MONITORING DISPLAYS -

A COMPARISON OF NUCLEAR AND AVIATION PRACTICE

by

Eric Davey
Crew Systems Solutions
Deep River, Ontario, K0J 1P0

ABSTRACT

Operations in both the nuclear and aviation domains are supervised and controlled from centralized control facilities. In both domains, displays for monitoring mission and system status have evolved to electronic display media from earlier electromechanical instruments and indicators. However, the information provided to support supervisory staff in monitoring tasks takes on substantially different forms in each domain.

This paper will discuss the findings from a comparison of monitoring displays commonly employed in nuclear and aviation operations. The paper will outline monitoring objectives and operational practices, review the evolution of display forms in each domain, examine how automation has influenced information content and presentation, and discuss examples of the insights and challenges to accepted practices that cross-domain comparisons can highlight.

BACKGROUND

CANDU plants and commercial transport aircraft are designed and operated with the understanding that key personnel (i.e., control room operators and pilots) are responsible for supervising and controlling all aspects of mission operations. In this role, control room operators and pilots plan, organize and direct operating actions; oversee and configure automated systems and crew resources; and coordinate operations with external authorities. An essential aspect of this tasking is the development and continual maintenance of operational and system awareness throughout mission and/or shift assignment duration.

In the study of human supervisory performance, the comprehensive understanding of operational and system awareness in real-time environments is characterized by the term Situation Awareness (SA). Situation Awareness is a state of mind that is developed and maintained through the repetitive application of three cognitive processes [1]:

- Perception of relevant elements in the work environment within a volume of time and space,
- Comprehension of their meaning, and

- Projection of their status forward into the near future.

Developing and maintaining SA is the means by which control room operators and pilots remain current with mission status; and have the basis for judging current mission progress against success criteria, identifying anomalies, and planning operational actions and interventions.

Control room operators and pilots employ a number of information sources to develop and maintain SA. These sources can include control room and cockpit displays, annunciation, and verbal and data communication with mission team members. However, the primary source of mission and system status information is obtained from monitoring the data presented in console, panel and wall displays in nuclear power plants and cockpit instrumentation in aircraft.

A common and pervasive aspect of maintaining SA in both domains is the role played by automation. Operations in both domains are highly automated during large portions of mission operations requiring minimal need for human intervention beyond mode selection and setpoint entry in accordance with mission objectives. As a consequence, operators and pilots are deprived of a key source of system status that involvement in continuous or periodic control affords. At the same time, automation is increasing being employed to mediate between the thousands of data elements representative of operational and system status and the summarized information presented to operators and pilots. The completeness, organization, relevancy and transparency with which operational and system status is presented in monitoring displays can enhance or hinder the ability of operators and pilots to maintain adequate SA across all operational situations.

STUDY OBJECTIVE

An attribute of 'learning' organizations is the practice of routinely comparing internal work practices with similar practices in other fields. Such comparisons can lead to insights for improving work practices and equipment designs to enhance overall system performance and safety.

A comparison of system monitoring displays in nuclear and aviation operations was undertaken as the first stage of a project to explore ways in which monitoring practices and display support might be improved for future nuclear plant applications. The aviation domain was chosen for comparison for two reasons:

- Mission Environment - Similarities in mission objectives, supervisory demands, application of automation, and personnel responsibilities and teaming.

- Display Design - Substantial differences in the manner with which operational and system status information important to establishing and maintaining SA is presented in interface displays.

It was expected that this similarity in mission environments and differences in display design traditions would offer a rich context for challenging current practices and developing improvement insights.

The operational contexts of operations at full power steady state for a CANDU nuclear power plant and long-distance cruise at mission altitude under instrument flight conditions for commercial transport aircraft were selected for initial monitoring display comparison. In both these contexts, plant and aircraft operation is continuously controlled by automation (i.e., Plant control - Plant Control System, and Aircraft control - Autopilot and Flight Management System); and operators and pilots are reliant on attending to monitoring displays for maintaining SA.

INFORMATION PRESENTATION TRADITIONS

CANDU Nuclear Power Plants

Control room information displays in CANDU nuclear power plants evolved from a parameter dedicated instrument and recorder base characteristic of early thermal generation and process plants. Beginning with the Pickering A plant in the early 1970's, CRT displays were introduced as multi-purpose presentation devices as a means to accommodate the expanding amount of process and systems information to be presented to control room operators. With CRT displays, information on process and system status was provided as trends that mimicked the former recorder format, and suites of 'current value' status displays organized as tabular listings or system schematics. With all utilities, the display of process and system status in the form of trended parameters has become the preferred form of information presentation for maintaining SA in control room operations [2].

An example of a typical CANDU plant trend format display employed for maintaining plant SA is shown in Figure 1.

Commercial Transport Aircraft

Cockpit displays in commercial transport aircraft were initially based on the dedicated instrument and indicator tradition that evolved from the development of large multi-engine military aircraft. This information presentation practice persisted with limited format changes until the late 1980's when CRT displays were introduced as the primary means of information display in third generation aircraft. With the introduction of CRT display media, substantial changes were introduced in how flight and system status information was presented to pilots (i.e., all digital and fixed location 'current value' representations on partial range moving tapes) [3]. While the form and some aspects of the organization of information presentation changed, displays retained the tradition of providing only 'current value' data as the information from which pilots develop and maintain SA.

An example of a typical commercial aircraft flight status display employed for maintaining SA is shown in Figure 2.

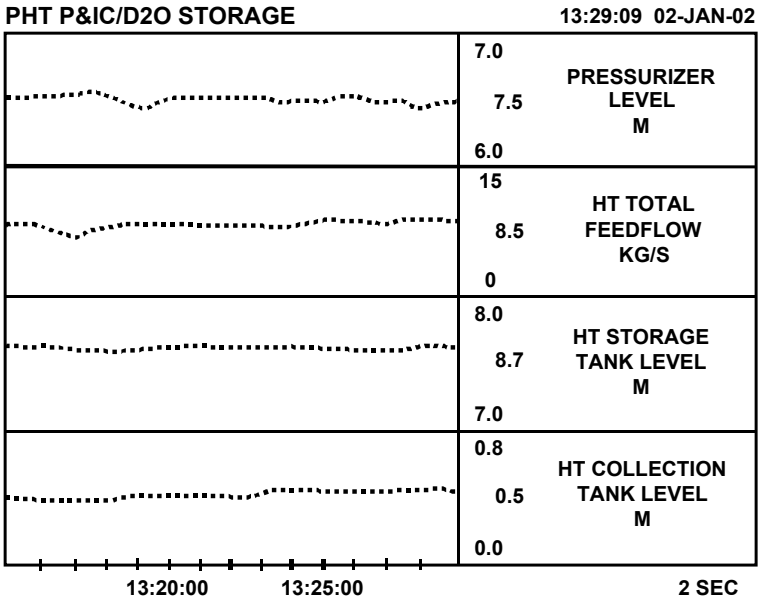

Figure 1 - CANDU Nuclear Plant Trend Display format

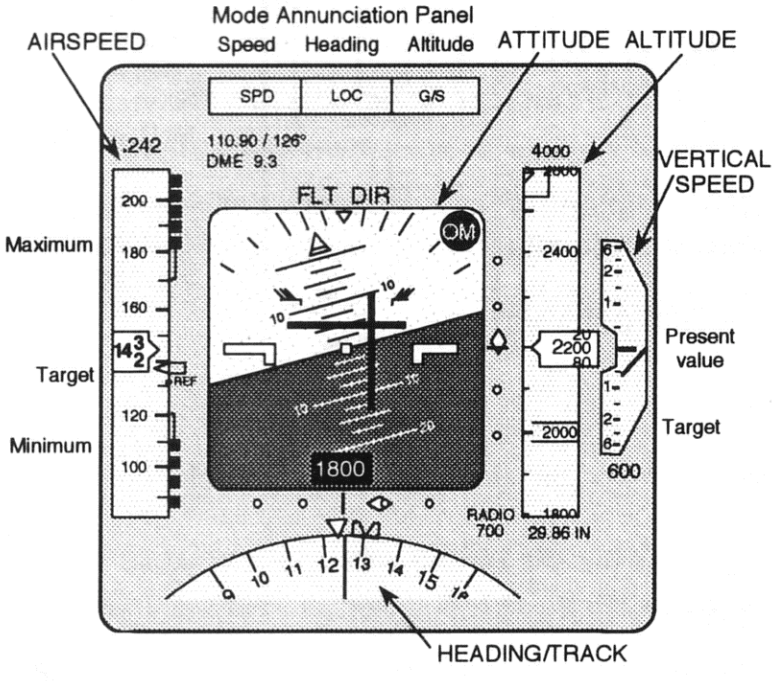

Figure 2 - Flight Director Display [3].

MONITORING STRATEGY

Operators and pilots employ very similar strategies in monitoring control room or cockpit displays to maintain SA for automated operations. In each monitoring scan, they look for information that will:

- Confirm Goal Achievement - Confirm the primary automated functions are and will continue to maintain the plant or aircraft operating at established setpoints.

- Detect Anomalies - Identify departures in system performance or health from reference values.

The primary functions monitored in each domain are listed in Table 1.

Table 1 - Monitored Automated Functions in Each Domain

CANDU Nuclear Power Plant	Commercial Air Transport Aircraft
Power Transfer:	Flight Status:
• Reactor power control	• Altitude control
• Boiler pressure control	• Airspeed control
• Turbine/generator control	• Heading control
Conditions for Power Transfer	Attitude:
• HT pressure and inventory control	• Pitch control
• Boiler level control	• Roll control
• Deaerator level control	• Yaw control
	Thrust:
	• Engine power control

DISPLAY COMPARISON

A listing of monitoring display characteristics in each domain is summarized in Table 2. This comparison highlights a number of significant differences in content and representation strategies between the two domains, for example:

- Parameter Content - Nuclear plant displays show information on both function performance and health while aircraft displays show only function performance information.

- Parameter Number - Nuclear plant displays show more parameters per function but are limited to four parameters per display by the trend format. Aircraft displays show few parameters per function but more parameters per display.

Table 2 - Comparison of Monitoring Display Characteristics

Characteristic	CANDU Nuclear Display	Aircraft Display
Parameter Content:		
• Function performance	Yes	Yes
• Function health	Yes	No
Parameter Number:		
• Per function	2 to 4	1 to 2
• Per display	4	9+
Displays Monitored:	5 to 7	1 to 3
Area Assignment (%):		
• Past values	90%	0%
• Current value	10%	100%
• Future values	0%	0%
Area Usage Efficiency:	Low	High
Current Value:		
• Indication Form	Digital and Analog	Digital
• Location:	Digital - Fixed Analog - Variable	Fixed
Setpoint Indication:	None - Can be shown as separate trended variable for comparison purpose	Digital Value on Range
Context:		
• Range indication	Independent of current value	Dynamically centered on current value
• Range span	Fixed % of full range	Fixed % of full range
• Operating band	Indicated	Indicated

- Displays Monitored - In power plants, operators must monitor several displays to ensure monitoring coverage. Typically a single display is used to show information on one function. In aircraft, all monitored information is shown on 1 to 3 displays due to cockpit space constraints.

- Area Assignment - Monitoring displays in nuclear power plants devote most of the display area to showing past parameter values. In contrast, aircraft monitoring displays devote all the display area to current parameter values. Displays in both domains devote no display area to future parameter value representation.

- Area Usage Efficiency - With the use of the trend format, the area efficiency usage of nuclear plant monitoring displays is low in comparison to aircraft monitoring displays.

- Current Value Representation - Both domains employ a fixed location and digital form for representing the current value of monitored parameters concisely and accurately. The nuclear plant displays also represent parameter current value in analog form as the most recent value of the parameter history trend.

- Setpoint Indication - A comparison of current parameter value with the control setpoint is the means operators and pilots use to detect disturbances and to judge the acceptability of control system behaviour during automated operations. Nuclear plant monitoring displays only show setpoint values for comparison purposes, if the setpoint is assigned as a separate trended variable. Aircraft monitoring displays indicate current setpoint as a digital value superimposed on the parameter range indication.

- Context Representation - Context provides background on the operational space and constraints to operation for each parameter. Nuclear plant monitoring displays employ fixed contexts that show current values in relation to the full or a portion of the parameter range. In aircraft monitoring displays, the background parameter range indication is always centered about the current parameter value and operating limits are explicitly shown.

SUPPORT FOR SITUATIONAL AWARENESS

The design choices in display content and information representation for monitoring displays can influence operator/pilot observational behaviour and ultimately the ease and completeness with which SA is developed and maintained. Some of the observations on how specific display features support the development and maintenance of SA in each domain that were identified through this display comparison include:

- Perception

    - Information Basis - In the nuclear domain both past and current value, and function and health information is presented using a combination of analog and digital representations as the information base for developing SA. In contrast, the aviation domain only presents current value information concerning function performance, and most parameters only in digital form. Information on function health is communicated by alternative means.

- Comprehension

    - Parameter Dynamics - In the nuclear domain, current and recent parameter dynamics can be directly observed but additional parameters (i.e., setpoint) must be trended to assist goal achievement determination. In the aviation domain, only

current parameter dynamics can be directly observed as the rate of change of the range context on each parameter format. Pilots must mentally remember past parameter dynamics if it is important to do so.

- Guidance - In the aviation domain, director indicators may provide visual guidance to pilots on the direction for corrective actions to realign flight status with mission objectives. In the nuclear domain, such information must be inferred from a comparison of 'current value' indications with any setpoint values.

- Projection

  - Future Parameter Value Prediction - Displays in neither domain currently provide explicit support to users in predicting the future status of critical mission and system variables.

    In the aviation domain, a number of organizations have studied the merits of dynamically indicating the future flight path envelope for the aircraft on the flight director attitude display [3]. Such displays have been found to be useful in helping pilots visualize future aircraft location and status, during response to disturbances or manoeuvres given current flight control system inputs.

The findings from this comparison opens the door to challenge conventional monitoring display design preferences and practices, for example:

- What balance between past, current and future value parameter representation is needed or desirable to support disturbance detection, confirmation of goal achievement, or accurately predict future operational state?

- What tradeoffs between parameter/display and display number are acceptable in terms of supporting monitoring effort efficiency, minimizing observational errors, and SA development and maintenance?

- Is there a role for incorporating predictive guidance in monitoring displays and how should this be done to assist operators and pilots in SA development and maintenance?

CONCLUSION

This paper has outlined the rationale for and representative observations from a comparison of displays used to support monitoring in the nuclear and aviation domains. While the tasks supported are similar, the information content and form used to convey operational status to operators and pilots is substantially different.

As nuclear control rooms become more compact and the need to display both process and business information increases, designers will be challenged to increase the information density of current monitoring displays and perhaps reduce their number. The experience

from other domains that have already responded to such challenges may help identify practical options for successfully meeting these evolving nuclear control room challenges.

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