Adaptive Automation: Potential for Improving Human-Automation Team Performance

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Background
- Automation Trends
- Modern automation is becoming much more broadly used and increasingly capable
  - Greater use of automation for normal operations
  - Operator aids and decision support
  - Application to interface management, e.g., automatic display retrieval
- There is very little that goes on in a modern control room that does not involve automation

Background
- Where are We Now
- While automation technology has rapidly advanced, the technology for human-automation interaction has not
- As a result, many of the same issues that have been known for a long time still remain in new systems
  - Excessive passive monitoring raising vigilance and complacency issues
  - Added complexity for operators to understand
  - New sources of workload
  - Skill degradation and loss
  - New types of human error, such as mode errors
- Failures of human-automation interaction can impact safety
  - In all high-risk, high-reliability domains, there is concern that the increased use of automation may not achieve its benefits and may fail to minimize potential negative effects on performance and safety
Background
- Safety Concern
- Despite the critical importance of human-automation interaction to plant safety, there is limited Human Factors Engineering guidance available to safety reviewers (and designers)
- The NRC is conducting research to address this gap
  - General human-automation interaction (BNL TR-91017-2010)
  - Current research on adaptive automation

Adaptive Automation Characterization
- Adaptive automation (AA) is the dynamic, real-time change in the degree of automation (DOA) in response to situational changes
- Why would operators want higher levels of automation?
  - Pace of the event may make it difficult to perform tasks
  - Need to perform too many tasks (e.g., operators can delegate some tasks to an automated system)
- Why would operators want lower levels of automation?
  - The situational context is important to interpreting task steps
  - To ensure a high level of awareness of task details
  - To increase workload
  - To prevent/minimize boredom
  - To maintain manual skills

Adaptive Automation Characterization
- AA may be a promising means of improving operator-automation interaction and addressing automation issues
- Design automation as part of a multi-agent system where human and machine agents work cooperatively to accomplish plant safety and production goals
Example
- Adaptive Computer-Based Procedure System
- Transitions from operator aid to a fully-automatic system
- System provides configurations loosely based on IEEE Std 1786-2011 (see IEEE table below)
- Procedure Type 3 can support increasing DOAs
  • operation by consent, operation by exception, and full automation
- Different means can be used to select the desired DOA

<table>
<thead>
<tr>
<th>Capability</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select and display procedure on computer screen</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Provide expert’s guidance on computer screen</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Display progress in color of procedure steps</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Provide visual and auditory prompts</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Provide operator’s control of configuration</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>On operator’s command, initiate procedure-level automation</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Adaptive Automation Characterization
- Key characteristics of AA systems include configurations, triggering conditions, and human-system interfaces (HSIs)

- Configurations
  • A configuration is a DOA that defines the roles and responsibilities of both operators and automation
  • Configurations involve dynamic changes in automation dimensions, such as the level of automation

- Decisions that are important to configuration design
  • Configuration Definition - Should the configurations be predefined, defined in real time, or some combination of the two?
  • DOA Change Selection - What type of DOA changes should be used to support operator task performance?
  • Number of Configurations - How many individual configurations should be designed?
  • Configuration Timing - What is the minimum length of time configurations should remain in effect?

Adaptive Automation Characterization
- Triggering conditions
  • Conditions that initiate changes in AA configurations

- Types of conditions
  • Operator Command
  • Operator Performance
  • Operator Functional State
  • Can include system state and events, but these are predefined and not truly adaptive (i.e., they are based on presumed changes in the demands on the crew)
  • Hybrid – combination of triggers

- Decisions that are important to trigger design
  • Appropriateness of Trigger Categories - Which category of trigger or combination of categories is appropriate for the specific AA system?
  • Invoking Thresholds - What are the specific points at which the triggers should change the AA configuration?
Adaptive Automation Characterization

- Relationship between configurations and triggers

<table>
<thead>
<tr>
<th>Time</th>
<th>Configuration 1</th>
<th>Configuration 2</th>
<th>Configuration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Trigger A</td>
<td>Trigger B</td>
<td>Trigger C</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<td>3</td>
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<tr>
<td>4</td>
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</tbody>
</table>

- HSIs
  - The alarms, displays, controls, and communications necessary for operators to interact with AA systems

- Decisions that are important to HSI design
  - Monitoring: How is configuration awareness and the detection of degraded conditions supported?
  - Control: How do operators configure and control AA and how is workload managed?
  - Communication: How is effective and efficient communication between operators and automation fostered?

Adaptive Automation Characterization

- In general, AA supports improvements in task performance
  - There are exceptions; which may have to do with mismatches of task demands and automation support

- Some studies find improved situational awareness
  - This result may be dependent of the specific nature of the tasks
  - Varying DOAs (not just through AA) improves operator’s understanding of how automation functions

- Effects on workload are mixed
  - This finding is, in part, due to what an AA system is compared with
    - If AA is compared to a manual condition, workload is likely to be lower
    - If AA is compared with a static automation condition, workload is likely to be higher

- There is some evidence that AA supports operators in the detection and management of automation failures
  - However, very little research specifically addressed this question
Conclusions

- The degree of automation has been increasing, yet many of the classic human performance issues still exist.
- Research suggests AA may help mitigate these issues:
  - Keeping operators in the loop (with good situation awareness)
  - Supporting vigilance (reduced complacency and boredom)
  - Maintaining workload at acceptable levels (not too high, low, or variable)
  - Maintaining skills by providing opportunities for manual performance
- AA applications are likely to become more widespread:
  - As experience is gained with AA systems
  - As industry standards and guidelines identify AA as an option and provide guidance for its design.

Conclusions

- Issues to Resolve

- Workload imposed by interacting with automation to achieve configuration changes
- Unexpected configuration changes (if shifts occur by non-operator-initiated triggers)
- Communicating roles and responsibilities associated with configuration changes
- Defining invoking thresholds
- Technical challenges have been noted for some operator functional state indicators, such as physiological parameters
- Operators being interrupted by automation

Conclusions

- Challenges Using the Results of Research

- How well do the findings generalize to our operational context, which is:
  - Commercial nuclear power plants (high-reliability engineering, redundant and diverse systems)
  - Highly-trained professional operators
  - Complex tasks and detailed procedures
  - Full suite of HSIs
- Generalization from studies of:
  - Other complex-system domains, such as aviation
  - Simple systems represented in microworlds
  - Studies with college students
  - Unrealistic representation of conditions
- Research will be needed to “validate” lessons learned.