The Plant Panel: Feasibility Study of an Interactive Large Screen Concept for Process Monitoring and Operation

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ABSTRACT

Control room modernization projects worldwide are currently replacing or supplementing traditional wall-sized "boards" with computerized solutions. These solutions typically consist of multiple small screens that the operators need to navigate and arrange. Shared overview displays have been introduced to compensate for some of their perceived shortcomings, such as increased workload and a loss of process overview. This paper presents a study that investigates the feasibility of taking this approach a step further. Could we utilize modern screen technology to improve operator performance by introducing what we have called a "Plant Panel": a single, all-purpose, wall-sized, interactive display that shows the whole nuclear process in a coherent manner, blending detailed component and system information with useful plant overview information? To address this question we developed a prototype of the Plant Panel limited to the reactor-side of a Boiling Water Reactor and tested it with a number of potential users. This prototype is a 1.5 x 4 meter paper mock-up of the Plant Panel with an overlay of digitally projected interface elements.

This study indicates that the Plant Panel concept may have several strengths compared to current computerized control room designs. The results of the feasibility tests show that features of the design related to supporting collaboration and process overview seem particularly promising. The main feasibility concern was related to how users could potentially lose their overview when positioned too close to the display. We recommend that further work should address this issue particularly, as well as exploring the areas for improvements that users identified.

Key Words: Shared Overview Displays, Large Screens, Human Computer Interaction, Human System Interfaces, Collaboration Surfaces

1 INTRODUCTION

Control rooms traditionally feature large analogue control panels with spatially fixed physical controls. Modern control rooms are increasingly computerized, enabling operators to perform control actions from more compact workstations. Many control rooms are “hybrid”, situated across the spectrum between traditional or fully computerized control rooms. The gradual transition from analogue to digital control rooms presents opportunities to investigate the effects of computerized Human System Interfaces (HSIs) on operator performance. Table 1 summarizes some of the many strengths and weaknesses of traditional and computerized HMIs.

Table 1: Commonly identified strengths and weaknesses in traditional and computerized control environments

	Traditional (panel based)	Computerized
Strengths	• Display elements are spatially dedicated and continuously visible. • Communication is enhanced by open space. • Operators more easily maintain awareness of others actions. Activity is inferred by physical location.	• Controls and information graphics can be shaped as desired: Task-related Information can be integrated, and displays can more easily be customized to fit operators tasks and information needs. • Flexible control environment layout, meaning that operators can bring controls and information to where they are instead of having to move to locate them.
Weaknesses	• Large physical size of controls and resulting control rooms. • Costly to maintain and reorganize equipment. • Limited flexibility in terms of information presentation and customization.	• Additional work is required to navigate multiple process formats. • “Keyhole effect”: Mental integration of information is required when the process is represented on numerous display pages, reducing process overview. • Reduced “team transparency”: The operators’ activities are less visible for others when seated in front of a screen than when moving about.

As we can see from the table above, one of the key concerns with current computerized HSIs is the negative influence of added interface management tasks and the potential loss of process overview resulting from spreading HSI elements across a multitude of relatively small displays, creating the so-called “keyhole” effect. A study by O´Hara et. al. [1] suggests that operators tend to avoid interface management if possible, and thus run the risk of losing overall situation awareness. This is referred to as the “data-limited” effect:

> “Operators manage workload by prioritizing all their tasks – primary and secondary tasks. Interface management tasks are not prioritized as highly as primary tasks and frequently are not performed. Operators will use several strategies to minimize interface management demands, such as configuring their workspace as a spatially dedicated one. Operators often prefer to use the displays that are currently presented, rather than try to retrieve the best displays for the task”. (p. 4)

Table 1 suggests that unavoidable trade-offs exist between traditional and computerized control rooms. There have been different responses to this problem. For example, Large Screen Displays (LSDs) have been introduced in both traditional and computerized control rooms to create a shared overview of the process. This solution generally allocates supervisory activities to the LSD and control activities to individual operator workstations, and is generally found useful to support a number of key operator tasks [2], [3], [4].

In the Halden Man-Machine Laboratory (HAMMLAB), another approach has been to utilize larger operator workstation screens. Desks containing three to five 30” high-resolution LCD screens have replaced workstation desks with five to eight 19” LCD or CRT screens. The P&ID “mimic” formats have been redesigned to fit the increased screen size and higher resolution, enabling better integration of related process information and reducing screen navigation. This approach has received strong positive feedback from users [5].

In this paper, we will present an alternative approach where we envision a “Plant Panel” – a design that utilizes capabilities offered by modern, interactive display technology, to build on the strengths of both traditional and computerized control environments, while seeking to mitigate their respective weaknesses. With the Plant Panel we explore the feasibility of representing a familiar, mimic-based view of the whole plant process on a single, spatially dedicated, interactive display. The goal of this display is to simultaneously support both supervision and control, and thus practically eliminate the need for interface management in a conventional sense. The concept can be seen as a step back towards the traditional panel-based interface, but more closely integrating supervisory and control activities into a much more compact surface, as illustrated in Figure 1.

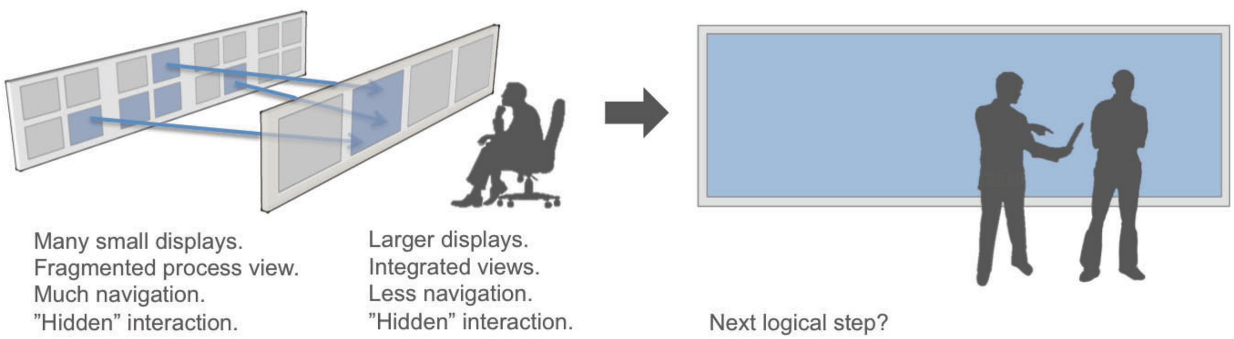

Figure 1: Could a single, large display for both process monitoring and control be utilized to solve some of the known challenges associated with current computerized HSIs?

We anticipate several advantages of this approach, the main ones being:

- Reduced workload due to less display navigation.
- Improved shared process overview, process understanding and problem solving capabilities due to an integrated and coherent process representation.
- Improved “team transparency”: An increased ability to see the activity of other team-members, created by making operator activity directly visible throughout the control environment.

It seemed clear that to design such a concept successfully was not a straightforward task, and we expected that more detailed feasibility criteria include:

- The extent to which the entire process can be presented on a single display sufficiently compact to fit within a typical control room.
- The extent to which display elements that are required for supervision are legible from the distance suited to supervising the whole process simultaneously.
- The extent to which display interaction is appropriately designed to fit this new type of display, making process manipulations fluent and robust to error.

- The extent to which screen technology with sufficient size and resolution is commercially available within a relatively near-future time perspective.

Among the main challenges we anticipated with the Plant Panel design was the difficulty of integrating high-level and low-level information into a single view, while maintaining an organized and uncluttered appearance. In the initial phase of the design process we formulated a set of strategies to help us overcome this challenge based on earlier LSD work (such as the ones described in [2]), including layering and clustering techniques, utilizing different colours, sizes and backgrounds to create order.

This paper is based on a Halden Work Report [6] where the Plant Panel feasibility study is described in more detail.

2 THE PLANT PANEL PROTOTYPE

We limited the Plant Panel prototype design to cover the reactor side of a BWR plant, and we based it on the HAMMLAB Boiling Water simulator (HAMBO) process and existing HSIs. This HSI contains all the reactor-side controls and information available in HAMBO. The design team made an effort to represent every element of the existing HSI in the new design to allow for a realistic feasibility assessment. Since this was not a study on innovative graphics per se, we adopted a process representation that would be familiar to users of industry standard solutions. The "mimic" diagram is a dominant characteristic of such interfaces, and by closely aligning the Plant Panel with this visual style we sought to make it easy for users to make relevant comparisons between the new design and what they already were accustomed to.

The final prototype was a 4x1.5 m paper mock-up of the Plant Panel. Paper prototyping is commonly regarded as suited for making initial design inquiries [7], and we found this technique effective for synthesizing all of the reference HAMBO HSI reactor side interfaces into a single view. Duplicate systems and interface elements were discounted, accounting for approximately 20-30% of display content. By projecting digital images on top of this printed surface, we sought to emulate a large, high-resolution, interactive display that would be effective for gathering relevant user feedback.

The overall layout of the proposed design may be best described as a system-oriented process mimic. The reactor pressure vessel is highly salient and centrally located. The containment walls are similarly prominent, providing a sense of orientation for the organization of other systems around the reactor. We relied on a schematic of plant systems to create a familiar layout, see Figure 2.

Within and around the reactor vessel, key parameters are displayed. The central location of this information allows for monitoring while interacting with another part of the display. Primary cooling systems are located to either side of the containment building, with secondary cooling systems located below. Located above this are the feed water lines and residual heat removal system. The steam lines are located at the top of the display, flowing off-screen to the right, where we envision that they could continue on to a turbine-side display. Several systems that were not easily integrated are located to the left of the display, including the automatic reactor protection systems and compressed nitrogen system.

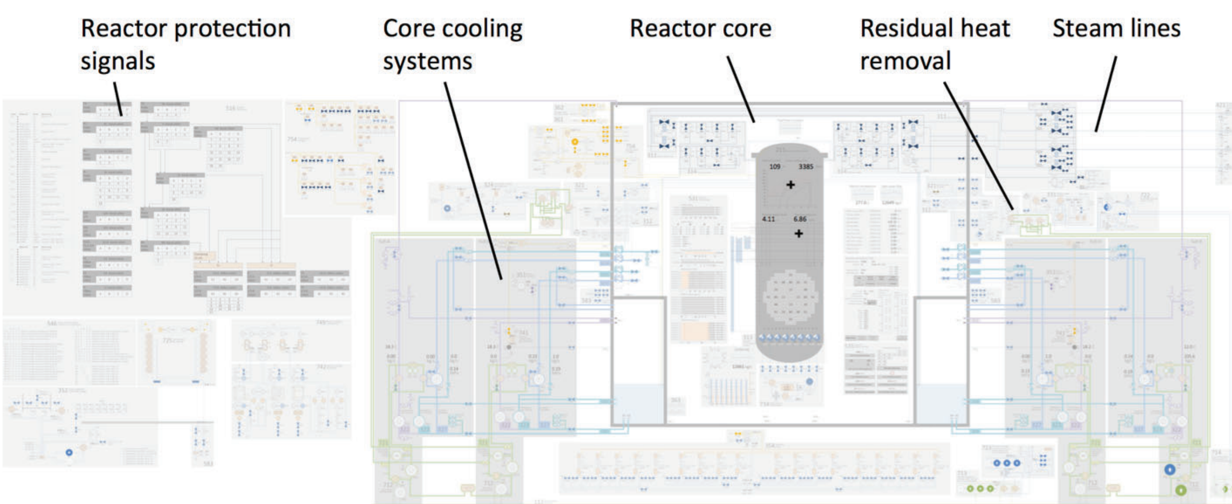

Figure 2: Overall screen layout of the final prototype (4x1.5 m)

Several modes of interactions with the Plant Panel were considered, included pop-up menus or networked tablet devices. For this study, we simulated interactions with small pop-up menus. By selecting (touching) a component in the display, the pop-up menu would appear. There is sufficient open space throughout most of the display to allow for pop-up menus with some detailed information or touch elements to perform control actions, without covering other display elements. The background of the pop-up menu was translucent to allow the menu to overlap flow lines if necessary. It is unlikely that these menus could be displayed in a consistent location relative to the corresponding element, as the mimic approach does not create consistent spacing between elements. To compensate for this, the pop-up menu contained an arrow pointing to the corresponding element. Figure 3 shows the prototype.

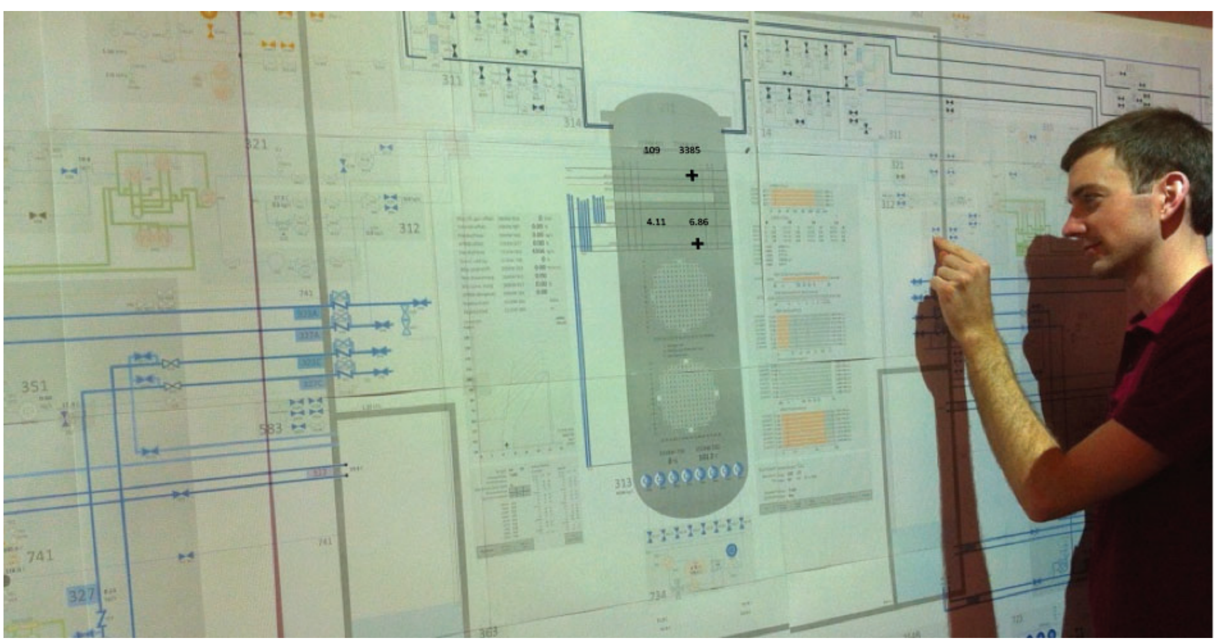

Figure 3: The final paper prototype with projected overlay elements.

3 THE FEASIBILITY TEST

In Halden Project research related to future operational concepts we have found the term "feasibility" useful to frame and describe efforts that seek to explore and uncover the potential usefulness of highly innovative concepts: their strengths and weaknesses, technical requirements related to industrial realization, and ultimately their prospects for success. We believe that research of this kind should focus on potential usefulness rather than on usability and validation, and have developed a dedicated method for performing such studies [6]. This method builds on traditional usability testing but emphasizes isssues related to usefulness, and includes:

- A prototype sufficiently advanced to support feasibility evaluations. Visual and responsive characteristics needs to be developed to a level where the user experience is not a hindrance to the perceived usefulness, such as eliminating usability issues that could divert the participants' attention away from design principles and the underlying concept.
- A realistic and standardized use-case covering the design features under evaluation. A separate use-case description includes a storyboard with sequences of events, anticipated interactions with the prototype.
- Specification of the laboratory set-up (limited to the elements of the test environment that are not dictated by the prototype design itself).
- Test procedures, including an introduction to the feasibility test, training sessions (if needed), time schedule per trial, and the consent form.

For the Plant Panel feasibility test, the printed mock-up was attached to a smart board, which projected predefined, non-simulated plant behavior (i.e. not connected to a process simulator) on top of the printed surface as required by the test scenarios, see Figure 3. The illusion of real display behavior was created by controlling the projected image with a mouse/keyboard, and was performed by test staff, timed with user input.

The test consisted of seven one-hour sessions, each with one participant. Six of the participants were process experts or operators with extensive experience from Swedish nuclear control rooms (both BWR and PWR plants), and one participant was a human factors specialist. Minor adjustments were made to the prototype and use-cases based on the first two sessions. Four use-cases were prepared as starting points for user feedback: 1) Performing parts of a start-up procedure, 2) normal operation, 3) a disturbance (single alarm situation), and 4) reactor scram (automatic shutdown).

Participants were informed of the basic limitations of the prototype and the imagined context of use: a familiar concept of operation, with systems not represented on the Plant Panel available on similar displays nearby. Although the number of display elements that would produce an actual response was limited (projected overlays on top of the paper-based representation), participants were encouraged to *use* the screen as they would have in a real situation and pretend it was a large touch screen.

The focus of participants´ attention was allowed to shift freely based on their own initiative, while the test leader guided the dialogue to cover the main topics of the study: Overall usefulness, structure and organization of the display, process monitoring vs. detailed control, interaction, collaboration, and screen size and resolution.

4 RESULTS

In the following we present the results from the user feedback sessions.

4.1 Organization of the display

All participants stated that the display provided them with a relatively tidy and well-organized view of the plant (reactor side only), which is in itself a promising result for such an early prototype. The feedback from BWR experts confirmed that nearly all relevant content was included. They generally appreciated the way colour, size and layout was used to help them to distinguish between different structural areas of the display. For example, text that was considered less important for a general overview was given low salience through small size, and thus didn´t attract much attention when monitored from a distance. This seemed to have the intended effect, and such text was still legible up close.

4.2 Process monitoring and detailed control

Most participants moved slightly forward and back during the sessions, shifting their view to accommodate their changing information and control needs. The transition from supervision to control (i.e. a need for detailed information and interaction) was made by approaching the screen. Distinct "zones" of use emerged as the participants shifted their focus and intentions, as illustrated in Figure 4.

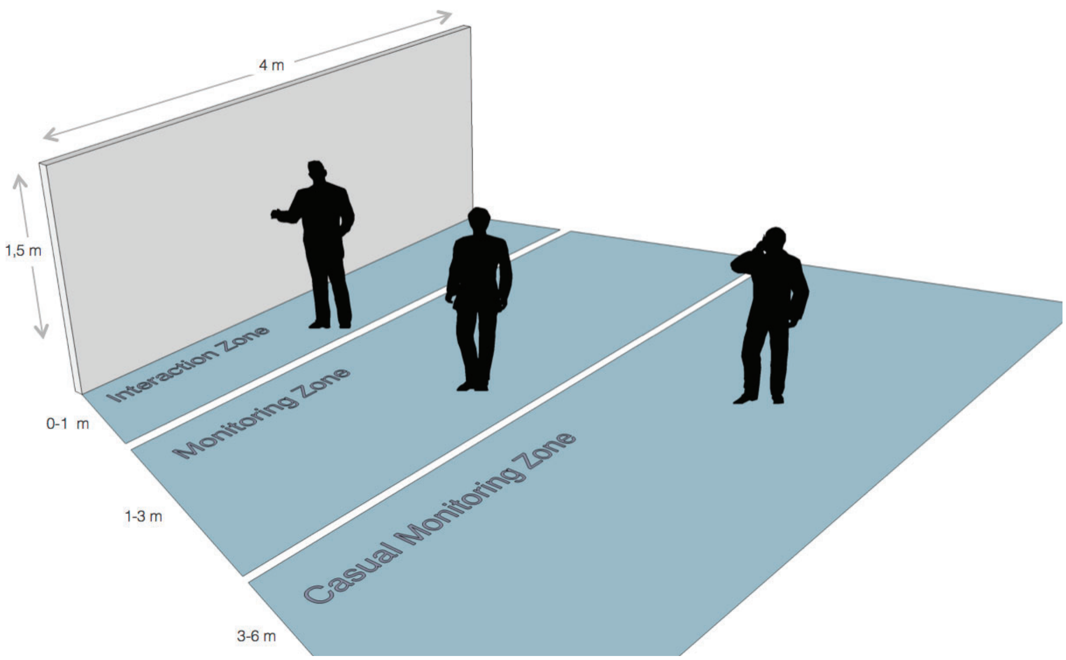

Figure 4: Distinct "zones" of use emerged during the test

When the participants needed to directly interact with the display they positioned themselves in a distance of about 0.5 meter, which we have called the "interaction zone". Most found a distance of 2-3 meters suited for broad overview, where they claimed to be able to see all the relevant information quite clearly, including reading relevant text comfortably. We termed this the "monitoring zone". Several participants also deemed it potentially useful to perform casual monitoring of key process parameters from a greater distance, about 3-6 meters. Based on feedback from the participants we increased the size of a few key information objects related to reactor core conditions, making them easier to see from a greater distance, thus supporting what we called the "casual monitoring zone".

A concern was raised that users might remain too close to the display after approaching it, and thus risk losing the process overview. Because the display is so large, limited overview is obtained in the "interaction zone", and thus a single user might miss important events taking place elsewhere on the display if positioned there for a prolonged time. We discussed whether this situation is in fact similar to the panel-based control room, where an additional operator is always positioned at a distance from the panels to ensure good overview. It was suggested that the Plant Panel concept might in fact require an additional operator for this reason, but that it potentially better supports a single operator since the design can be made more compact and thus drastically reducing the amount of movement necessary to shift views.

Another issue was raised about how such an integrated display concept might go against the industry trend towards *separating* interfaces for normal and emergency operation into completely different workstations and areas of the control room.

4.3 Interaction

All participants found it natural to press the element they wanted to act on with their fingers. The interaction in the prototype was made through a popup "faceplate" with buttons adjoining the selected element. Some felt that this could hide important elements beneath it, while others had no concern about such a popup as long as they could move it freely (so long as it remained visually connected to the selected element). The popup seemed transparent due to the overlay on the printed prototype, and several participants stressed this as a nice feature. Other options for interaction were discussed, such as locating the faceplate below the display or on a handheld device. The main challenge with both these solutions was deemed to be the increased distance between object and interaction, which could potentially be confusing and cause errors.

Several participants could easily imagine wanting to do control actions both by approaching the display directly and while seated in front of it, using a mouse. The method they would choose would depend on circumstances. It was suggested that a wall display such as the Plant Panel is useful for casual interaction, but is probably less suited for intensive manipulation, such as removing control rods during a typical plant start-up. To address this issue a "cockpit" variant of the Plant Panel was proposed, where a small team seated in front of a shared display could monitor and interact with the process more comfortably.

4.4 Collaboration and learnability

A feature of this concept is that it enables operators to directly observe the activity of other crewmembers, since the interaction is performed by walking up to a spatially dedicated display. It might be argued that even if interaction was to be performed while seated in front of the display, as suggested by participants for some use-cases, the cursor might be emphasized to better support direct visibility for others. Several participants highlighted such direct visibility as a potential advantage in terms of collaboration and situation awareness. It was also commented that such a screen could be very useful for shared problem solving, especially in a mixed team. Several participants commented that the display was probably easy to learn for a novice, and as such useful as a common frame of reference when collaborating with non-control room staff. Mirroring the display at other locations in the plant (read-only versions), such as outage and emergency control centres, was also proposed as a potential advantage.

4.5 Screen size and resolution

Overall, the participants in the study expressed that display elements were comfortably viewed relative to their chosen viewing distance, but could perhaps be slightly larger to further improve legibility. The smallest text in the prototype was 0.3 cm high, which is within the recommended range for a viewing distance of 30-40 cm (approximate distance when standing close to the display). The interactive elements were minimum 1.5 cm wide (or high), which for example is 2-3 times the size one typically finds on a smartphone.

Based on this font size, and our own judgment from viewing the prototype at various screen resolutions, we estimate that a pixel density of 45 ppi would be sufficient to secure good legibility for realizing the prototype in its current form (ppi is a measurement that is independent of screen size). By comparison, a typical 65-inch "HD" touchscreen has a resolution of about 34 ppi, while a standard laptop computer has a resolution of 70-100 ppi. Naturally, if display elements are reduced in size the resolution needs to increase accordingly.

5 CONCLUSION

In this study we found some promising approaches to the design of wall-sized, interactive overview displays. We made a relatively simple prototype of the "Plant Panel" concept to investigate the feasibility of supporting both process monitoring from a distance and control actions up close. This method of rapid prototyping proved to be an effective tool for exploring such an innovative concept. We further tailored a test methodology to assess the overall feasibility of the Plant Panel idea, which demonstrates that the concept is potentially effective in terms of addressing known challenges with current computerized HSIs.

The study indicates particularly promising effects in terms of improved team collaboration and process overview. Being able to see, and directly perform control actions, on a comprehensive representation of the plant with all its interconnected systems was appreciated by most participants in the study, as was the potentially improved ability to observe the activity of other members of the control team. Three distinct "zones of use" emerged from the test. We termed them the "interaction zone" (0-1 m), the "monitoring zone" (1-3 m) and the "casual monitoring zone" (3-6 m). During the test, each zone served a particular control need associated with different situations. Designing with these zones in mind seems like a critical success criterion for displays of this kind, and can probably be applied to similar solutions as well.

Based on the prototype design and the current technological development in high-quality, interactive screen technology, we deem that an industry realization of this concept is feasible in a relatively near-future time perspective.

Participants in the study suggested several noteworthy improvements to the design, such as how the display could respond in smart and dynamic ways to user input and changing plant states, thus taking further advantage of the new capabilities of modern screen technology. The main concern was related to how users could potentially lose their overview when positioned too close to the display. Further iterations of the concept should address this issue particularly, as well as exploring the areas for improvements that were identified by users.

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