

**Australian Research in Power System
Transformation**

Topic 3 – Control Room of the Future

**2025/26 Human-Centred Information
Visualisation for Improved Situational
Awareness and Critical Decision Making
in Energy Control Rooms**

Commonwealth Scientific and Industrial Research
Organisation

19 December 2025

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1. Introduction

Monash University is conducting research on (AR-PST Topic 3) Control Room of the Future (CROF). The original 2021 roadmap outlined pathways for innovation around key pillars. This research focuses on the CROF Pillars of Human Factors and Operator Interactions and aligns with the other pillars, in particular relating to Software Applications. The project is focused on human-centred information visualisation for improved situation awareness and critical decision making.

The project involves close interaction between the Monash team and AEMO for data collection, workshops and feedback sessions. Regular communication between the Monash team and AEMO has ensured that data is collected efficiently, findings are validated and clarified, ideas are discussed, recommendations prioritised and outcomes evaluated. The project has four main phases of research:

- Phase 1: A: Understanding Current Control Room Operations, and B: Future Control Room Scenarios
- Phase 2: Initial Guidelines and Early Prototyping
- Phase 3: Prototyping and Evaluation
- Phase 4: Write up and Roadmap to Adoption

Phase 1 and 2 are completed, with 3 and 4 in progress.

Due to unforeseen legal complexities in finalising the research agreements between the stakeholders, the research for AR-PST Topic 3 Stage 4 was not able to commence in 2024, but in early 2025. The Stage 4 research then merged into Stage 5 to stay aligned with the other topics in the AR-PST program. This stage 5 work is due to be completed early 2026. The findings from this work connects to research from Stage 1 (the AR-PST research roadmap), as well as Stages 2 and 3 on ML for alarm management which was led by EPRI and RMIT.

2. Research completed

The Stage 5 project team consists of a diverse set of Monash academic researchers, particularly from the Human-Centred Computing department, together with AEMO and CSIRO. The Monash academics have particular expertise in human-computer interaction, data visualisation, interaction design, decision support, optimisation, data science and explainable AI. A dedicated Research Fellow with the correct expertise was quickly identified, hired and began work to collect and analyse the results. The project has a mixed-methods approach where both quantitative and qualitative data was collected. The project team has made excellent progress on the work to date. The team meets every week with reports to the CSIRO project management team every 4 weeks. The project runs via an iterative process, whereby continued work phases dynamically change based on previous results. The following work has been completed:

Phase 1: Understanding Current Operations and Future Scenarios

Part A captured current control room practices. The following research has been completed by Monash in collaboration with AEMO:

- Designed and conducted **structured observations** of control room training sessions using representative operational scenarios.
- Collected different types of data (eye-tracking, video, questionnaires, and observer notes) to capture operator behaviour, workflows, decision making and situational awareness.
- Undertook live **control room observations** to contextualise training findings and identify differences between training and operational environments.
- Merged data sources and performed **data wrangling** to enable **initial analysis** of eye-tracking and observational datasets, including mapping gaze data to multi-screen workstations.
- Developed **preliminary analytical artefacts** (Areas of Interest (AOIs), Time windows of interest (TWIs), timelines, and sequence diagrams) to support continued analysis in later work phases.
- Compiled and validated a comprehensive **list of applications and interfaces** used by operators, including purposes and usage contexts.

Part B explored future control room scenarios. The following tasks have been completed by Monash in collaboration with AEMO and other control room operators:

- Planned and conducted a structured **ideation workshop** on the Control Room of the Future with AEMO stakeholders using the Creative Visualization–Opportunities (CVO) method.
- Collected **workshop outputs** through digital post-its, sketches, and storyboards capturing envisioned future control room concepts.
- Performed initial **qualitative analysis** to cluster ideas, identify themes, and synthesise insights across activities.
- Identified key **aspirations** and **challenges** for future control rooms, highlighting **opportunities** for automation, AI-supported assistance, unified interfaces, and streamlined information presentation.

The Monash lead was also invited to run a “Designing the Control Room of the Future” workshop at the Australian Control Room Network Association (ACRNA) Conference, October 2025 in Sydney. This workshop allowed the Monash team to glean CROF insights beyond AEMO to other energy control rooms and other sectors.

Phase 2: Initial guidelines and early prototyping

The following tasks have been completed by the Monash team in collaboration with AEMO:

- **Combined and synthesised analysis** from Phase 1 to identify initial **CROF guidelines and recommendations**.
- Identified **seven core pain points** affecting situational awareness, decision-making efficiency, collaboration, system integration, and training alignment.
- Outlined **five future-oriented design principle visions** and **10 initial recommendations** that form the foundation of the CROF guidelines and are grouped into three categories: *Visualisation and Interaction*, *Unified Context-Aware Systems* and *Context-Aware Interfaces*.
- **Review** of pain points, design principles and recommendations and **ranking** for expected feasibility and priority.

These pain points, principles and initial recommendations are provided in **Appendix A** for transparency and benefit of continued research for Topic 3 and the connection of the research progress to the roadmap in Section 4 of this report. These findings have been reviewed by AEMO, with initial ranking and prioritisations. These will be finalised in Phase 3 and 4 below. Full information that illustrates and documents these findings will be in the final report (expanding the write up of Appendix A with detail). Our continued work for Stage 5 as described in Section 3 moves towards visualisation standards and guidelines for recommendation A as well as full mapping of the recommendations to a roadmap for adoption.

3. Outstanding activities

Phase 3: Visualisation Guidelines and evaluation is currently underway (Dec-Feb).

The Monash team and AEMO are finalising the prioritisation and feasibility positions for the core **recommendations and guidelines** toward the **roadmap for adoption**, which is to be completed in Phase 4. The team has started a **deeper dive** into AEMO’s new internal interfaces where new dashboards are being created. Interviews with developers and face-to-face observations and discussions with the AEMO UX/UI team, dashboard developers and control room operators have initiated, and we move closer to reaching the goal of visualisation guidelines. These visualisation guidelines are being finalised and will be evaluated with AEMO.

Phase 4: Write up and roadmap for adoption is occurring in parallel to other Phases. The final write up will be completed in February. (Jan-Feb)

4. Progress against the Roadmap

Stage 5 focused on the *Operator and Human Factors* pillar shown in green in Figure 2-1 from the 2021 Roadmap below; specifically, data visualisation and user interfaces for improved situational awareness and decision support (highlighted in yellow). However, our mixed method human-centred approach drew far more broadly across many other pillars of the CROF. The results of Stage 5 are broad and cover a number of areas of the roadmap. They take us a step closer in understanding how to reach the overarching CROF Vision “*Operators are Effective Supervisors*”

of a More Automated Australian Power System” and CROF Purpose at the top the figure:

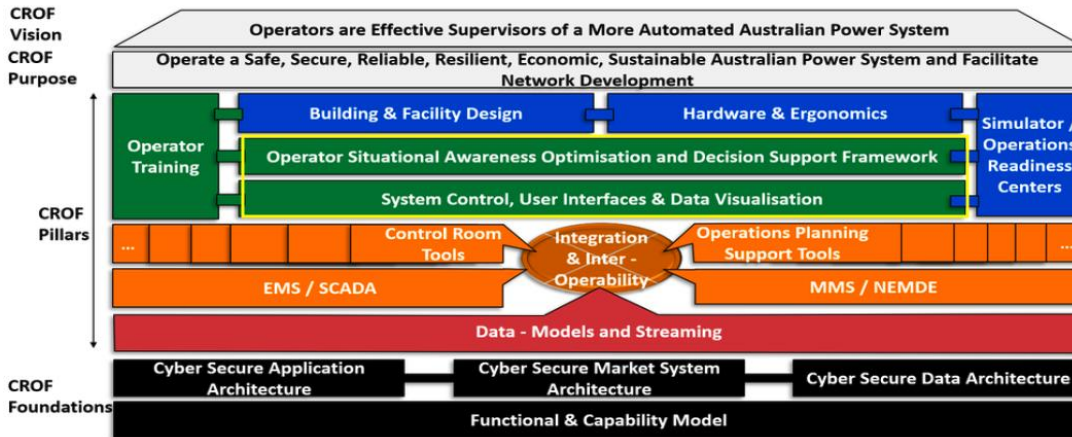


Figure 2-1 EPRI Model of aspects of the control room of the future, applied to the Australian context. Includes the CROF vision, purpose, pillars, and foundations.

The research outcomes of Stage 5 will help toward a visualisation philosophy for the CROF, with specified standards and guidelines. The outcomes also demonstrate the important *interdependencies* of the Operator and Human Factors innovations pillar. The initial 10 recommendations (A-J, see Appendix A) identified in Stage 5 have been tentatively mapped (in pink) into the 2021 roadmap for Operator and Human Factors research to ensure the recommendations are taken into account in future work:

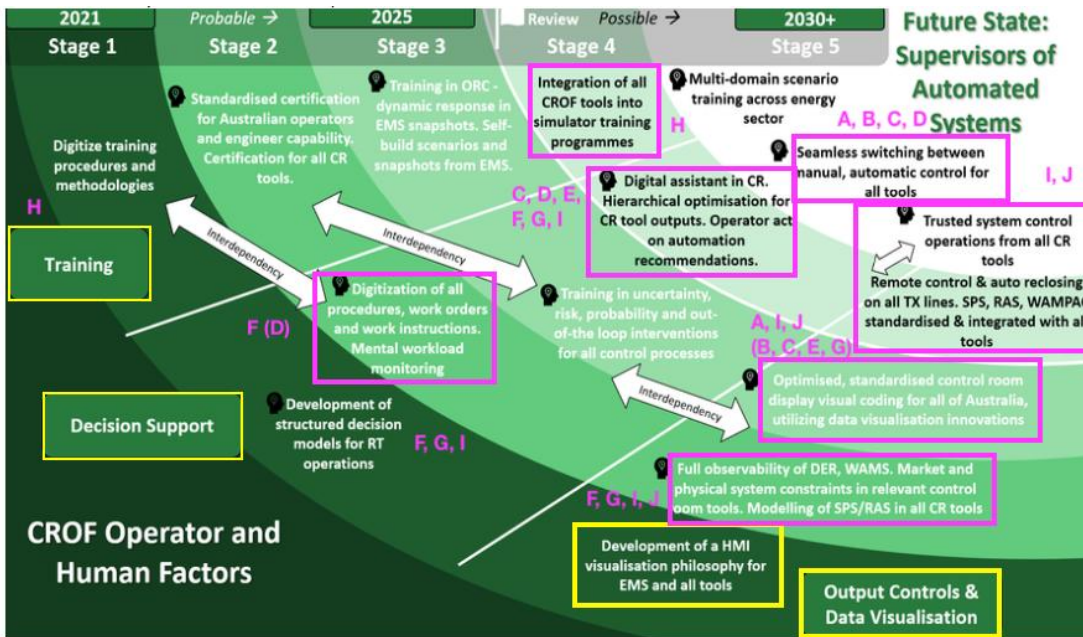


Figure 4-5 CROF Roadmap for Operator and Human Factors innovations

Through our continued Stage 5 work we are moving towards visual standards and guidelines (i.e. recommendation A). We have identified insights that form early stages of work towards other recommendations such as C and E.

5. Research relevance to Australia

Australia has only one energy market operator, the Australian Energy Market Operator (AEMO). In this project Monash researchers have been collaborating directly with AEMO to ensure that the research we have been undertaking is highly relevant and has actionable results for immediate improvement of AEMO operational control rooms both now and into the future. The AEMO NEM has been the testbed for this CROF research but adopted processes will follow into the WEM control room and AEMO Gas control rooms can also benefit. Other control rooms across the energy sector in Australia and internationally can also learn from this research. Furthermore, other sectors with control rooms can benefit.

The Stage 5 research aims to enable improved data-driven decision making in control rooms of the future. The research outcomes including the final design principles vision, CROF recommendations and roadmap to adoption aim to enable more efficient and informed decisions for control room operations going forward. Ultimately, reduced cognitive load of operators and improved control room operations aims to reduce risk of the impact of power system events externally, thus through this CROF research we hope to see a wider benefit for all Australians.

6. Recommended research priorities

Topic 3 CROF is extremely broad, but the five new principles for CROF vision identified during Stage 5: *1) Flexible yet Consistent, 2) Zero-click to Critical, 3) One model, many Views, 4) Automate the Known, and 5) Rapid Explainable Suggestions* (see Appendix A for more information); should be taken into account during future Topic 3 research in order to reach the ultimate vision of “Operators are Effective Supervisors of a More Automated Australian Power System”.

Stage 5 has identified many open and urgent Operator and Human Factors recommendations for future work that range in their priority and feasibility. These fall under three categories of Visualisation and Interaction (A-D), Unified Context-aware Systems (E-H), and Integrated Context-aware Solutions (I & J). In particular, further innovative research is needed in: (F, E, J) providing context-aware interfaces, (I) intelligent yet explainable AI suggestions, (C & E) optimising profiles and workspaces, (B & D) enabling fast interaction patterns and rapid digital collaboration.

Appendix A: Initial CROF Guidelines

Key Pain Points:

1. Individual **preferences vary** across roles, experience levels, and shifts;
2. **Inconsistent UI patterns** across applications increases visual load;
3. **Operators switch applications** frequently and use different layouts;
4. Slowed support for decision making due to **excessive manual effort and limited automation**;
5. Shared situational awareness **lacks rapid digital collaboration tools**;
6. **Disconnected systems** and lack of centralisation;
7. **Training environment not fully aligned** with live control room;

Design Principles for CROF Vision

1. **Flexible yet Consistent:** Interfaces adapt to tasks and individual preferences while maintaining shared, intuitive consistency across screens, operators, and contexts.
2. **Zero-click to Critical:** The system surfaces what matters without hunting.
3. **One model, many Views:** A consistent data model feeding every interface.
4. **Automate the Known:** Where facts are certain, automate by default. Enable intervention where necessary.
5. **Rapid Explainable Suggestions:** Integrate AI recommendations with explainable interfaces, which enable operators to respond with caution.

10 Initial Recommendations for the CROF, grouped into 3 categories (verified by AEMO):

| Recommendation | Description |
|---|---|
| Visualisation and Interaction | |
| A | Visual load minimisation & cross-system interface standards Standardise background colour across core tools rather than mixing white/grey/dark grey/black. Limit dense tables and flashing elements to reduce constant effort. Be consistent in the use of visual elements, such as colour, and limit the use of colour for aesthetics. Enable linked views where possible. Enable rapid creation of standardised dashboards. |
| B | Low-effort interaction patterns Reduce repeated clicks and pointer travel by keeping common actions close at hand, using larger targets, and supporting simple keyboard shortcuts. Making actions fluid. |
| C | Adaptive and optimal profiles Allow operators to pick from simple preset profiles and switch in one click. Not standardising, removing personal preferences, but providing optimal and adaptable profiles. |
| D | Fluid and effective collaboration & handover Allow shared, digital workspace or notepads where operators can easily add or “drag and drop” information, images, and notes from all workstations to collaborate for smooth handover and event management |
| Unified Context-aware Systems | |
| E | Task-bundled workspaces Grouping the usual application combinations needed for a task into one bundled view so operators avoid frequent switching between multiple interfaces. |
| F | Context-aware, explainable procedures When an alarm is investigated, the system opens the relevant step menu automatically, highlights the exact step, recommended action (e.g. revoking constraint) and procedure. Operators still review and confirm. |
| G | Event management portal For each event, present a case-centric portal showing what happened, what’s affected, recommended next steps, and links to the necessary tools. Opens required apps automatically. |
| H | Training twin with scenario library Keep training and live environments aligned. Build a library of past scenarios so operators can practice and compare approaches. |
| Integrated Context-aware Solutions | |

| | | |
|---|--|---|
| I | Explainable guidance for AI integration | Where AI is implemented the system must ensure the operator has short, human-readable detail of why that suggestion or guidance is being provided. Some example implementations based on our observations include suggested reasoning and explainable guidance for 1) <i>Smart Alarm Management</i> (see Topic 3: Stage 2 and 3) where duplicate or cascading alarms are grouped and related. 2) <i>Intelligent Procedure Search</i> , where contextual information is recognised and relevant procedures are identified. |
| J | Innovate relevant information on SLDs | The single-line diagram (SLD) is a crucial visualisation in the control room, but lacks full integration to provide complete situational awareness. Contextual data can be innovatively embedded into the SLD to provide fast and effective overviews and enable direct action. Some potential examples identified through our observations and discussions include: 1) <i>constraint advisor</i> : display and invoke constraints directly on the SLD with clear visual status and short explanations. 2) <i>natural hazard information</i> : integrate topology with geospatial information so relevant natural hazard information can be rapidly reported and directly recognised. 3) <i>procedural information</i> : document and action procedural information directly via the SLD. |