CAAP Quarterly Report 1

December 29, 2025

Project Name: Human-Centered HMI Protocol Development for Pipeline Control Rooms Using a Functional Digital Twin Technology

Contract Number: 693JK32550002CAAP

Prime University: Texas A&M University-Corpus Christi

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Reporting Period: 09/30/2025 – 12/30/2025

Project Activities for Reporting Period:

During the first reporting period, project activities focused on establishing the **technical networks, regulatory knowledgea, and collaborative foundation** necessary to support the development of **human-centered HMI design guidance for pipeline control rooms**. Efforts during this quarter emphasized alignment with PHMSA expectations, review of existing industry standards, early engagement with industry stakeholders, and refinement of the functional digital twin concept proposed in the project.

1.1 DOT PHMSA Kick-off Meeting and Project Alignment

A formal project kick-off meeting was held on **December 8, 2025** with representatives from the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA), including the Agreement Official (AO), Agreement Official's Representative (AOR), and Technical Task Inspector (TTI). Members of the research team, Technical Advisory Panel (TAP), and industry collaborators also participated.

Key outcomes of the meeting included:

- Confirmation that the project's primary goal is the **development of human-centered HMI design protocols**, rather than deployment of a specific SCADA system
- Emphasis on addressing the **gap between regulatory control room management requirements (49 CFR Parts 192 and 195)** and the lack of empirically validated HMI design guidance
- Reinforcement of PHMSA's interest in **operator performance, workload, and decision-making**, particularly under abnormal and emergency conditions

Feedback from PHMSA informed refinements to the project scope and reinforced the importance of grounding all design recommendations in observable human performance outcomes.

1.2 Relationship to API Recommended Practice 1165

A central activity during this reporting period was an in-depth review of **API Recommended Practice 1165 (RP 1165), *Recommended Practice for Pipeline SCADA Displays***, which serves as the primary industry reference for control room HMI design.

API RP 1165 documents are widely accepted best practices related to display hierarchy, navigation, color usage, symbols, text, alarm presentation, and general human factors considerations. While RP 1165 provides valuable qualitative guidance, it explicitly acknowledges that:

- Not all recommendations are universally applicable
- The guidance is not all-inclusive
- Design practices are based largely on industry experience rather than controlled experimentation

Based on this review, the research team identified several limitations that motivate the present study:

- The absence of **experimental validation** linking HMI design choices to operator performance metrics
- Limited guidance for **high-stress and abnormal operating scenarios**
- Lack of a structured framework for **testing, comparing, and refining alternative HMI designs** prior to operational deployment

The goal of this project is therefore **not to replace RP 1165**, but to **systematically evaluate, refine, and extend it** through human factors experimentation and functional digital twin–based simulation. In addition, insights gained from recent on-site control room visits further highlighted an important gap that is not explicitly addressed in API RP 1165. While the recommended practice provides substantial guidance on display content, hierarchy, and information presentation, it offers limited direction regarding the physical characteristics of the HMI environment itself. Specifically, RP 1165 does not provide empirically grounded guidance on appropriate monitor size, resolution, spatial arrangement, or viewing geometry, nor does it establish clear design principles for the placement, orientation, and sizing of large overview displays commonly used in modern control rooms.

Across the observed control rooms, critical design decisions related to console layout, table geometry (e.g., height-adjustable versus fixed configurations), monitor positioning, and large-screen integration appeared to be driven largely by legacy practices, vendor preferences, or spatial constraints, rather than by experimentally validated human factors criteria. These physical design elements directly influence operator visual scanning behavior, posture, workload, and situation awareness, yet remain underrepresented in existing industry standards. This gap presents a significant opportunity for controlled, experiment-based research to establish evidence-informed design ranges and practical recommendations that complement and extend the cognitive and informational guidance provided in API RP 1165.

1.3 Functional Digital Twin Concept Development

Figure 1 illustrates the conceptual layout of the control room simulator environment proposed for this study. The configuration reflects common elements observed in modern pipeline control rooms, including multi-monitor operator consoles and overhead displays, while allowing systematic manipulation of monitor size, placement, viewing distance, and console geometry. This physical layout provides the foundation for controlled evaluation of human performance outcomes associated with alternative HMI design configurations.

Informed by PHMSA feedback and the RP 1165 review, the research team refined the scope of the proposed **functional digital twin**. The digital twin is designed to:

- Emphasize **functional and cognitive fidelity** over full physical replication of pipeline infrastructure
- Represent realistic operator tasks, workflows, and decision-making processes
- Enable controlled manipulation of HMI design variables derived from RP 1165 (e.g., display hierarchy, alarm presentation, navigation depth)

This approach allows the research team to isolate the effects of HMI design features on operator performance while maintaining feasibility and cost efficiency.

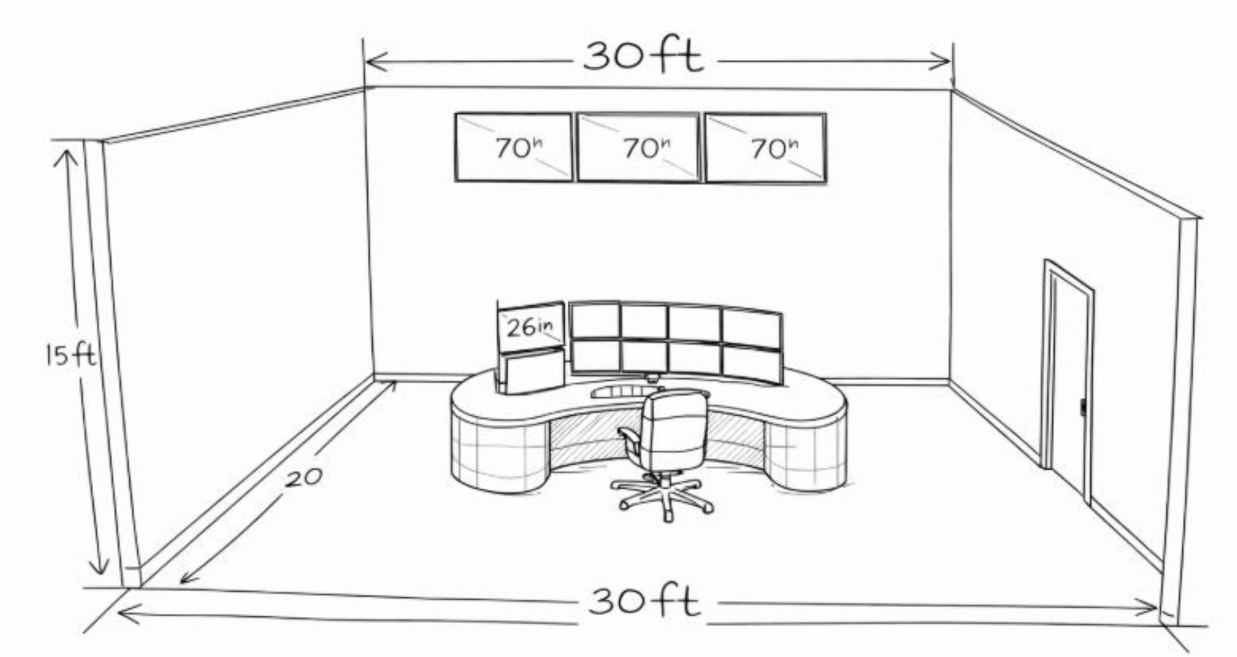

Figure 1. Conceptual 3D line drawing of the proposed control room simulator layout in Engineering Lab Room 105 at Texas A&M University–Corpus Christi. The rectangular room (30 ft × 20 ft × 15 ft) includes a curved operator console with a two-tier monitor configuration, overhead wall-mounted displays, and representative viewing distances and working heights. The layout is intended to support controlled human factors experiments examining the effects of HMI display configuration, spatial arrangement, and viewing geometry on operator performance.

1.4 Control Room Task Analysis and Workflow Decomposition

Preliminary task analysis activities were initiated to support later experimental design. These activities included:

- Identification of core control room operator tasks
- Initial decomposition of tasks associated with monitoring, alarm handling, and command execution
- Mapping of tasks to HMI elements defined in RP 1165

This work ensures that subsequent experiments are grounded in realistic operational contexts rather than abstract interface evaluations.

1.5 Industry Engagement and Site Familiarization

Industry engagement activities during this reporting period supported scenario development and ecological validity. These activities included:

- A completed control room visit at **OxyChem (Ingleside, TX)** on November 5, 2025
- A scheduled site visit to **Howard Energy Partners (San Antonio, TX)** on December 15, 2025
- Planning for a virtual technical meeting with **Honeywell** in January 2026

Additional collaborators include Oxea Chemicals, Plains All American, and Buckeye Partners.

Project Financial Activities Incurred during the Reporting Period:

During this reporting period, project expenditures were primarily associated with **project initiation, planning, and early coordination activities**, consistent with the approved budget and the early phase of the project.

2.1 Personnel

- Partial salary support for the Principal Investigator (pro-rated based on project start date)
- Graduate Research Assistant support for literature review, task analysis, and simulator concept development

2.2 Fringe Benefits

- Fringe benefits applied in accordance with university policy

2.3 Travel (UPDATED)

During the reporting period, the Principal Investigator conducted a project-related site visit to **San Antonio, Texas**, in support of industry engagement and control room familiarization activities.

- Travel was conducted using a **personal vehicle**, and a **mileage reimbursement** is expected to be submitted in accordance with university and federal travel reimbursement policies.
- At the time of this report, the reimbursement process is pending completion.

2.4 Equipment and Software (Planning and Cost Estimation Phase – UPDATED)

While no major equipment or software purchases were executed during this reporting period, the research team has initiated **market search and vendor outreach** to support upcoming procurement decisions.

Based on preliminary assessments:

- The combined cost for a **DeltaV process skid and associated software and hardware components** is currently estimated to be **approximately $100,000 (see Figure 2)**.
- Additional infrastructure required to support a realistic control room research environment—including a **large round conference table, monitor mounting systems, operator chairs, and furnishings for a small break/rest area**—is estimated at **approximately $30,000**.

At present, the research team is:

- Identifying and contacting multiple vendors
- Requesting and comparing price quotations
- Evaluating alternative configurations to balance **research fidelity, experimental control, and cost efficiency**

Final procurement decisions will be made with careful consideration of the overall project budget and the goal of achieving **maximum research impact with cost-effective equipment selections**.

2.5 Indirect Costs

- Indirect costs were applied in accordance with the approved budget and the university's negotiated indirect cost rate

Overall, expenditures during Quarter 1 remain aligned with the planned spending profile for the project's startup and planning phase.

Figure 2. Representative example of a DeltaV process skid used in industrial automation environments. This image illustrates the type of modular, small-scale process hardware under consideration for developing a virtualized control room research environment focused on human–machine interface (HMI) evaluation and operator performance studies.

Project Activities with Cost Share Partners:

Cost-share activities during this reporting period focused on planning and advisory contributions. These included:

- Faculty effort supporting methodological development
- Institutional support for simulator space planning
- Advisory input on human factors methods and experimental design

More substantial cost-share activities are anticipated in later phases as experimental work increases.

Project Activities with External Partners:

External partner engagement emphasized coordination and alignment. Activities included:

- Formal integration of a **Technical Advisory Panel (TAP)** consisting of representatives from PRCI and major pipeline operators
- Industry discussions focused on validating operator tasks and HMI challenges
- Early coordination with system vendors and integrators in advisory roles

No subcontracted research activities were conducted during this reporting period.

Potential Project Risks:

Identified risks include:

- Access limitations to operational control rooms due to security and NDA requirements
- Balancing simulator realism with budget and complexity constraints
- Scheduling dependencies with external partners

Mitigation strategies include modular simulator design, abstraction of sensitive scenarios, and flexible experimental protocols.

Future Project Work:

Next 30 Days

- Finalize functional digital twin architecture
- Complete detailed task analysis framework

Next 60 Days

- Develop baseline virtual control room environment
- Prepare IRB documentation, if required

Next 90 Days

- Pilot-test HMI configurations
- Refine experimental protocols with TAP input
- Initiate controlled HMI evaluation experiments

Potential Impacts to Pipeline Safety:

At this stage, the project’s impact lies in establishing a rigorous foundation for evidence-based HMI evaluation. By systematically examining and extending API RP 1165 through controlled experimentation, this project aims to:

- Improve operator situational awareness
- Reduce cognitive overload and error likelihood
- Support PHMSA’s mission to enhance pipeline safety through human-centered system design

In later phases, results from this work are expected to inform future updates to industry guidance and recommended practices.