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Improving Grid Resilience through Informed Decision-Making (IGRID)

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Sandia National Laboratories

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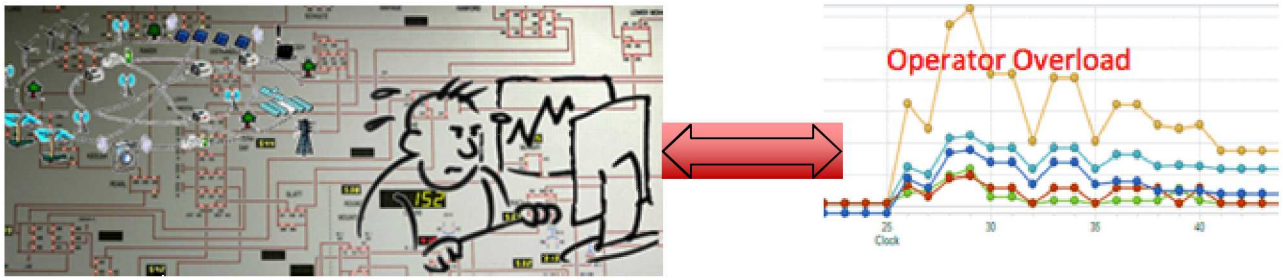
Improving Grid Resilience (through) Informed Decision-making (IGRID)

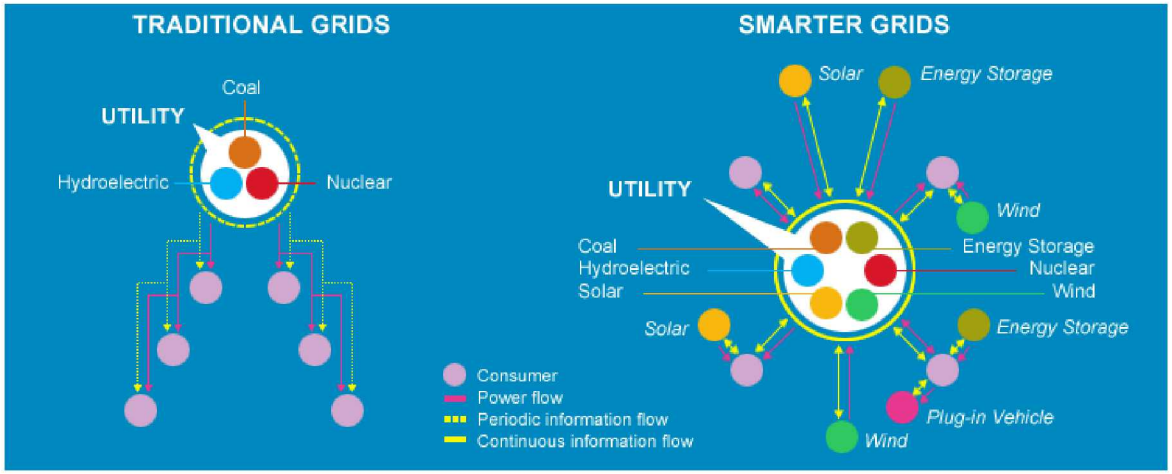
- Funded by Laboratory-Directed Research & Development (LDRD) funds
- Multi-disciplinary research effort, involving national lab staff and DUs
- Aligns with DOE's Strategic Plan (2014-2018); Grid Mod Roadmap
- Objective is to model and analyze the impact of the distribution grid's technological transformation on operator performance…
- Ultimate goal is to Inform tools and strategies that will help operators maintain/optimize essential skills as the grid becomes more automated



"…new data-visualization methods and tools to improve decision making by system operators" is key DOE objective." -- DOE Grid Modernization Roadmap

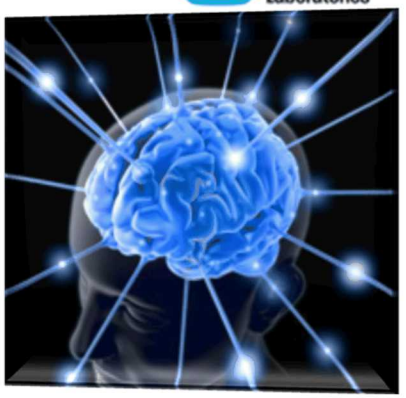
Why This Research Matters

- Modernization of the US electric grid is said to be the greatest engineering event of the 21st century.



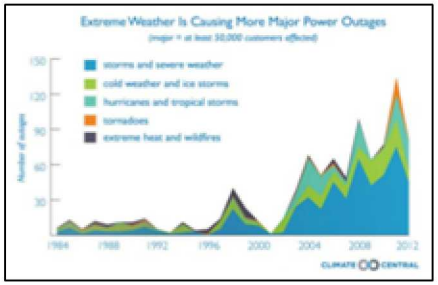
- Billions of dollars invested to date in technological upgrades, including communications and data-acquisition systems and automation. Much of the investment jumpstarted by ARRA funds.

…But There Are Human Impacts



- Increase in data:
  - Harder to identify actionable events; harder to interpret data and respond under stress
- Increase in automation:
  - Can introduce complacency and reduce situation awareness, which leads to diminished decision-making
- Emergence of a new architecture has impact:
  - More moving parts, more interfaces
  - Operators need a fundamentally different mental model
  - Changing skill set/expertise being redefined
- Less predictable operating environment
  - Cyber uncertainties; hardware/software failure
  - Changing climate
  - Blue-sky surprises

What is the impact on critical thinking?



IGRID Research Shows Utilities Are Already Feeling the Impact

1. Automation and alarms
   - Too many increases stress; need to match alarm to a specific set of actions; better methods of displaying alarms.
   - Senior operator “paralyzed with fear” when faced with too many alarms.
2. Penetration of renewables
   - Operator focus may shift from managing reliability to managing distributed generation (worried about impact.)
3. 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?
4. Operator Skills and Training
   - IT vs field-based
   - Balance between rote decision-making and critical thinking
5. Complexity

IGRID's Research Objectives

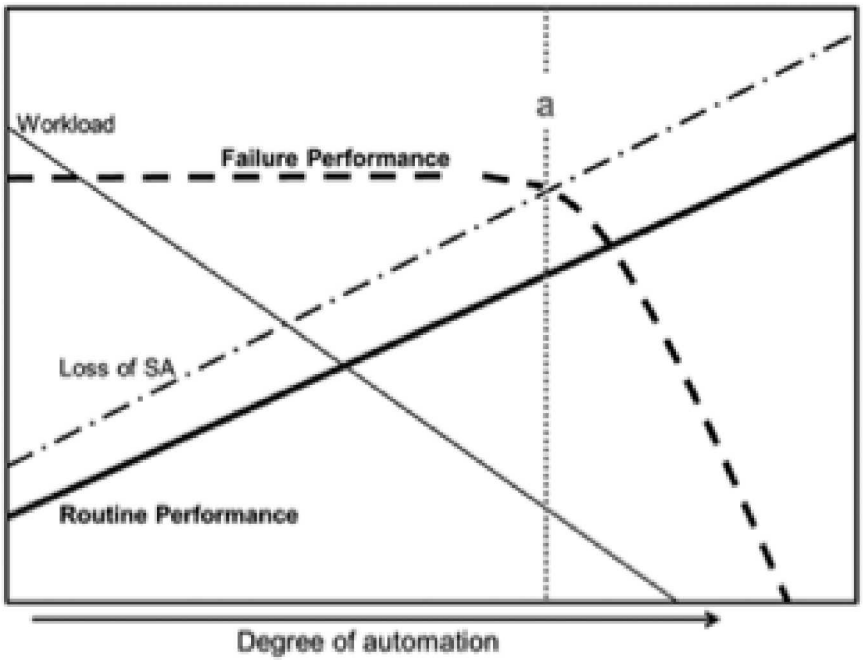
1) Quantify the impact of grid automation on operator performance
2) Identify and mitigate probabilities of operator error associated with increased automation
3) Develop a model to inform the build-out of distribution automation and identify strategies to optimize operator performance.

Focus of IGRID: Impact of Automation

- Smart grid (fully automated, self-healing) = "biggest engineering project of the 21st century" ….yet bad things happen when humans are outside the decision-making loop.
- What is the right balance between machine- and human-directed actions? When is there too much automation?
- But automation is hard to measure/quantify
- Studies to date have focused on other domains (aviation, medicine, even the transmission grid)…
- Focus of IGRID is on the distribution grid.
  - Transformation of the distribution grid is unparalleled; automation is enabling a radical change in grid functionality.
  - Grid automation is on an exponential trajectory
  - Stakes are high

Automation Impacts Human Performance

Automation degrades situation awareness…



* Onnasch et al 2014, *Human Factors* 56:3, pp 476-488

And when humans lose situation awareness…bad things happen.

Fukushima, 2011

Air France, 2009

Manhattan, 2003

So California, 2009

"Structurally sound aircraft plummet to earth, ships run aground in calm seas, industrial machines run awry…*all because of incompatibilities between the way things are designed and the way people perceive, think, and act."* **- Steven Casey, 1993**

Trend Away from Automation in Aviation

- Robots as team members; creating a tighter bond *
- Robots augment rather than automate
- Use humans for what humans are really good at and automation for what automation is really good at
- DARPA funded project

Co-Pilot Alias (Aircrew Labor In-Cockpit Automation System)– *New York Times* July.20 2015

* Based on “Man-Computer Symbiosis” by J.C.R. Licklider

Two-Part Study

I. Model Development

- Measure automation, collect and input relevant SCADA data, outage data, grid topology, restoration procedures, contingencies

II. Cognitive Research

- Subject Matter Expert Interviews
- Operational Observations
- Empirical Study/Data Collection

Part I. Our Study Begins in Vermont

- Senator Bernie Sanders visits Sandia (2008)
- Laboratory and state interests align:
  - Grid modernization (VT first to have a statewide smart grid) is a collaborative effort
  - Commitment to renewables (90 percent by 2050)
  - Recognized need for better energy security (Hurricane Irene)
- Innovative electric utilities
- DOE funding to launch partnership
- Internal funding from Sandia

Partnering with Four Utilities

Burlington Electric – David Kresock

Green Mountain Power – Ken Couture

Vermont Electric Company – David Haass

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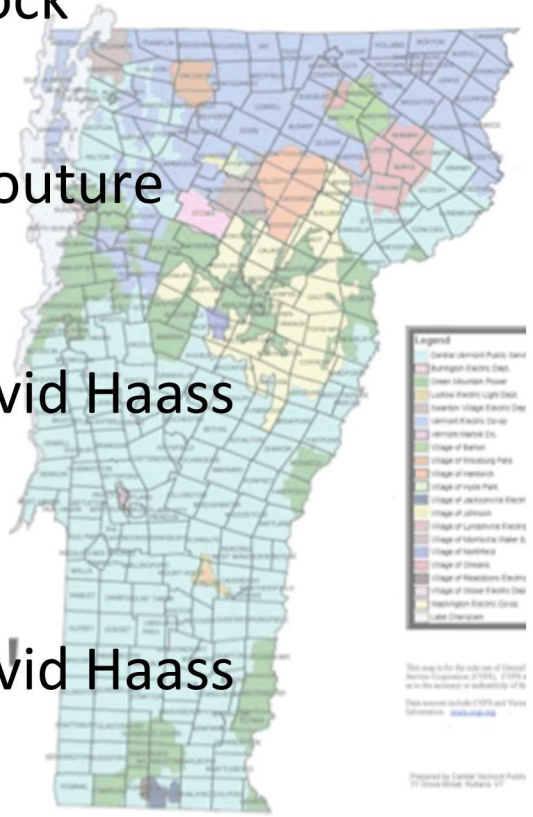
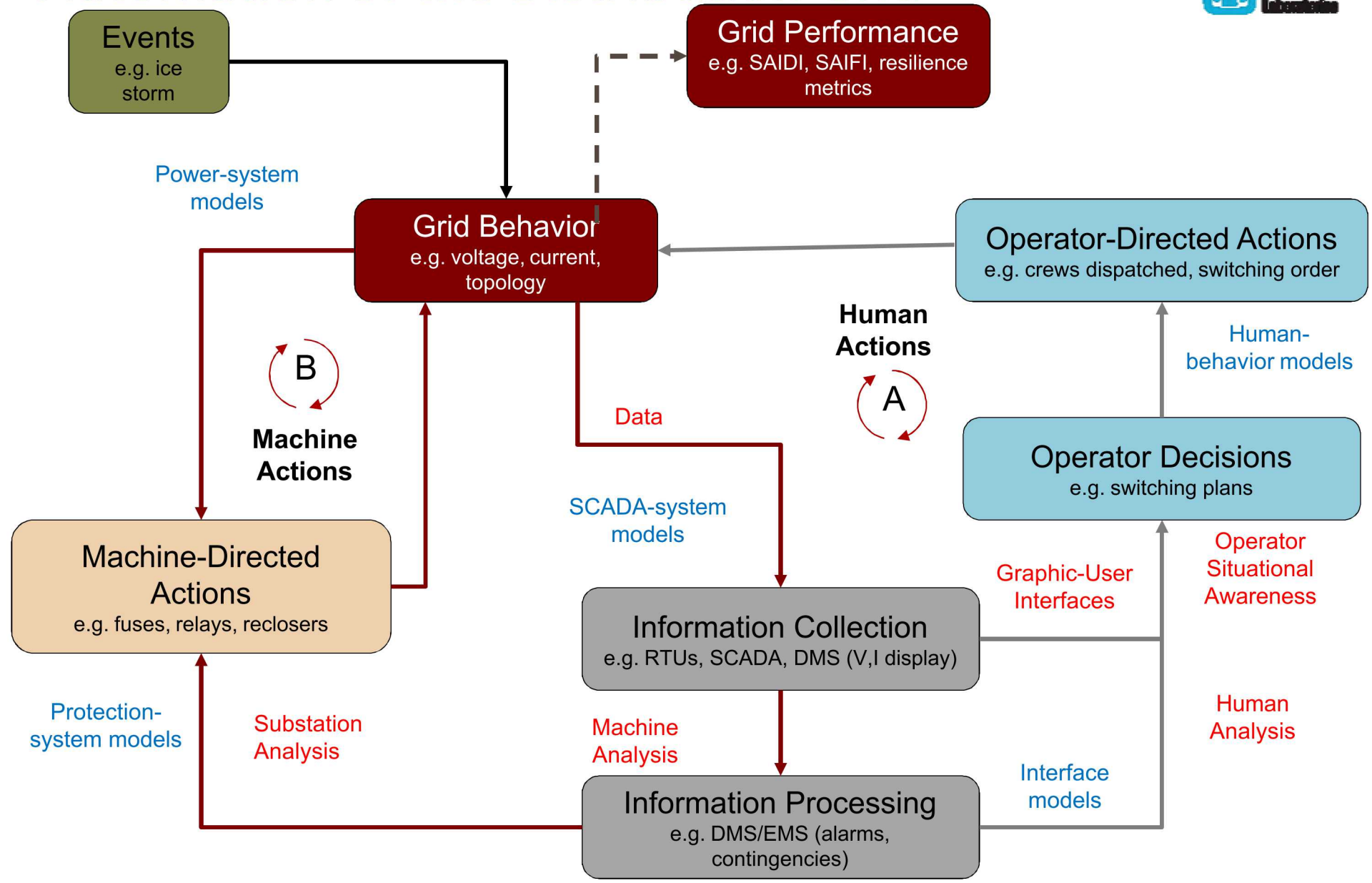


Automation of the Distribution Grid



IGRID Model

Scenario

- Literature
- SCADA data
- System documentation
- SME

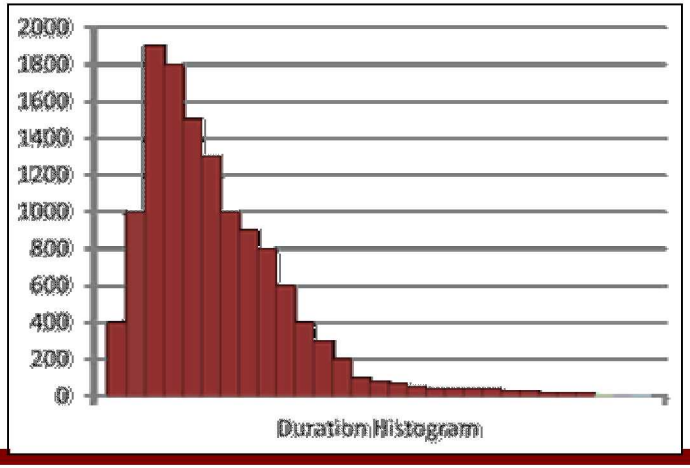
Level of *Automation*

Predictive Model

- Literature
- Utility Input

Level of *Expertise*

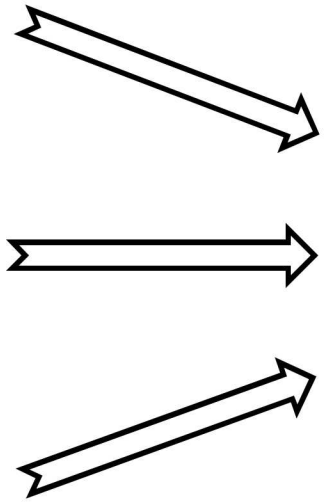
Design / Implementation Comparative Data

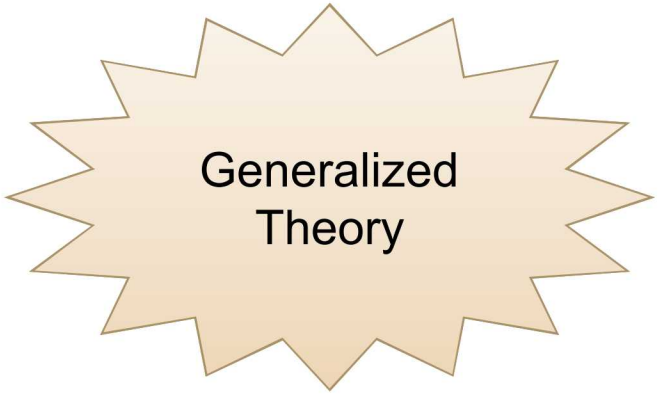


Optimal combination of automation and expertise for task/domain

Measure Automation

Overarching goal – characterize, quantify, model and predict impact of automation on ***reliability*** and ***resilience*** of human-in-the-loop critical infrastructure systems



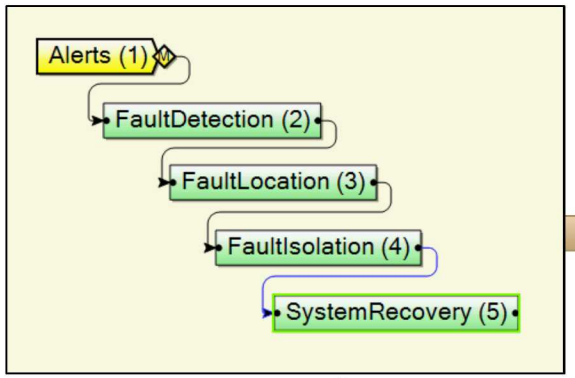


Level of automation is typically measured only once for a given system - ***not very descriptive*** for critical infrastructure systems where ***operators can override*** automation, or are forced to step in during critical events

Dynamics of Automation

Measure level of automation

- For each stage of automation (à la Parasuraman[1])
- For each system function
- At any point in time



$$DofA^2 = 1 - \frac{\sum_{i=1}^{N} t_i w_i}{\sum_{i=1}^{N} w_i}$$

Stage of Automation

System Functions

	Information Acquisition	Information Processing	Decision Support	Decision Implementation
Fault Detection	1	0.7	0.3	0.1
Fault Location	0.8	0.6	0.2	0.8
Fault Isolation	0.9	0.6	0.3	0.7
System Recovery	0.6	0.5	0.1	0.9

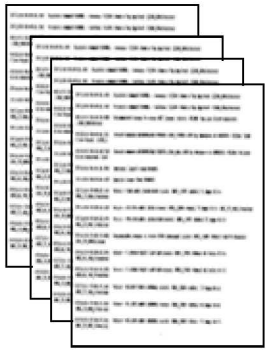
[1]Parasuraman, R., T.B. Sheridan, and C.D. Wickens, *A model for types and levels of human interaction with automation.* IEEE Transactions on Systems Man and Cybernetics Part a-Systems and Humans, 2000. **30**(3): p. 286-297.

[2]Wei, Z.G., A.P. Macwan, and P.A. Wieringa, A quantitative measure for degree of automation and its relation to system performance and mental load. Human Factors, 1998. 40(2): p. 277-295.

Leverage Existing Information Systems

Supervisory control and data acquisition (SCADA) systems provide rich information stores of operator and machine actions

- SCADA log message can be mapped to stage of automation and system function



	Information Acquisition	Information Analysis	Decision Selection	Action Implementation
Machine				
Automated Action	Value = [OFF]	low limit exceeded	N/A	device change of state [OPEN, OFF]
Result of operator commanded action	N/A	N/A	N/A	control succeeded [OPEN, CLOSED, TAG]
Operator				
Acknowledge machine action	N/A	Issued command [ACKNOWLEDGE]	N/A	N/A
Command machine action	Issued command [REPORT STATE]	operator control, note added	N/A	Operator control [OPEN, CLOSED, TAG]

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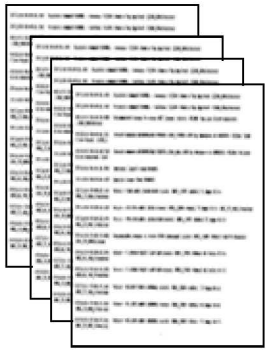

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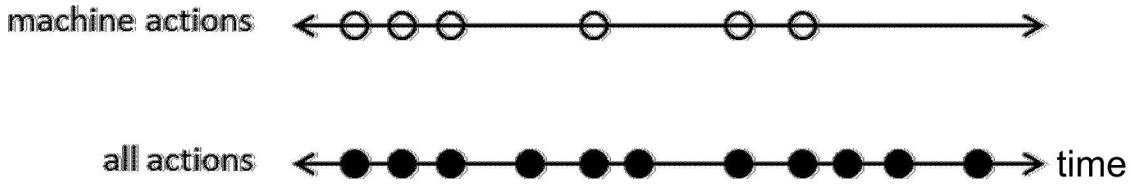
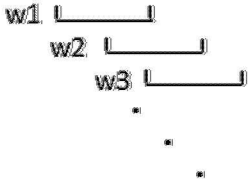
Implementation Method

SCADA Samples



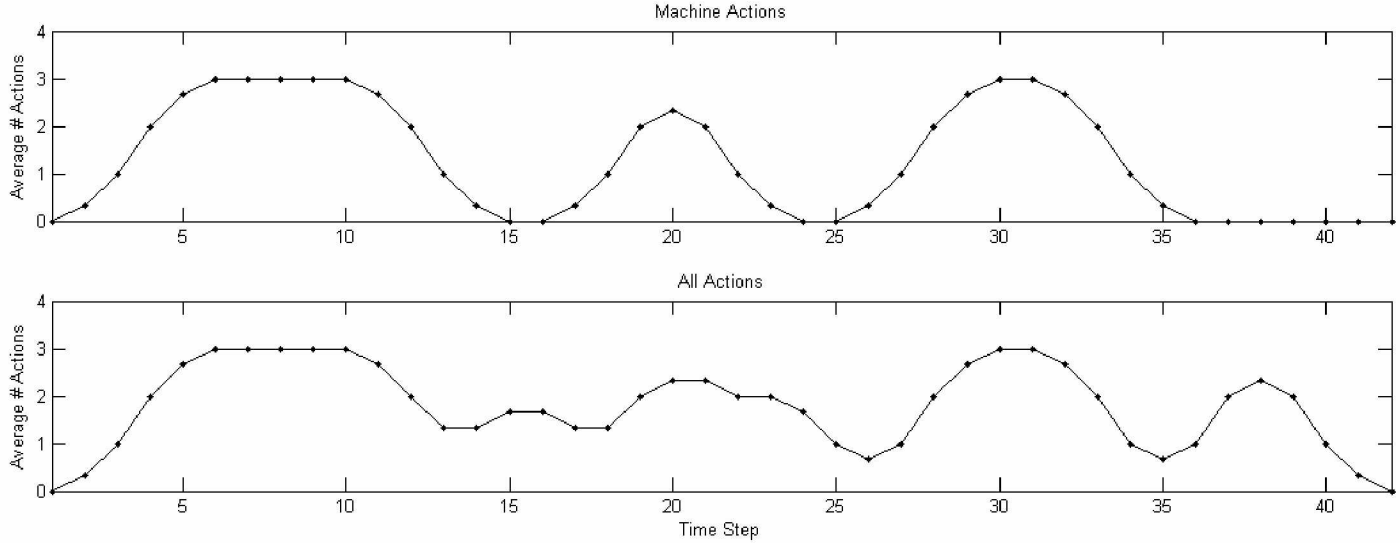
Moving Window Average[1]

$$y_k = \sum_{n=0}^{N-1} x_{k-n}; \quad k \geq N\text{-}1$$



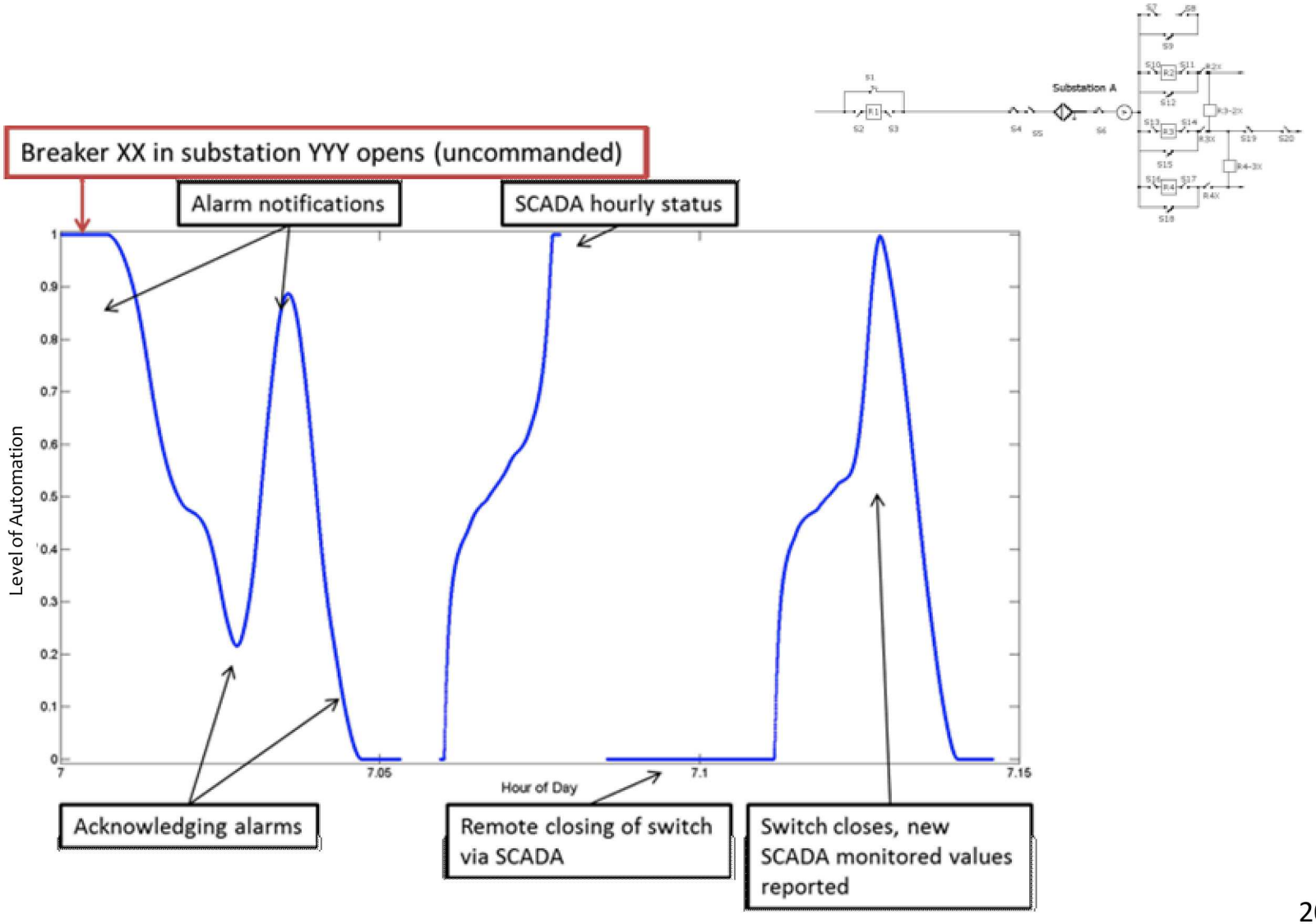
Tuning Parameters

- *Window size*
- *Action duration*
- *Sampling rate*



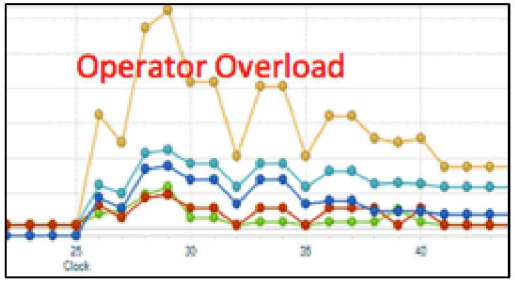
[1] For example implementations in MATLAB (® The Mathworks), see Sterns & Hush, Digital Signal Processing with Examples in MATLAB, 2nd Edition, CCR press, 2011

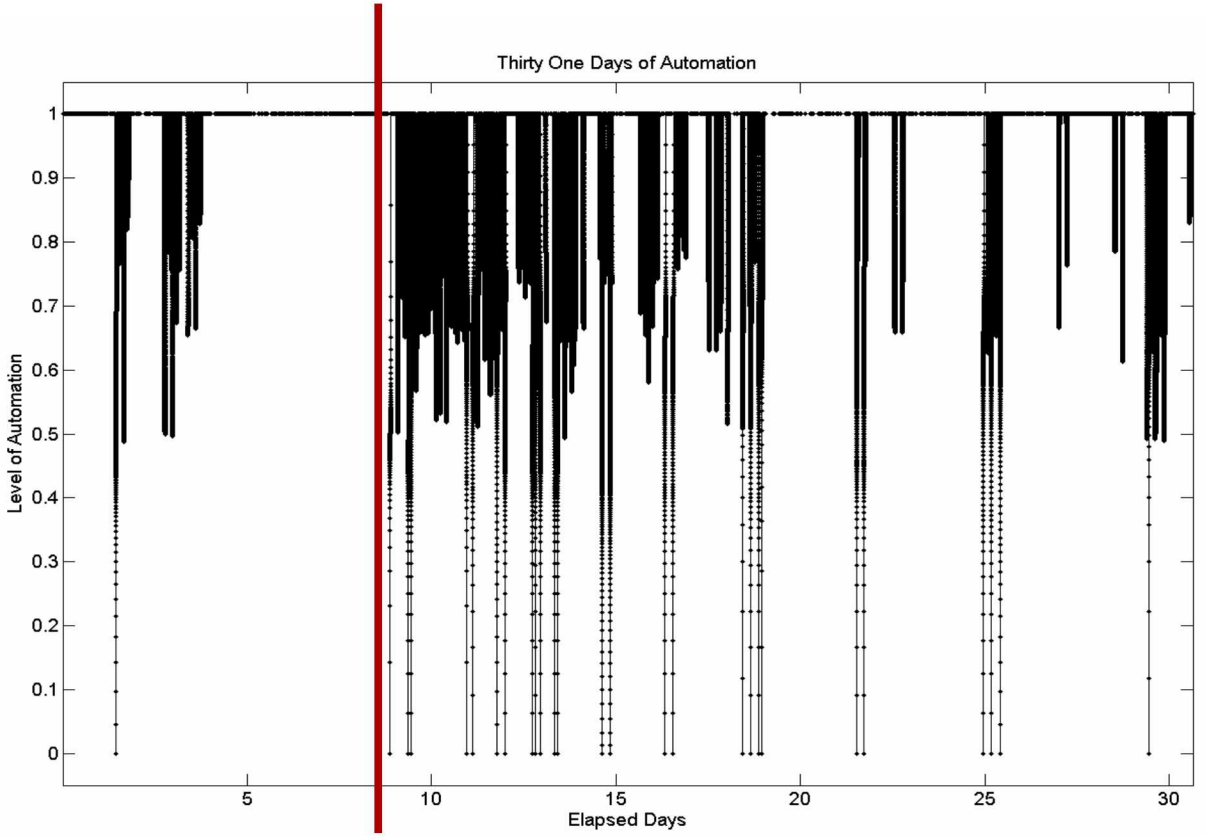
Example – Unplanned Outage



Widespread Outages

"Vermont storm leaves 13,000 without power days after snowfall" – NY Daily News, December 13, 2014





Summary of Automation Work

New, dynamic measure of automation

- Track the changing level of automation as a critical infrastructure system moves through its natural system dynamics
- Sufficiently general to be applied across different work domains and critical infrastructure systems
- Provides richly detailed view of factors that may affect system performance, including operator workload weaknesses or gaps in system automation

Moment-by-moment details can be analyzed over

- Periodic time periods (for example, weekly, or monthly)
- During critical events (such as storms or system upgrades)
- For specific subsystems (substation, type of protection device, etc.)

Potential Impact & Next Steps

Dynamic measure of automation enables analyses to guide infrastructure investment decisions

- Personnel allocations
- Infrastructure investment decisions

Can also be used to guide human-computer interaction design for future control rooms

- For example, when automation is high, there is an increased risk of human complacency
- Future systems could be designed to maintain operator engagement during highly automated time periods so that situational awareness is maintained

Next - collaborations with utilities and distribution solution vendors to expand range of logged actions

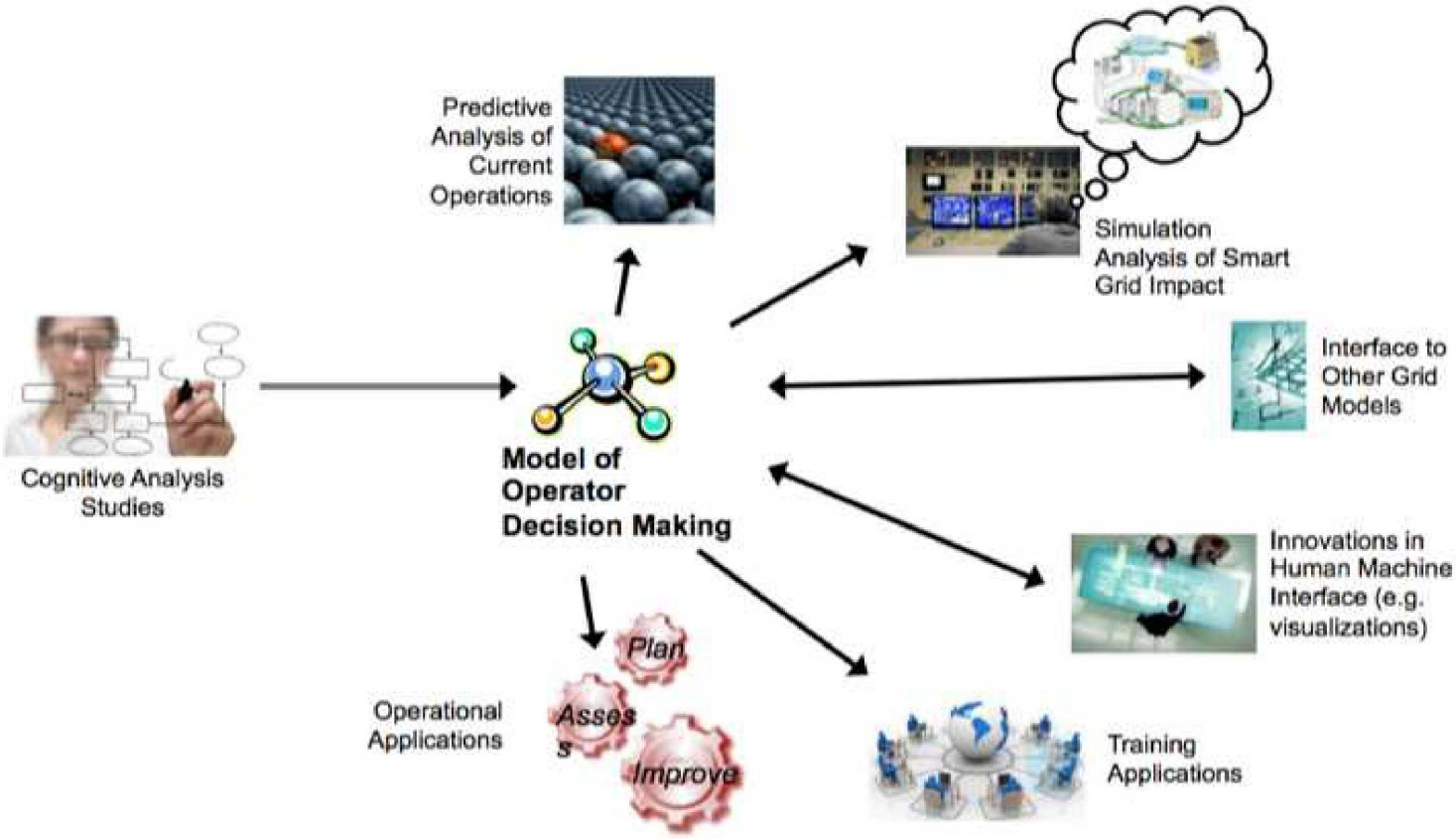
Part II. Research Approach

- Determine domain-specific expertise
  - Conduct interviews of management and non-management
  - Review training materials
  - Review HR materials (time on job, education, etc…)
- Inventory the automation-operator interface
  - Identify data available to the operator and its presentation (visualization)
  - Elicit expert knowledge (operators and engineers)
  - Distinguish which interfaces are “touched” by the operator and which interfaces are not
  - Review operating manuals/procedures
  - Conduct system “walkthrough” with experts

Research Approach cont.

- Design and Execute Empirical Study
  - Using levels of expertise and levels of automation as independent variables
  - Measure scenario task completion, accuracy, timing, decision-making
  - Build scenarios
  - Validate model framework
  - Make the model more robust for the domain
- Publish Findings

The IGRID Model Value



Model has potential to provide:

- Early indications of impending loss of operator SA
- Evaluation of existing/proposed control rooms to identify vulnerabilities
- Evaluation of existing/proposed GUIs to identify vulnerabilities
- Training support

Value in Partnership

- Oracle will have access to SNL Human Factors and Cognitive Modeling experts
- Oracle will benefit from first-hand knowledge of fundamental research in the domain
  - This may allow for integration of study findings into future designs to enhance the human-system interface, allowing for greater system resilience
- Sandia may require support from Oracle experts
- Sandia may require the use of Oracle's training simulator for study purposes.

What's Next

1. Further refinement and expansion of the IGRID model to include data from before/after study of automation technology.
2. Methodology for measuring control-room expertise; a key challenge.
3. Additional field studies and simulation exercises
4. Cognitive study of HMI – mapping expertise to complexity and visualization of data.

Questions?

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