SAND2014-16547PE

# Improving Grid Resilience through Informed Decision-Making (IGRID)

## "Empowering the People Who Power the Grid"

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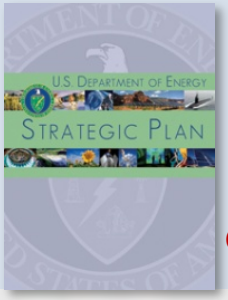
# Meeting Objectives

- Present/Discuss Sandia's IGRID study
  - Overview of project
  - Update on control-room and modeling work
  - Present options for direction of research
  - Solicit feedback on path forward and opportunities for collaboration
- Provide Overview of Sandia's Broader Capabililities in the Cognitive Sciences
- Introduce Other Studies of Possible Interest to SCE
  - TSA study
  - Efficient human-system Interaction
  - Grid integration

# Brief Introduction to Sandia


**US DOE National Laboratory**

**DEPARTMENT OF ENERGY**




*2014 Strategic Plan*

**GOALS**

Diversify energy mix & reduce dependence on foreign petroleum

Reduce green house gas emissions & other environmental impacts

Create a more flexible, more resilient & higher capacity US energy infrastructure

A Sandia Goal:
To accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

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# Sandia offers a unique combination of capabilities…

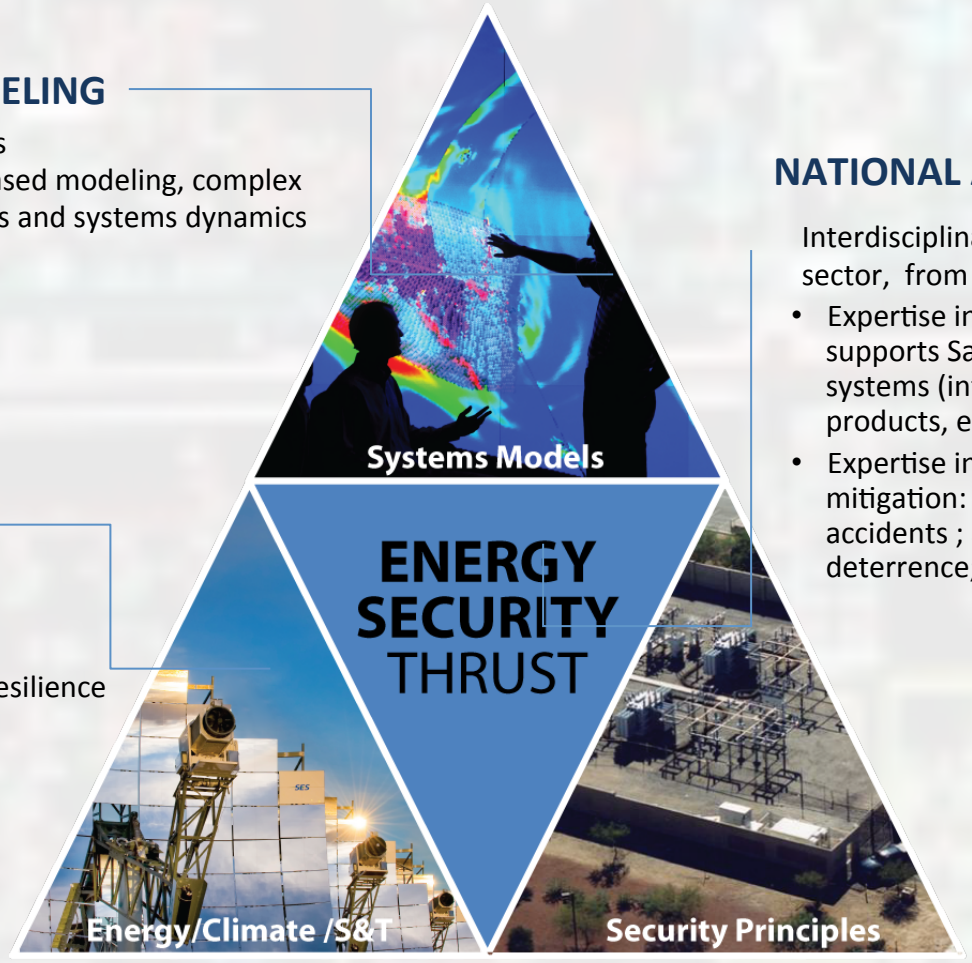
## SYSTEM MODELING

Systems modeling and analysis

- Decision-support– agent-based modeling, complex adaptive systems of systems and systems dynamics

## ENERGY/CLIMATE

- Energy storage
- Combustion
- Nuclear energy
- Power systems/gird resilience
- Renewable energy




## NATIONAL AND ENERGY SECURITY

Interdisciplinary programs across the energy sector, from open to highly secure

- Expertise in cyber and nuclear security supports Sandia's efforts to secure energy systems (infrastructure, supply routes, products, enterprises, etc.)
- Expertise in Human reliability analysis and mitigation: human error contributions to accidents ; adversarial threats and deterrence; situational awareness.

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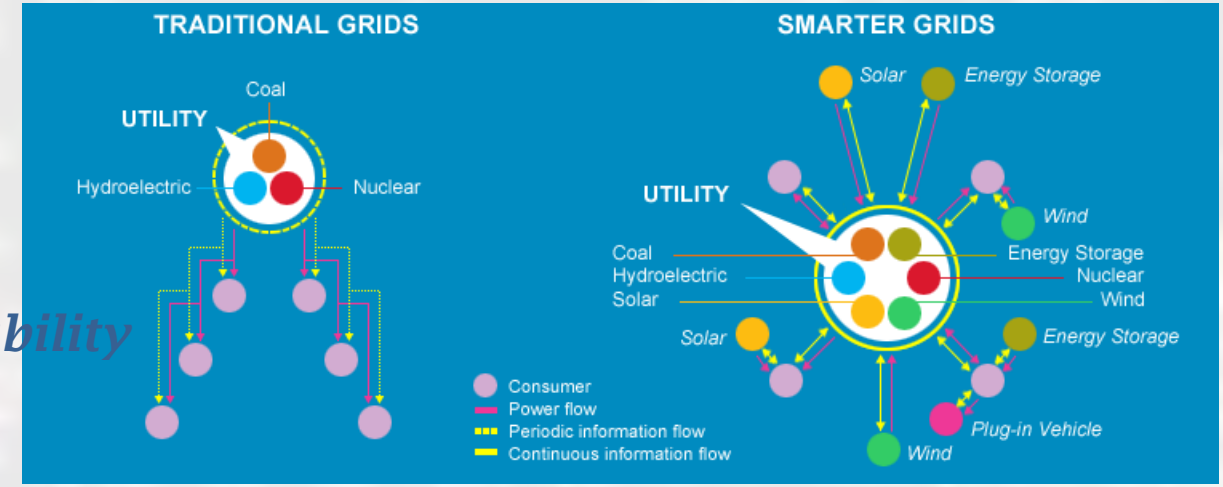
# A Transformational Time: the Grid Is…

- More complex. Includes two-way communications, distributed and diverse energy sources, storage, demand-response
- More automated. Has sensors, management systems, intelligent alarms
- More data-centric. More integration of systems and applications

*Data*

*Storage*

*Interoperability*




*Integration*

*Electric cars*

*Automation*

*Distributed generation*

*Demand Response*

*Cybersecurity*

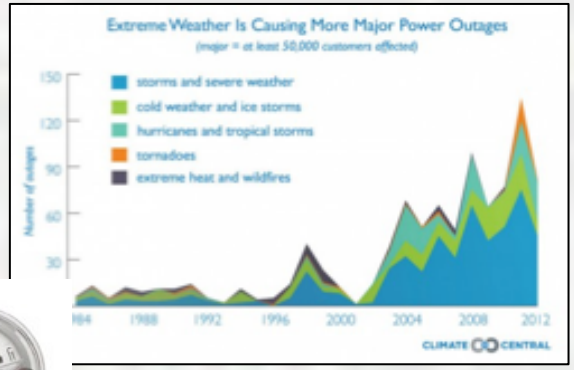
"The technological transformation of the grid] may well be described as the first great engineering achievement of the 21st century."

…a paradigm shift

# Understanding the Impact on System Operators

**Transformation of the distribution control center is rapid and profound**

- Increase in data:
  -- Harder to identify actionable events; harder to interpret the validity of data; harder to respond under stress
- Increase in automation:
  -- Proliferation of sensors translates into too many alarms and can diminish decision-making
- Increase in complexity (DG, DR, etc.):
  -- Changing skill set (need to define operator performance)
  -- More moving parts and interdependencies
- Less predictable operating environment
  -- Cyber uncertainties; hardware/software fairlire
  -- Changing climate
  -- Blue-sky surprises

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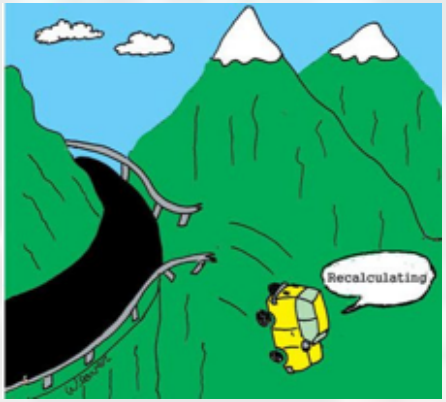
# Is the Distribution Grid Approaching a Precipice?




- Studies show automation negatively impacts critical-thinking skills.
- Complexity correlates with mental workload and can affect performance.
- Training after new technologies are introduced is not optimal.
- Stress created by frequent shift changes.
- Human error responsible for most grid outages and industrial accidents.

**…**But impact of grid's technical transformation on the distribution control room not well understood.

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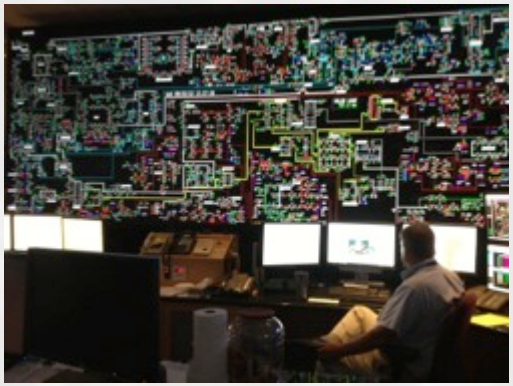
# IGRID Hypothesis

The grid's technological transformation will introduce multiple and novel challenges that will increase an operator's cognitive load and impact his/her critical thinking and decision-making abilities…the consequences of which are unknown.



# IGRID Objectives

- *Advance the science of control-room decision-making by understanding and modeling the impact of grid modernization on operator performance*

- *Inform tools and strategies that will help system operators adapt to a changing grid, respond to critical incidents and maintain critical performance skills.*

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# A Three-Part Technical Approach

- Conduct a cognitive analysis to acquire baseline understanding of distribution control-room operators (tasks, decisions)
- Develop model to map the linkages between operator decision-making and system vulnerabilities
- Employ model to provide predictive analytics and thereby inform and improve control-room operations

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# I. Building the Foundation: Cognitive Analysis

**Direct viewing of work, in real time, including:**

- Structured and unstructured interviews
- "Think aloud" observations of daily routines

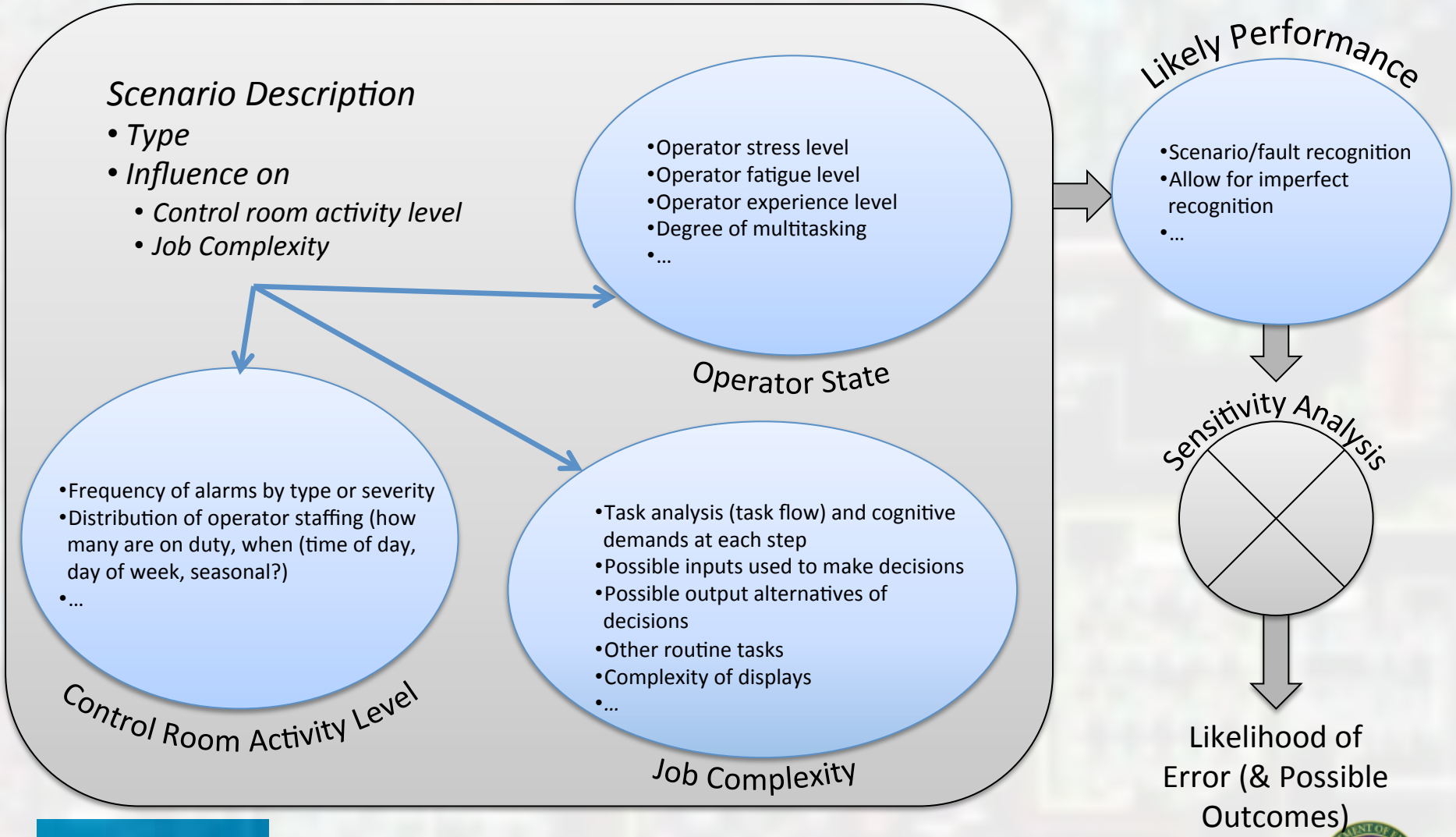
**Application of cognitive methodologies:**

- Critical Decision Method (CDM)
  Interviews to understand situational awareness and decision-making in non-routine situations.
- Applied Cognitive Task Analysis (ACTA)
  Interview methods to extract information about the cognitive demands and skills required for a task

**Analytic model of cognitive work**

- Describe work flow
- Identify decision points, describe accompanying decision processes
- Characterize team processes and information flow
- Develop metrics for cognitive performance and decision making

# II. Building a Model: Conceptual Approach

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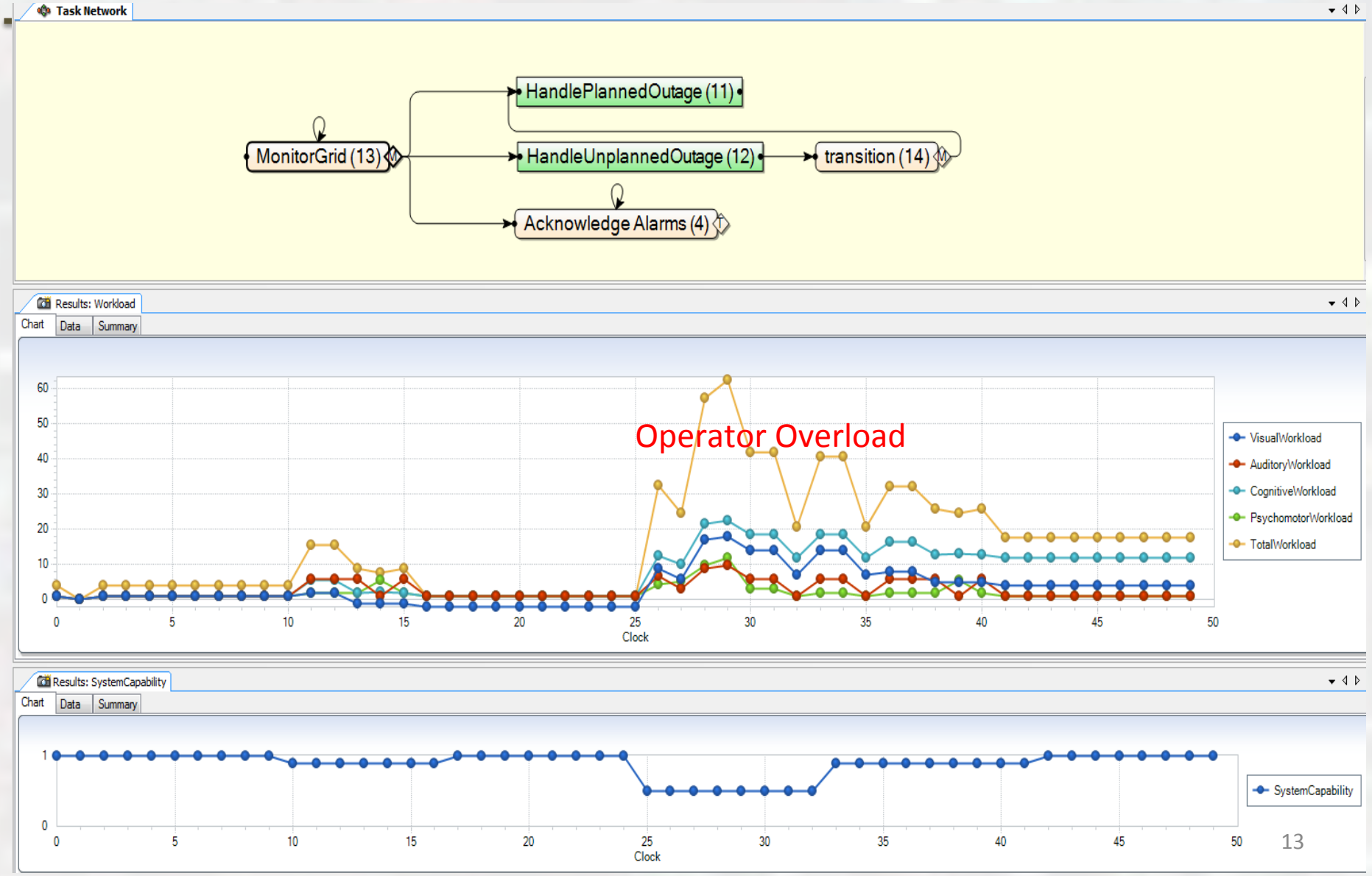
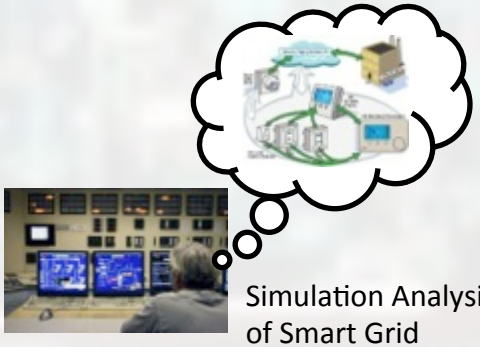
# Example Simulation



# Extensible Model Supports Multiple R&D Goals

Predictive Analysis of Current Operations



Simulation Analysis of Smart Grid Impact

Cognitive Analysis Studies

**Model of Operator Decision Making (Extensible)**

Interface to Other Grid Models

Innovations in Human Machine Interface (e.g. visualizations)


Operational Applications

Training Applications

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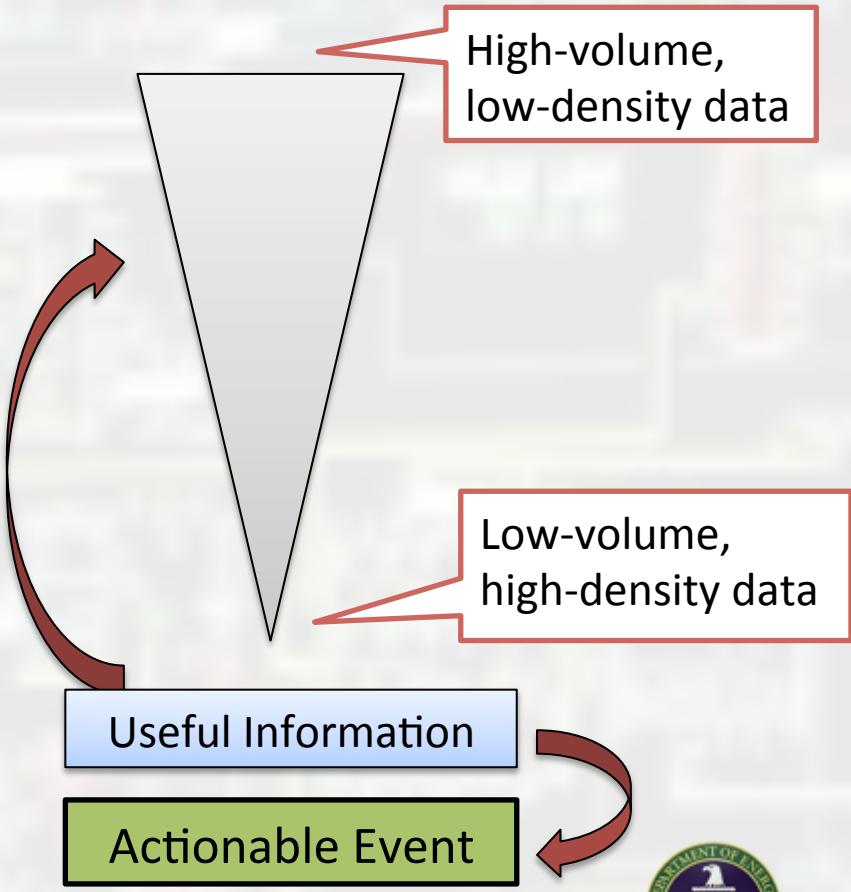
# III: Developing Tools to Enhance Performance

Create decision-making tools that:

- Reflect grid operations and contingencies
- Incorporate and prioritize/condense the metadata
- Reduce/cope with error-inducing situations

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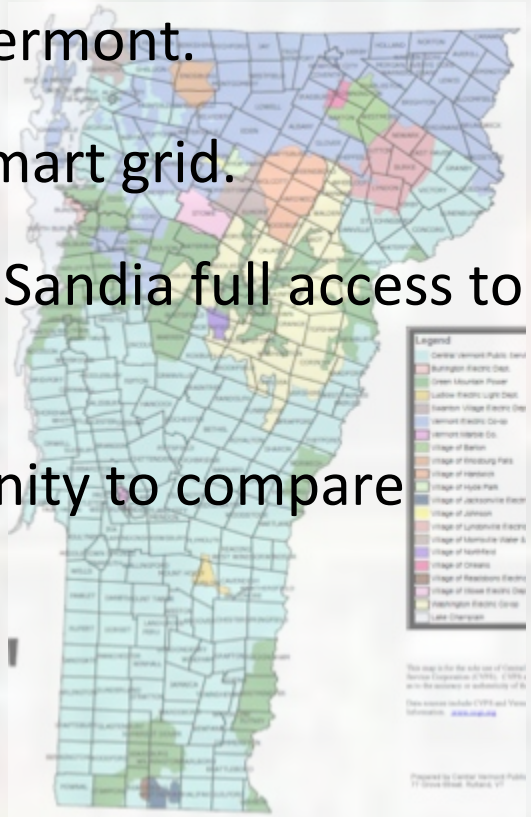
# Beginning Our Study in Vermont

- Sandia has an ongoing partnership with Vermont.
- First state in the US to have a statewide smart grid.
- The utilities support I-GRID and are giving Sandia full access to their control rooms and operators.
- Four utilities, five control rooms. Opportunity to compare distribution and transmission operations.

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GREEN MOUNTAIN POWER

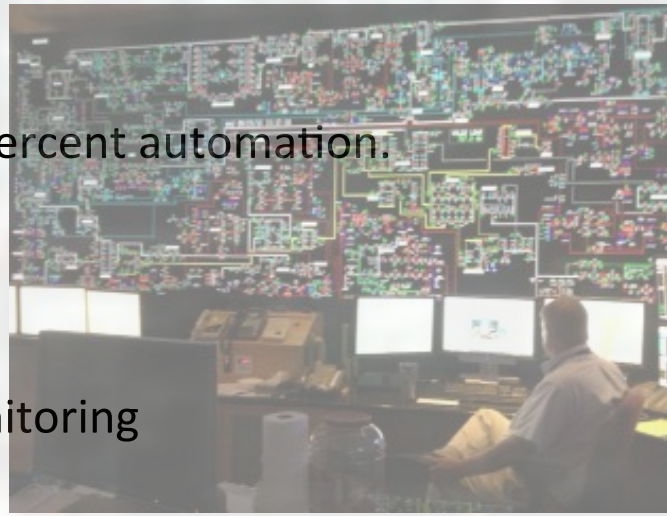
VERMONT ELECTRIC CO OP INC

BURLINGTON Electric DEPARTMENT

VT TRANSCO VELCO VETCO

# The Vermont Smart Grid

- Distribution Network
  - SCADA down to 34.5 kV substations
    - VEC: 100 percent of substations have 100 percent automation.
  - Fault Indicators
    - In distribution circuits with worst reliability
    - Supported by AMI systems
  - Voltage regulation
    - Supported by AMI meters with voltage monitoring
- AMI Infrastructure:
  - Over 95% of all VT electric customers
  - Most AMI meters will have service switches
- AMI Interfaces with:
  - Outage Management System (OMS)
  - MDMS in 3 utilities
- AMI will support:
  - ZigBee - HAN communications in all single phase meters
  - Existing load control systems
  - Existing and new time-based rates



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## Vermont Smart Grid Deployment (SGIG)

| Utility | GMP | BED | VEC | VELCO |
|---|---|---|---|---|
| **Advanced Metering Infrastructure** | | | | |
| Smart Meters | √ | √ | √ | |
| TOU / Dynamic Rates | √ | √ | √ | |
| Dynamic Rate Statistical Trial | √ | √ | | |
| Web Presentment kWh [(1)] Data | √ | √ | √ | |
| **Electric Distribution System** | | | | |
| Distribution Line Breakers | √ | √ | √ | |
| Fault Indicators | √ | √ | √ | |
| Direct Load Control | √ | √ | √ | |
| Relay Enhancement | √ | √ | √ | |
| SCADA [(2)] | √ | √ | √ | |
| Substation / Feeder Metering | √ | √ | √ | |
| Voltage Regulation | | | √ | |
| **Electric Transmission** | | | | |
| Relay Enhancement | | | | √ |
| Data Acquisition Enhancements | | | | √ |
| **Customer Systems** | | | | |
| Displays [(3)] | | | √ | |
| Home Area Networks [(3)] | | | √ | |
| Outage Management | √ | √ | √ | |
| Service Switch | √ | | √ | |
| Social Networking | √ | √ | √ | |

# Top Challenges Facing the VT Utilities

- Automation and alarms
  - Too many increases stress; need to match each type of alarm to a specific set of actions; have better methods of displaying alarms.
- Penetration of renewables
  - Operator focus may shift from managing reliability to managing distributed generation (worried about impact.)
- Information overload
  - Need to reduce the amount of data or present it more effectively.
  - Faulty data can be hard to distinguish from good data.
  - Impact of data on decision-making is unclear: will more data take more time? Reduce efficiency? Create a distraction?

# Preliminary Results of our Cognitive Analysis

**Activities**

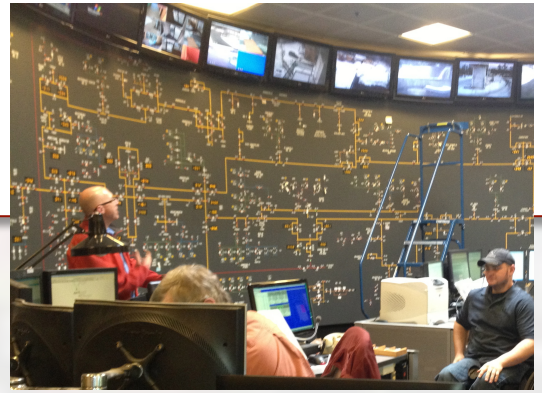
- Collected more than 30 hrs data from 15 distribution operators in VT; analyzed activity logs
- Created task flows; mapped tasks per frequency and duration

**Findings: Job Environment Stressful**

- Rotating shift work
- State of "punctuated equilibrium"
- Lengthy training period
- Shifting skill set
- Unique cultures/little standardization
- Aging workforce
- No good performance metrics

**Findings: Fault restoration**

- Grid operators rely heavily on field crews to develop plans and make decisions when faults occur; crews provide situational awareness
- Increased automation will change that relationship and may reduce operators' situational awareness, reduce their response times and negatively affect operators' diagnostic accuracy



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# Value of Decision-Making Model

- Core model of operator decision making provides capability for multiple application domains:
  - Engineering analysis
  - Training and assessing multi-tasking
  - Operational tool that recognizes when operator demands are being challenged and modulates/stops competing tasks

- We need your help/expertise to fill in the details

# How to Proceed?

**Need to narrow the scope:**

Unrealistic during project's early stages for IGRID to take on all the smart grid challenges affecting distribution operators.

**Need to focus on a challenge that is:**

- Interesting and lends itself to innovative solutions
- Will be affected by grid modernization and
- Is of widespread importance to distribution utilities

# Distribution Utilities Identify Challenges

- Growth in Grid-Tied Distributed Generation
  - Balance of load will shift to the distribution level
  - Operator focus may shift from managing reliability to managing distributed generation (worried about impact)
  - How to optimize?
- Increased Complexity
  - Many more moving parts: outages will be more stressful, maybe more error prone
  - Technological evolution means more change, more often = more stress
  - Electric vehicles will add complexity
- Automation and Alarms
  - Automation may increase risk : e.g., supply side issues. What if fault indicators all failed at the same time? Also operators will rely more on automation and thus not always be in the loop.
  - Operators need to distinguish false alarms from legitimate ones and to match each type of alarm to a specific set of actions.

# Challenges, Con't.

- Data Management
  - Operators will likely have to cope with the influx of smart-meter data.
  - Data load is growing: need to reduce the amount or present it more effectively. Want to minimize distraction.
  - Faulty data can be hard to distinguish from good data. What is the risk of inaccuracy?
  - The impact of data on decision-making is unclear: will more data mean more time? Less efficiency?
- Operator Skills
  - Training of distribution operators is likely to undergo a paradigm shift.
  - Seeing a transition in skill sets: more multi-tasking needed, not something previously valued. Also need operators who are adaptable.
  - Unsure how impending retirements and loss of skills will impact operations.

# Three Possible Paths Forward

- Increasing complexity and its impact on switching
- Growth in grid-tied solar generation
- Enabling diagnostics and situational awareness: focus on automation and alarms

# Why This Project Matters

- **Minimal Attention Paid to Date to Grid's Human Side**
- **Meets an Identified Need**
  - -- Eight utilities have validated the importance of our study
  - -- SCADA vendors have expressed interest in partnering
- **Aligns with Sandia and DOE goals**
  - -- Develop a comprehensive program to support modernization of the U.S. electric grid, with a focus on security and resiliency (Sandia)
  - -- Develop technologies to modernize the electric grid to improve resiliency, flexibility and better integrate [new] generation…and to facilitate innovation… (DOE Strategic Plan 2014-2018)

Questions?