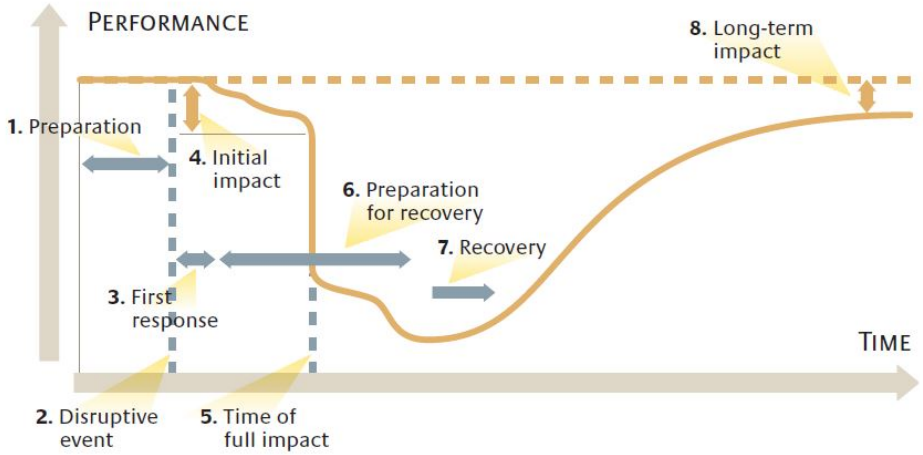
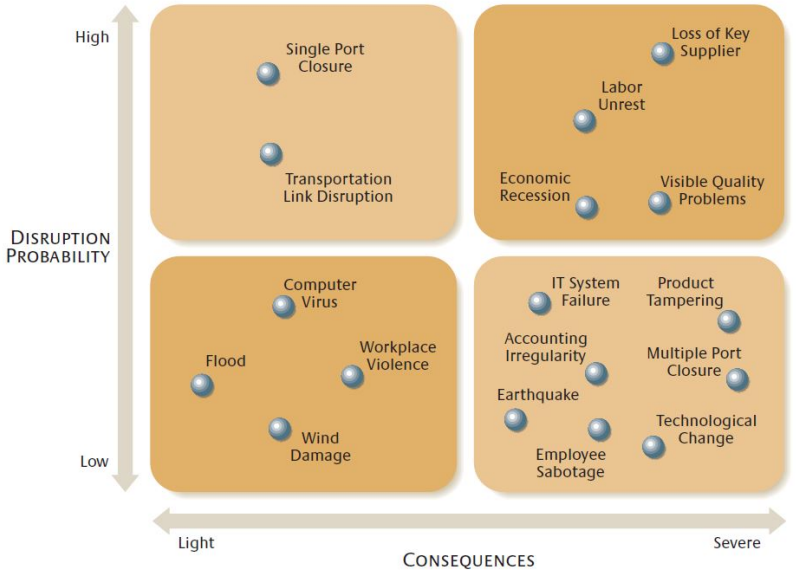
The Disruption Profile

Any serious disruption will affect the performance of a company in predictable ways. A plotting of any relevant performance metric over time will reveal eight distinct phases.



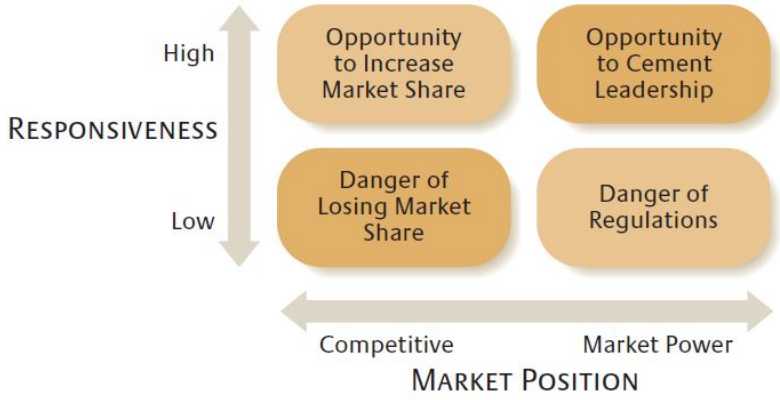
A Vulnerability Map for a Single Company

An enterprise vulnerability map categorizes the relative likelihood of potential threats to an organization and the company's relative resilience to such disruptions. Such maps can then direct management attention and prioritize the planning.



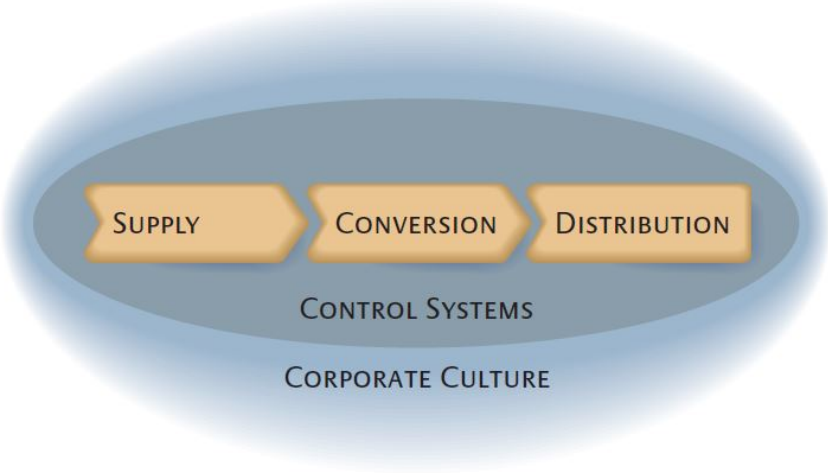
Company Position and Responsiveness

Two important variables determine a company's resilience: the competitive position of the enterprise and the responsiveness of the supply chain. In competitive situations with low switching costs, a company must be able to respond quickly or else risk loss of market share. Conversely, companies that are very responsive will have an opportunity to gain market share in competitive environments or solidify their leadership position in areas they already dominate.



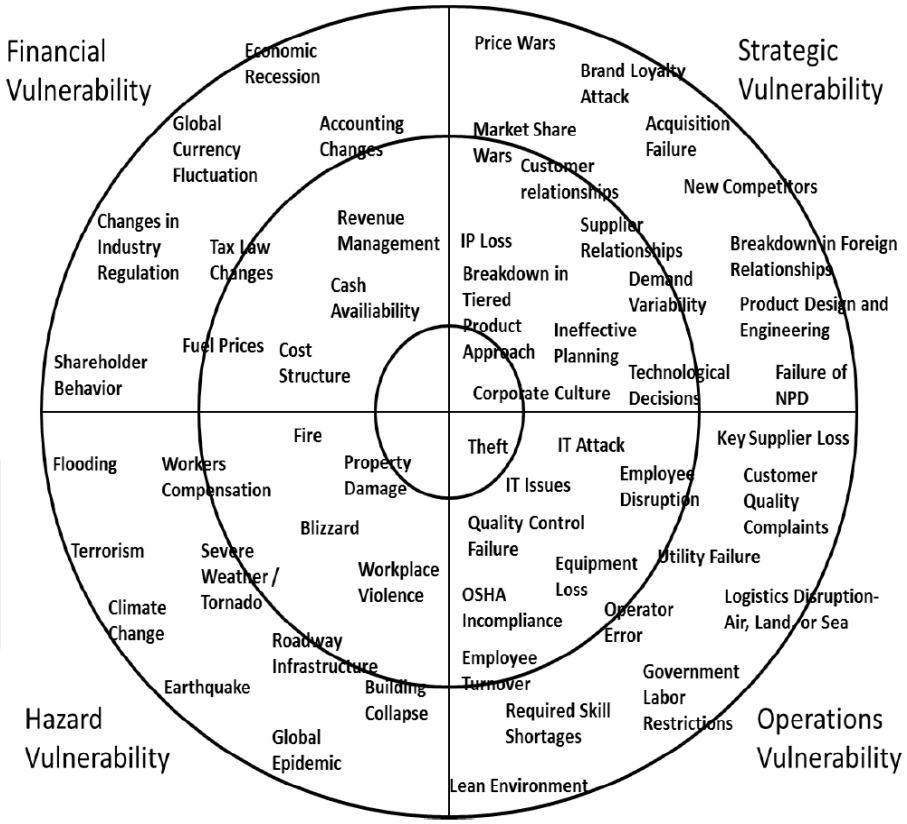
Supply Chain Elements

In any company's supply chain, material flows from supplier through a conversion process through distribution channels and is controlled by various systems, all working in the context of the corporate culture. Each of those five elements represents an opportunity to introduce flexibility and, by doing so, create organizational resilience.



Approach

- **Vulnerability mapping**

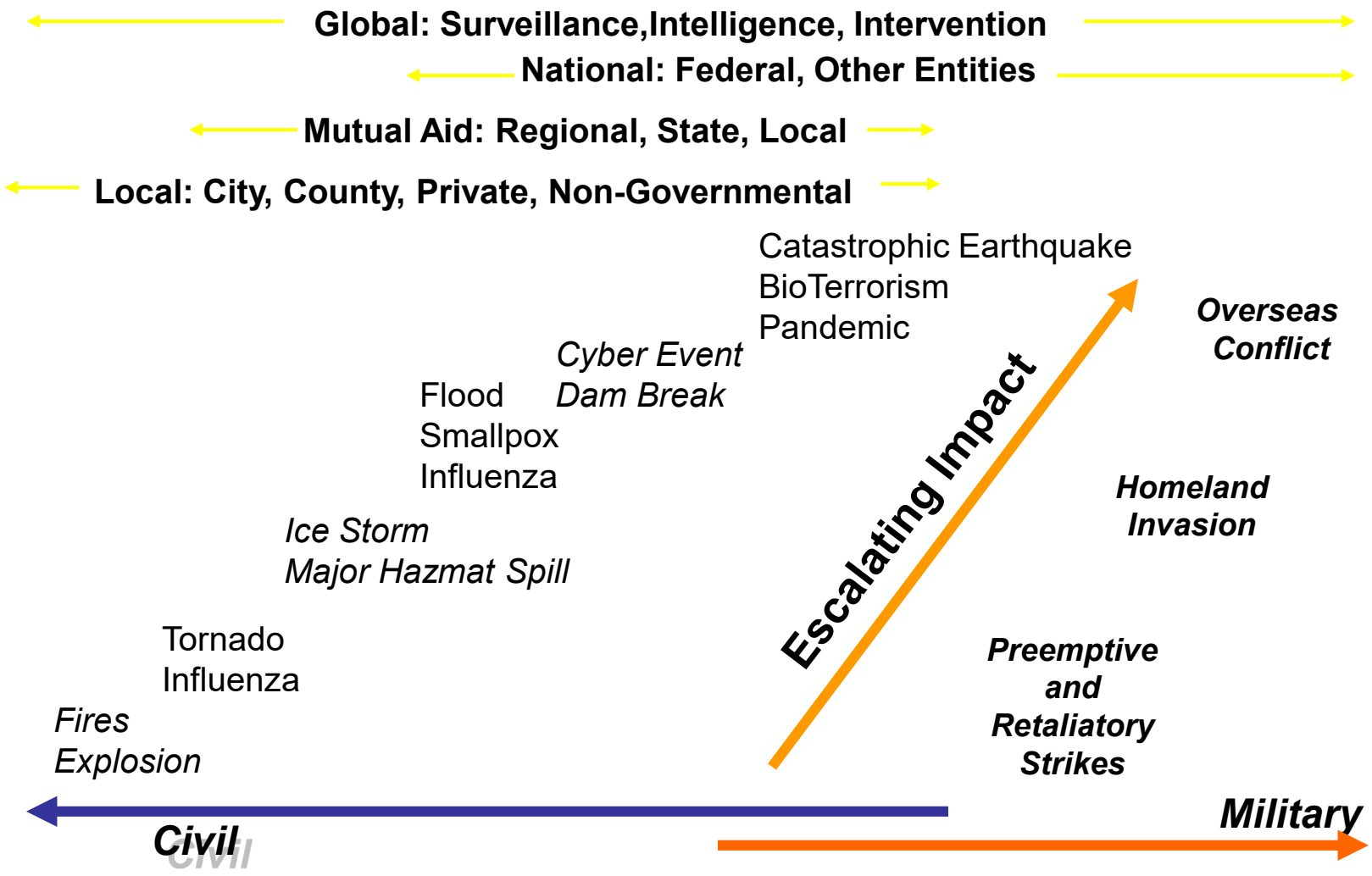


- **Scenario analysis**
  - **The green movement**
    - Resilience requirement for new suppliers
  - **Middle East embargo**
    - New projects require improved delivery
  - **Non-renewable energy abundance**
    - Supplier and product distribution will provide snapshot of product portfolio health

Figure 2

This illustration provides a target-and-crosshairs model for vulnerability mapping to prioritize risk factors across four sectors, including operational, hazard, financial and strategic vulnerabilities

Resilience: Triage for all Hazards … and Layered Responsibilities



18 (now 16) Critical Infrastructures

- Agriculture and Food
- Defense Industrial Base
- Energy
- Public Health and Healthcare
- Banking and Finance
- Drinking Water and Water Treatment Systems
- Transportation System
- Government Facilities
- Chemical
- Commercial Facilities
- Dams
- Emergency Services
- Commercial Nuclear Reactors
- Materials and Waste
- Information Technology
- Communication
- National Monuments and Icons
- Postal and Shipping

Currently, there are 16 industry sectors defined as critical infrastructure

85% of critical infrastructure is in private sector *hands*[1]

Trends exposing industry to increased risk

- Interconnectedness of sectors
- Proliferation of exposure points
- Concentration of assets

Critical infrastructure sectors

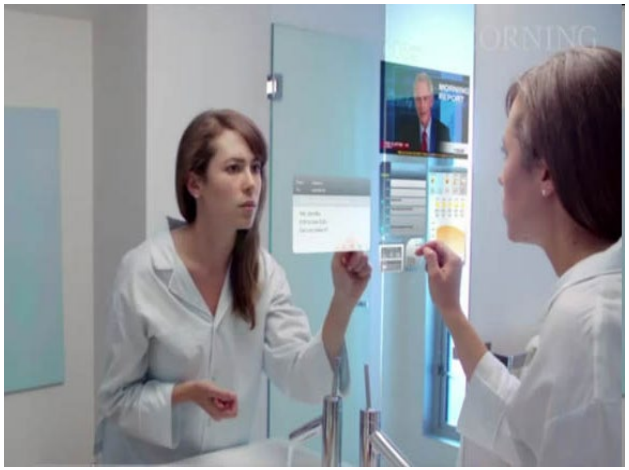
1 GAO Report, Critical Infrastructure Protection: Sector Plans and Sector Councils Continue to Evolve. July 2007, http://www.gao.gov/assets/100/95010.pdf

Example: Interdependencies

- Transportation
- Water, Natural Gas, Fuel Supply
- Electricity/Power/Energy
- Telecom Networks
- More

More “Things” are being connected

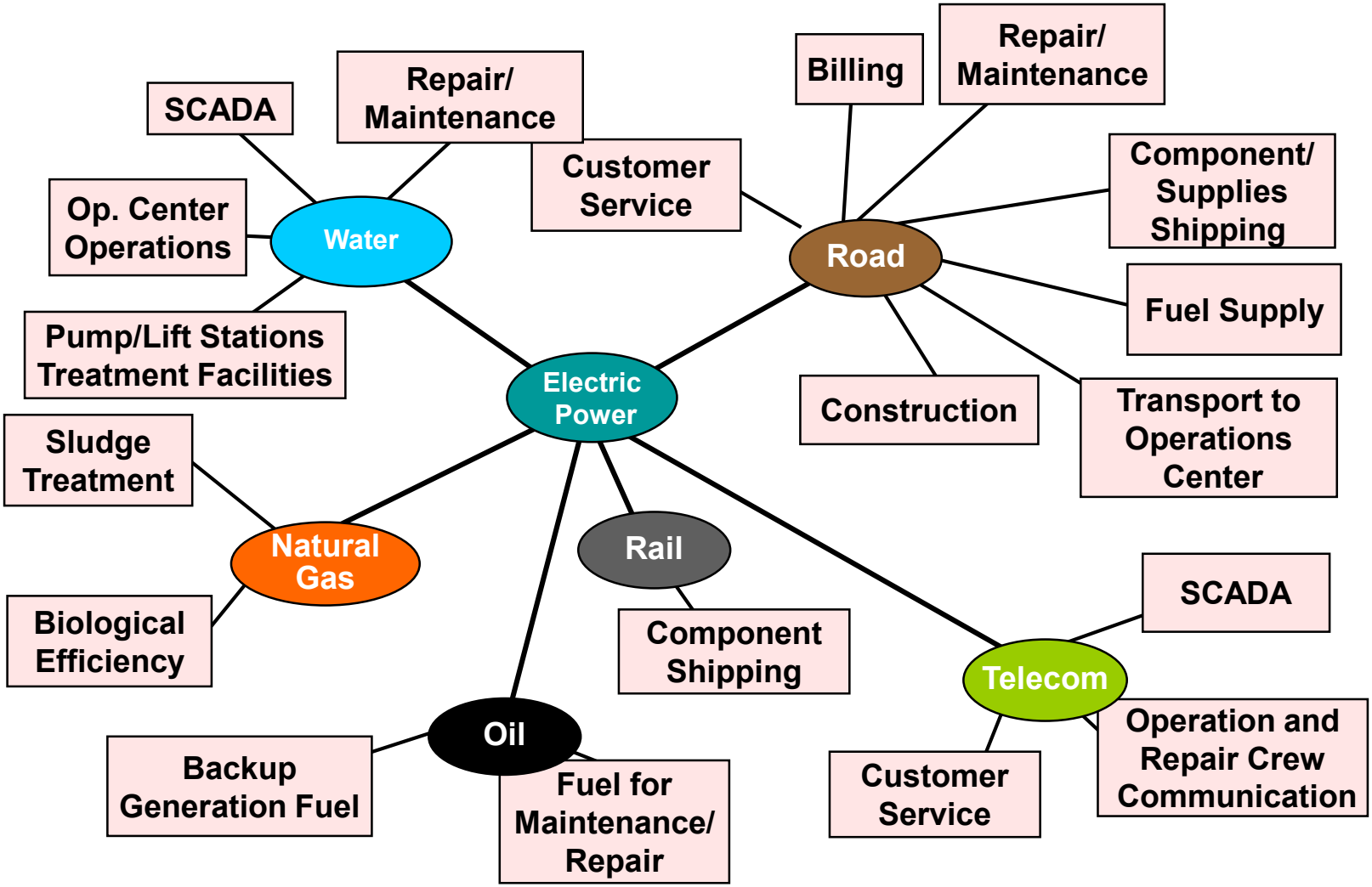
Home/daily-life devices
Business and
Public infrastructure
Health-care
Environment & Climate
Security vs. Privacy
…

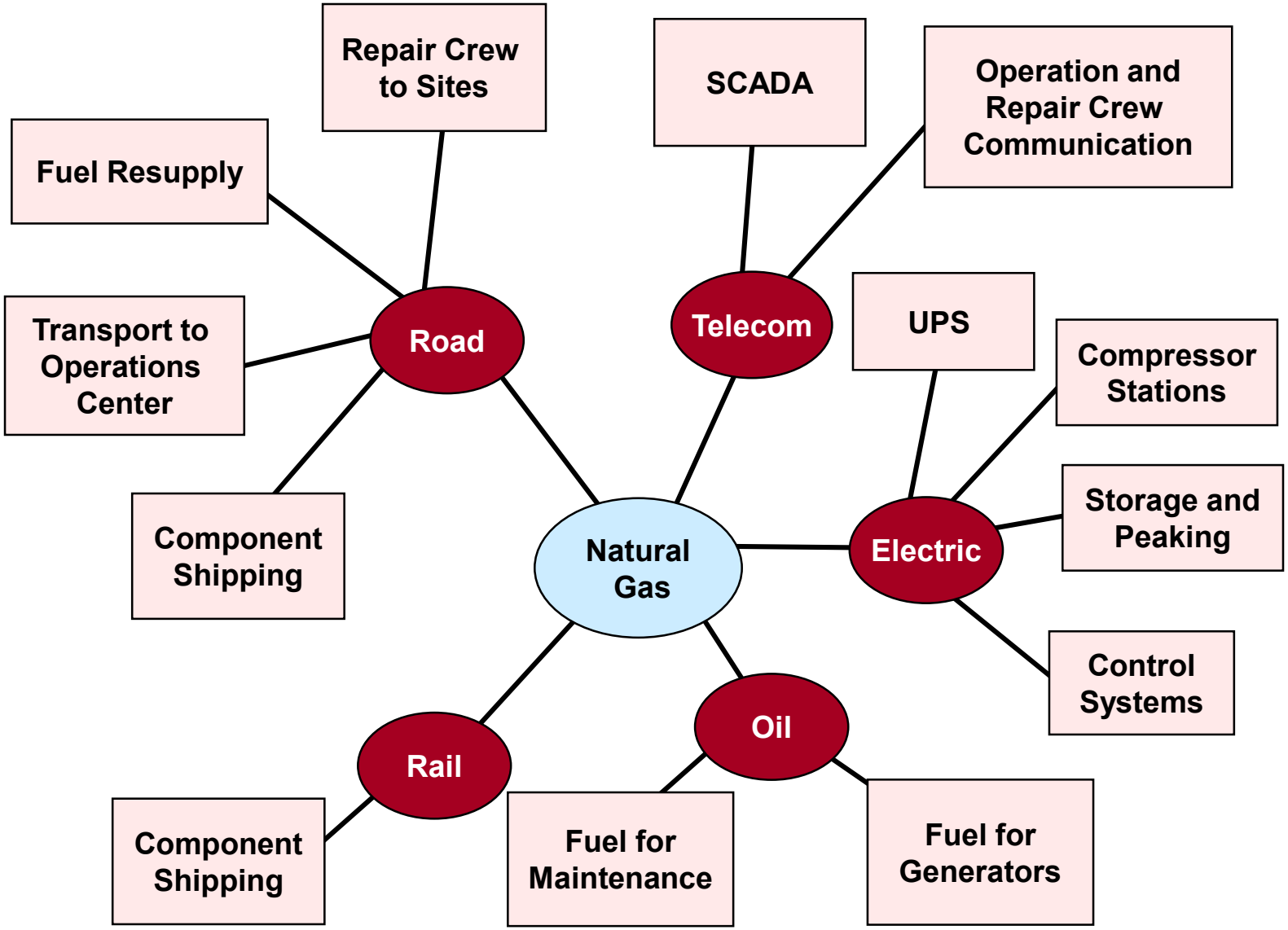


Types of Interdependencies

- Physical (e.g., material output of one infrastructure used by another)
- Cyber (e.g., electronic, informational linkages)
- Geographic (e.g., common corridor)
- Other (e.g., dependency through financial markets)

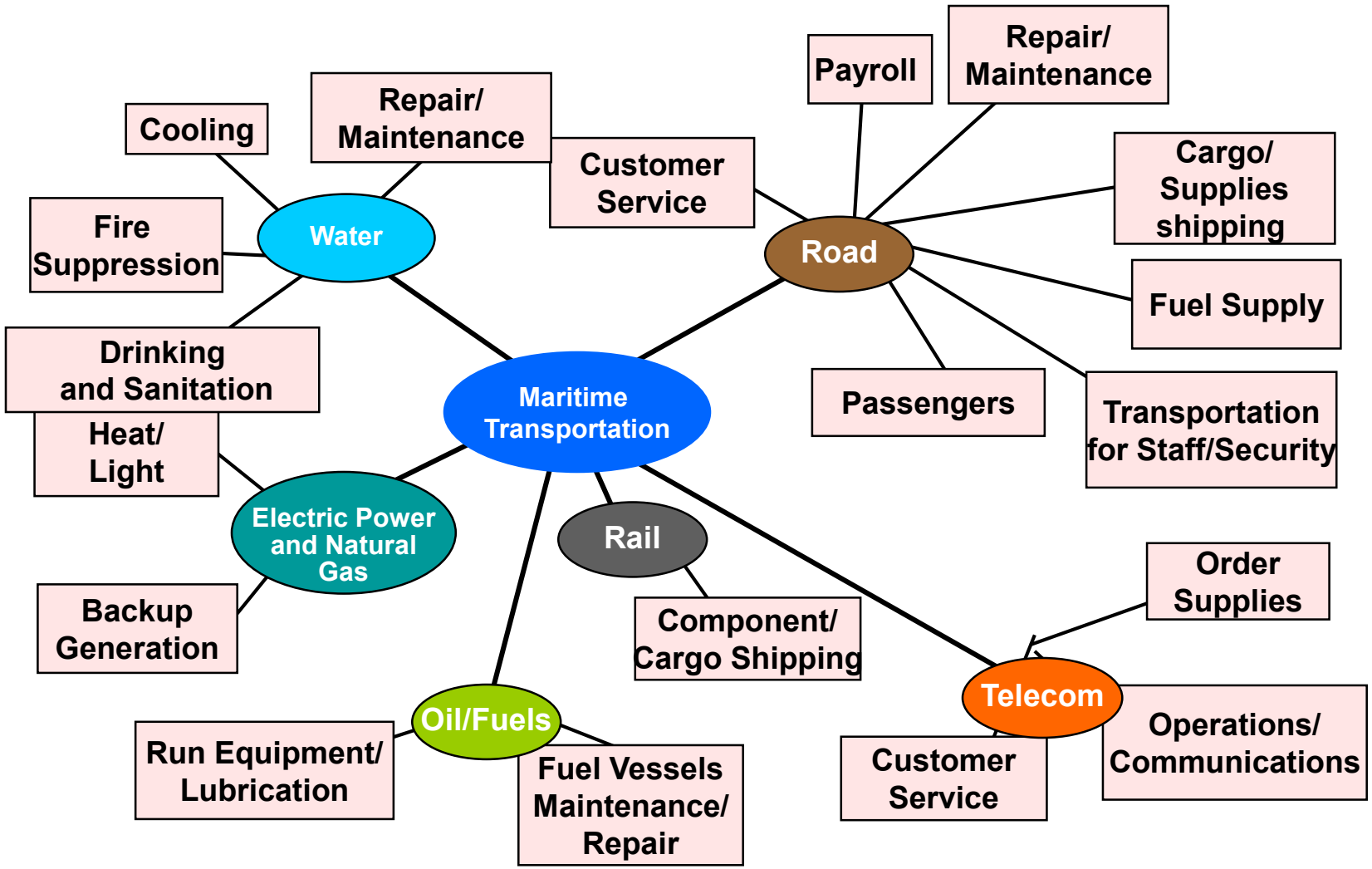
Illustrative Infrastructure Dependencies
Electric Power



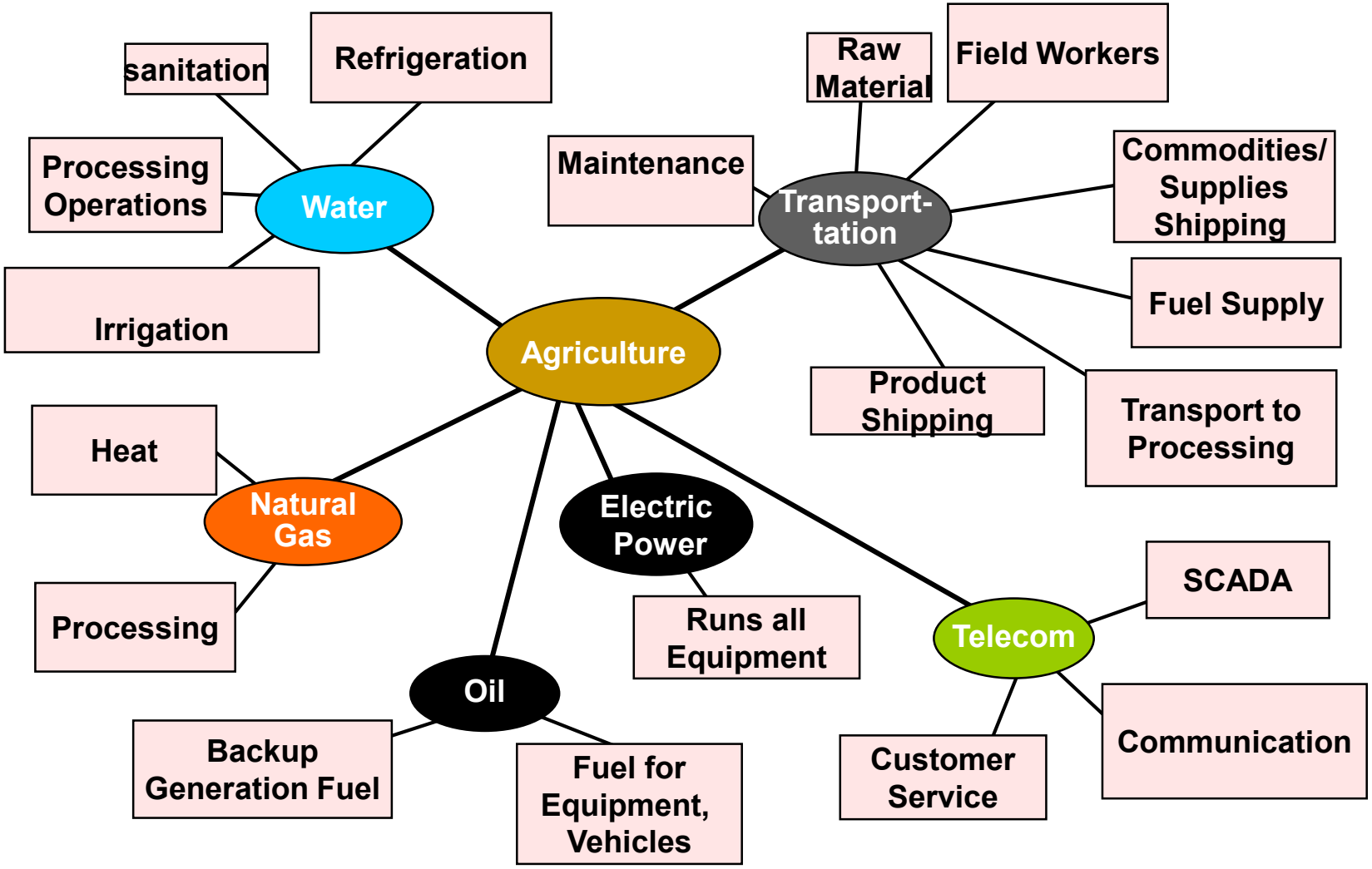


ANL

Illustrative Infrastructure Dependencies
Maritime Transportation



Illustrative Agriculture Dependencies



Types of Interdependence Failures

- Cascading failure – a disruption or unavailable product of service in one infrastructure or organization causes a disruption in a second

- Escalating failure – a disruption or unavailable service or product in one infrastructure or organization exacerbates, or impedes recovery of an independent disruption elsewhere

- Common cause failure –disruption of two or more components or assets simultaneously because of a common cause (e.g., natural disaster, right–of–way corridor)

Power/Energy: Threats to Security

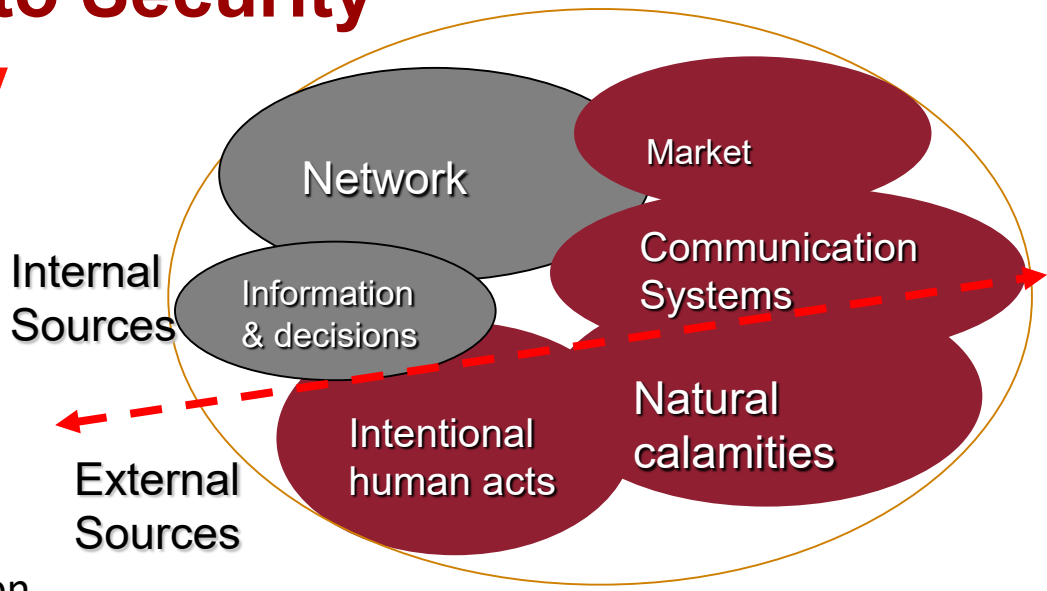
Sources of Vulnerability

- Transformer, line reactors, series capacitors, transmission lines...
- Protection of ALL the widely diverse and dispersed assets is impractical

-- over 215,000 miles of HV lines (230 kV and above

-- 6,644 transformers in Eastern Interconnection

- Control Centers
- Interdependence: Gas pipelines, compressor stations, etc.; Dams; Rail lines; Telecom – monitoring & control of system
- Combinations of the above and more using a variety of weapons:
- Truck bombs; Small airplanes; Gun shots – line insulators, transformers; more sophisticated modes of attack…



- EMP
- Biological contamination (real or threat)
- Over-reaction to isolated incidents
- Internet Attacks
- Over 80,000 hits/day at an ISO
- Hijacking of control
- Storms, Earthquakes, Forest fires & grass land fires… Loss of major equipment – especially transformers…

"… for want of a horseshoe nail … "

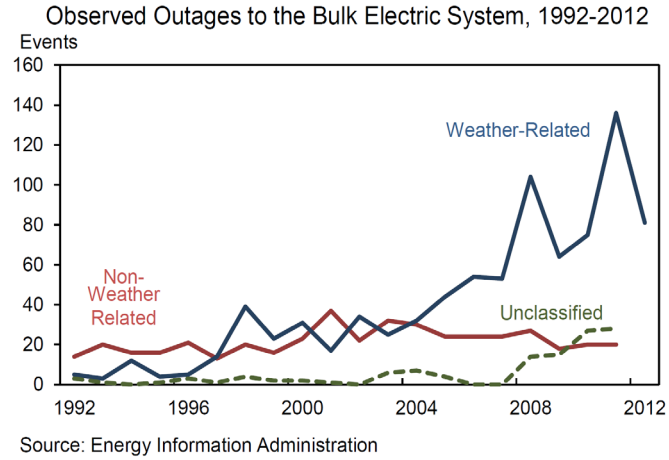
Trends: Resilience and Asset Investments

Complex grid structures require "Smart Grid" solutions

Achieving Electric System Resilience

– Energy Sector is uniquely critical infrastructure as it provides an "enabling function"

- Aging Infrastructure ***Investment***
- **Reliability/Hardening *Investment* – Outage cost of $125B/y (DOE), with weather-related ~ ($18B - $33B)/y**
- Natural Gas, Renewable, Microgrids, Electric Vehicles, Storage, and Demand response ***Investment***
- Electrical – Natural Gas Interdependency



Source: Energy Information Administration

Source: IEEE report to the U.S. DOE for the White House's Quadrennial Energy Review (QER) to guide U.S. energy policy. See Chapter 4, on implications and importance of aging infrastructure and the options for addressing them: http://www.ieee-pes.org/final-ieee-report-to-doe-qer-on-priority-issues

HOW TO SAVE AGING ASSETS

Applying limited resources to critical infrastructure

BY MASSOUD AMIN, IEEE Smart Grid, University of Minnesota

The Smart Grid's contributions to improving electric utilities' means of monitoring the condition of assets, providing enhanced situational awareness, and faster actionable intelligence have transformed the power industry's concept of asset management from a largely passive, time-based approach to a more proactive, condition-based assessment.

Condition-based asset management offers a big leap in accuracy, improved and, therefore, greater power grid reliability, as it is a sounder method for asset maintain/repair/replace strategies and related investments. Unfortunately, this "new" approach remains wholly inadequate to meet the challenge.

As the Smart Grid has evolved, so has the need for a much more robust and wide-ranging view of the critical nature of our power infrastructure and how to best manage it. Currently, condition-based asset management is simply one aspect of a more holistic quality management approach that weighs the relative risks and economics of asset maintenance, repair, and replacement to advance end-to-end power grid reliability, resilience, security, and modernization.

This holistic approach will require new, strategic alliances between the public and private sectors in which carrots are used more often than sticks. Moreover, it will require utilities to transform their cultures and organizations and, possibly, adopt new business models to monetize new services and achieve savings.

A FUNDAMENTAL SHIFT

Why should we turn to this more ambitious approach? Simply put, the electric power sector is uniquely foundational to every sector of our economy and quality of life. Virtually every crucial economic and social function in modern society depends on the secure, reliable delivery of electric energy, thus the urgent need for best practices in the operation of power and energy infrastructures. With a largely aging power infrastructure in the United States—particularly underground city networks—and limited resources to address the issue, we need a rational, evidence-based foundation for its operational integrity and security.

Trends such as urbanization, the power grid's interdependencies with other infrastructures (for example, water, gas, telecommunications) the extreme weather events that come with global climate change and the advent of terrorism all bring added urgency to our collective challenge.

The approach outlined in this feature is based on the familiar trio of technology, policy, and standards, but it also embraces a completely new outlook by all stakeholders towards our power infrastructure. Therefore, this feature closely reflects a report that an IEEE Joint Task Force provided to the U.S. Department of Energy (DOE) in the summer of 2014 on high priority issues for the White House's Quadrennial Energy Review (QER) to guide U.S. energy policy.

A GROWING NEED

In the U.S., the average system age is 40 to 60 years old. Fully 25 percent of our power assets are of an age in which condition is a concern. Power infrastructure build-outs in the U.S. largely ended in the 1980s. Moreover, according to the recently published book, *"Aging Power Delivery Infrastructures"*, the current focus is on the maintenance and modernization of existing infrastructure, and maintenance needs alone are expected to double over the next two decades.

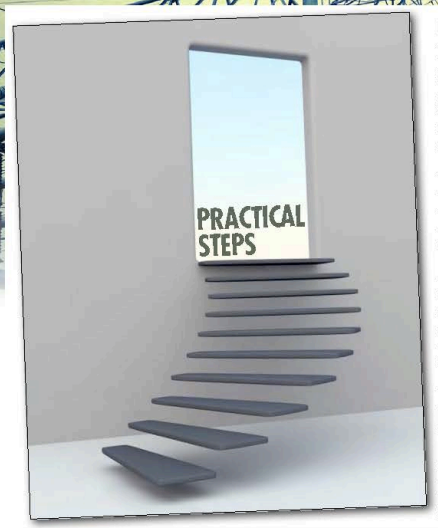


Photo credit (stairs and door): SiguridDerkoos

PRACTICAL STEPS

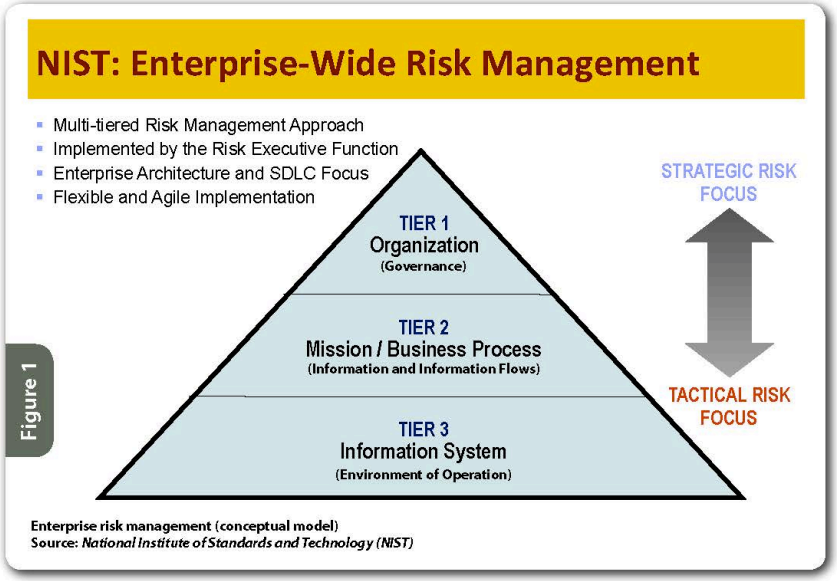
Achieving hardening and resiliency on the ground should be based on a particular utility's customers' needs, its legacy systems, location, and technology roadmap. Given the disparities between individual utilities, it is difficult to generalize, but a few universal concepts are worth discussion. Never forget that "resiliency" and "customers' needs" also cover the timely notification, through customers' preferred channels, of estimated time to restoration, which increases customer satisfaction.

Risk assessment of existing assets provides a data-based identification of weaknesses and a means of prioritizing maintenance, repair and replacement. Component and system failures are difficult to predict. However, it is possible to identify the components that, as a result of their location, configuration and electrical characteristics, pose the greatest risk for large-scale outages. Understanding these vulnerabilities can guide power grid investments.

Because the risk landscape is dynamic, risk assessment must be a perennial task. Additionally, adaptation strategies will shift as a utility invests in new technologies and operational practices change. Current and future investments in advanced metering infrastructure and distribution automation signal the beginning of a multi-decade, multi-billion-dollar effort to achieve an intelligent, secure, resilient, and self-healing system. The risk landscape will change as the power grid evolves.

Fortunately, risk assessment methods are well established, and they can be tailored to specific circumstances. Three figures offer insights related to this task. Figure 1, from the National Institute of Standards and Technology (NIST), provides a conceptual model for enterprise risk management.

Figure 2 is based on an adaptation of Dr. Steve Lee's work at EPRI on probabilistic risk assessment (PRA) as a part of the EPRI Grid Operations and Planning Task Force's Power Delivery Reliability Initiative, and my published works entitled, *"Fast Look-ahead Simulation, Modelling and Validation, January 2001 to May 2003"*.



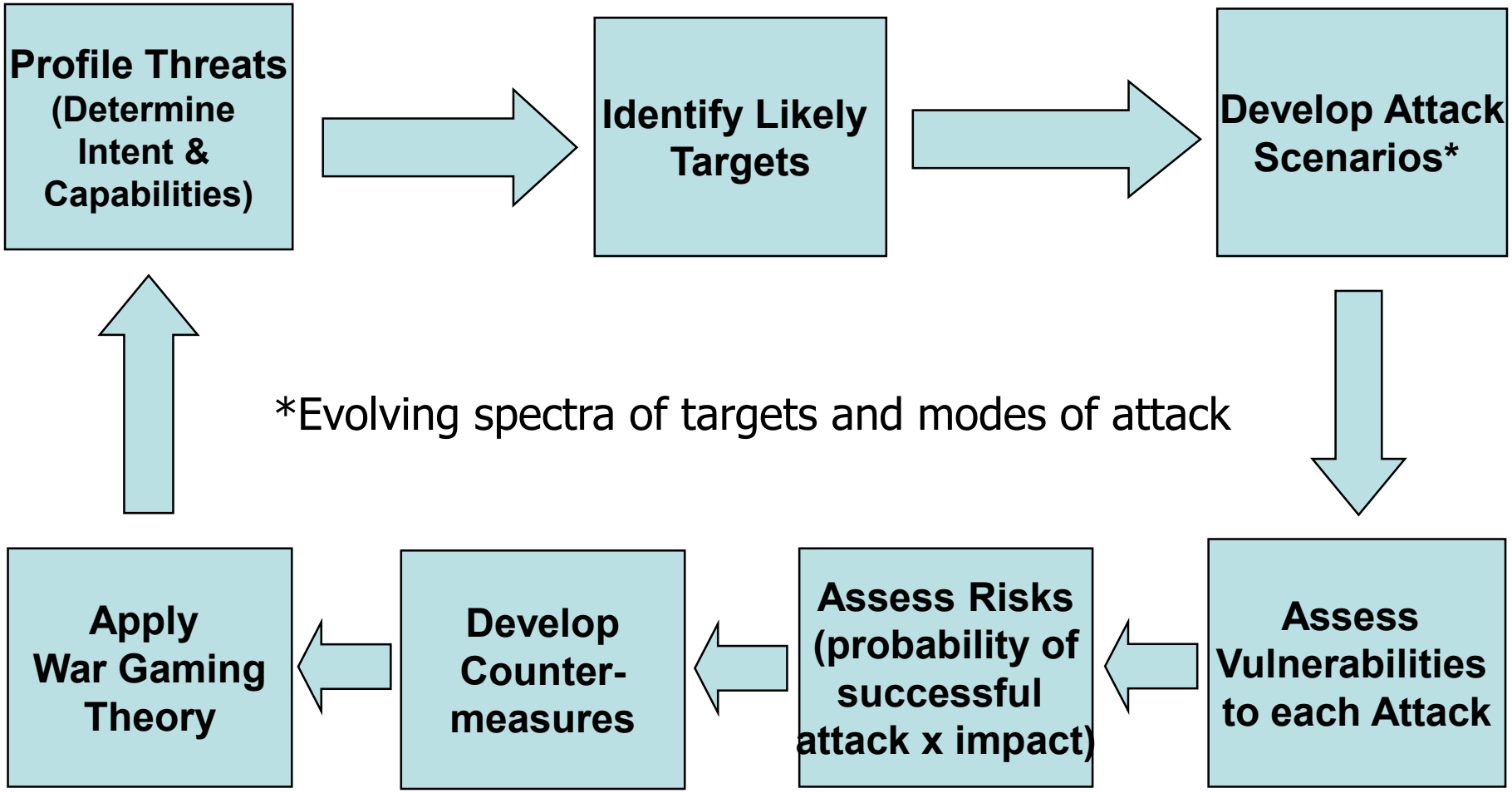
Self-healing Smart Grid (1998-present)
Critical System Dynamics and Capabilities

- Anticipation of disruptive events
- Look-ahead simulation capability
- Fast isolation and sectionalization
- Adaptive islanding
- Self-healing and restoration

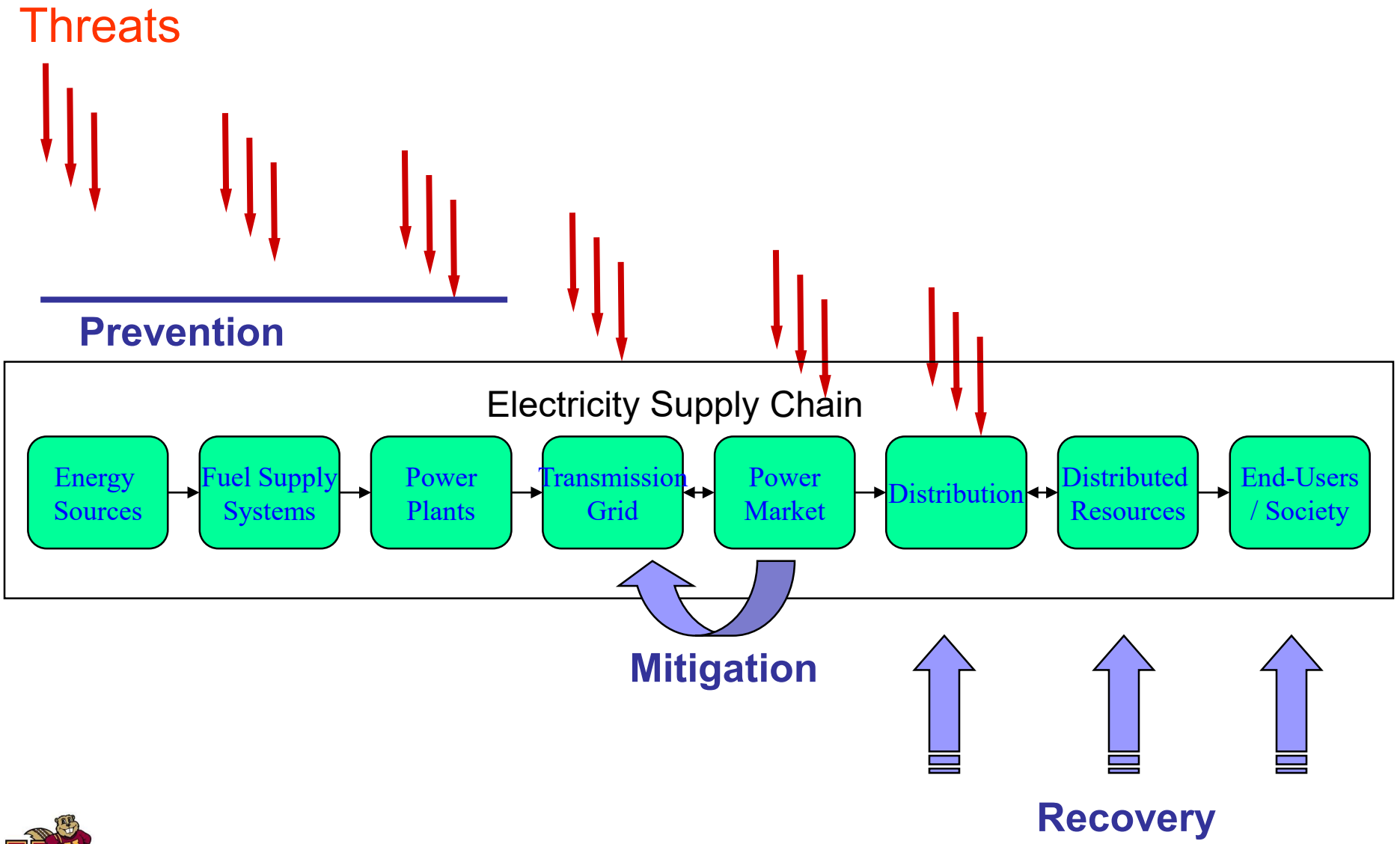
re·sil·ience, *noun,* 1824:
The capability of a strained body to recover its size and shape after deformation caused especially by compressive stress;
An ability to recover from or adjust easily to misfortune or change

Resilience enables “Robustness”: A system, organism or design may be said to be "robust" if it is capable of coping well with variations (internal or external and sometimes unpredictable) in its operating environment with minimal damage, alteration or loss of functionality.

Vulnerability Assessment: An iterative process



Vulnerability Assessment must be End-to-End



Sandstorm

Wildfire

Drought

Hoover Dam turbines set for upgrade to cope with drought

April 19, 2010

The US Bureau of Reclamation has awarded a $3.4 million contract to Andritz Hydro Corporation to upgrade generating facilities at the Hoover Dam.

The Hoover Dam's water store, Lake Mead, has record low water levels because of the drought downstream

Andritz Hydro, which is based in Charlotte, North Carolina, will design and manufacture a new "wide head" turbine runner for the Number Eight generating unit at the power plant on the Nevada side of the Colorado River.

Drought & extreme temps

Drought could shut down nuclear power plants

Southeast water shortage a factor in huge cooling requirements

jump to discuss
comments below

Below: Discuss Related

Recommend 3
Tweet 0
+1 0
Share 1

Jason E. Miczek / AP

A man fishes next to the water outflows of the McGuire Nuclear Station near Lake Norman, N.C., on Monday. Lake Norman has dropped to about a foot above the minimum level needed for a backup system at the plant.

Flood

TABLE 2.2 Example Resilience Metrics Proposed by the DOE-supported Grid Modernization Laboratory Consortium

Consequence Category	Resilience Metric
Direct	
Electrical Service	Cumulative customer-hours of outages
	Cumulative customer energy demand not served
	Average number (or percentage) of customers experience an outage during a specified time period
Critical Electrical Service	Cumulative critical customer-hours of outages
	Critical customer energy demand not served
	Average number (or percentage) of critical loads that experience an outage
Restoration	Time to recovery
	Cost of recovery
Monetary	Loss of utility revenue
	Cost of grid damages (e.g., repair or replace lines, transformers)
	Cost of recovery
	Avoided outage cost
Indirect	
Community function	Critical services without power (e.g., hospitals, fire stations, police stations)
	Critical services without power for more than N hours (e.g., N> hours or backup fuel requirement)

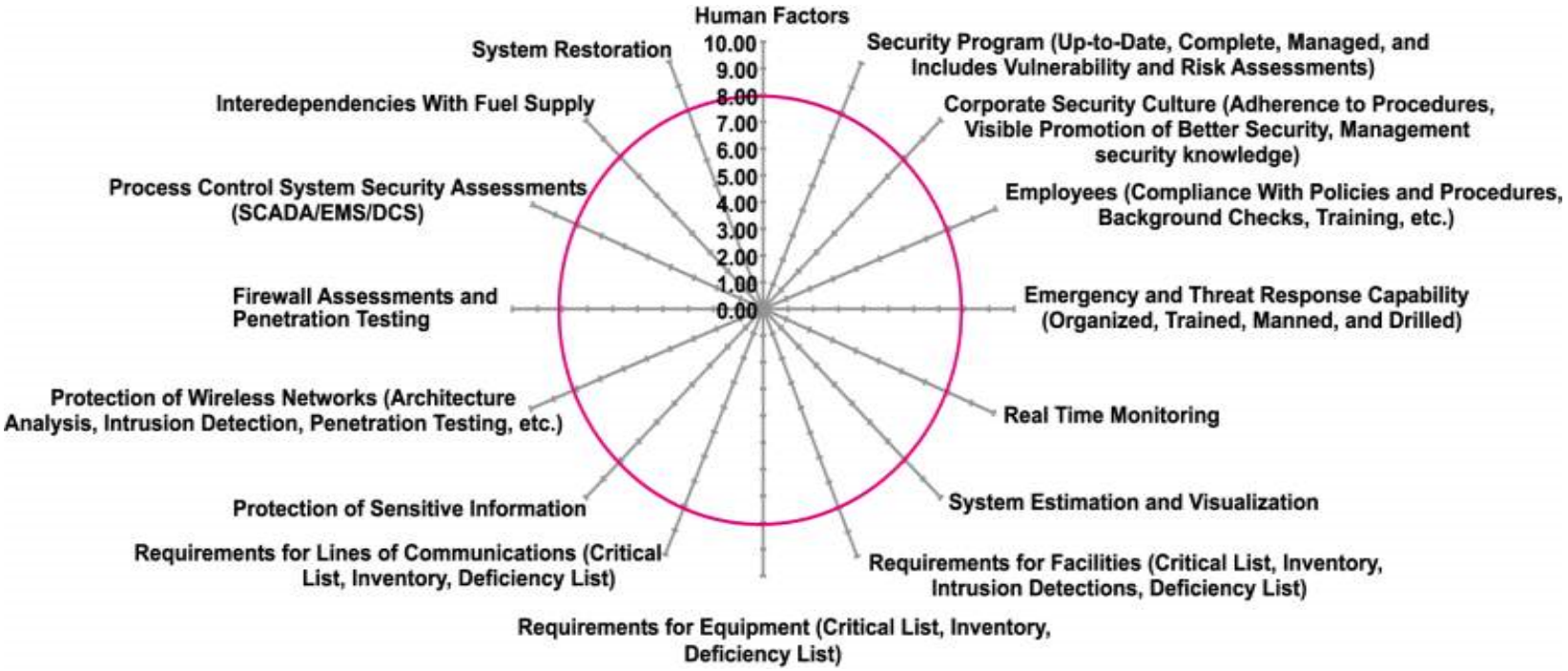
SOURCE: GMLC (2017).

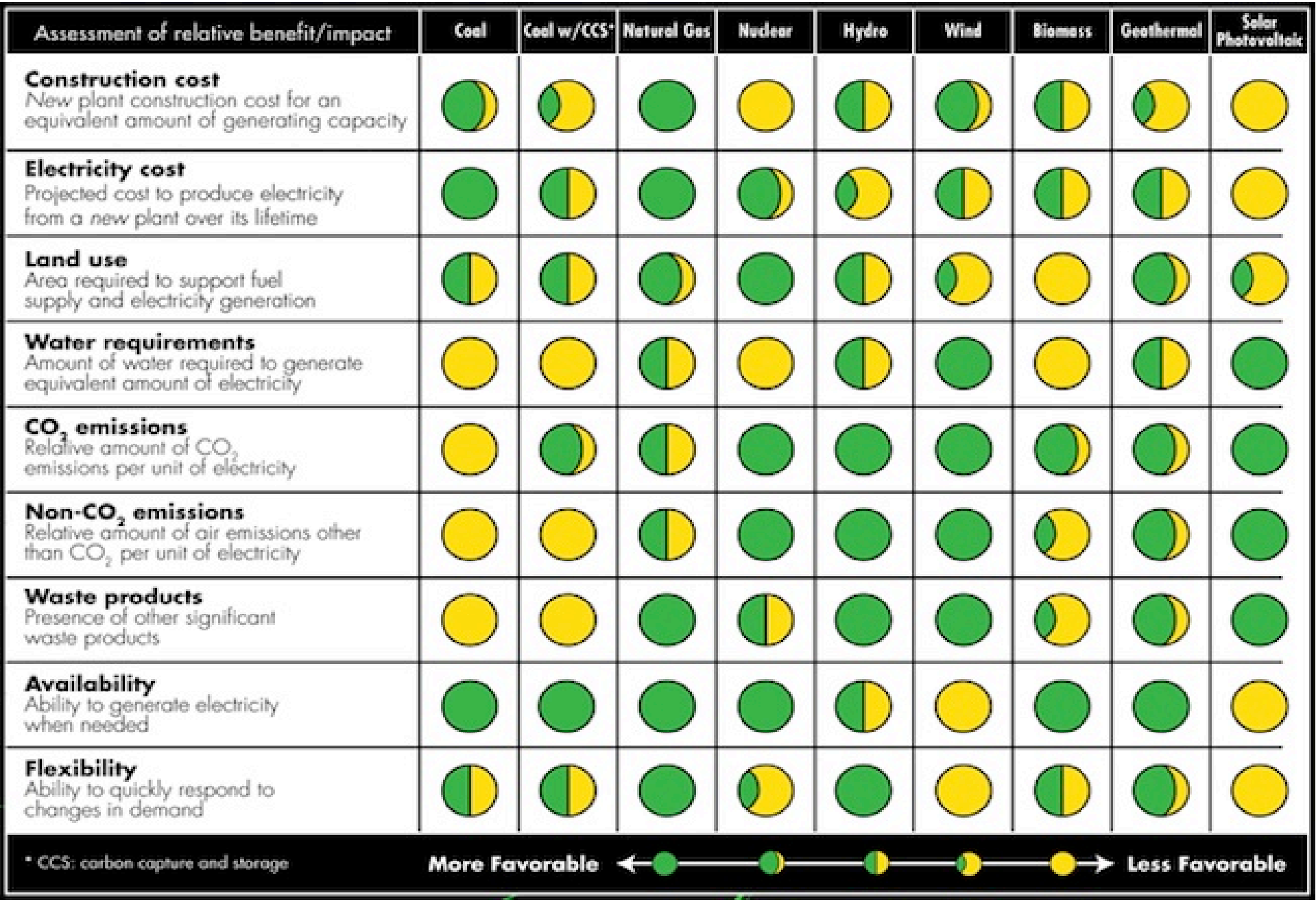
Source: Forthcoming "Enhancing the Resilience of the Nation's Electricity System," NAP, 2017

General	Corporate culture
	Security Program
	Employees
	Emergency and threat response capability
Physical	Requirements for facilities, equipment and lines of communication
	Protection of sensitive information
Cyber and IT	Protection of wired and wireless networks
	Firewall assessments
	Process control system security assessments

Assessment & Prioritization:

A Composite Spider Diagram to Display Security Indices



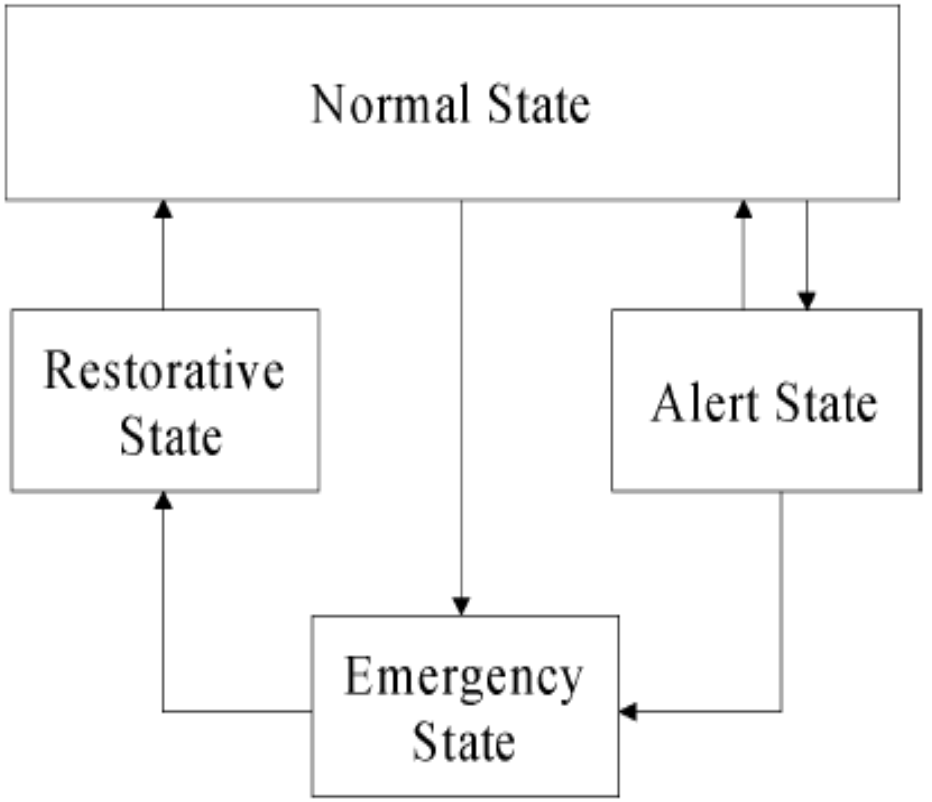


Source: EPRI http://sites.epri.com/refcard/comparison.html

Understanding Complex Dynamical Systems

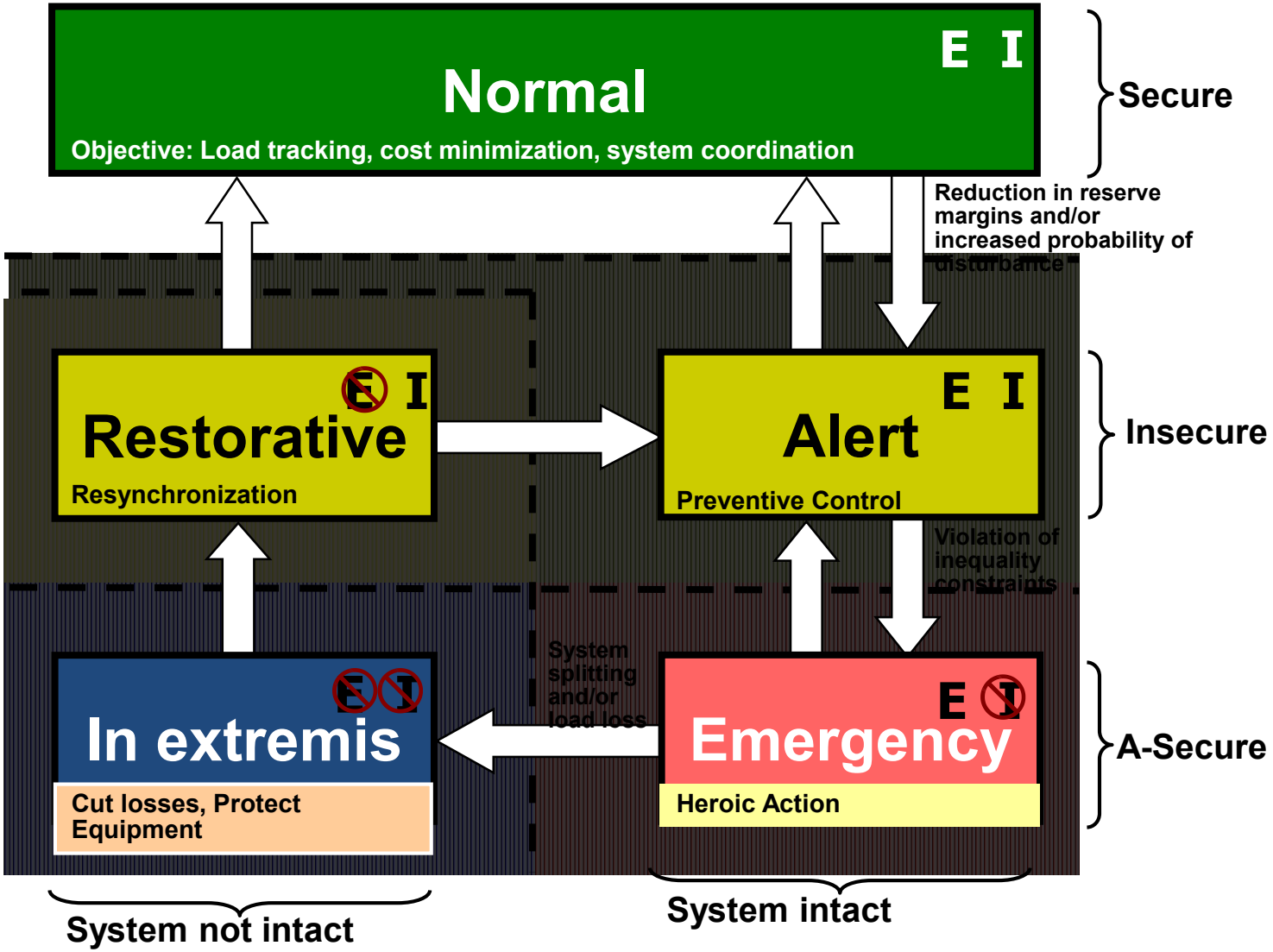
Modes of Electric Power Systems:

- *Normal mode:* economic dispatch, load frequency control, maintenance, forecasting, etc.;
- *Alert mode:* red flags, precursor detection, reconfiguration and response;
- *Emergency/Disturbance mode:* stability, viability, and integrity -- instability, load shedding, etc.;
- *Restorative mode:* rescheduling, resynchronization, load restoration, etc.



Dynamics of Power System Operating States

E = Demand is met
I = Constraints are met



Significant Goal-Setting Approaches/Tools

Approach/Tool	*Description*	*Unit of Analysis*
Management System Standards	**Management system standards that set benchmarks for a management system and objectives; specific performance standards left to the entity**	**Entity**
Scenario-Based Planning	**Identifies possible event, futures, and outcomes for planning; can have short and long-term horizons**	**Entity**
Risk Management	**Analysis and decision making to achieve an affordable, acceptable level of risk**	**Entity**
Capabilities-Based Planning and Assessment	**Identify capabilities to accomplish missions**	**Capabilities**

The Framework: National Preparedness Management System Standards

- *Standard*: a consensually-developed document that provides rules, guidelines or characteristics for activities or their results; provides uniform set of measures, conditions, or specifications between parties
- *Management system standards*: covers what an organization does to manage its processes or activities, applicable to any organization in any sector and is independent of products or services
  - ISO 9000 for quality management and ISO 14000 for environmental management
- *NFPA 1600* for public and private criteria to approach disaster management, emergency management, and business continuity; addresses mitigation, preparedness, response, and recovery
  - Endorsed by DHS and 9/11 Commission as national preparedness standard

NFPA 1600 Elements

- Laws and authorities
- Hazard identification, risk assessment, and impact analysis
- Hazard mitigation
- Resource management
- Mutual aid
- Planning
- Direction, control, and coordination
- Communications and warning
- Operations and procedures
- Logistics and facilities
- Training
- Exercises, evaluations, and corrective actions
- Crisis communication and public information
- Finance and administration

Grave New World: Security Challenges in the 21st Century

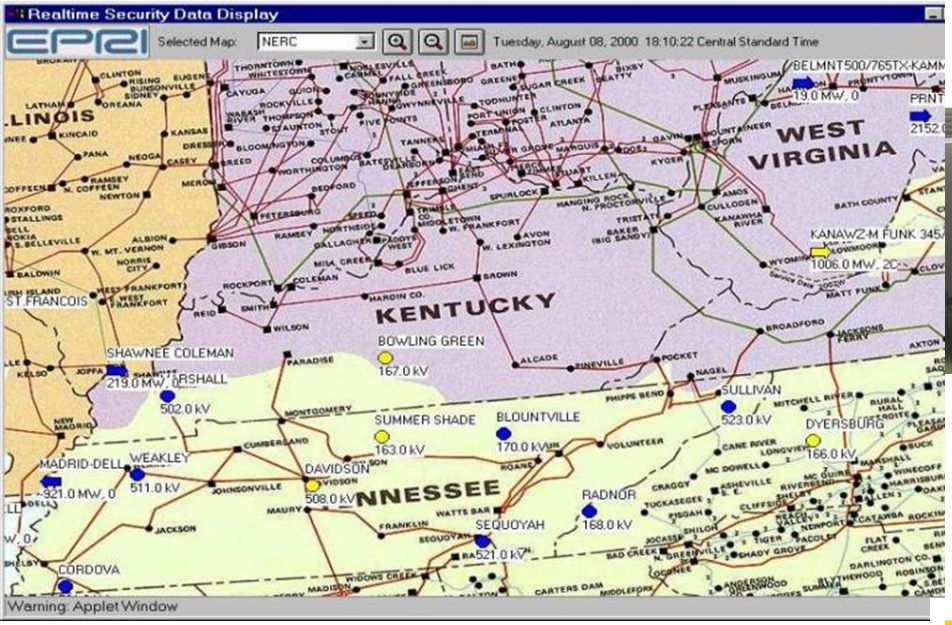
- Nuclear, Biological and Chemical Weapons
- Conventional Weapons
- Energy
- Environmental Change
- Demographic Developments
- Transnational Crime and Corruption
- Developing World
- Transnational Terrorism

The Greatest Challenge

- Putting aside the assumptions and the way you have always done business
- Being open and responsive to new ideas to meet the challenges of interdependence
- Cooperating across the stovepipes, beyond the fence, and working together

Think Regional!
Think Interdependencies!
Think Preparedness!

EPRI's Reliability Initiative-- Sample Screen of Real-time Security Data Display (RSDD)



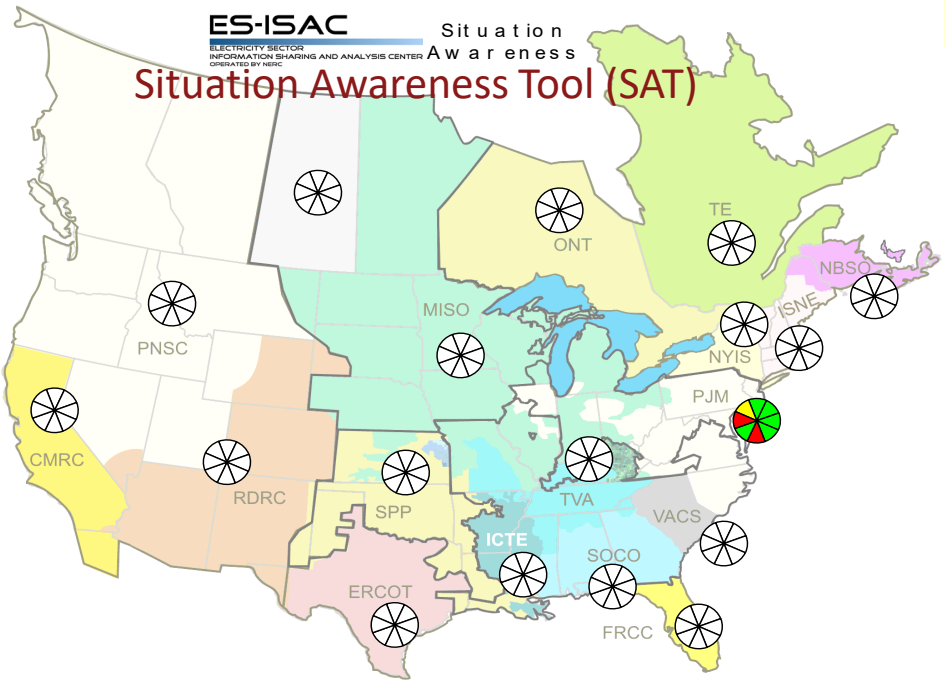
Fast Power Systems Risk Assessment

Doctoral Dissertation: Laurie Miller (June 2005-present)
ORNL contract, the U of MN start-up fund (2005-2008), and NSF grant (2008-2009), PI: Massoud Amin

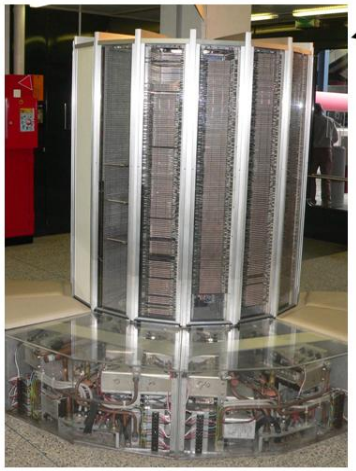
Connection Machine 2: $5 million in 1987, only a few dozen made

NVIDIA Tesla C870: $1300 in 2009, over 5 million sold

Situation Awareness Tool (SAT)



Fast Power Grid Simulation

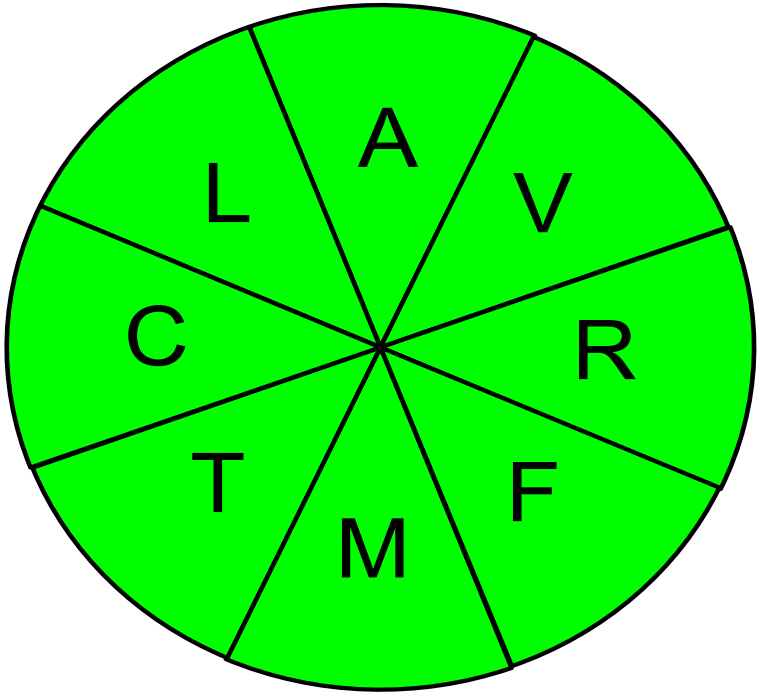


CRAY Supercomputer

Nvidia GeForce GPU card for PC

- Use Nvidia GeForce GPU card to gain 15 times faster power flow calculation on PC (Laurie Miller)

Situation Awareness Tool (SAT)



No “Telemetry” Data

Data Value Nominal

Data Value Approaching Warning

Data Value in Warning Range

Data value Returned to Normal

A – ACE
L – Deviation from Forecasted Load
C – Reserve Real-power Capacity
V – Voltage Deviation from Normal
R – Reserve Reactive-power Capacity
M – Text Message
T – Transmission Constraint
F – Frequency

Threats … a subset

Challenges for Security and Mission Assurance

Need to identify:

- What "threats" are of greatest concern and what of risk is tolerable
- Components assets, products or services that, if lost, unavailable or degraded, could adversely affect other infrastructures and organizations
  - Under normal and stressed operations
  - During disruptions, including coincident events
  - Repair and restoration
- How backup systems or other mitigation mechanisms can reduce interdependence problems
- The linkages between critical infrastructures and community assets

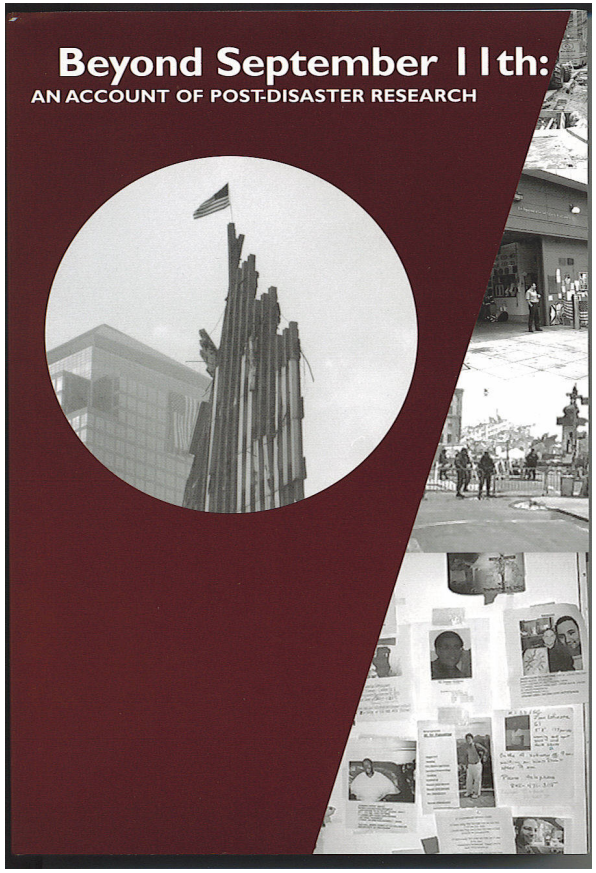
Why systems fail?

- Natural hazards
- Malevolent acts
- Wearout and breakdown
- Human error
- Close-coupling of system elements
- Focus on a single outcome

Providing reliable and resilient systems requires organizations that can

- Anticipate
- Plan
- Implement
- Adapt and improvise

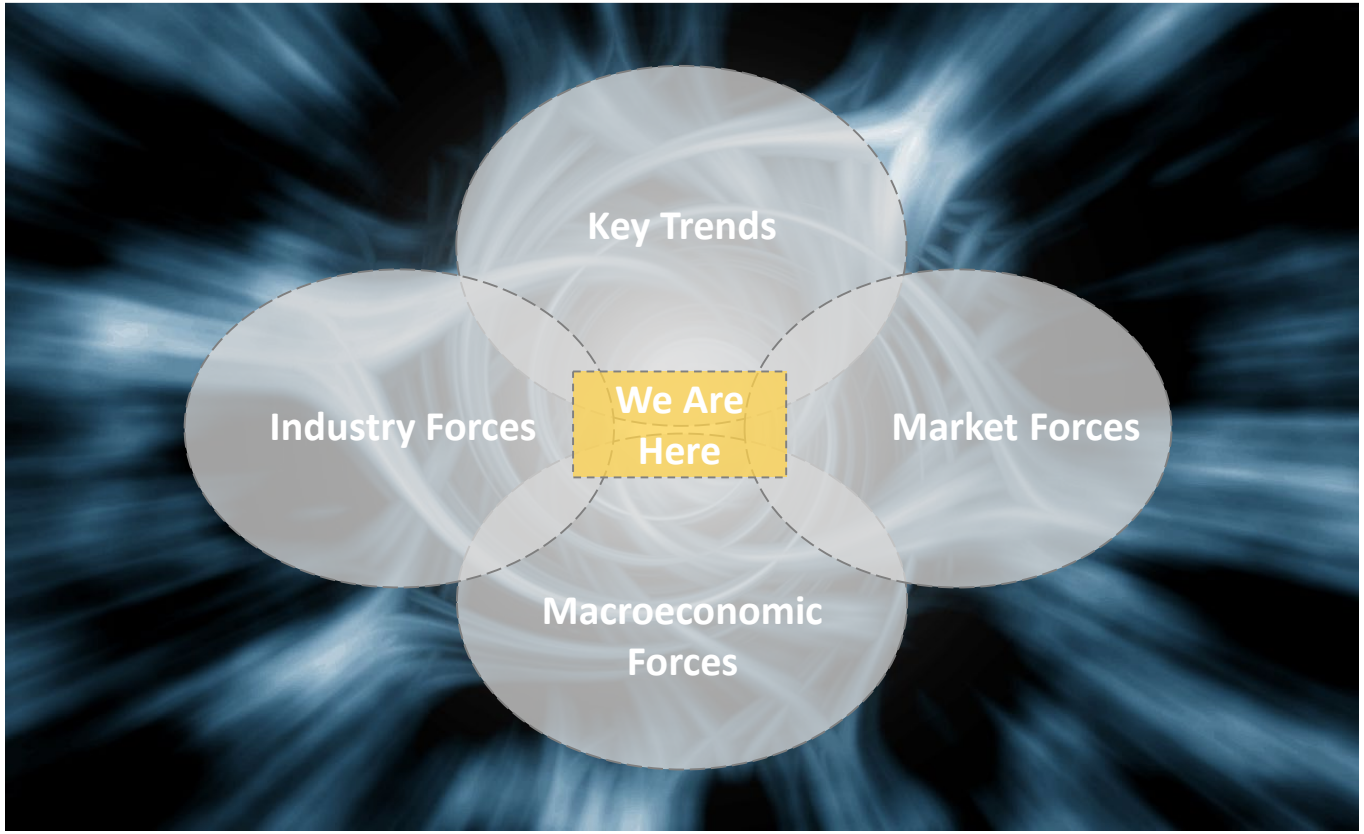
Critical Features of Survivable Systems: Lessons from September 11

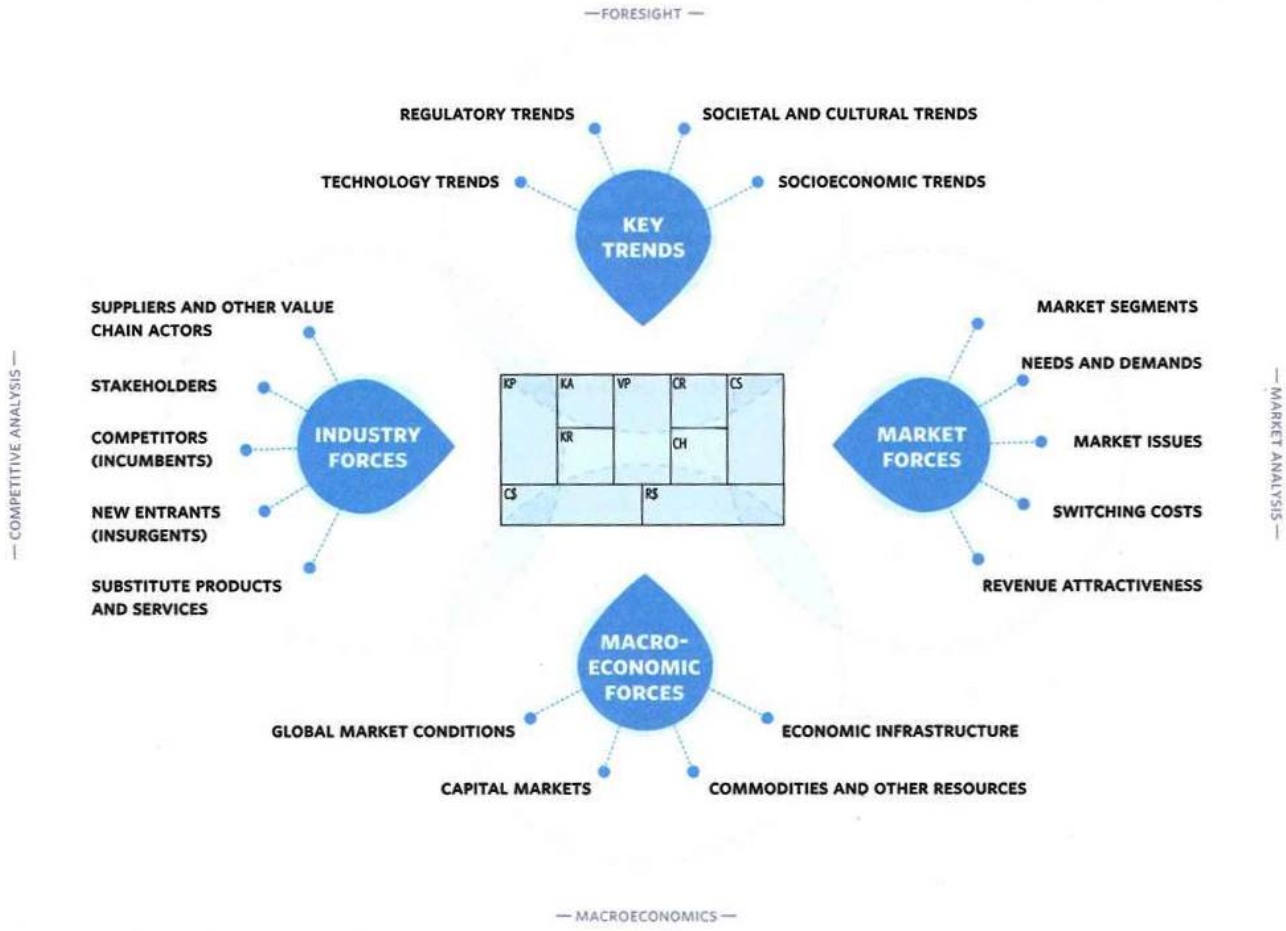


- ⌘ resilience: ability to recover quickly
- ⌘ robustness: failure-resistant through design and/or construction
- ⌘ redundancy: duplicative capacity for service delivery

Verizon, AT&T, ConEd, and MTA (among others) possessed all these attributes in equipment and people

Natural Hazards Research and Applications Information Center, University of Colorado, Boulder, 2003

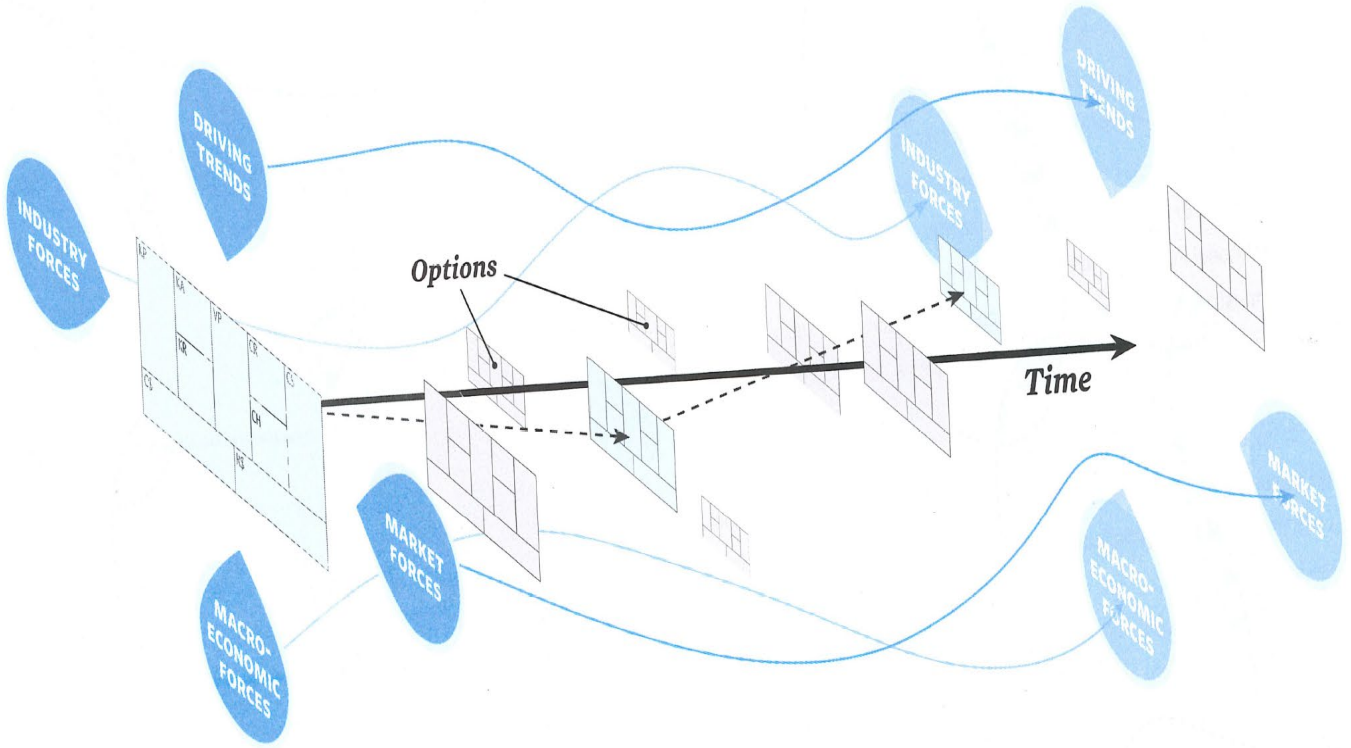




External context: The macro-environmental force field

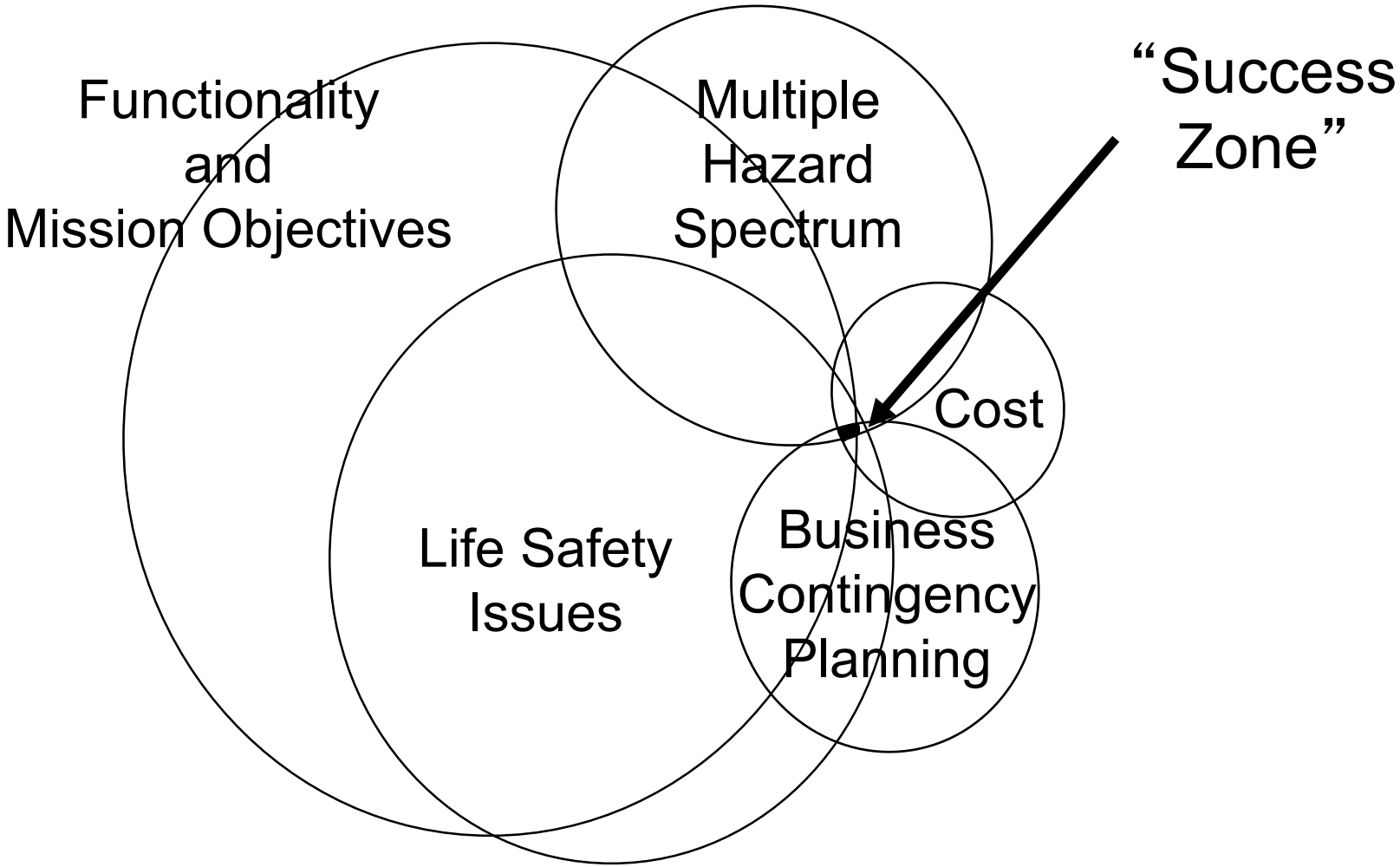
Source: Kirk Froggatt, TLI, UofM. ACS 2013, NOLA, with N. Rao for Nalco case study.

Macro-environmental Forces:
Strategic Technology Assessment and Foresight



Source: Adopted from *Business Model Generation,* by Osterwalder & Pigneur

Real world solutions may be elusive



Short-term Moves

BS = Business Strategy
CS = Corporate Strategy
IS = Innovation Strategy
GS =Government Strategy

Short-term focus is addressing high risks,
or defining the market niche and addressing its early needs

Strategy/Move	Who	What/Why	How	When	Cost/Risk

Long-term Moves

BS = Business Strategy
CS = Corporate Strategy
IS = Innovation Strategy
GS =Government Strategy

Long-term focus is satisfying strategic security (or customer) needs and reducing vulnerabilities (or expanding niche market for corresponding products)

Strategy/Move	Who	What/Why	How	When	Cost/Risk