Modeling and Simulation for Emergency Response: NSF's Role

Modeling and Simulation for Emergency Response Workshop

National Institute of Standards and Technology

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Messages

- National Science Foundation has played a key role in disaster research and emergency response
- Emergency Response can benefit from research in the full range of disaster life-cycle areas, including social science
- Practitioners, developers, other government agencies should partner with fundamental researchers
  - Problem definition
  - Solution conception and development
  - Technology transfer

Topics

- Background on NSF
- CMS' Disaster Orientation
  - NEHRP, NEES
  - Interdependence and the (Disaster) Life-Cycle
  - Learning from Earthquakes / Urban Disasters
  - Other Research
- Funding Modes / Opportunities

NSF's Mission is To Initiate & Support:

- Basic scientific research and research fundamental to the engineering process.
- Programs to strengthen scientific and engineering research potential.
- Science & engineering education programs at all levels.
- Programs that inform policy formulation

NSF Investment Strategies

Goals

- **People** - A diverse, internationally competitive and globally-engaged workforce of scientists, engineers and well-prepared citizens.
- **Ideas** - Discovery at and across the frontier of science and engineering, and connections to its use in the service of society.
- **Tools** - Broadly accessible, state-of-the-art information bases and shared research and education tools.

National Science Foundation

FY2003 Requested

Rita Coldwell

Joe Bordogna

- National Science Board
  - Office of the Inspector General
- Director - Rita Colwell
  - Staff Offices

$5,036M Total

- $304M — Polar and Antarctic Programs
- $526M — Directorate for Biological Sciences
- $527M — Directorate for Computer and Information Science and Engineering
- $908M — Directorate for Education and Human Resources
- $111M — Integrative Activities (MRE, STC)
- $488M — Directorate for Engineering
- $691M — Directorate for Geosciences
- $942M — Directorate for Mathematical and Physical Sciences
- $196M — Directorate for Social, Behavioral, and Economic Sciences

Esin Gulari

Division of Civil & Mechanical Systems

The Mission of CMS:

- Provide a fundamental underpinning for the engineering profession in application to mechanical systems and the constructed environment including infrastructure systems, and
- Support the rapid development of new technology in service to society and to reduce risks induced by natural, technological, and intentional hazards.

Critical Infrastructures *(PDD 63)*

Innovation

Transportation

Deterioration

Potable & Waste Water

Regulation

Telecom-munications

Banking & Insurance

Global-ization

Natural Threats

Government

Electricity

Devol-ution

Oil & Gas

Emergency Response

Deregulation

Accidental Threats

Deliberate Threats

Division of Civil and Mechanical Systems (CMS)

– **Solid Mechanics and Materials Engineering**
  Program Directors: Ken Chong (kchong@nsf.gov) and Jorn Larsen-Basse (jlarsenb@nsf.gov)

– **Geotechnical and GeoHazards Engineering**
  Program Directors: Clifford Astill (castill@nsf.gov) and Richard Fragaszy (rfragasz@nsf.gov)

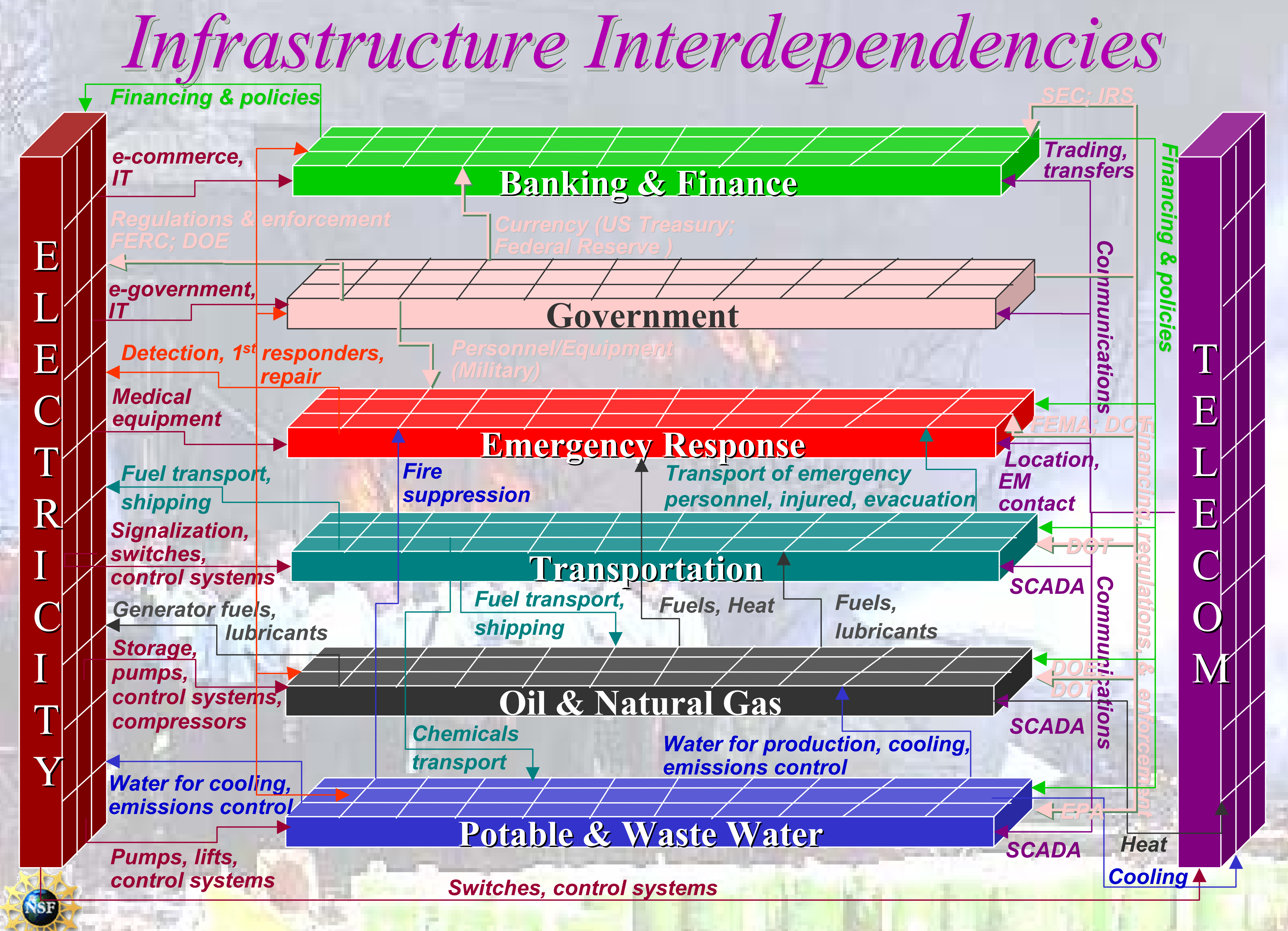
– **Structural Systems and Engineering**
  Program Directors: Steven McCabe (smccabe@nsf.gov) and P. Balaguru (pbalagur@nsf.gov)

– **Dynamic System Modeling, Sensing & Control**
  Program Directors: Shi-Chi Liu (sliu@nsf.gov) and Tomizuka (tomizuka@nsf.gov) and

– **Infrastructure and Information Systems**
  Program Directors: Miriam Heller (mheller@nsf.gov) and Dennis Wenger (in 11/01)

– **George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)**
  Program Directors: Joy Pauschke (jpauschk@nsf.gov) and Vilas (tanderso@nsf.gov)

CMS Represents NSF as a NEHRP (National Earthquake Hazards Reduction Program) Agency


Infrastructure Interdependencies
Financing & policies
e-commerce, IT
Banking & Finance
SEC; IRS
Trading, transfers
Regulations & enforcement FERC; DOE
Currency (US Treasury; Federal Reserve)
e-government, IT
Government
Communications
Financing & policies
Detection, 1st responders, repair
Personnel/Equipment (Military)
Medical equipment
Emergency Response
FEMA; DOT
Location, EM contact
Fuel transport, shipping
Fire suppression
Transport of emergency personnel, injured, evacuation
Signalization, switches, control systems
Transportation
DOT
SCADA
Generator fuels, lubricants
Fuel transport, shipping
Fuels, Heat
Fuels, lubricants
Storage, pumps, control systems, compressors
Oil & Natural Gas
DOE; DOT
SCADA
Financing, regulations, & enforcement
Chemicals transport
Water for production, cooling, emissions control
Water for cooling, emissions control
Potable & Waste Water
EPA
SCADA
Heat
Pumps, lifts, control systems
Cooling
Switches, control systems
ELECTRICITY
TELECOM
NSF

System Risk is a Function of System State

$P(H_{t,s})$ = probability of a hazard at time t (and system state s)

$P(D_s|H_{t,s})$ = probability of a particular level of vulnerability of a system in state s given a hazard at time t (and system state s)

$E(L|D_s)$ = expected losses conditioned on the vulnerability of system in state s

$$E(L) = \sum_{h_{t,s}} \sum_{d_s} E(L|d_s) * P(d_s|h_{t,s}) * P(h_{t,s})$$

Risk-Based Life-Cycle Infrastructure Engineering & Management

Detection, Preventive Maintenance,
Lifetime Extension, Early Warning

Planning, Training and Preparedness

Emergency Response, Diagnosis

Recovery, Corrective Maintenance

Modeling, Simulation, Prediction

Predictive Maintenance, Sensing, Monitoring, Data (Storage, Transmission, Retrieval)

Life-Cycle Design

Post-Event Analysis
- Internal, Direct Impacts
- External, Indirect Impacts
- Systems Evaluation

Challenges: Complex Systems & Interdependencies Modeling Needs

- **Theoretical frameworks for large-scale CAS**
  - **Non-linear coupled subsystems**
  - **System interdependencies**
  - **Spatially distributed, adaptive**

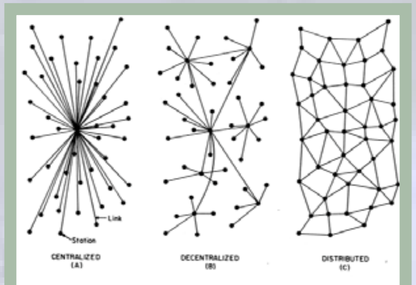


FIG. 1 — Centralized, Decentralized and Distributed Networks

- **Centralized, decentralized, distributed control**
- **Multiple agents / DM's**
  - **Multiple system operational objectives: efficiency, reliability, security, resiliency, sustainability**
  - **Multiple agencies with different missions, resources, timetables, and agendas**
- **Data security, accessibility, and reliability**
- **Organizational and human errors and failures**
- **Education and training implications for workforce and R&D**

Complex Systems & Interdependencies Modeling, Simulation, & Prediction

- *Advanced computing paradigms*: NNs, GAs, Complex (Adaptive) Systems, KD-DM
- *Visualization, Virtual Reality, Haptics, and other Human Computer Interfaces*
  - models are not in themselves solutions and the translation of model into usable forms draws on a range of disciplines
- Develop or enhance computer simulators to predict system behavior, including
  - Materials and design options
  - Internal monitoring, control, and optimization systems
  - Human and organizational behavior interactions

Challenges: Prediction

- Various level of prediction (Pielke, Sr., NCAR)
  - Guessing
  - Sensitivity Experiments (don't include all feedbacks)
  - Realization (include all feedbacks)
  - Projection (envelop)
  - Perfect Foresight (unachievable)
- Estimating and modeling risk
  - Mean Value, MLE, Order Statistics, Extreme Value Theory, Simulation
  - Component vs. system vs. interdependent systems
  - Multi-objective Risk
  - Integrated environmental, health, ecological, financial, technological
- Uncertainty: Bayesian, sensitivity, bounding methods
- Vulnerability and consequence assessment

Planning, Training, Preparedness

- (Multi-objective, Multi-stage) Decision Theory/Optimization under Risk and Uncertainty
- Expert systems/simulation
- Standards development
- Certification
- Organization theory
- Risk management/communication

Emergency Response, Diagnosis

- Infrastructure databases
- Database on emergency responders and their role
- Information flows
- Risk management / communication
- Group dynamics
- Organization theory
- Psychological biases in decision making

Recovery, Corrective Maintenance

- System resiliency modeling
- Short-term restoration vs long-term recovery
- Recovery vis-à-vis the rest of cycle:
  - Pre-event maintenance (predictive, preventive)
  - Pre-event recovery planning
  - Mitigation: "window of opportunity" post-event
  - Funding options
  - Federal programs (in search of a policy)
- Political science / public decision-making

Post-Event Analysis

- Impact (natural, built, human, social, cultural systems) characterization and inventories
- Data storage and transmission
- Impact valuation (e.g., engineering economics, contingent valuation; environmental risk assessment)
- Multiobjective risk assessment
- Post-event systems evaluation
  - Sensing, monitoring, control, and optimization systems
  - Modeling and prediction systems
  - Preparedness, detection, early warning
  - Emergency response, diagnosis, repair

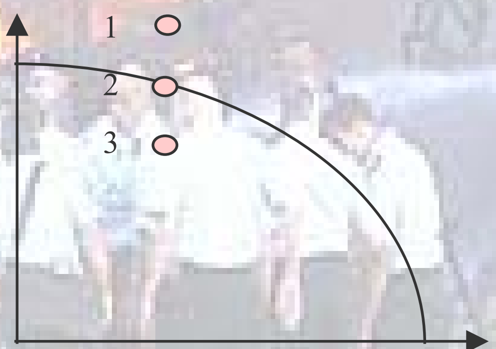
Life-Cycle Design

- Engineering and technological aspects of design
  - Thermal stresses, impact loading, plasticity, and stability of structural systems as well as fire proofing and blast resistance
  - New (smart) materials and designs to prevent or postpone collapse of building structures
- Social and behavioral aspects of design (worker productivity, organizational communication, egress modes)
- Simulation of structural and users' response to design
- Concurrent design methods
- Risk-based life-cycle assessment
- Non-structural design hedging mechanisms

Multi-Objective Multi-stakeholder Decision-Making

- *Allocation problem* **over various investment options, over various stages of development (R&D, development, implementation) over time with risk/uncertainty**
- *Multiple objectives* **: efficiency, reliability, security, resiliency, sustainability**

B/C (S&M)



B/C (ER)

1 ~ 2 ~ 3 : indifferent wrt ER

1 is infeasible wrt obj. S&M

2 >> 3 : 2 dominates 3

- *Multiple stakeholders* **: different missions, resources, timetables, and agendas**

Overarching Issues

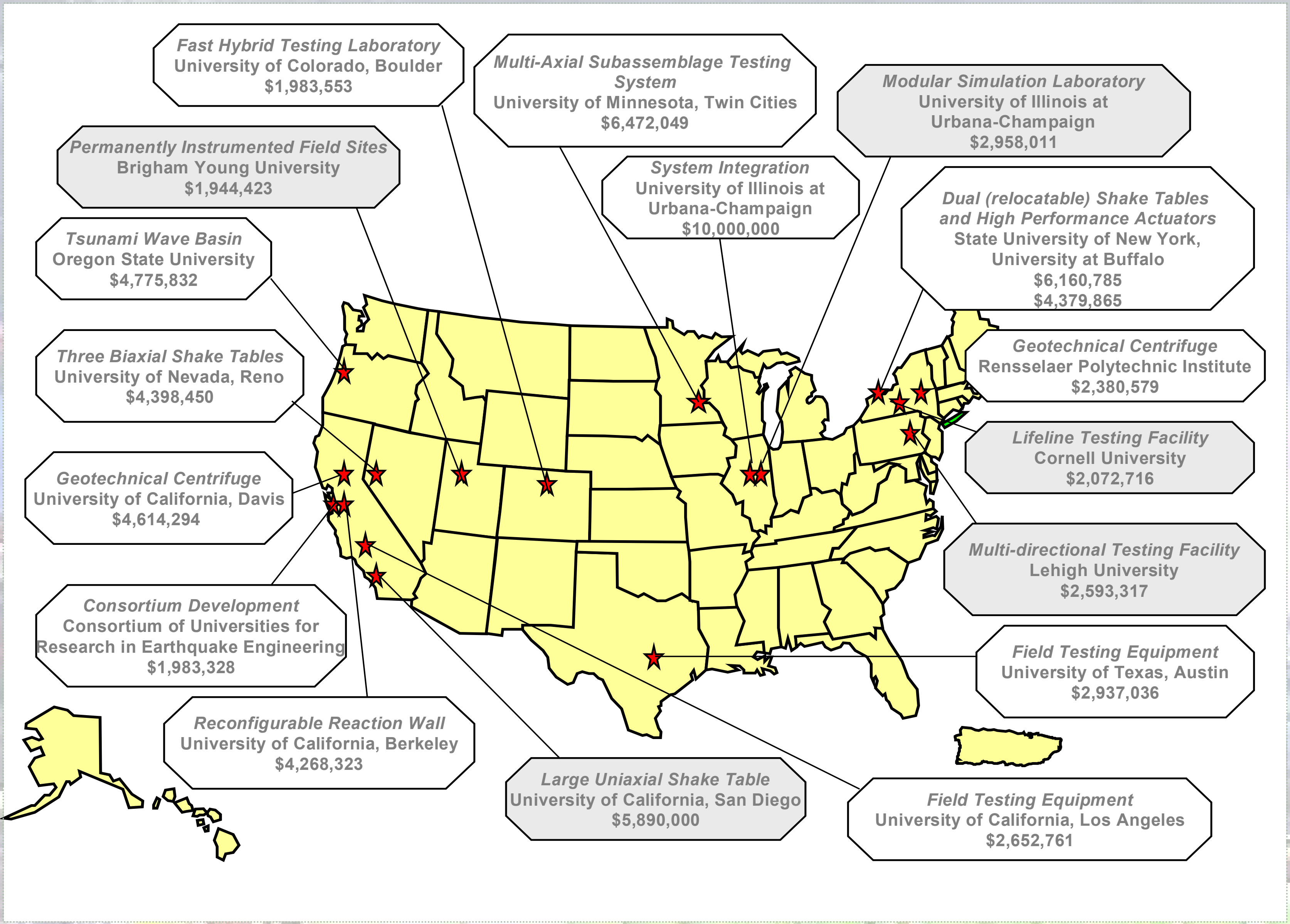
- **More than terrorism**
  - **Multiple hazards and stressors**
  - **System of interdependent infrastructure systems**
  - **Vulnerability is a function of system state**
- **Need a portfolio of risk intervention options**
  - **At different stages of technological develop**
  - **Over the system life-cycle**
- **Long-view / sustainability**
  - **Address security without compromising other objectives**
  - **Exploit synergistic objectives and collateral benefits**
- **Non-inconsequential issues that must be addressed**
  - **Workforce education & training (White House Workshop)**
  - **Sensors, "Acts of God" versus responsibility**
  - **Data sensitivity, accessibility, quality**

George E. Brown Network for Earthquake Engineering Simulation (NEES)

An $81.8 million revolution in earthquake engineering

- **Change focus from physical testing to seamless integration of testing, analysis and simulation**
- **Full-scale testing of complex structural and lifeline systems**
- **Network for real-time experiment sharing, access to curated databases and to advanced computational resources and visualization tools through the NEES collaboratory**
- **National and international resource for research and education**
  - expanded and diverse research community
  - outreach to the engineering profession, industry, policy makers, andpublic

NEES Award Portfolio



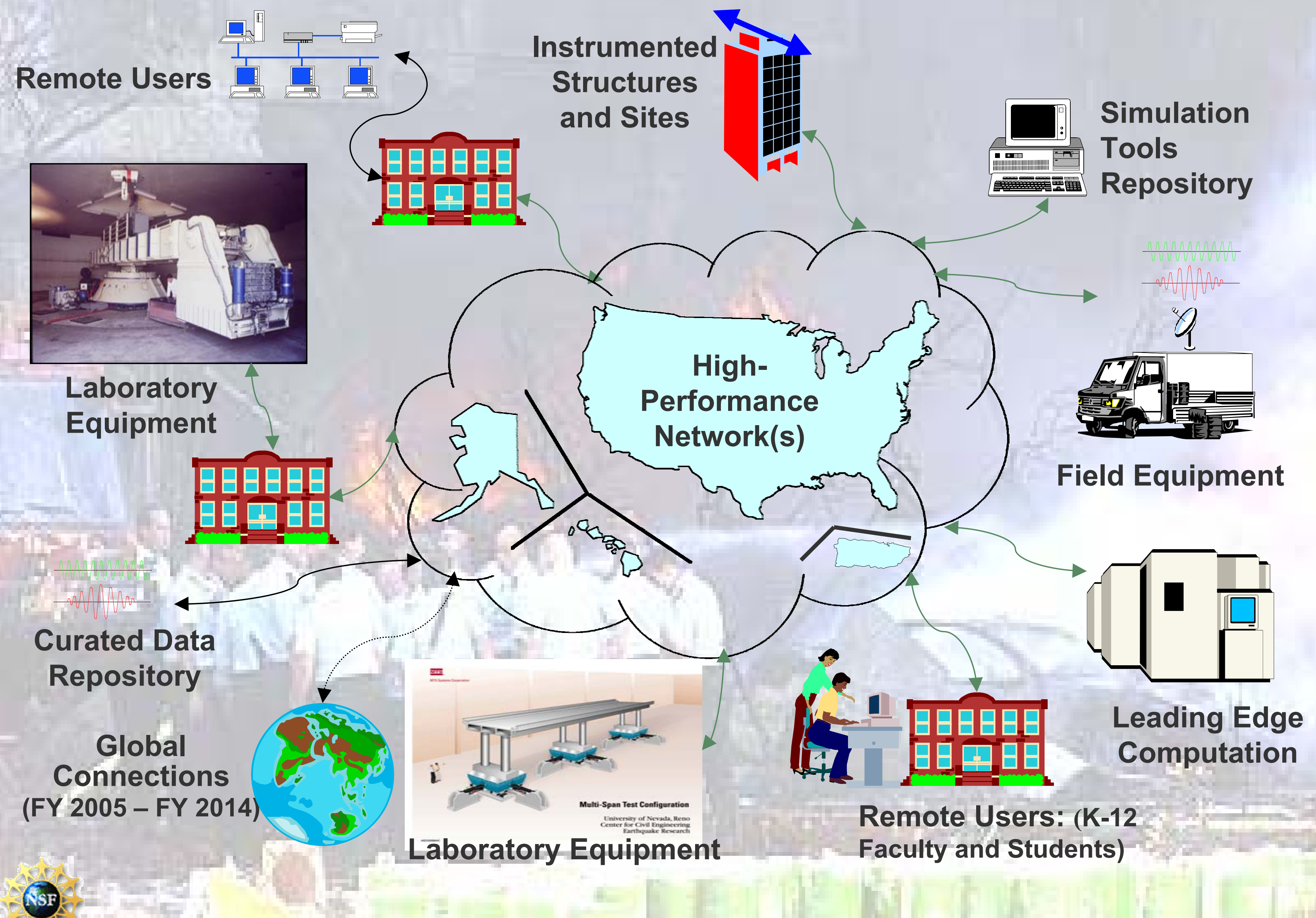
NEES Resources: Equipment Sites

Geotechnical Centrifuge
University of California, Davis

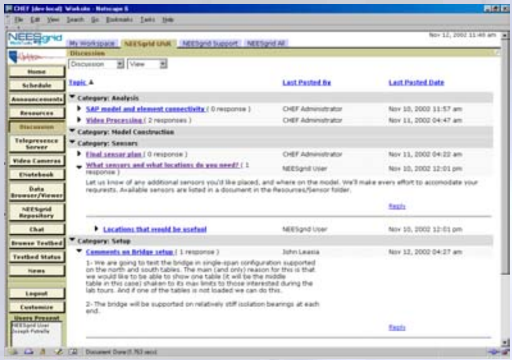
Three 2DOF Shake Tables
University of Nevada, Reno

Tsunami Wave Basin
Oregon State University

Reconfigurable Reaction Wall
University of California, Berkeley


Remote Users
Instrumented Structures and Sites
Simulation Tools Repository
Laboratory Equipment
High-Performance Network(s)
Field Equipment
Curated Data Repository
Leading Edge Computation
Global Connections (FY 2005 – FY 2014)
Multi-Span Test Configuration
University of Nevada, Reno
Center for Civil Engineering
Earthquake Research
Laboratory Equipment
Remote Users: (K-12 Faculty and Students)
NSF

Working Together: NEES Infrastructure



- Telepresence
  - Teleobservation
  - Teleoperation
  - Large/full-scale testing: structures, subassemblages, nonstructural components, lifeline/pipeline/utility/buried systems, multi-span and long span systems
  - Soil-foundation-structure interaction
  - Site characterization, liquefaction, lateral spreading
  - Near source high velocity input excitation
  - High density 3D strong motion arrays
  - Tsunami modeling/effects on the natural and built environments
  - Fast hybrid simulation – substructuring (≥1 physically tested components and ≥1 numerically simulated substructures)
  - Geographically distributed hybrid simulation

Working Together: NEES Infrastructure

- Collaboration support
  - collaborative tools to support distributed R&D teams
  - community codes to provide software tools for engineers
  - collaborative frameworks (e.g., CHEF)
  - frameworks for simulation (e.g., OpenSees)
  - structural and geotechnical systems
- Repositories of NEESgrid resources
  - experimental data, numeric simulation results
  - digital content (e.g., movies, video)
  - software tools

Simulation in Earthquake Engineering

- Three levels of physical processes
  - Real-world physical problem (e.g., a dam)
  - Real-world physical simulation (e.g., a dam model)
  - Virtual numeric simulation (e.g., a FE dam model)

real-world system	real-world model	virtual system
hard to measure	instrumented	good as its data
large scale	small scale	scale & resolution
fine resolution	scaling relations	MPP numerics

←→ **NEES ES Domain** (spans real-world system and real-world model)

←→ NSF MBS/DOE ASCI (spans virtual system)

Establishing the NEES/Earthquake Engineering Research Agenda

- Developing a Long-Term Research Agenda for the Network for Earthquake Engineering Simulation
  – Richard Little, PI, National Academy of Sciences, rlittle@nas.edu
  – https://www.fastlane.nsf.gov/servlet/showaward?award=0135915
- The Earthquake Research Plan: Research Needs and Opportunities for Earthquake Engineering
  – Susan K. Tubbesing, PI, Earthquake Engineering Research Institute, skt@eeri.org
  – https://www.fastlane.nsf.gov/servlet/showaward?award=0130009

Learning from Urban Disasters

PI	Institution	Title
Aboulhassan Astaneh-Asl	U California Berkeley (collaboration with LLNL)	World Trade Center Post-Disaster Reconnaissance and Perishable Structural Engineering Data Collection
David Bloomquist	U Florida (working with NOAA)	Infrastructural Damage Assessment Using Land-Based Laser Swath Mapping Technology
J. David Frost	Georgia Tech (collaboration with UIUC)	Digital Data Collection for Damage Assessment at World Trade Center
John R. Harrald	George Washington University	Observing and Documenting the Inter-Organizational Response to the 9/11 Terror Attacks
Jose Holguin-Veras Robert Paaswell	CUNY City College	Impacts of Extreme Events on Passenger Travel Behavior
George Lee Kathleen Tierney	MCEER at SUNY Buffalo (with U. Delaware)	Multidisciplinary Center for Earthquake Engineering Research
Dennis Mileti Mary Fran Myers	U. Colorado Boulder	Natural Hazards Research Application and Information Center
Frederick Mowrer	U Maryland	World Trade Center Post-Disaster Fire Reconnaissance and Perishable Data Collection
Tom O'Rourke Arthur Lembo	Cornell University	Improved Security And Management Of Underground Infrastructure Systems: Lessons Learned From September 11, 2001
W. Al Wallace Joe Chow David Mendonca	RPI (subaward to NJIT)	"Impact of World Trade Center Disaster on Critical Infrastructure Interdependence
Rae Zimmerman	New York University	SGER - Urban Infrastructure Services in a Time of Crisis: Lessons from September 11th

Learning from Urban Disasters : Structures and Fire

Fig. 1. A Beam from WTC-7 that is Burned

Fig. 2. A Column from Towers Appears to be hit with a Round and Fast Moving Object

Abolhassan Astaneh-Asl, University of California Berkeley

- Forensic studies of WTC's mechanical and structural properties
- Goal: realistic computer simulation of impact and fire on structures

Fred W. Mowrer, University of Maryland

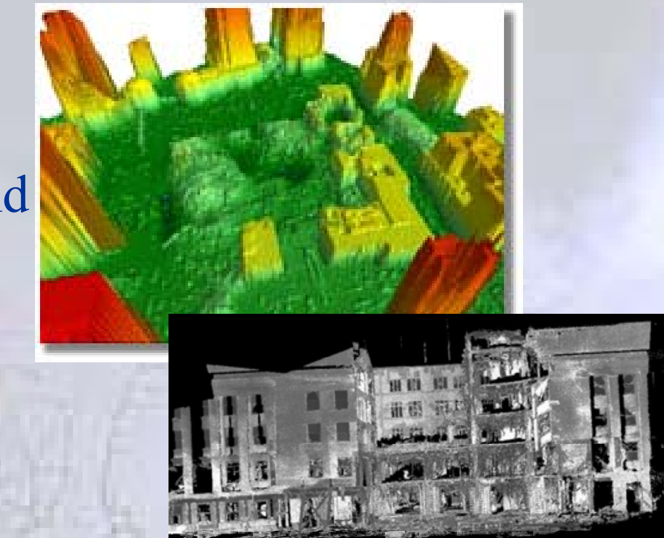
Pre-event condition assessment of

- Fireproofing
- Structural stability
- Automatic sprinklers
- Exit stairs/elevators
- Ventilation systems

Learning from Urban Disasters : Information

David Bloomquist, University of Florida

- New land-based laser system
- Yields high-resolution 3-D "maps" of interior and exterior of damaged buildings
- Identifies displacements and cracks for damage appraisal

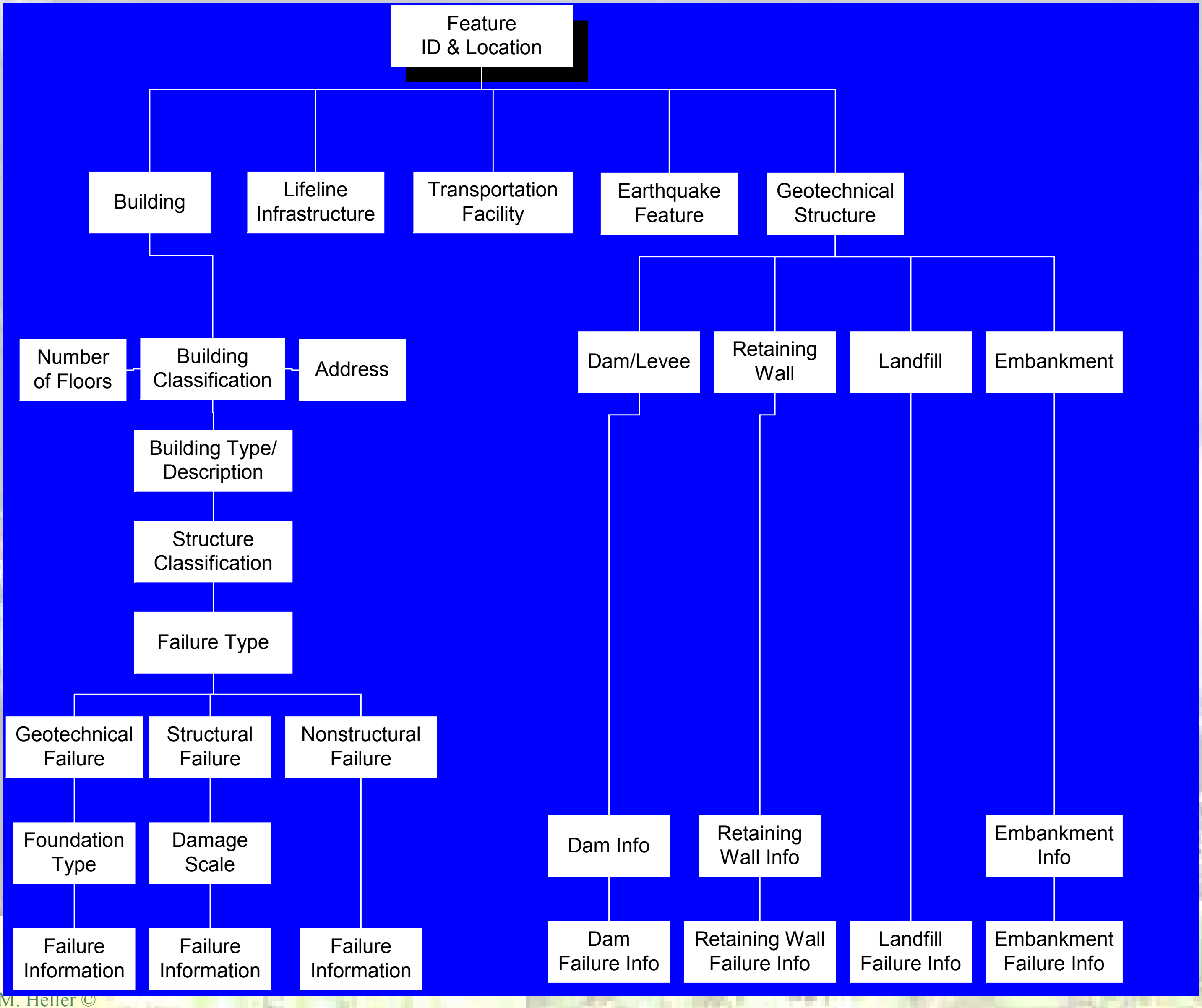


J. David Frost, Georgia Inst. Technology

- Structural damage data collection/integration
- Handheld technology for earthquakes data collection
- Includes GPS, digital camera, handheld computer

Hand-held Digital Data Collection for Damage Assessment

David Frost, Georgia Tech



Learning from Urban Disasters : Infrastructure Systems & Services

Thomas O'Rourke, Cornell University

- Critical infrastructure case studies
- Compile damage information on water supply, electric power, gas, steam, wasterwater conveyance, telecommunications, U/G transportation in GIS
- Compare with extreme events damage
- Generalize vulnerability & resiliency

Rae Zimmerman, NYU

- Pre-event assessment of transport, energy, telecommunications, water, sewer, solid waste management services
- Characterization of service interruptions
- Infrastructure service resiliency
- Performance frameworks

Learning from Urban Disasters : Emergency Response

John Harrald, George Washington University

- Extend emergency response knowledge base
- Interorganizational coordination of emergency management, medical efforts, law enforcement and military resources `
- Document information flows
- Compare to natural disasters

Dennis Mileti, Natural Hazards Center (U Co-Boulder)

17 travel grants awarded for QR, e.g.:

- Use of GIS in emergency response (S. Cutter)
- Institutional warning response (P. O'Brien)
- Victim identification (D. Simpson)
- Community response (S. Lowe)
- http://www.Colorado.EDU/hazards/qrsept.html
- http://www.nyu.edu/icis/Recovery/

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Emergency Response Related Research : Other Examples

- Learning Emergency Preparedness Planning and On-Line Evacuation of Large Buildings (Miller-Hooks: 0218621)
- Develop An Evacuation Management Decision Support System (Lindell: 0219155)
- CAREER: Identification, Modeling and Computational Simulations of Soil and Soil-Structure Using Earthquake Records and Experimental Data (Zeghal: 9984754)
- CAREER: Modeling and Simulation of Wind Loads for Wind Hazard Mitigation (Gurley: 9984635)
- Forecasting Change in Hurricane Risk over Time (Davidson: 0114215)
- CAREER: Robust On-Line Location and Routing for Urban Service Systems (Miller-Hooks: 9875305)
- COSMOS Virtual Data Center (Archuleta: 0201264)

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Opportunities

- Learning from Disasters: NSF Response and Opportunities for Future Research
  - **www.nyu.edu/icis/Recovery**
  - Relationships / connections between human and physical systems
  - Simulation of building systems
  - Simulation of emergency management and human response
- Workshop on HAZUS : The Next Generation
- NEES Grand Challenges Program (Spring FY2003)
- Multidisciplinary Research into Critical Infrastructure and Related Systems - Mitigation, Preparedness, Response and Recovery Regarding Disasters and Other Extreme Events [nsf03518]
- Human Dimensions - SBE

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Research Modes

- Unsolicited research (single investigator/small groups)
- Special initiatives (CAREER, NSF/USDOT, PATH)
- Center-based research (ERC)
- Industry partnerships (I/UCRC; GOALI)
- International collaborations
- Information centers
- Education projects (research, curriculum development, informal education)
- Workshops/U.S. attendance at international meetings

Questions

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