# RETHINKING GROUP-VIEW DISPLAY ALTERNATIVES

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## ABSTRACT

Main control rooms in new nuclear power plants feature large-screen displays with few, if any, exceptions. However, the technical basis for the prevalence of large-screen displays is unclear in the published literature, and has not been established, to our knowledge, in any proprietary study. On the contrary, the most thorough evaluation comparing large-screen displays to a redundant individual display condition demonstrated similar task performance and workload ratings.

This paper reviews existing group-view display design approaches found in the nuclear and petrochemical domains, in addition to emerging group-view display concepts such as touchscreen large-screen displays, tabletop displays, and mobile devices. These design approaches are reviewed with respect to the original (and still current) criteria established for group-view displays in the nuclear industry. Additionally, we consider the potential impact of evolving concepts of operation. How might these influence operator needs and the effectiveness of group-view display alternatives? This review provides insight into group-view display design approaches suited for present and future control rooms.

*Key Words*: Group-view displays, wall-panel displays, large-screen displays, control room design

## 1 INTRODUCTION

Group-view displays, as defined in NUREG-0700, allow "multiple personnel to simultaneously view the same information when they are in the [control room (CR)] or distributed throughout the plant" [1]. Large-screen (or wall-panel) displays (LSDs) are the dominant form of group-view display technology presently used in the nuclear power and peer domains (e.g., petrochemical) and are also widely used in command and control, security, and transportation. NUREG-0700 defines a LSD as "a device, which due to its large size, can be simultaneously viewed from multiple workstations and locations in a control room" [1]. At present, the archetypal LSD arrangement (in the nuclear domain, at least) consists of multiple screens located centrally in the control room (e.g., two 100" projection screens, or 6-8 50" LCD screens).

In the petrochemical domain, group-view display approaches reflect greater variety with respect to screen size and placement, information content, and information visualization. Group-view displays may take the form of massive LSDs placed well away from operators, LSDs at or near operator workstations, more traditional LSD configurations, or redundant individual displays in various arrangements. It is difficult to bound the LSD category in particular; in some cases, LSDs may not be wall-mounted (e.g., they may be standalone displays or ceiling-mounted displays). LSDs may be located in multiple locations throughout the control room. LSDs may be too small for all crew members to view from their respective work areas. Conversely, the LSD may be too large for anyone to view the entire screen at once.

Experiences with LSDs in the petrochemical domain are overwhelmingly negative [2]. Two factors, broadly speaking, contribute to this: 1) some aspect(s) of the design may have received insufficient design effort, or 2) the screen format may be inappropriate for the application. Some human-machine interface (HMI) designers report success with the redundant individual display approach, citing increased flexibility in HMI design and control room layout. Thus, the selection and design of LSDs continues to be a human factors issue.

While LSD implementations are now common, the technical basis for their use is unclear in the published literature, and has not been established, to our knowledge, in any proprietary study [2]. On the contrary, the most thorough evaluation of LSDs demonstrated similar task performance and workload ratings compared to a "local wall panel" display condition (i.e., redundant individual displays) [3, 4]. Participants reportedly preferred the LSD due to: 1) their own ability to view the display while away from their workstations and 2) the ability of other observers to view the display. Other LSD studies are comprised of integrated HMI verification and validation activities or usability evaluations. These studies do not compare viable group-view display alternatives. Therefore, apparent positive outcomes may be in spite of, rather than because of, the LSD. Alternative group-view display approaches may support operator performance more effectively than the LSD. These alternative approaches warrant further investigation, particularly in light of changing operator responsibilities and rapidly evolving technologies.

This paper seeks to provide an update and reexamination of existing nuclear industry guidance on group-view display alternatives and selection criteria. We hope this will aid in identifying which group-view display approach is suited for a particular application. A few cautions are warranted: 1) There can be substantial variability within the categories of technologies presented here, the full spectrum of which may warrant consideration; 2) It may be useful to consider solutions that lie at the intersections of these categories, as well as those that incorporate aspects of multiple categories; and 3) Numerous detailed design decisions, beyond the selection of the most appropriate technology, contribute to the success or failure of a group-view display system.

# 2 TRADITIONAL GROUP-VIEW DISPLAY ALTERNATIVES AND SELECTION CRITERIA

Brookhaven National Laboratory (BNL) Technical Report E2090-T4-4-12/94, "Group-view displays: Functional characteristics and review criteria," outlines the rationale for group-view display use, the categories of technological alternatives available at the time to fulfill group-view display functions, criteria for the selection between these alternatives, and a brief discussion of the trade-offs associated with these alternatives [5]. For context, these topics are summarized here.

## 2.1 Group-View Display Rationale and Functions

Most nuclear power plant main control rooms historically featured large, stand-to-operate, hard-wired analogue instrument panels. The panels provided a shared point of reference and an at-a-glance overview enabling operators to view many instruments in parallel [6]. As control room displays have become increasingly computerized, (at least) four negative consequences for operator crews have been identified: 1) difficulty maintaining awareness of overall plant status, 2) difficulty and time delay associated with accessing computer-based controls and displays, 3) difficulty maintaining awareness of crew member actions, and 4) difficulty communicating [5].

Group-view displays are intended to compensate for these negative consequences. Industry design guidelines [1, 5] identify four group-view display functions: 1) provide an overview, 2) direct operators to additional information, 3) support crew coordination (i.e., awareness of other operators while performing separate tasks), and 4) support personnel communication and collaboration (i.e., active participation in the same task as other operators).

## 2.2 Selection Criteria

The BNL report provides four criteria for selecting between group-view display hardware categories.

1. "Need for access to the group-view display – Does the nature of the operators' tasks require them to have immediate access to the group-view display?
2. "Need to view the group-view display from multiple locations in the CR – Can operator performance be enhanced by viewing the group-view display information from multiple, fixed locations in the CR or while walking around the CR?
3. "Ability to leave usual work area to go to a walkup display – Does the nature of the operators' tasks confine them to specific locations in the CR when the group-view display may be needed?
4. "Type of crew interaction required – Does the use of information presented on the group-view display involve independent actions of operators, verbal communication between operators, or both verbal communication and gesturing?" [5]

As suggested by the associated questions, the applicability of each of these criteria must be considered for the application under consideration.

## 2.3 Traditional Group-View Display Alternatives

The BNL report describes three categories of group-view display systems that were anticipated at the time: 1) large-screen displays; 2) redundant individual displays; and 3) walk-up display devices [5]. LSDs are the dominant form used in current practice. Redundant individual displays are less common but advocated by some HMI designers in the petrochemical domain (and supported by some furniture system manufacturers). As with LSDs, the appearance of redundant individual display systems varies. NUREG-0700 describes the category as "devices located throughout the [control room] in areas where operators often work" [1]. In some petrochemical applications, operator workstations consist of an array of displays, with a dedicated group-view display area that is identical at each workstation. Finally, walk-up display devices are described as "a smaller display device that is not located in the operators' immediate work area. Operators must walk to it from their usual work stations" [1]. This solution is not commonly observed, and we have difficulty envisioning this as the sole group-view display system in modern control rooms. Therefore, this alternative will not be further discussed.

## 2.4 Selection Trade-Offs

The BNL report offers the following considerations to select between LSDs and redundant individual displays: "1) the adequacy of space for these devices and 2) the flexibility that the LSD provides for viewing the group-view display from multiple locations in the CR compared to the redundant smaller displays which have more restricted viewing areas" [5].

# 3 REEVALUATION OF SELECTION CRITERIA AND TRADE-OFFS

The BNL report provides initial criteria for selection between group-view display categories, but a thorough and systematic analysis of additional factors is needed. We introduce some of those factors and consider the associated trade-offs for group-view display categories.

## 3.1 Reevaluation of Selection Criteria

The criteria from the BNL report remain relevant. We restate these criteria slightly: 1) *access from primary work area*, 2) *continuous access within control room*, 3) *access outside of control room*, 4) *support for coordination with independent operator actions*, 5) *support for verbal communication*, and 6) *support for gesturing*. Notably, we emphasize the need to consider viewability from all relevant locations – including access to the group-view display from outside of the control room – as well as the role of multiple types of operator interactions.

We propose additional criteria derived from issues reported in prior discussions with subject-matter experts [2]. These include: 1) *support for monitoring and supervision* 2) *impact to control room layout*, 3) *ease of redesign*, 4) *workstation ergonomics*, 5) *cost*, and 6) *visual appeal*.

1. *Support for monitoring and supervision* – Is the group-view display intended to support one or more supervisors or management personnel? Is the group-view display intended to support supervision of detailed operation, or to provide an overview, or both? Does the group-view display enable monitoring and supervision without disrupting other operator activities?
2. *Impact to control room layout* – Is control room layout affected by candidate group-view display technologies? Is operator coordination, verbal communication, ability to make eye contact, or ability to gesture impacted?
3. *Ease of redesign* – If subsequent display redesign is required, can this be readily achieved? If more or less group-view display area is required, can this be readily achieved?
4. *Workstation ergonomics* – Are operator ergonomic needs satisfied by candidate technologies? Are viewing and angles appropriate and comfortable for all personnel? If multiple viewing distances and angles exist for group-view displays, does this negatively impact operators' ability to view all content on the display?
5. *Cost* – What are the long-term costs associated with candidate technologies? Could high or unpredictable operating costs arise (e.g., projector bulb replacement or electricity for continuous operation)? Does the benefit of increased screen size or resolution justify increased costs?
6. *Visual appeal* – Are particular technologies favored due to management or marketing objectives? Might operator performance be negatively impacted as a result? Are there alternative, appropriate purposes for visually appealing hardware within the control room?

Evolving concepts of operation influence the weight assigned to each criterion during selection between group-view display alternatives. For example, decreasing crew sizes may reduce communication demands. Conversely, operators in smaller crews may work more closely together. In some applications, operators may incur responsibilities that move them away from workstations more frequently. In highly automated applications, the nature of operator collaboration may change, possibly involving increased verbal communication demands and fewer control actions made independently (see [7] for examples). Meanwhile in other applications, operators may perform most responsibilities independently at their respective workstations, with relatively little collaboration. These divergent trends suggest that the relative importance of each selection criterion will differ greatly in different applications.

## 3.2 Reevaluation of Trade-Offs

Table 1 outlines anticipated trade-offs associated with each category of group-view display. The relative importance of each criterion should be evaluated for each application. For instance, the importance of *support for verbal communication* will increase for applications where a large amount of verbal communication is anticipated, especially when nonverbal communication is anticipated to be less common. Additionally, there may be ways of mitigating the weaknesses of a particular category. For instance, one solution for mitigating problems with viewing distances and angles that may occur with large-screen displays is to place a larger screen further from operators. However, this solution may require a larger control room footprint and come at greater expense. This simple example reflects the complex interactions between the considerations presented here. Furthermore, it warrants repetition that categories of group-view display technology could conceivably be combined, obtaining the advantages of each and mitigating the weaknesses.

**Table 1. Trade-offs associated with traditional group-view display categories**

| | Large-screen displays | Redundant individual displays |
|---|---|---|
| **Access from primary work area** | ☑ Likely viewable from all workstations<br>☒ Viewing angles and distances may not be appropriate from all workstations | ☑ Viewable, provided placement at all workstations<br>☑ Viewing angles and distances appropriate |
| **Continuous access within control room** | ☑ Viewable from multiple locations<br>☒ Viewing angles and distances may not be appropriate from all areas | ☑ Viewable from multiple locations<br>☒ Viewable only in close proximity; may not be viewable in all areas |
| **Access outside of control room** | ☑ Additional displays outside of control room may be useful for discussion<br>☒ Additional displays outside of control room may not be practical, given space or cost limitations | ☑ Additional displays outside of control room may be useful for single operators to access information |
| **Support for coordination, independent operator actions** | ☑ May enhance coordination, if relevant content is provided | ☑ May enhance coordination, if relevant content is provided |
| **Support for verbal communication** | ☑ Ability for multiple operators to view display simultaneously may support verbal communication | ☒ Ability to see and hear other operators may be reduced with multiple tiers of screens |
| **Support for gesturing** | ☒ Limited support for gesturing, provided that operators can approach screen | ☒ Limited support for gesturing, provided that operators can approach screen |
| **Support for monitoring and supervision** | ☑ Ability to monitoring throughout control room may be beneficial<br>☒ Crowding in operator work areas may result in some configurations | ☒ May not allow supervision from all locations in control room<br>☒ Crowding in operator work areas may result in some configurations |
| **Impact to control room layout** | ☒ Control room layout may be limited to ensure operators can adequately view screen | ☑ Increased flexibility (e.g., circular outward-facing or inward-facing) may enable improved collaboration |
| **Ease of redesign** | ☒ May be challenging or expensive to redesign displays, or add or remove screens | ☑ May be easier or less expensive to redesign displays, or add or remove screens |
| **Workstation ergonomics** | ☒ Viewing angles and distances may present ergonomic challenges | ☒ Large arrays of screens may present ergonomic challenges |
| **Cost** | ☒ Up-front and operating costs likely to be moderate or high, depending on hardware characteristics | ☑ Up-front and operating costs likely to be lower |
| **Visual appeal** | ☑ Visual appeal may be preferred for management or marketing | ☒ May lack visual appeal |

Both classes of group-view display technology offer unique strengths and weaknesses that may make one better suited for certain applications. For example, large-screen displays may be better suited for applications where continuous access is required throughout the control room, or where a common frame of reference is needed for discussion. Redundant individual displays may be better suited for applications where operator interaction occurs infrequently, or primary using computer-based tools rather than verbal communication and gesturing. This solution additionally offers flexibility to control room layout, reduced costs, and may simplify subsequent redesign of displays or workstation configurations.

## 4 EMERGING GROUP-VIEW DISPLAY ALTERNATIVES

Emerging display technologies afford new design approaches for group-view displays. We discuss how the following categories of technology may be better suited to the criteria we have established: 1) touchscreen large-screen displays, 2) tabletop displays, and 3) mobile devices. Other categories may exist in the emerging technologies landscape; this list serves as an introduction rather than a compendium.

1. Touchscreen large-screen displays, similarly to LSDs, are large enough to enable operators to view them from multiple locations in the control room. Additionally, the touchscreen capability enables operators to interact with the display, possibly including navigation between displays, manipulation of display content, or the performance of control actions (see [8]).
2. Tabletop displays, similarly to touchscreen large-screen displays, allow operators to interact with them using a touchscreen interface. They are configured horizontally, or on a slight angle from horizontal. They are large enough to allow multiple operators to view or interact with them simultaneously; however, they are likely smaller than touchscreen large-screen displays. They can only be used in close proximity, and may be used in conjunction with other group-view display technologies (see [7]).
3. Mobile devices may include tablets or wearable technologies. These devices enable operators to view information throughout the control room and other areas of the plant. Wireless technologies are likely essential to the functionality of mobile devices, enabling real time data entry and other forms of collaboration in settings such as field operations.

These categories of technology are analyzed with respect to the group-view display selection criteria in Table 2.

**Table 2. Trade-offs associated with emerging group-view display categories**

| | Touchscreen LSDs | Tabletop displays | Mobile devices |
|---|---|---|---|
| **Access from primary work area** | ☑ Likely visible from all workstations<br>☒ Interaction requires moving from primary work area | ☒ Access or interaction requires movement from primary work area | ☑ Continuously available |
| **Continuous access within control room** | ☑ Viewable from multiple locations<br>☒ Interaction only in close proximity | ☒ Access and interaction only in close proximity | ☑ Access throughout control room |
| **Access outside of control room** | ☑ May be useful to operators in locations outside of control room<br>☒ Additional displays outside of control room may not be practical | ☑ May be useful to operators in locations outside of control room<br>☒ Additional displays outside of control room may not be practical | ☑ Continuous access outside of control room<br>☒ Access contingent upon wireless connectivity |
| **Support for coordination, independent operator actions** | ☑ May enhance coordination in close proximity<br>☒ May inhibit coordination if others cannot see screen | ☑ May enhance coordination in close proximity<br>☒ May inhibit coordination if others cannot see screen | ☑ May enhance coordination, if relevant content is provided<br>☑ May enhance coordination with crew outside of control room |
| **Support for verbal communication** | ☑ May enhance verbal communication between operators | ☑ May enhance verbal communication between operators | ☒ May inhibit verbal communication between operators |
| **Support for gesturing** | ☑ May enhance gesturing | ☑ May enhance gesturing | ☒ May inhibit gesturing |
| **Support for monitoring and supervision** | ☑ May enhance monitoring and supervision | ☒ May offer limited support for monitoring and supervision | ☑ May enhance monitoring and supervision from multiple locations |
| **Impact to control room layout** | ☒ May restrict control room layout | ☑ May be less restrictive to control room layout | ☑ May be suited for multiple layouts |
| **Ease of redesign** | ☒ May be difficult or expensive to add, remove, or redesign screens | ☒ May be difficult or expensive to add, remove, or redesign screens | ☑ May be easier or less expensive to add, remove, or redesign screens |
| **Workstation ergonomics** | ☒ Use may cause discomfort or fatigue | ☑ Use may cause less discomfort or fatigue compared to vertical configuration | ☒ Use may be challenging while operators perform other duties |
| **Cost** | ☒ Hardware and programming costs may be prohibitive | ☒ Hardware and programming costs may be prohibitive | ☑ Up-front and operating costs likely to be lower |
| **Visual appeal** | ☑ May be appealing for management/marketing | ☑ May be appealing for management/marketing | ☑ May be appealing for management/marketing |

Each class of emerging group-view display technology presents strengths and weaknesses that may make it better suited for certain applications. Notably, touchscreen large-screen displays and tabletop displays may be suited for applications with a high degree of interaction between operators, where operators may benefit from the ability to gather around the group-view display to engage in discussion, to manipulate the display, and to perform control actions. The vertical touchscreen large-screen display configuration may offer greater transparency for improved coordination and monitoring capabilities. However, the horizontal tabletop configuration may cause less fatigue, and may be easier to incorporate into various control room layouts. Finally, the mobile device category may be well suited for future control room concepts where operators need to interact while mobile and not physically collocated.

## 5 CONCLUSIONS

In nearly all modern control rooms, large-screen displays are used to fulfill group-view display functions, with little apparent consideration of alternative technologies. Redundant individual displays have several strengths that may make them better suited for some applications. Furthermore, several categories of emerging technologies offer advantages that may make them well suited for group-view display needs in future control rooms. We have introduced additional criteria necessary for systematically selecting between categories of group-view display technologies in both modern and future control room applications.

## 6 ACKNOWLEDGMENTS

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