Situation Awareness for the Power Transmission & Distribution Industry

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SA is Critical to Power Systems

July 13, 1965 - Northeast US/Canada
- “System control centers should be equipped with display and recording equipment which provide the operator with as clear a picture of system conditions as possible”

July 2, 1996 - Western US
- “review need … to monitor operating conditions on a regional scale”

August 10, 1996 - Western US
- “train operators to make them aware of system conditions and changes”
- “develop displays that give operators immediate information on changes in status”

August 14, 2003 - Northeast US/Canada
- “Inadequate situation awareness”
Overview

What Is SA?

What Factors Affect SA?

Designing Systems for Situation Awareness
What is Situation Awareness?

Situation Awareness is the **Perception** of elements in the environment within a volume of time and space, the **Comprehension** of their meaning, and the **Projection** of their status in the near future.*

*Endsley, 1988
Situation Awareness

Data

Perception
- Frequency
- System voltage
- Direction of flow
- Breaker status

Comprehension
- Impact of interchange
- Violation of thermal limit
- Frequency violation

Projection
- Projected impact on system of losing element
- Projected limit violations

What? What does this mean to me? What do I think will happen?

So What? Projected impacts on system of losing element

Now What? Know the Situation. Know the Solution.
Overview

What Is SA?

What Factors Affect SA?

Designing Systems for Situation Awareness
Factors affecting situation awareness

- Real World
  - Stress
  - Workload
  - Fatigue

- Abilities
  - Knowledge
  - Skills
  - Training
  - Experience

- System Capabilities
  - Interface
  - Complexity
  - Automation
<table>
<thead>
<tr>
<th>The Eight SA Demons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attentional Tunneling</strong></td>
</tr>
<tr>
<td>- Fixating on one set of info to the exclusion of others</td>
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<tr>
<td>- Can be intentional or un-intentional, worse under stress</td>
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<tr>
<td><strong>Requisite Memory Trap</strong></td>
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<tr>
<td>- Reliance on limited working memory</td>
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<tr>
<td>- Experience losses over time, worse for audio cues</td>
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<tr>
<td><strong>Data Overload</strong></td>
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<tr>
<td>- Refers to both volume of information and its rate of change</td>
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<tr>
<td>- Humans have a limited bandwidth for input</td>
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<tr>
<td><strong>Misplaced Salience</strong></td>
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<tr>
<td>- Attention is drawn to pre-attentive features (colors, lights, animation)</td>
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<tr>
<td>- Inappropriate use draws attention to less important info</td>
</tr>
<tr>
<td><strong>Complexity Creep</strong></td>
</tr>
<tr>
<td>- Tendency to add more and more features to systems</td>
</tr>
<tr>
<td>- Too many features make it difficult to develop accurate mental models</td>
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<tr>
<td><strong>Errant Mental Models</strong></td>
</tr>
<tr>
<td>- Matching to the wrong mental model leads to misinterpretation</td>
</tr>
<tr>
<td>- Difficulties in breaking out of representational errors</td>
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<tr>
<td><strong>Workload, Fatigue, &amp; Other Stressors (WAFOS)</strong></td>
</tr>
<tr>
<td>- Makes one less efficient at gathering information</td>
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<tr>
<td>- Reduces already limited working memory</td>
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<tr>
<td><strong>Out-of-the-loop Syndrome</strong></td>
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<tr>
<td>- Reduced SA on how automation is performing</td>
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<tr>
<td>- Reduced SA on the state of the system, slow to detect problems</td>
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</table>
What Makes Some People Better at SA?

Abilities
- Spatial
- Attention
- Memory
- Perceptual
- Cognitive

Knowledge
- Mental Models
  - schema
  - critical cues
- Goals
- Preconceptions & Objectives

Skills
- Information Management
- Communications
- System operations
- Scan patterns

Training & Experience

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Overview

What Is SA?

What Factors Affect SA?

Designing Systems for Situation Awareness
Technology-Centered Design Philosophy

Problem

- Humans can only adapt so far
- “Human Error”
- Resulting human-machine system is sub-optimal

Design Technology, Let The Human Adapt
When Systems are Not Designed to Fit People

This is how people typically look

This is how they would need to look to “fit” the technology
Common Pitfalls

Requires more than putting data on the same display

- Must be the “right” data
- Must be transformed into true meaning
- Like beauty “information” is in the eye of the beholder

Cool is not necessarily functional

- Useful information display must be based on good human factors
- Must optimize decision making processes
  - Support Situation Awareness

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Know the Situation. Know the Solution.
Lack of real-time information on global state of system
  • Data is piece-meal, questionable reliability, difficult to find & integrate

Plethora of alarms, many with high false alarm rates
  • Leads to reduced usage of tools

Support for diagnostics and projection of future events is limited
  • Automation that is not integrated into tasks
  • SA regarding state of automation is low

Lack of shared SA across various control centers, outside footprints
  • Even though systems are inter-related
SA Demons Present in Power Systems

Data Overload

- Tremendous Volume of Information
- Swift Rate of Change of Information
- Limited Bandwidth for Input
  - Humans can only process so much

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Misplaced Salience

Attention drawn by pre-attentive features
- Color, lights, movement
- Loud noises, size, etc.

Inappropriate use draws attention to less important information

Overuse fights for attention

Complexity Creep

Systems with too many features make it difficult to develop an accurate mental model of how the system works

Leads to misinterpretation of cues
Human-Centered Design Philosophy

Results

• Reduced Error
• Improved Safety & Reduced Injury
• Improved User Acceptance & Satisfaction
• Improved Productivity

Design Technology to Fit the Capability of Humans
SA-Oriented Design Process

Three Stage Process for Designing Integrated Systems that Support and Enhance Situation Awareness

SA Requirements
- Requirements Analysis
- Technology Analysis

SA Design
- Design Concepts
- Human Factors Design Guidelines & Standards

SA Measurement
- Test & Evaluation
- Final Design

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Know the Situation. Know the Solution.
SA-Oriented Design

Goal-Directed Task Analysis
- Goals, Sub-goals, Decisions
- Requirements for:
  - Projection
  - Comprehension
  - Perception

SA-Oriented Design Principles
- Confidence & Uncertainty
- Dealing with Complexity
- Alarms, Diagnosis, & SA
- Automation & SA
- Supporting SA in Multi-Person Operations

Measurement
- Objective
- Subjective
- Workload
- Performance

Data → SA REQ’s → Practice

Integration of SA Oriented Design
SA Requirements Analysis

• No prioritization among goals assumed
  • Will vary over time
  • Some may be active or inactive at any point in time

• Technology Independent
  • What — not how
  • How varies between individuals, situations and technologies

• Focus on Ideal SA
  • What do you really want to know?
  • Often must operate on less than perfect knowledge
  • Creates design goal

• Focus on dynamic information needs
  • Static knowledge is not modeled
  • rules procedures, doctrine captured elsewhere

• Analysis conducted for each position
  • Division of tasks may be varied
GDTA for Power Systems

Maintain power grid operation reliably and economically

1.0 Economically balance generation with load
   1.1 Ensure generation produced matches load requirements
   1.2 Maintain economic balance of grid operations

2.0 Maintain transmission lines to avoid overload
   2.1 Monitor grid operations
   2.2 Identify violations
   2.3 Control violations
GDTA Detail: Monitor Grid Operations

2.1 Monitor grid operations

D1: What is the status of the system?

- Projected system architecture
  - Impact of region's structure
    - Connections
      - Substations
      - Zones
      - Neighboring companies
    - Tie lines
  - System limitations
    - Loop flows
    - Problem pockets
    - Electrically weak areas
  - Impact of region's trends
    - Load source
    - Time of day
    - Proximity to peak
    - Outages
    - Violations
    - Flow direction
    - System alarms
      - Rate of change
      - Past contingencies
      - Non-convergence
      - Transfer limits
      - Variability
  - Area of responsibility
    - Southern
    - Eastern
    - Western
    - Central
    - Impact of specific relays
    - Impact of generation operation schemes
      - Procedures
      - Manuals
      - SPOG (system planning operating guide)

- Projected system status
  - Impact of interchange
  - Impact of contingencies
  - Impact of current load pattern
  - Impact of voltages across the system
    - Flows
    - Capacitors
    - Temperature
    - Capacitor status
    - Reactor status
  - Impact of equipment status
    - Line limitations
      - Stability
      - Voltage
      - Thermal
    - Line Ratings
      - Normal
      - Emergency
      - Load dump
    - Breakers
      - Start up
    - Bus
      - Effect of generation on transmission system
        - Line trips
        - Transfers
      - Impact of limits for generation
        - Time limitations
        - MW range
        - Physical limits of generating plant
        - Market limits
    - Projected generation required to support load*** (See D1 Goal 1.1 Master Scheduler GDTA)
SA-Oriented Design Examples

Power Transmission & Distribution Control Rooms

Poor SA: Leading Cause of Blackouts

- Data is piece-meal
- “Las Vegas” presentation
- High false alarm rates
- Limited diagnostics
- No integration across control centers

SA-Oriented Design

- Integrated to provide information, not just data
- SA at a glance
- Support for alarms
- Built in diagnostics
- Approach for shared SA

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Issues: Color Consistency

- Lines
- Equipment
- Alarm Text
### Issues: Semantic Value, Appropriate Salience, Color Relevance

#### Red Gridlines

- Dispatchable
- Base Load
- Hydro
- ICU's

<table>
<thead>
<tr>
<th>Dispatchable</th>
<th>Base Load</th>
<th>Hydro</th>
<th>ICU's</th>
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<tbody>
<tr>
<td>UCM</td>
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#### Cyan Text

- Red
- Green Text
- Yellow Titles
- Yellow Text

#### Orange Text

- Green Titles
- Green Text
- Orange Text
- Yellow Text

#### Yellow Text

- Pink Text

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Issues: Color Proliferation

- 4 different alarm colors
- 10+ different colors
- 9 different colors & reverse video
- 7+ different colors & reverse video

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Know the Situation. Know the Solution.
Issues: Use of Contrast

Dark color text and symbols on dark backgrounds

Poor contrast ratios between colors hinders ability to distinguish items.
SA-Oriented Designs for Power Systems

Reservation of color to improve salience

Know the Situation. Know the Solution.
Using redundant cues along with color to convey meaning

Different warning or significance levels for similar data
- Low
- Medium
- High

Different states of the same symbol
- = Closed
- = Open

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Know the Situation. Know the Solution.
Limit the use of colors on a single display

12+ different colors fighting for attention

Colors reduced, reserved for salient items
Issues with Automation & SA

Appropriate Level of Automation

• To what degree does the automation place the dispatcher out-of-the-loop?
  ▪ Can the dispatcher initiate manual control?
  ▪ Is there difficulty in taking control under conditions where automation fails or cannot function?
  ▪ Is the dispatcher able to diagnose problems with the automated system?

• Automatic process examples:
  ▪ State Estimation
  ▪ Contingency/Security Analysis

Supporting user interaction and active processing with automation

• Is automation applied appropriately to meet dispatcher goals?
  » Do dispatchers have to constantly double-check the results of automation?
  » How do dispatchers deal with unusual results or bad data from the system?
Issues with Automation & SA

Automation consistency
• Are there inconsistencies between dispatchers’ expectations and the results of the automation?
• Does the automation behave in a consistent manner?

Mode Awareness & Proliferation of Modes
• Is the dispatcher aware of what mode the automation/system is in?
• Are there too many system modes?
  » Real-time operations, study modes, training modes
  » Monitored stations, unmonitored stations, SCADA controlled stations
Issues with Automation & SA

Automation Transparency and Feedback

• Is the system keeping the dispatcher aware of what the automation is doing?
• What types of feedback are provided to the dispatcher?

Automation Reliability

• Is the automation performing reliably?
  » Example: Did a breaker automatically reclose?
• Is the data collected and provided by the automated systems accurate?
Effective Use of Automated Alarms

- Are dispatchers constantly subjected to a plethora of alarms?
- Which alarms are nuisances or distracters?
- Can dispatchers diagnose the cause of alarms quickly and efficiently?
Guidelines & Recommendations

Automate only if necessary
• Optimize the user interface first, then introduce automation

Use automation for routine tasks
• Mathematical calculations
• Remembering data or actions
• Fusion of data from multiple sources
• Routine tasks carried out the same way time after time
Provide SA support in conjunction with decision support (avoid follow the yellow brick road)

- Provide factors relevant to solutions
  - Example: contingent elements, time to implement, costs
- And allow dispatchers to select based on current priorities
  - Example: cost vs. time to implement
- This allows operator to make decisions based on current priorities and consider factors the computer may not know about.

Operator should have the final decision
Guidelines & Recommendations

Keep the operator in control and in the loop

• Avoid full automation unless monitoring is not required
• Human should be active participant
• Dispatcher should be in control of automation, not the other way around
## Guidelines & Recommendations

### Avoid the proliferation of automation modes
- Minimize the number of modes available when possible
- Makes understanding the system much more difficult and prone to error

### Make modes and system states salient

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<tr>
<th>Bus</th>
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<th>Bus MVA</th>
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Enforce automation consistency
• Terms (go, start, begin, run...)
• Information placement across screens
• Functionality (behaviors across modes/systems)

Provide automation transparency
• Show what the automation is doing and will do in the future
• Show what assumptions & goals the system has
Use methods of decision support that support decision processes

- Supporting ‘what-if’ analysis, encouraging people to consider multiple possibilities and performing contingency planning that can help people formulate Level 3 SA
  - E.g. consider multiple events that could occur and develop contingency plans for each
- Systems that help people consider alternate interpretations of data, helping to avoid representational errors
  - E.g. multiple diagnoses that fit current data
- Systems that directly support SA through calculations of Level 2 SA requirements and Level 3 SA projections
  - Provide better understanding of situation rather than just do X.
Support confidence assessments

- The amount of confidence people have in information greatly affect their SA and decision making
  - e.g. which system produced this information? How old is it? How reliable are its inputs?
- As information becomes more integrated, this confidence information can be lost and needs to be retained
- Identify when information is missing
  - e.g. lack of telemetry data
- Have information readily present that allows operator to assess information reliability
  - E.g. temperature, winds, limits, signal strength
Reduce false alarms

- False alarms greatly reduces the likelihood that people will attend to alarms with needed speed and attention (cry wolf)
- Makes new alarms less salient
SA-Oriented Designs for Power Systems

Organizing information to support goals and provide mechanisms for quick assimilation

- **Voltage Drop**
  - Drops: 1 0 0 6

- **Low Voltage**
  - Contingencies: 2 0 0 3
  - Actuals: 2 0 0 0
  - Specials: 0

- **High Voltage**
  - Contingencies: 0 3 0 5
  - Actuals: 1 0 0 0
  - Specials: 0

- **Thermals**
  - Contingencies: 1 1 1 13
  - Actuals: 1 1 1 3
  - Specials: 0
Data Visualizations to Support Comprehension (Level 2 SA)
SA-Oriented Designs for Power Systems

Integrated Information Dashboards to Support SA “at a glance”

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Know the Situation. Know the Solution.
Predictive Situation Awareness

**Predictive SA –**

- ....the projection of the status of the system into the near future (level 3 SA)
- Allows for proactive rather than reactive decision making
  » e.g. bringing on a backup system, switching lines
- Examples:

<table>
<thead>
<tr>
<th>Level 3 SA Requirements</th>
<th>Projected impact of interchange across system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected system status</td>
<td>Projected impact of interchange across system</td>
</tr>
<tr>
<td>Projected load forecast for day</td>
<td>Projected time to reach peak load</td>
</tr>
<tr>
<td>Projected violation type</td>
<td>Projected impact of scheduled outages</td>
</tr>
<tr>
<td>Projected violation severity</td>
<td>Projected generation required to support load</td>
</tr>
<tr>
<td>Projected reactive reserves</td>
<td>Projected impact of solutions on system violation</td>
</tr>
<tr>
<td>Projected impact of system constraints on reliability</td>
<td>Projected time of recovery</td>
</tr>
<tr>
<td>Projected ability to minimize system impact</td>
<td>Projected time of recovery</td>
</tr>
</tbody>
</table>
Guidelines & Recommendations

Effectively support and present information at lower SA levels
- Goal-oriented data presentation
- Clear, concise information presentation
- Minimization of extraneous data

Provide direct assistance for Level 3 SA projections
- Trending
- Graphics
- Patterns
Guidelines & Recommendations

Take advantage of parallel processing capabilities
e.g. visual and audio presentation of alarms

Provide direct support for system state confirmation & problem diagnosis

• Be able to confirm alarms
  » which stations, equipment, or systems are in alarm or non-alarm states
  » which alarms are new, valid, or critical
  » the temporal order or priority of alarm occurrence.

• Confirmation and diagnosis support greatly benefit predictive SA and speeds decision-making regarding potential solutions
Guidelines & Recommendations

Utilize effective data exploration methods & filter data carefully

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Bus MVA

Tree Pollen

Grass Pollen

Current Temperatures

This product is only available for the continental United States.

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Know the Situation. Know the Solution.
Support Development of Good Mental Models

- SA Training for inexperienced operators
- Make system states, behaviors and projections more directly observable through the system interface