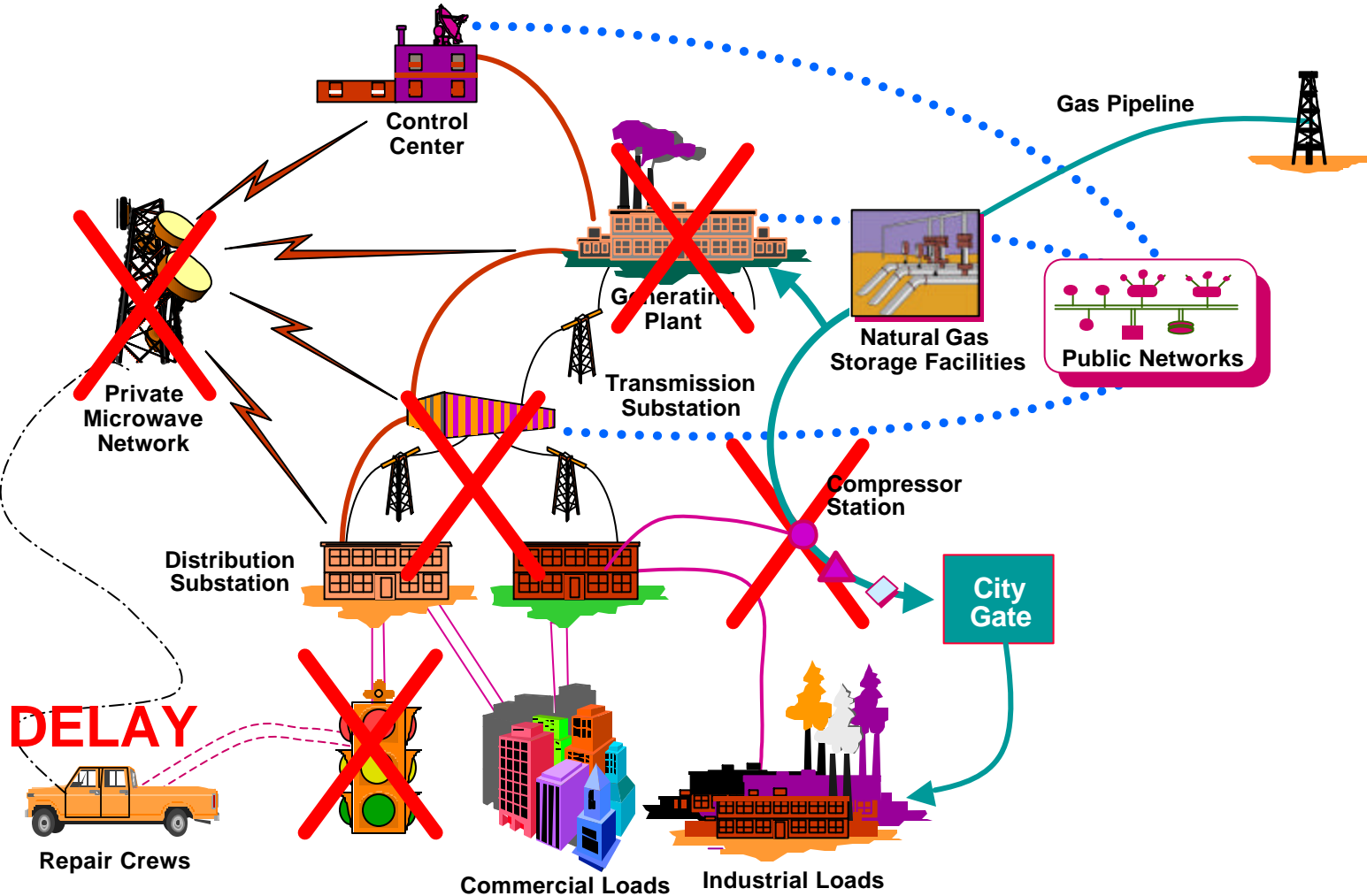
## Types of Failures

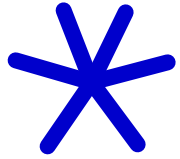
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- **Cascading failure** – a disruption in one infrastructure causes a disruption in a second infrastructure
- **Escalating failure** – a disruption in one infrastructure exacerbates an independent disruption of a second infrastructure (e.g., the time for recovery or restoration of an infrastructure increases because another infrastructure is not available)
- **Common cause failure** – a disruption of two or more infrastructures at the same time because of a common cause (e.g., natural disaster, right-of-way corridor)



# Examples of Cascading and Escalating Failures





# State of Operation

- Normal
- Stressed/disrupted
- Repair/restoration



Normal Operation

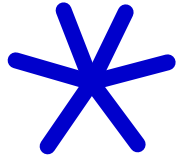


Disruptions



Power Outages

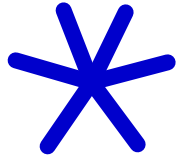
# Questions/Discussion



# Technical R&D Challenges - I

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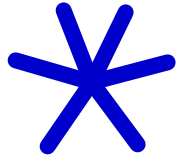
- **Problem Definition**
  - What are the operational requirements?
  - What is the existing state of the art?
  - What R&D programs exist to address the requirements?
  - What are the gaps and shortfalls in today's programs?
- **Architectures**
  - Designed to incorporate existing, legacy codes
  - Accommodate disparate model types – nodal analyses, agent-based analyses, stocks/flows, etc.
  - Flexible and open to allow “plugging in” modules
  - Can be tailored to multiple, different user communities



## Technical R&D Challenges - II

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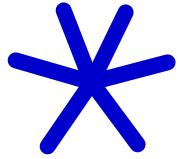
- **Data**
  - **Collection and real-time ingestion/updating**
  - **Degree of detail**
  - **Validation of data**
  - **Proprietary information & information sharing considerations**
  - **Required data vs data requirements**
  - **Classification and security concerns**
- **Scaling**
  - **Temporal -- dynamics span orders of magnitude**
  - **Spatial -- city to regional to national to international levels**
  - **Data considerations -- what level of detail is essential?**



## Technical R&D Challenges - III

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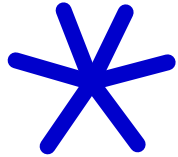
- **Metrics**
  - Determination of metrics
  - Development of M&S capabilities
- **Emergence**
  - “Theory” of emergent behaviors
  - Emergence and EBO
  - Emergence and targeting priorities
  - Relationship to enemy behaviors and options
- **Validation and verification**



# Practical Issues in Understanding Interdependencies

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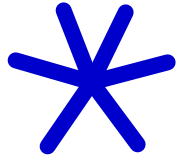
- **Importance to the operation of the infrastructures**
  - Normal operations
  - Disruptions (including coincident events)
  - Repair and restoration
- **How interdependencies change as a function of outage duration, frequency, and other factors**
- **What linkages exist between critical infrastructures and community assets**
- **How backup or other mitigation mechanisms can reduce interdependence problems**
- **How businesses, government, and other organizations understand and react to interdependencies**



# Policy Research Issues

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- **Legal - Policy - Technology**
- **What is the role of the federal government:**
  - National Security Council
  - Homeland Security Office
  - Dept of Defense
  - Dept of Commerce
  - Other Departments and Agencies
  - Regulatory agencies
- **What is the role of governments, and how do we handle the jurisdictional issues within states, between states, and between states and the federal government**
- **International and transnational issues**



# **Sociological, Business and Anthropological Research**

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- **Education/Training**
- **Business/Management**
  - Risk
  - Liability
  - Information Sharing
  - Antitrust
- **Organizational Behavioral issues**
- **Human factors**
- **Data/Information overflow**
- **etc.**