2009 EMS Users Conference

Expert Operator Decision Making: Application of the Expert Operator Decision Model for Developing and Evaluating EMS User Interfaces

Frank L. Greitzer, PhD

Pacific Northwest National Laboratory

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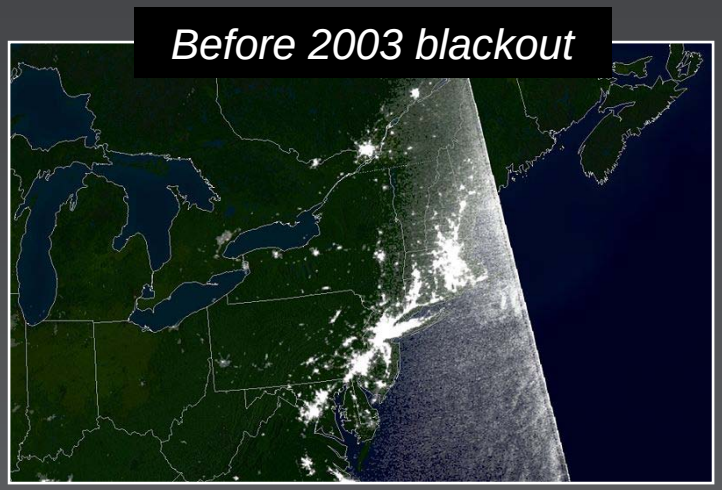
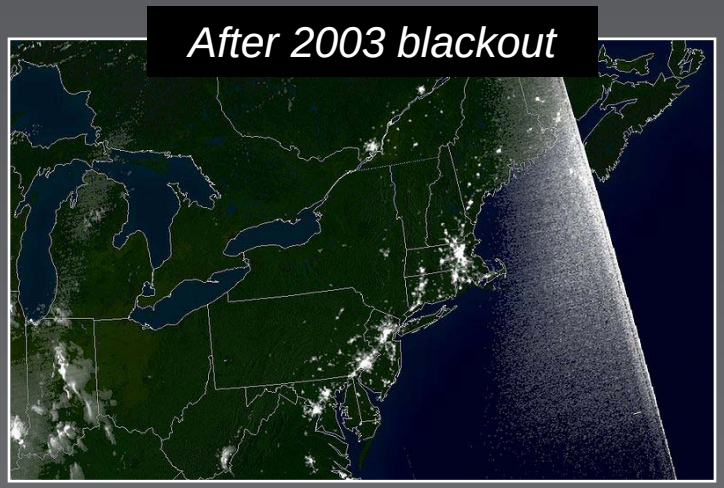
Overview

- Power Grid Expert Operator Decision Model (ODM)
- Applications
  - Training: PNNL distributed training demonstration
  - Evaluation:
    - Analysis/design of operator displays
    - Experiment assessing effectiveness of user interface/display/visualization options
- Conclusions

Background

- Large scale blackouts highlight major issues/challenges for power industry
  - August 1996: 30,000 MW
    - 8M customers
    - ~24M people
  - August 2003: 62,000 MW
    - 6M customers
    - ~50M people
- Lack of Situation Awareness (SA) identified as principal cause in 2003
  - ➔increased interest in training for SA
  - ➔increased interest in developing and testing new displays and visualizations that enhance SA.





NOAA Satellite Imagery.

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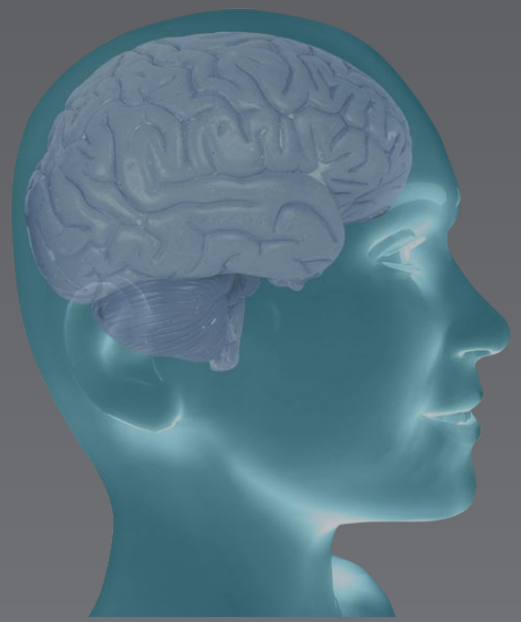
Enhancing Performance Through Design and Training Improvements

Operator Decision Model: An application of Cognitive Science

- Power grid operations: Complex information processing and decision-making activity
- Complexity of grid can yield information overload
- Display designs and visualizations impact performance
- Human factors design and application of cognitive principles improve displays and visualizations



- Design Principles:
  - Consistent user interface design
  - Efficient navigation between displays
  - Effective visualizations
  - Organizational principles
  - Error tolerance

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Problem

Grid operators need a more complete understanding of the state of the grid.

- Despite acknowledgment of the problem, most current approaches are *ad hoc*:
  - Grid operator training generally lacks systematic assessment and instruction based on critical learning objectives
  - Design, development and evaluation of new tools or visualizations similarly lack theoretical perspective and comprehensive operational needs assessment

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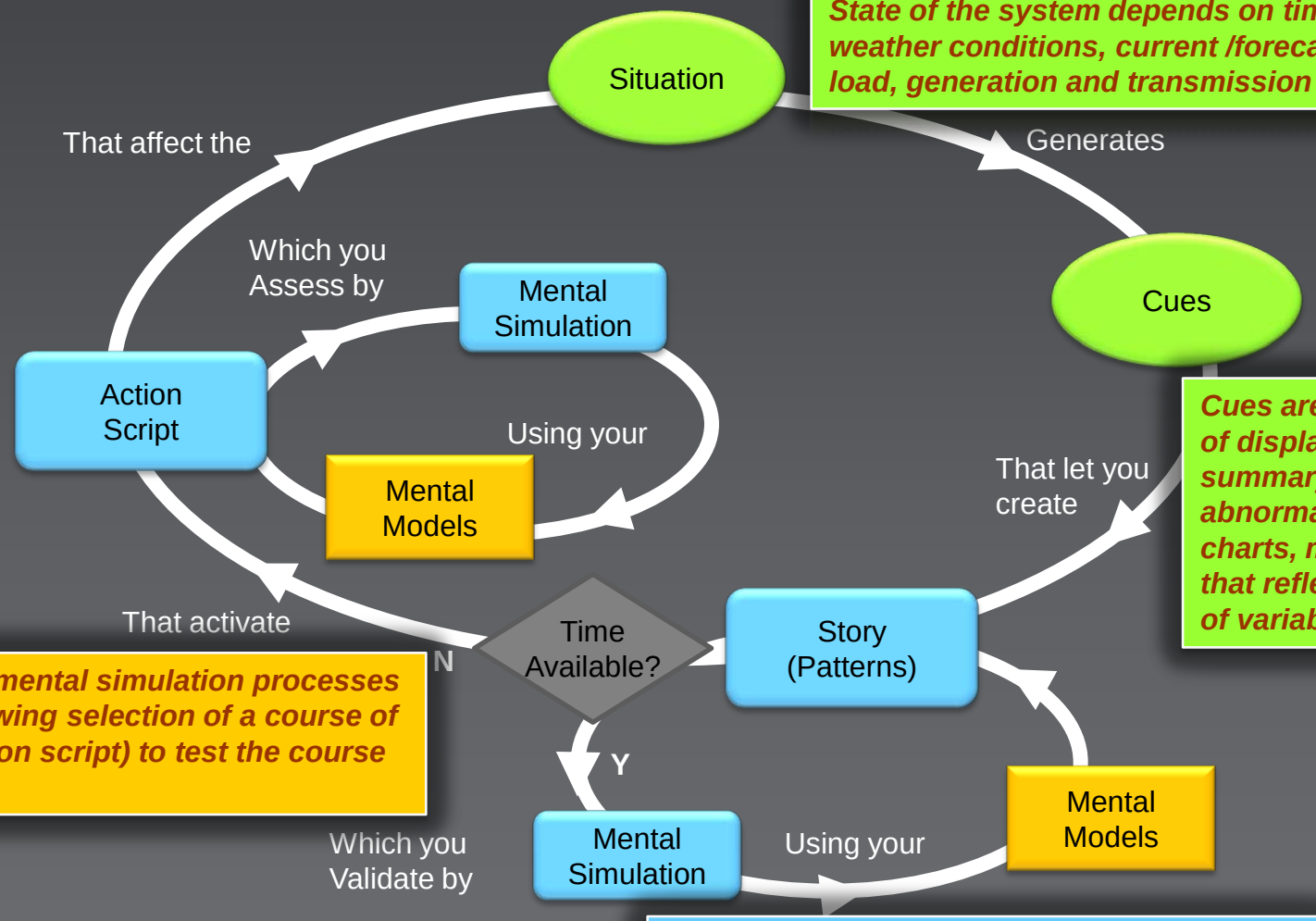
Approach

- We have adopted a Cognitive Engineering and Naturalistic Decision Making (NDM) approach
- We developed an integrated **Operator Decision Model** for power grid decision making
  - Strongly influenced by sensemaking concepts applied to power grid operational decision making
  - Incorporates concepts of SA, Recognition-Primed Decision making, and Recognition/Meta-cognition
  - Distinguishes levels of expertise
  - Acknowledges important role of mental models and mental simulations in the pattern recognition process…

Integrated Decision Model

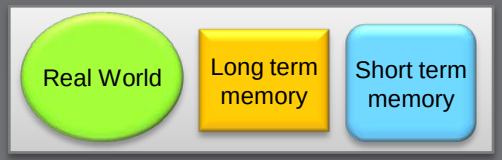


State of the system depends on time of day, weather conditions, current /forecasted system load, generation and transmission issues, …

Cues are on hundreds of displays (system summary, alarm logs, abnormal summaries, charts, map boards) that reflect thousands of variables

Additional mental simulation processes occur following selection of a course of action (action script) to test the course of action

Initial processing of cues and patterns may be modulated by a critiquing process, using mental models and simulations, that occurs early in the RPD process of SA



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Power Grid Operations Context

- An expert power system operator has thousands of relevant mental models in memory
- Mental models range along a continuum from simple to complex
- Required for but not limited to:
  - Physical, mechanical and electrical characterizations of different system components and how they work together
  - The abilities, sensibilities, limitations and motivations of the system operator's extended team
  - Operating procedures and policies
- Used to:
  - Validate that a complete and consistent *Story* has been built to explain the current situation
  - Anticipate the effects of candidate control actions.

Two Application Domains

- **Training Development and Management**
  - Cognitive Task Analysis methodology identifies mental models and cues that are critical to developing expertise
  - Training scenarios designed to focus on appropriate mental models and cues
  - These inform the definition of performance measures and metrics
- **System Evaluation**
  - CTA methodology used to identify mental models and cues that are associated with optimal performance
  - Design test scenarios to compare design options
  - Applicable models and cues inform definition of performance measures and metrics.

Training Development & Management

ODM Framework supports training development and management

- Used to specify mental models/cues/patterns
- These in turn help to define rigorous *Learning Objectives*
- This structure organizes the development of training scenarios

  (this process is diagrammed on the next slide…)

- Examples of learning objectives for a restoration scenario:
  - Understand need and process of tying Islands together
  - Reliability Coordinator and Balancing Authorities must collaborate to achieve objective
  - Match the voltages so two islands can be tied
  - Observe flows and voltages to detect bad breaker status
  - Recognize that an open transmission line can be used to lower/raise voltage.

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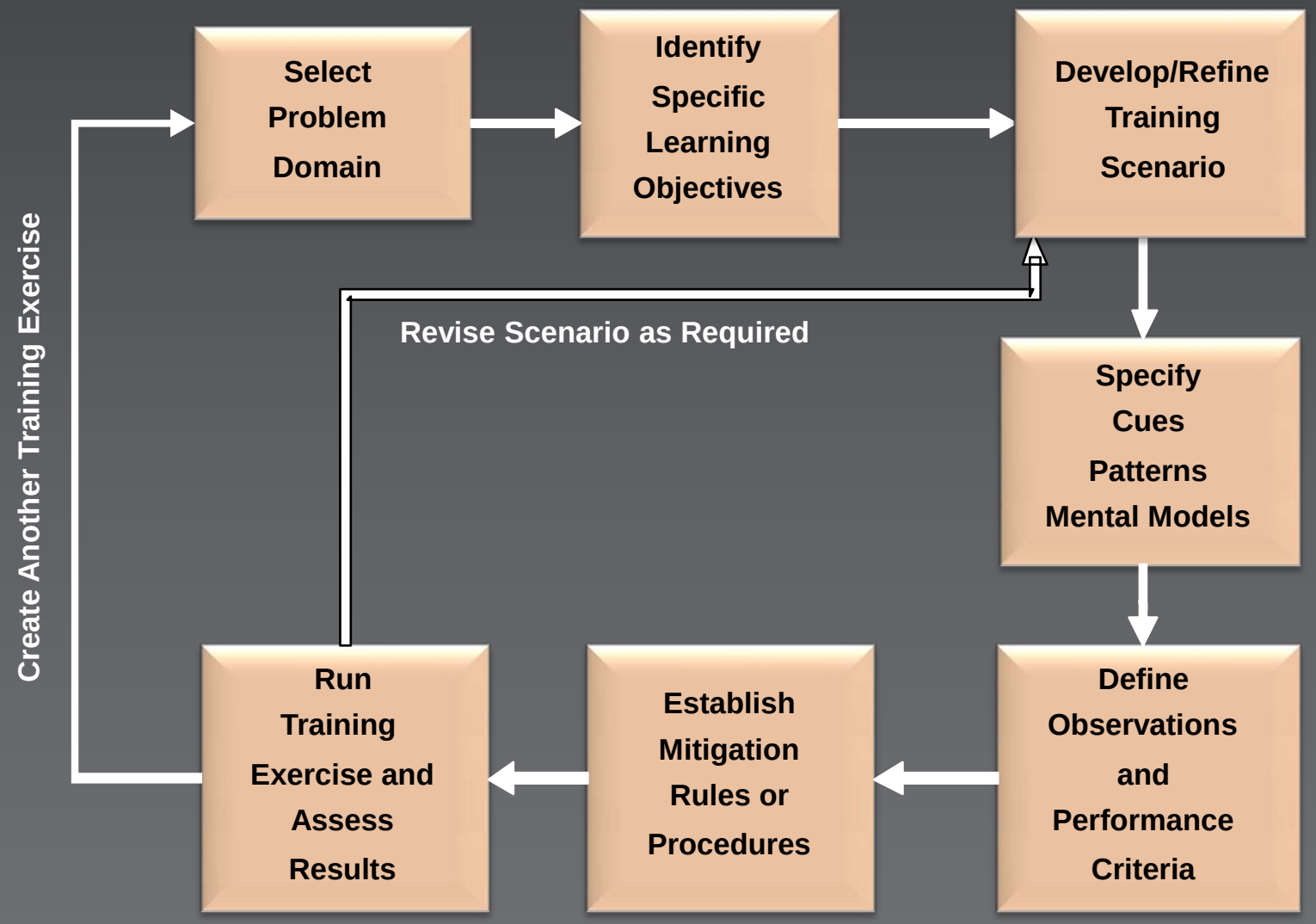
Training Management Process



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System Evaluation

ODM Framework supports system evaluation

- Analyze and evaluate effectiveness of proposed process, user interface design or visualization
- Create alternative designs
- Design experiment/study to compare effectiveness of the designs
- Conduct user studies and evaluations.

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Evaluation Framework

ODM and Cognitive Task Analysis

- Mental Model and Story Analysis
- State and Situation Awareness Level Analysis
- Object and Action Analysis

Conduct Scenario – Script of Expert Operator Communications

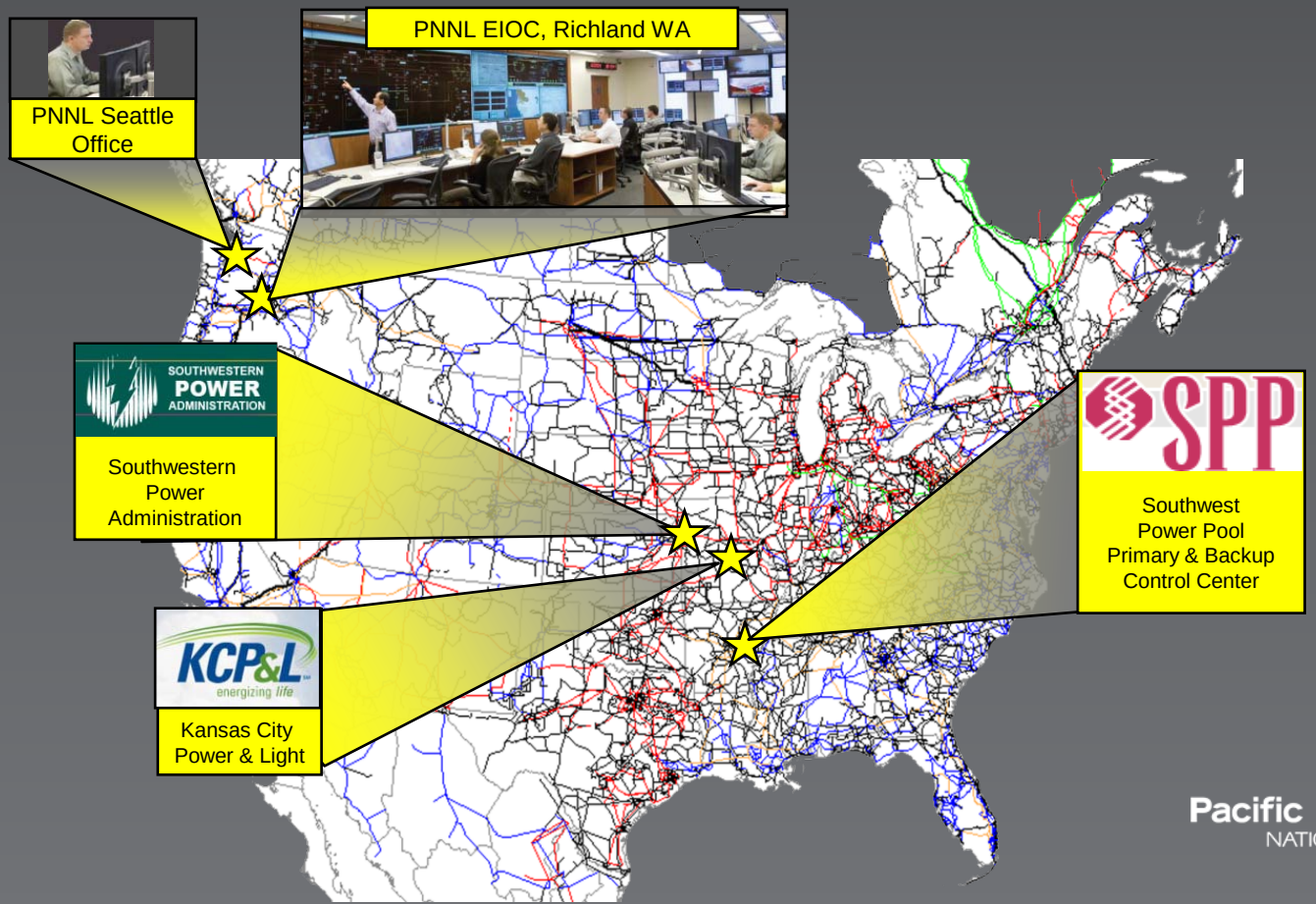
Scenario – {**Learning** / **Performance**} Objectives, Base Case, Events, Roles

Simulator Environment – Power System Simulator, Control Center Model, Operator Consoles, Projection Map Board

Example 1: Training

PNNL Electricity Infrastructure Operations Center (EIOC)

- Coordinated and distributed remote access to training simulation among several collaborating operators
- Multiple balancing authorities interact at the same time.



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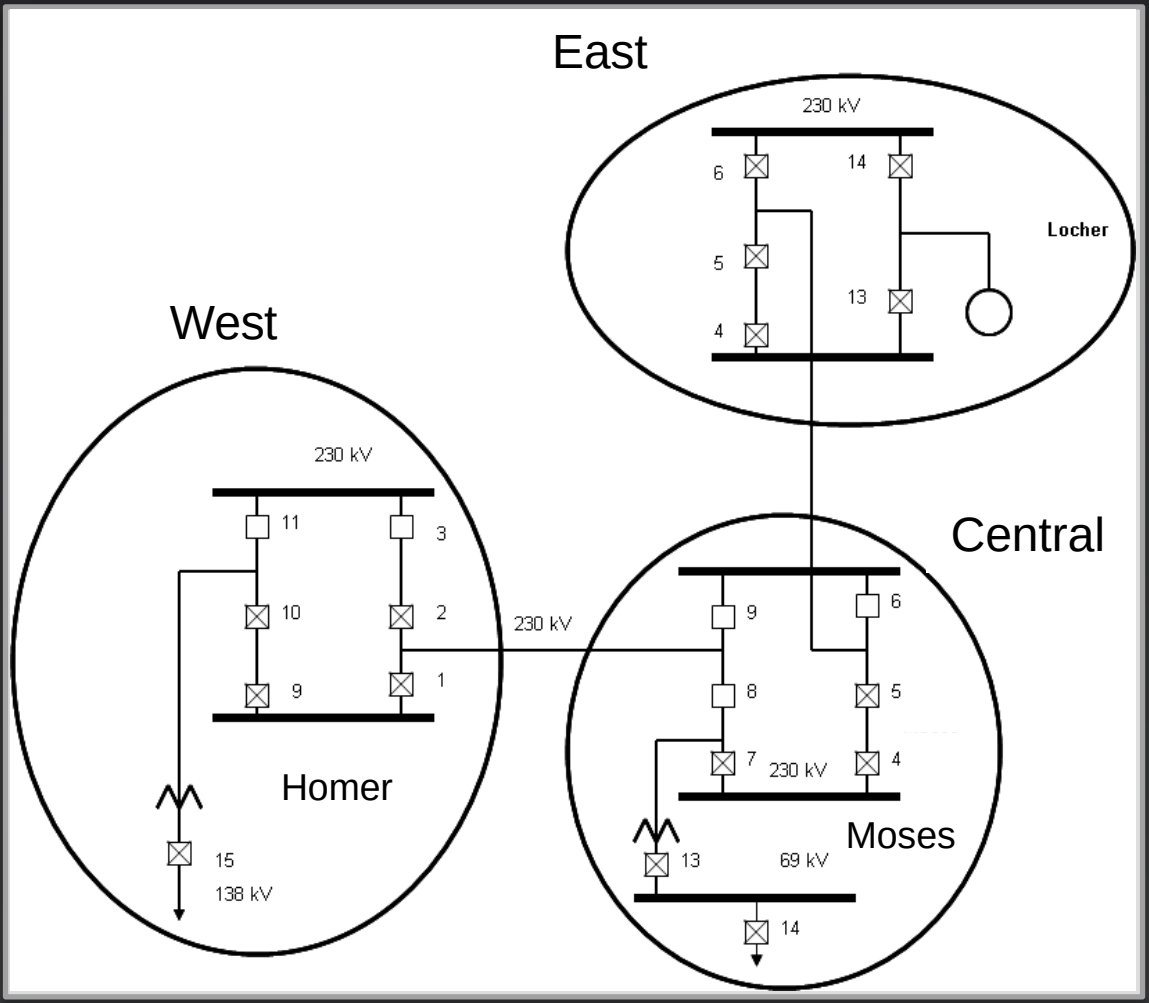
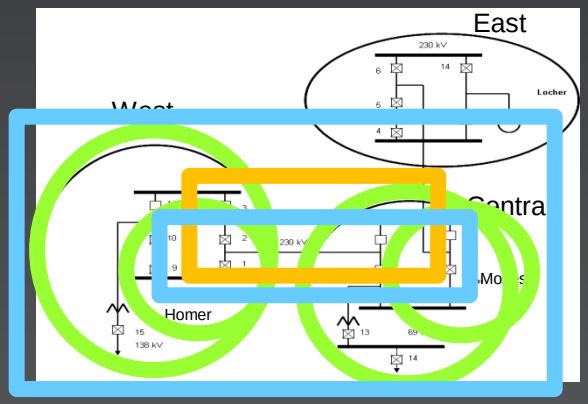
System Restoration Scenario

- "West" and "Central" systems are not connected
- Must connect these "islands" to the whole system
- Homer voltage is high
- Moses voltage is low…



Solution requires coordination (shared SA) and appropriate mental models.

Applying Framework to the Scenario



Situation
- ***Two electrical islands***

Mental Simulation
- ***Voltage at Homer will decrease***
- ***Voltage at Moses will increase***
- ***Voltage will be close enough to synchronize islands using 115 kV breakers at Homer***

Situation

Generates

Cues

Which you Assess by

Mental Simulation

Action Script

Using your

Mental Models

Cues
- ***High voltage at West***
- ***Low voltage at Central***

Action Script
- ***Open Homer end of Homer – Moses Line***
- ***Close Moses end of Homer – Moses Line***

Time

Story

Mental Models
- ***Open ended line is like a shunt capacitor***
- ***Weak bus / strong bus***

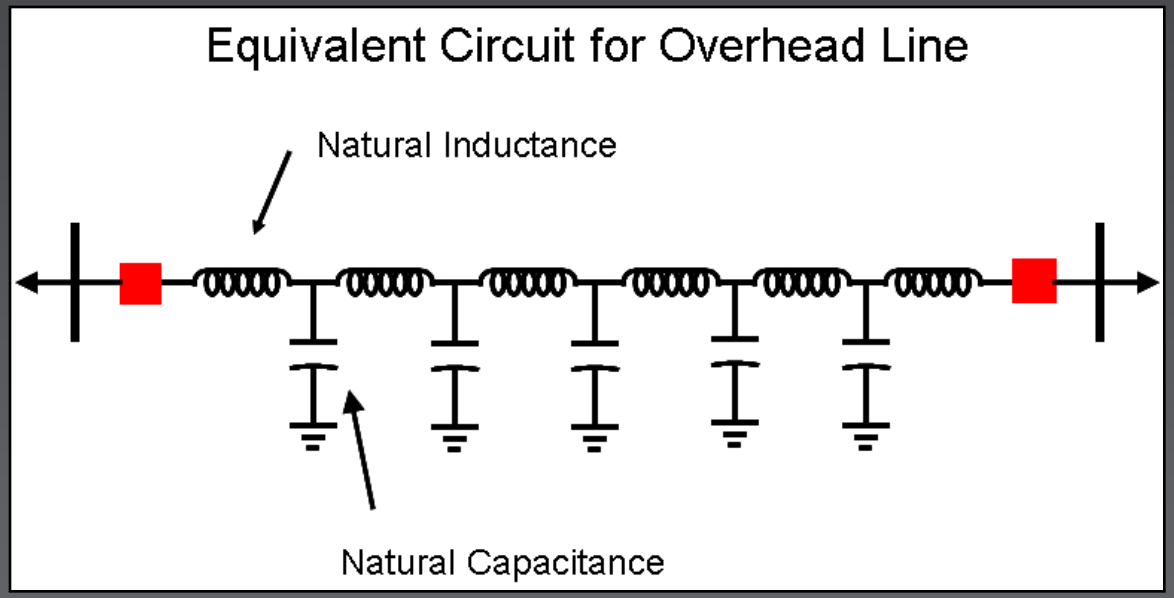
Which you Validate by

Mental Simulation

Using your

Mental Models

Applicable Mental Model: "Open-ended line is like a shunt capacitor"



When MW flow is zero, the line capacitance produces MVARs

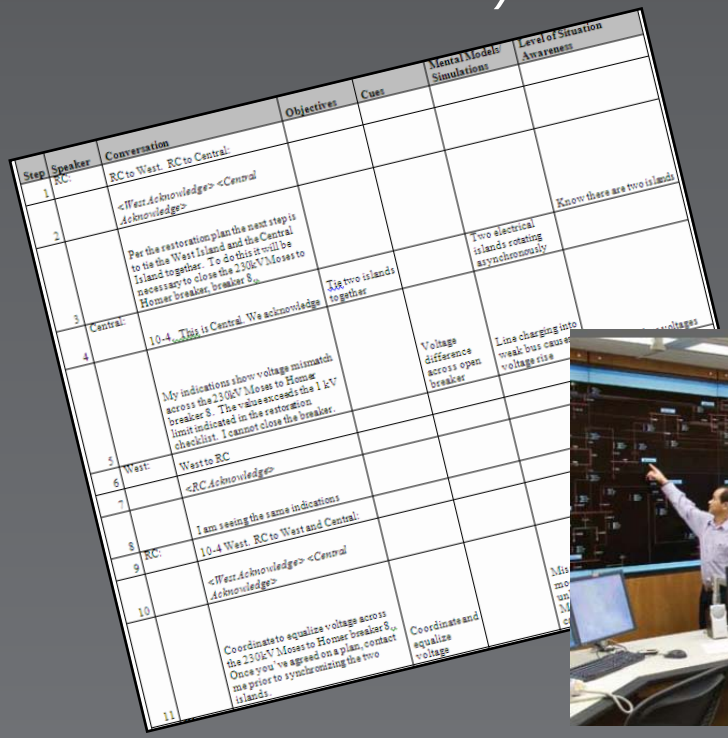
The MVARs produced will raise voltage at connected end.

Critical Decision Making requirement:

A critical learning objective for the restoration scenario is to understand, recall, and apply this mental model.

Analysis

- Transcripts of team of experts in problem-solving demonstration
  - Object Analysis – listing nouns in the transcripts to infer NDM elements (cues, patterns, mental models)
  - Action / Object Analysis – listing verb and noun combinations in the transcripts and control actions to infer processes (scripts, mental simulations)
  - State and SA Analysis – assesses SA Level
  - Mental Model and Story Analysis – identifies mental models used by operators.



Step	Speaker	Conversation	Objectives	Cues	Mental Models/ Simulations	Level of Situation Awareness
1	RC:	RC to West. RC to Central:				
2		<West Acknowledge> <Central Acknowledge>				Know there are two islands
3		Per the restoration plan the next step is to tie the West Island and the Central Island together. To do this it will be necessary to close the 230kV Moses to Homer breaker, breaker 8.	Tie two islands together		Two electrical islands rotating asynchronously	
4	Central:	10-4. This is Central. We acknowledge				
5		My indications show voltage mismatch across the 230kV Moses to Homer breaker 8. The value exceeds the 1 kV limit indicated in the restoration checklist. I cannot close the breaker.		Voltage difference across open breaker	Line charging into weak bus causes voltage rise	
6	West:	West to RC				
7		<RC Acknowledge>				
8		I am seeing the same indications				
9	RC:	10-4 West. RC to West and Central:				
10		<West Acknowledge> <Central Acknowledge>				
11		Coordinate to equalize voltage across the 230kV Moses to Homer breaker 8. Once you've agreed on a plan, contact me prior to synchronizing the two islands	Coordinate and equalize voltage			

Results

Analysis of illustrative scenario identified 72 objects and 55 action / object combinations.

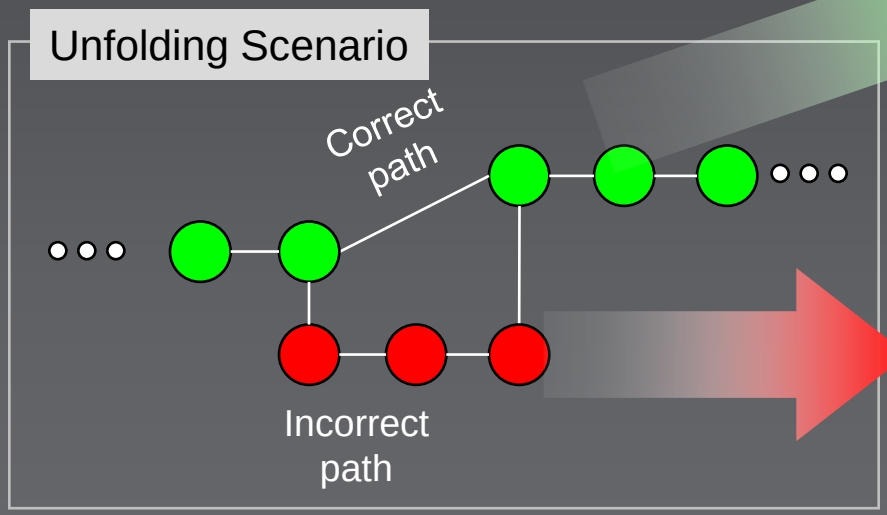
Examples:

- Objects
  - faulty breaker position indicator
  - frequency specification
  - Generator
  - generator MVAR output
  - independent islands
  - indications of line flows
  - line breaker
  - line capacitance
  - line crews.
- Action/object combinations
  - interconnect west and central areas
  - interfere with restoration efforts
  - isolate line
  - lower system voltage
  - make a note in system
  - synchronize islands
  - transfer line capacitance
  - try to synchronize across breaker
  - update status boards.

Example 1: Training

Improving Training Management Process

- Identify cues, patterns, mental models, scripts provide specific criteria for feedback to reinforce correct performance and mitigate incorrect performance



Step	Speaker	Conversation	Objectives	Cues	Mental Models/ Simulations	Level of Situation Awareness
78	Central:	10-4. The voltage difference is still too high and we can't wait for restoration of the 138kV load centers. Do you have any cap banks at Homer that can be switched out of service?		Voltage difference remain[illegible]		Observes again that voltage difference is too high to close breaker.
79	West:	No, the only Mega[illegible] Homer are from [illegible] 230[illegible] Homer-Moses line which is [illegible]ted at our end but open on your end. The Homer - Moses 230 kV line [illegible] about 15 MVAR at no load.			Observes that Homer - Moses line is really a capacitor	Observes that Homer - Moses line is really a capacitor
	Central:	If you [illegible]ened the 230kV [illegible] breaker and [illegible] 230kV Homer-[illegible] that significan[illegible] impact the voltage level [illegible] any of th[illegible]ther substations in your			Opening the line and removing its charging will reduce the	Realizes that opening the line and removing its charging will reduce the [illegible]ge
						[illegible]ge at Homer will be [illegible]red
						[illegible]gizing line from [illegible]s will raise voltage [illegible]oses

Correct Performance

Step	Speaker	Conversation	Objectives	Cues	Mental Models/ Simulations	Level of Situation Awareness
14	West:	West to Central:				
15		<Central acknowledge>				
16		Is there anything you can do at the Moses substation to raise the voltage?				
17	Central:	No, is there anything you can do to lower the voltage at Homer?			Mi[illegible]ental [illegible]odel that the unloaded Homer - Moses line is a capacito[illegible]	Misses mental model that the unloaded Homer - Moses line is a capacitor
18	West:	We don't [illegible] voltage control devices at [illegible], or any adjacent substation.			H[illegible] a[illegible]us, [illegible]ecause it is being [illegible]ed from the 69 kV system. Misses mental model that the unloaded Homer - Moses line is a capacitor. Misses the standard operating procedure on Open Weak end First or Close the Strong End First.	Homer 230 kV is a weak bus, because it is being fed from the 69 kV system. Misses mental model that the unloaded Homer - Moses line is a capacitor. Misses the standard operating procedure on Open Weak end First or Close the Strong End First.
19	Central:	West, do you have an estimate on how long it will take for the restoration to lower voltage by that level?				
20	West:	I would estimate at Central another six hours before we can begin to lower the Homer sub-station voltage to a level that would allow closing the 230kV Moses breaker 8. Are there any actions that you can take outside of the Moses substation to raise the voltage?			Substation operators are restoring feeders as MW MVAR load is added voltages will decrease	

Performance Deficiencies

This methodology is used to assess:

- Basic skills (e.g., communication protocols)
- Effective decision making (e.g., use of effective mental models)
- Collaborative problem solving strategies.

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Excerpt From Transcript and HF Analysis

RC operator directs the West and Central operators to coordinate to equalize the voltage.
He could have advised them at this point that the voltage at Homer could be lowered and voltage at Moses could be raised by disconnecting Homer– Moses line from Homer and then re-energizing it from Moses.

The Central operator stated that he did not have any way of controlling voltage at the Moses station. He overlooks that the Homer– Moses line can be used to raise voltage at Moses.
He does not take the time to consider if there are taps on adjacent transformers that can be used to control the weak bus at Moses.

The West operator stated that he did not have voltage control devices at the Homer station.
- ***The Homer–Moses transmission is in fact a voltage control device.***
- ***The taps on the 230 / 115 kV transformer might also be used to control the 230 kV bus when the 230 kV bus is weak.***

Missed mental models

	Objectives	Cues	Mental Models/ Simulations	Level of Situation Awareness
ral:				
owledge>				
g you can do at the n to raise the voltage?				
ing you can do to at Homer?			Misses mental model that the unloaded Homer - Moses line is a capacitor	Misses mental model that the unloaded Homer - Moses line is a capacitor
age control y adjacent			Homer 230 kV is a weak bus, because it is being fed from the 69 kV system. Misses mental model that the unloaded Homer - Moses line is a capacitor. Misses the standard operating procedure on Open Weak end First or Close the Strong End First.	Homer 230 kV is a weak bus, because it is being fed from the 69 kV system. Misses mental model that the unloaded Homer - Moses line is a capacitor. Misses the standard operating procedure on Open Weak end First or Close the Strong End First.
mate on how toration to ?				
another n to lower ge to a the there outside to raise the			Substation operators are restoring feeders as MW MVAR load is added voltages will decrease	

across the 230kV
Once you've
prior to
agreed on a plan, contact me
synchronizing the two islands.

West: < Central Acknowledge>
Is there anything you can do at the Moses
voltage?
can do to lower the
ge control devices at
substation.

West: Homer, or any adjacent

Central and West operators could have observed earlier in the scenario that voltage at Homer can be lowered and voltage at Moses can be raised by disconnecting Homer– Moses line from Homer and then re-energizing it from Moses.

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Training Implications

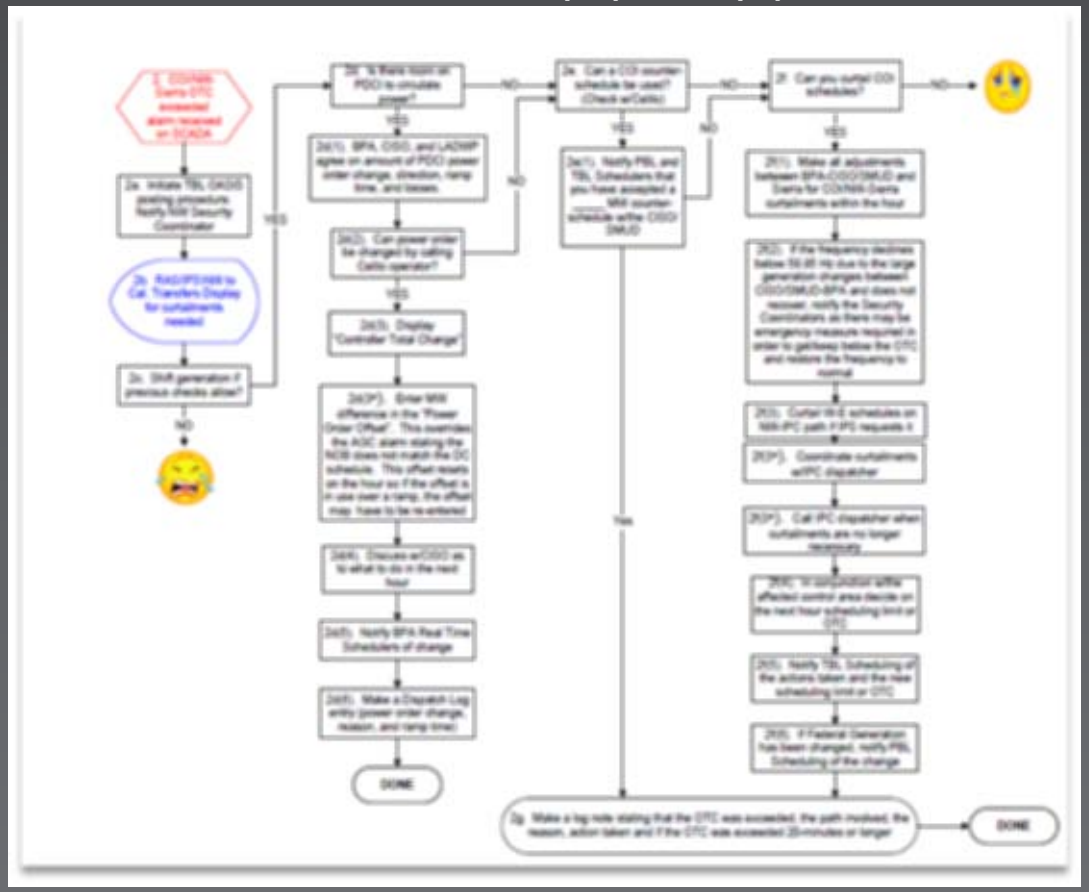
Application of ODM and cognitive task analysis …

- Enable more specific and rigorous performance criteria
- Enable development of detailed training plan based on defined cues, patterns, mental models, action scripts, etc.
- Recorded operator actions and transcripts during training scenarios may be analyzed to assess SA levels of each operator at each step of the scenario
- This provides the trainer with specific guidelines or behavioral/performance indicators that identify possible deficiencies—to which mitigations may be applied.

System Evaluation Applications
Example 2: Display/Visualization Analysis

- PNNL project conducted human factors and cognitive task analyses of dispatcher displays and processes
- We worked with operators and stakeholders to select an appropriate "event"
- We examined current process and displays through interviews, documentation
- We documented process and identified display and design issues…

Process map (excerpt)



Display/Visualization Analysis

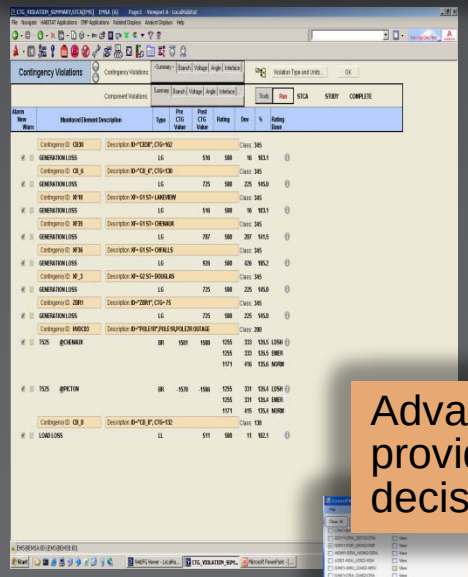
- Based on cognitive task analysis and detailed examination of existing process and displays, we developed specific recommendations for improvements in processes, displays and visualizations.

Modifications are being implemented.

System Evaluation Applications

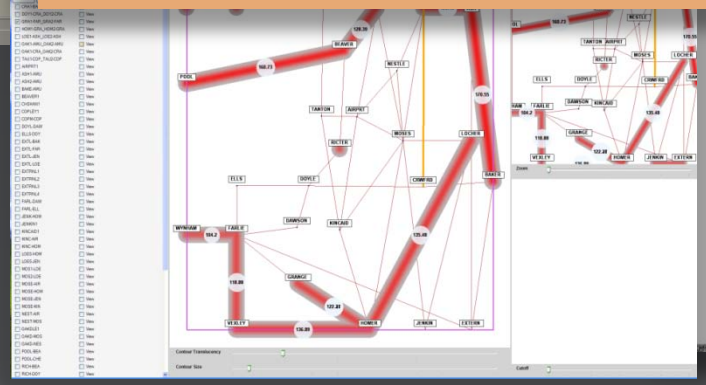
Example 3: Evaluating Effectiveness of Advanced Visualizations

Raw/tabular presentations dominate today's network operation tools



- Under internally funded research within the EIOC, PNNL has developed a collection of analysis tools and displays/visualizations designed to improve performance
- We are currently conducting simulation-based studies in the EIOC (in collaboration with IncSys and PowerSimulator) to evaluate effectiveness of selected advanced

Advanced analysis and visualization tools aim to provide real-time situational awareness to improve decision making



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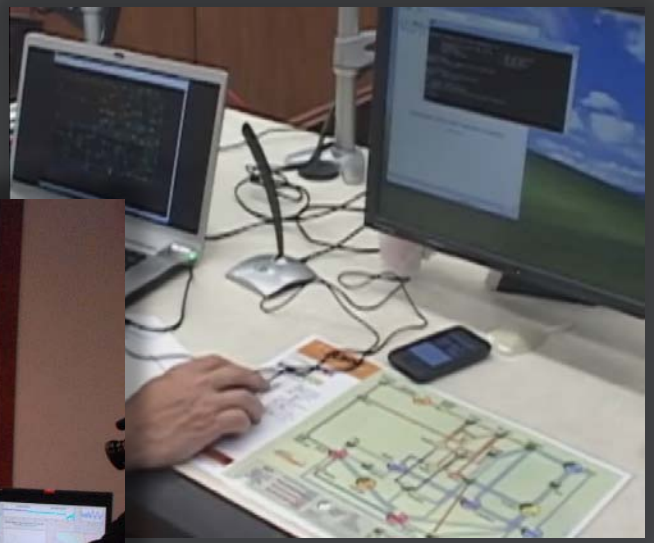
EIOC Experiment on Advanced Visualizations

- Experiment compared standard operational processes and displays with advanced visualizations in a simulation based scenario
- ODM and cognitive task analysis constructs helped define mental models and cues used in identifying performance measures
- Results: data are being analyzed now…

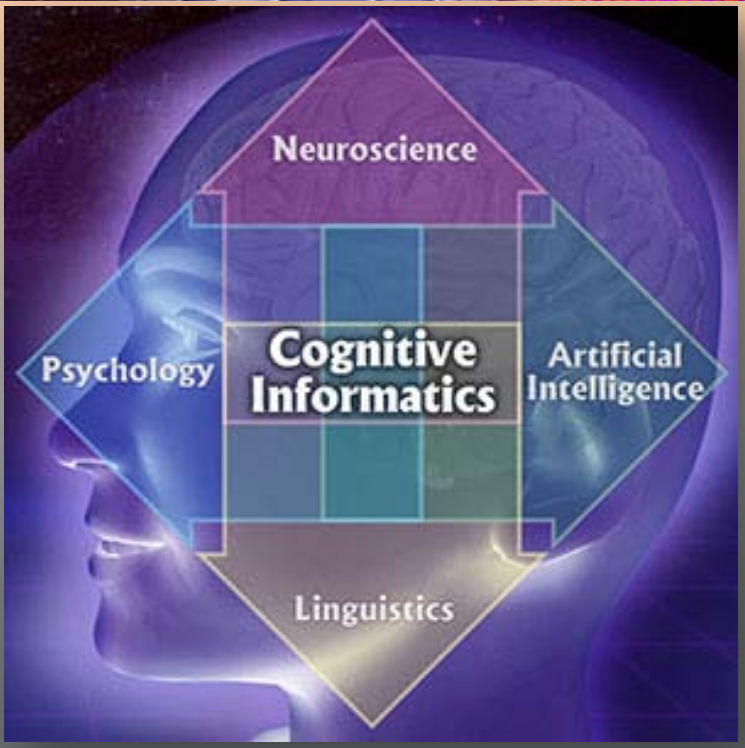
  Preliminary/informal interviews suggest that operators immediately appreciated and valued at least one of two advanced visualizations over current processes and displays.



Conclusions

- Naturalistic Decision Making paradigm and associated Operator Decision Model, cognitive task analysis methods, and standard human factors analyses may be applied within a rigorous framework to …
  - Enhance operator training
  - Identify training objectives and performance measures
  - Design new operational displays, processes and visualizations
  - Provide a foundation for evaluating effectiveness of tools, displays, processes and visualizations.

For information…



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Frank L. Greitzer, PhD
Chief Scientist, Cognitive Informatics
Pacific Northwest National Laboratory
✉ frank.greitzer@pnl.gov
☎ (509) 372-4251

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