

Seeing the Big Picture: Situation Awareness Assessment in Highly Automated Control Rooms

Amber Drinkwater¹ & Steve Baker²

¹Amentum, ²EDF Energy

SUMMARY

As control systems in high-risk industries become increasingly automated, we see the human Control Room Operator's role evolve from a high degree of reliance on human control, to a supervisory role of the control by automated systems. As automation increases, the role of the operator may change e.g., they may perform more monitoring activities and perform fewer control actions. This affects how humans interact with these systems, and what demand is placed on them versus the system; impacting the procedures, communications and expected team dynamics amongst other factors.

The gathering, maintaining and purposefully utilising Situation Awareness (SA) in modern nuclear control room environments is important; however, it can be difficult for Human Factors (HF) practitioners to define and assess, particularly with increasing levels of automation. It may be inappropriate to expect the operator to know every low-level detail about the status of each system, but more important to expect awareness of higher-level information such as what the other team members are managing or understanding the procedural objectives.

Many of the existing methods to assess SA for HF validation activities present limitations, and do not consider the changes in Situation Awareness requirements of the operator resulting from increased automation. This affects the ability to assess the degree to which operators can successfully gather, maintain and utilise SA. We will share some of our challenges and experiences of applying a multi-method approach to SA assessment during Integrated Systems Validation (ISV) of a highly automated main control room.

KEYWORDS

Situation Awareness, Integrated Systems Validation, highly automated control rooms

Introduction

SA is described in HF as the perception, comprehension, and projection of information in one's environment (Endsley, 2000). A lack of consideration of how system design contributes to operator SA in the nuclear industry can be observed in the catastrophic events of Three Mile Island and Chernobyl, and in many other disasters cross-industry (Endsley, 2003). The assurance that modern-day control rooms provide the means to detect, diagnose, prevent and mitigate these types of events is a key pillar to HF consideration in Safety Cases.

Control Room Operator SA is critical to plant safety, with emphasis on this during the validation of nuclear control rooms, such as Integrated Systems Validation (ISV) programmes (O'Hara, 2012). ISV is a performance-based evaluation conducted on a high-fidelity simulator at a high level of

design maturity, to determine whether an integrated system (considering hardware, software, procedures, and people), supports safe and effective plant operation (O'Hara, 2012).

This paper touches upon the evolution of main control rooms, focusing on the impact on the SA requirements of the Control Room Operator. The scope of this paper focuses on SA and its assessment; we acknowledge that modern control rooms and HF validation are complexed topics, so we do not try to cover these in depth. We will share our approach to assessing SA in highly automated main control rooms, including some of the challenges experienced, the approach to methods selection and testing, and the final multi-method approach selected for ISV SA assessment to overcome some of the challenges we experienced.

Situation Awareness: The evolving role of the human in Main Control Rooms

It is becoming increasingly common to see the role of the nuclear Control Room Operator in 'the back seat'. Automation can now collect, process, and present large amounts of data accurately and quickly to the human operator, therefore the operator role may take a focus on monitoring and confirming that the automatic control of the plant is working. This removes some of the cognitive burden from the operator and may mean we see fewer humans in the control room.

Direct operator intervention may even only be necessary when the automation fails, or in hazardous fault scenarios where SA, i.e. perception, comprehension and the ability to anticipate projection of the situation become vital. Increased automation, while helping to reduce the cognitive burden on the operator, can pose challenges to SA such as complacency and difficulty getting 'back in the loop'. Therefore, it is important that HF validation activities ensure that modern main control room designs enable operators to gather, maintain and utilise SA (O'Hara, 2012).

Assessment of operator SA accurately is essential to support performance evaluations and validation of the design. However, we found that guidance on SA assessment during ISV, to provide evidence to a safety case, is limited. This creates a complicated picture!

Assessment of Situation Awareness in Modern Control Rooms: A Challenge

There is minimal precedent, and UK nuclear-specific guidance available, on how to conduct an ISV programme, with most guidance coming from the United States Nuclear Regulatory Commission (NUREG) 0711 HF engineering program review model paper (O'Hara, 2012), as well as research conducted by the Halden Reactor Project on HF validation best practice (Braarud, 2018).

We conducted a thorough literature review, utilising HF good practice and experience from international ISV programmes where available. NUREG-0711 recommends use of ISV methods which have construct validity, and are sensitive, reliable, objective, and minimally intrusive to the operator's tasks during ISV simulated scenarios.

We found that while several methods for SA assessment exist (Braarud, 2018, Fernandes, 2015, Hogg, 1995) and are widely used in nuclear HF, each method presented limitations against the NUREG-0711 criteria for ISV methods (O'Hara, 2012). One of the most apparent limitations surrounded construct validity and reliability of the methods for HF validation activities, with research often reporting weak correlations and prediction analyses between methods (Braarud, 2018, Salmon, 2006, Fernandes, 2015).

The most widely used methods for ISV evaluations are freeze-probe approaches such as the Situation Awareness Control Room Inventory (SACRI, (Hogg, 1995)), which involve mid-scenario pauses to ask operators questions relating to their awareness of the scenario.

Research by the Halden Reactor Project on SA assessment for HF validation suggests that ISV programmes should be cautious of relying on cognitive assessment methods such as freeze-probe

techniques for ISV given limited evidence of their validation (Braarud, 2018). Challenges with the construct validity of freeze-probe methods were identified, where the methods may be limited to capturing low level knowledge of plant parameter status, excluding some of the high-level Situation Awareness requirements of a scenario such as knowing what other team members are doing (Refs. Braarud, 2018, Salmon, 2006). Literature on HF validation suggests that supplementing cognitive assessment methods with methods that assess observable performance outcomes e.g. completion of tasks required, may offer a more comprehensive assessment (Braarud, 2018).

Expert observation methods, such as the Supervisory Control and Resilience Evaluation (SCORE, (Braarud, 2016)), may offer a more diverse assessment of SA. Expert observation methods require an 'expert' in the domain i.e. a trained operator, to define, observe and report on key main control room behavioural markers such as monitoring, strategy, and interpretation of plant information. These expert observations methods of task performance may offer an 'indirect' measure of SA, by measuring behavioural markers that are impacted by SA.

Piloting Situation Awareness Methods

We conducted several dynamic simulator tests on a high-fidelity control room simulator between 2022 and 2025, with early tests facilitating dynamic testing of Situation Awareness methods. This included trials of a variety of freeze-probe methods including SACRI and the Quantitative Assessment of Situation Awareness (QASA, (Edgar, 2018)), as well as expert observation methods, including SCORE, as well as other methods developed by the Halden Reactor Project. The methods were tested and reviewed against the NUREG-0711 (O'Hara, 2012) criteria using expert feedback from HF and operations personnel. In addition, an alignment check was done against the task performance outputs from other ISV methods (e.g., timing of safety critical tasks), to identify whether the outputs from the SA methods aligned with alternative measures of task performance. There is a known positive correlation between task performance and SA, so this alignment check offered confidence about whether the methods were informing us about SA (Fernandes, 2015). A key part of testing, as well as a method to collect SA data, were thorough debriefs with the operators after the scenarios were finished to further understand any degradations in SA, and the factors which may have contributed e.g. communications, task allocation, visibility of information. The pilot test included testing a multi-method approach for SA (applying several methods in one scenario), as well as many other ISV methods not mentioned, e.g. debriefs, workload methods, observation methods.

Findings and Takeaways

Through our own testing, we found that randomised item freeze-probe methods such as SACRI, appeared to assess memory as opposed to awareness of important information, and that the outputs were not particularly informative for debrief investigations or to understand performance degradations. Freeze-probe methods that offered flexibility to HF analysts to tailor questions asked to each scenario pause, such as QASA, (Edgar, 2018)), provided more diagnostic data, especially when answers were followed up during operator debriefs to understand where the system could have supported SA better. QASA also offered a diverse assessment of operator's perceived SA for each probe (how confident they were in their answer), which provided useful insights into the information they had available to them from the system to support their SA.

Expert observation method SCORE was found to be a useful indicator of task performance and the identification of SCORE items was a useful activity in itself for identifying the SA requirements of the scenario being tested. Expert observers also reported finding the tool useful to structure their observations. SCORE alone however did not provide significant insight into the operator's mental models and SA at that time, since it is completed by an expert 'looking in'.

We trialled a combined approach, hypothesising that applying multiple diverse SA methods, as well as exploring SA specifically during post-scenario operator debriefs, may reduce the limitations of using a singular method for ISV. Although more time consuming and resource intensive than applying just one SA method, we found this approach offered a comprehensive assessment of SA, and the methods complemented each other. Given the limited validation evidence for a singular SA method for use in ISV, the assessment of SA from three angles (freeze-probe self-report, expert observations and an SA focused debrief) provided us with more confidence that our combined approach meets the criteria set out by NUREG-0711. In some instances, one of the methods will offer us insights into SA during the scenario that was not captured in another method, reinforcing the value of multiple methods.

Ultimately, we believe that this multi-method approach gives us confidence in our ISV programme that we have the methodological approach to assess whether the highly automated control room design supports operator SA than if we were to rely on a singular SA method.

References

- Braarud, P.Ø., Eitrheim, M.H.R., Holmgren, L., & McDonald, R. (2016). Review of the SCORE Measure for the Assessment of Safe Control Room Operation: A HAMMLAB Study of the Content Validity and Usability. HWR-1175. OECD Halden Reactor Project, Halden, Norway.
- Braarud, P.O., Svengren, H., Ulrich, T.A., Boring, R.L., Joe, J.C., & Hanes, L. (2018). Lessons Learned from Performing a Human Factors Engineering Validation of an Upgraded Digital Control System in a Nuclear Power Plant Control Room (No. INL/EXT-18-44618-Rev000). Idaho National Laboratory, Idaho Falls, ID, United States.
- Edgar, G.K., Catherwood, D., Baker, S., Sallis, G., Bertels, M., Edgar, H.E., Nikolla, D., Buckle, S., Goodwin, C., & Whelan, A. (2018). Quantitative Analysis of Situation Awareness (QASA): Modelling and measuring situation awareness using signal detection theory. *Ergonomics*, 61(6), 762–777.
- Endsley, M.R., & Garland, D.J. (2000). Theoretical underpinnings of situation awareness: A critical review. *Situation Awareness Analysis and Measurement*, 1(1), 3–21.
- Endsley, M., Bolté, B., & Jones, D. (2003). *Designing for Situation Awareness*. Taylor & Francis.
- Fernandes, A., & Braarud, P.Ø. (2015). Exploring measures of workload, situation awareness, and task performance in the main control room. *Procedia Manufacturing*, 3, 1281–1288.
- Fernandes, A., & Braarud, P.Ø. (2015). Exploring measures of workload, situation awareness, and task performance in the Main Control Room. In *Proceedings of the 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015)*. OECD Halden Reactor Project, Halden, Norway.
- Hogg, D.N., Follesø, K., Strand-Volden, F., & Torralba, B. (1995). Development of a situation awareness measure to evaluate advanced alarm systems in nuclear power plant control rooms. *Ergonomics*, 38(11), 2394–2413.
- O'Hara, J., Higgins, J., & Fleger, S. (2012). Human factors engineering program review model (NUREG-0711) revision 3: Update methodology and key revisions. In *Proceedings of the 8th International Topical Meeting on Nuclear Plant Instrumentation and Control and Human-Machine Interface Technologies*.
- Salmon, P., Stanton, N., Walker, G., & Green, D. (2006). Situation awareness measurement: A review of applicability for C4i environments. *Applied Ergonomics*, 37(2), 225–238.