THE INTERACTION BETWEEN LARGE SCREEN TECHNOLOGIES, OVERVIEW DISPLAYS & EFFECTIVE CONTROL ROOM LAYOUT: A WORKSHOP

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A significant challenge in the design of control rooms for operators of large industrial processes pertains to the use of large screen technology for the presentation of overview displays in a multi-console environment. Without an effective rationalization of the operator interaction requirements, control room designs can fail to provide an effective, efficient work environment. This workshop presents some common failure modes observed in recently designed control rooms with large screen technology. Moreover, the workshop covers specific design interactions between screen technology, console layout, console ergonomics, and display content that result in potential design trade-offs that impact the efficiency and effectiveness of the control room work environment.

Introduction

Large screen technologies installed in centralized control rooms is a growing trend in the refining and petrochemical industries. Large screen technologies are intended to enable operators to observe data in real-time to enable total surveillance of an entire production facility, identification of failures and emerging process interruptions, and facilitate response to those conditions in short order (Herrique, Lindegaard, & Hunt, 2008). However, as other researchers have found, such capabilities are more dependent upon the content of those displays rather than the technology itself (Roth et al., 1998). Without careful consideration of what should be displayed, large screen technologies can be little more than technological fascinations. Moreover, the introduction of large screen technologies can have a significant impact on the layout of workstation consoles that the numerous process control operators would use to control the various processing units in a refinery or chemical plant.

Human Centered Solutions (HCS) has evaluated the practices of off-console large screens in the control rooms of several refineries (Bullemer & Zapata, 2009). The off-console large screens were used to present overview information for console operators. The evaluation was requested because anecdotal reports from the operating sites indicated that
the operations teams were not using the large screens (or the displays shown on them). HCS evaluated the deployed screens both in terms of ergonomic design criteria as well as information requirements criteria for overview displays. Some of the reasons provide for why these screens were not effective included not having the correct information displayed and the information was displayed poorly or in a way incompatible with monitoring and orienting activities for which the operator should be using the overview display.

This workshop will cover the results of this evaluation in the context of the larger design considerations for an effective centralized control room that supports the situation awareness, communication, and collaboration between the operator console positions that inhabit the control room. In particular, off-console, large screen installations often result in a ‘theater-style’ control room where all consoles are facing the same wall, on which the large screens have been mounted. The workshop will compare and contrast this de facto ‘industry standard’ control room layout with other, arguably more effective, control room layouts. The types of console layouts in the control room that will be covered include: facing rows, horseshoe (semi-circle) facing in, and horseshoe facing out.

Design considerations for each of the layouts that must be weighed from a human-centered systems design perspective include, but not limited to:

- line-of-sight to other console positions,
- ambient noise management,
- ambient and task lighting requirements,
- foot traffic and access management,
- process unit interactions for which collaborations between console positions must be supported, and
- dual- vs. single-tier workstation design.

In addition, the workshop will cover a series of design requirement decision points that should be addressed before deciding on off-console, in-console, in-control room, or out-of-control room, large screen installations. The decision points address who the expected end user would be – and under what operational scenarios – of the large screens.

Depending on the answer, the large screens may be required in the control room only, in the control room, upset response leadership room, and/or field operator houses, or outside of the control room in a ‘war room’ and/or field houses only. The workshop will draw on examples and lessons learned from HCS’s research and practitioner experience of more than thirty-five control room feasibility studies and design projects.

**Operation Situation Awareness**

An important responsibility of console operators is to prevent and respond to abnormal situations by identifying the cause of the situation and executing corrective action in a timely and efficient manner. To effectively prevent and respond to abnormal situations when they arise, operators must proactively maintain their situation awareness of the process, that is, where the process is, where it is going, and how quickly it is going there (Bullemer & Reising, 2008).
Before the advent of digital, distributed control systems (DCS), operators, supervisors, and managers could quickly scan their plant’s pneumatic panel (the control wall) to quickly discern the overall health of their plant, and during a major upset everyone in the control room knew the plant’s status as all pertinent data required to maintain situation awareness was directly in front of them (Lyche, 1999). One of the first major casualties of the digital DCS revolution was the loss of this capability – of being able to view and assess all key operating parameters with a glance. Instead, the DCS platform provided the capability to show more detailed information about each individual operating parameter, although limited to a handful of points at a time.

DCS capabilities have continued to evolve to the point where we are now able to display detailed drawings of units, subsystems and equipment. However, plants are still behest by process and control failures that negatively impact production, safety, and the environment.

In order to improve operator situation awareness, recent trends have involved employing these capabilities in a manner to capture the information that was lost when the industry moved away from the pneumatic control walls – the ability to ascertain at a glance the health of the entire area under an operator’s span of control – the overview display, and some operating sites – particularly in the hydrocarbon processing industry – have even gone so far as to use large screens to recreate, in a sense, the ‘pneumatic wall’. However, implementation of overview displays, whether on a large screens or not, can lead to failure when these capabilities are designed without taking into consideration user information requirements as well as the other design requirements for the entire control room layout.

**Observations of Design Failures and Successes**

Many of the hydrocarbon processing sites HCS has observed with regard to the use of large screen technologies failed because these sites lacked an overall operator interface approach that addressed (1) on-console operator interaction requirements, and (2) the overall control room layout and ergonomics.

Operator interaction requirements define the information, action, and collaboration requirements that support operator situation awareness and abnormal situation response. In short, information requirements define what the content of the operator interface should be. After evaluating large screen installations at several sites, HCS observed that many sites failed to consider operator interaction requirements and as a result, the information displays presented on the large screens contained information content of little or no use to operators in maintaining situation awareness (e.g., Bullemer & Zapata, 2009). The decision to install large screens to present overview displays was made before a clear determination of who the intended users were and of what should be displayed for those users.

Control room layout and ergonomic considerations pertain to the design of the physical control room space (i.e., ceiling height, console configuration – single vs. dual tier screens, console arrangements, console-to-console collaborations, etc.). Some sites that were evaluated had mounted their displays in poor physical positions that required excessive head movement in order for operators to view the large screens. Other sites
mounted their displays with poor lines of site for operators over the top of their console displays. Still others had to sacrifice critical line of sight communications between console operators in order to orient all console positions towards a common large screen display.

Conversely, HCS found that sites that were successful in deploying large screen displays had certain design activities in common. Successful sites had an early, shared vision on how to use large screens and this vision was part of their overall interface and control room design strategies. In addition, successful sites were those where (a) their technical support staff was continually available following deployment to make improvements based on operator experience, and (b) individual operators took the initiative to improve use with good intuitions about what works.

**Interaction Considerations for Design Success**

Following a human-centred control room design methodology consistent with BS/EN/ISO 11064 (Ergonomic Design of Control Centers) can significantly increase the likelihood of a successful outcome. Control room design can impact – positively or negatively – operator effectiveness in a number of ways. In addition to other design intents, effective control room designs should:

- support operator job responsibilities and situation awareness
- support collaboration and communication amongst the operations team inside and outside of the control room
- minimize audible and visual distraction for each console position
- provide a comfortable and ergonomically acceptable work environment

When designing a control room, there are a number of factors such as these listed above that must be taken into account. First, the size of the console must be determined based on the site’s operator interface design philosophy and each operator position’s scope of responsibility. Second, consoles must be arranged in a manner that improves operator situation awareness, promotes collaboration, and minimizes the impact of noise or other distractions from the surrounding consoles. Third, the consoles themselves – and additional furniture, pathways, etc. – should be laid out within the control room in a manner that minimizes distractions from non-critical personnel traffic without limiting legitimate interactions with field operators and support personnel. Fourth, physical space requirements for each console, as well as space requirements between each console and permanent room structures (such as walls) must be assessed. Fifth, specific operational and ergonomic needs for the control room, such as console workstation requirements, ambient and task lighting, HVAC delivery, large screen technologies – either wall- or console-mounted, and so on, must be taken into consideration. While these factors are listed as sequential steps, in reality, the process is interactive and iterative. Taken together, these factors help identify not only the type of console configuration to employ, but also the arrangement of those consoles within the control room, and ultimately the overall control room design.

Successful control room designs ultimately support the console operator interaction requirements – whether that is interacting with the process, automation, technology, or other personnel. Therefore, effective design requires a good understand of these
interaction requirements. Interaction requirements are driven by the nature of the process, equipment composition, control system functionality, process interactions between console positions and the operator job responsibilities. Moreover, the console operator interaction requirements must be addressed in the design of the operating displays, console workstation and control room (see Figure 1). Each of these operator interface components is highly dependent and therefore, they must all be designed to support each other and ultimately the operator tasks.

Control room design decision points implemented from the HMI framework out to the control room layout include:

- **Operator Interface Philosophy**: The operator interface philosophy sets the strategic direction in terms of key design principles and associated design considerations of the HMI as well as development lifecycle considerations for the HMI.
- **Console Configuration**: Operator console arrangement for screens, keyboards, telephone(s), field radio keyset(s), hardwired switches, and so on that can impact operator efficiency and effectiveness.
- **Console Adjacency**: console-to-console co-location based on process unit interactions between consoles that can impact communication interactions between operators.
- **Control Room Layout**: Operator workspace separation and layout that can affect traffic of non-production personnel through the control room.
- **Environmental Ergonomics**: The control room ambient environment (lighting and noise levels, as well as climate control).

Although at first glance, starting with the operator interface philosophy may seem a non-intuitive place to start, when attempting to design a control room that truly supports the operator’s scope of work and considering that much of that work is monitoring, analyzing and controlling the process via those displays, the logic of starting with the operator’s true workspace becomes obvious.

Consequently, the need – or non-need – for large screen technologies should follow from:

1. Identification of the primary user of the information to be displayed and the tasks and decision making that is meant to be supported
2. Determination of requirements resulting from the analysis of information and collaboration needs for that user group and their tasks / decision making for the various modes of operation anticipated (e.g., normal operation, upset, start-up)
3. Assessment of trade-offs and compromises in the overall control room design (e.g., console design, console adjacencies, control room layout, environmental design) that might result from installing large screen technologies versus supporting the requirements identified in (2) with alternative solutions.
Trade-off Considerations for Control Room Designs

Table 1 presents a qualitative summary—based on HCS observations from practice—of how various design requirements are addressed by a simplified characterization of alternative control room layouts. The layout alternatives do not consider what might be called “console-mounted” large screen technologies, which are possible from today’s custom console furniture vendors. Arguably, the most effective control room layout from a systems-perspective that considers all design requirements would be the facing rows, particularly if large screen technology is to be installed (and mounted from the ceiling). Theatre-style layouts tend towards the negative while the horseshoe facing out tends towards the very negative. A possible compromise would be a horseshoe facing in when the facing row layout is not chosen.

Table 1: Qualitative summary of design requirement satisfaction for various control room layouts (assumes dual-tier screens for consoles in all layouts; LST = large screen technology)

<table>
<thead>
<tr>
<th></th>
<th>Theatre-style Rolls</th>
<th>Facing rows</th>
<th>Horseshoe, Facing Out</th>
<th>Horseshoe, Facing In</th>
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</thead>
<tbody>
<tr>
<td>LST wall-mounted</td>
<td>Negative</td>
<td>Positive</td>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>LST ceiling-mounted</td>
<td></td>
<td></td>
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<td>Lighting</td>
<td>Negative</td>
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<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td>Noise management</td>
<td>Negative</td>
<td>Positive</td>
<td>Very negative</td>
<td>Positive</td>
</tr>
<tr>
<td>Traffic management</td>
<td>Negative</td>
<td>Neutral</td>
<td>Very negative</td>
<td>Neutral</td>
</tr>
<tr>
<td>Viewing angles &amp; Visual (retinal) angle for large screen</td>
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<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Console adjacencies / Operational Communication</td>
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<td>Control room size</td>
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Trade-off Considerations for Large Screen Technologies

Researchers and practitioners alike have discussed the potential benefits of using large screen technologies in control room environments (Lyche, 1999; Roth et al, 1998). For those potential benefits, additional considerations are listed that should assist designers when weighing trade-offs when making a decision to deploy large screens and simultaneously selecting the most effective control room layout.

- Console operators can also anticipate possible upsets in their own area by monitoring the displays of the adjacent console’s display wall (Lyche, 1999); Support an console operator’s “At-a-glance” monitoring ability to get the “big picture” (Roth et al, 1998)
Can this be done just as effectively with console-mounted large screens or console-mounted 20” screens that present an overview display that incorporates information about upstream or downstream impacts of adjacent consoles?

- Console operators assist neighbouring console operators by making them aware of situations they may have overlooked (Lyche, 1999); Support a “common frame-of-reference” by the operations team, to support collaboration (Roth et al, 1998)

Can this be done just as effectively with console-mounted large screens or console-mounted 20” screens that present an overview display that incorporates information about upstream or downstream impacts of adjacent consoles?

- Head operator and production engineer now discuss the process during upsets by gathering data from the display wall without disrupting the console operators (Lyche, 1999); Support a “common frame-of-reference” by the operations team to improve collaboration (Roth et al, 1998)

Should this discussion take place in the control room at all, possibly creating to the background noise and distracting activity for console operators? Would it be more effective to have the shared display (possibly presented on a large screen) in an ‘emergency response room’, conference room, or other location outside of the control room, where the management team can congregate and monitor, without intruding on the console operations in the control room during the abnormal event?

- Outside operators are now more aware of the plant status. When they come back to the control room they quickly assess the plant status by scanning the display wall (Lyche, 1999; Roth et al, 1998)

Would putting these large screens outside of the control room better minimize the traffic and distraction to the console operators? Would it be better to provide these large screens in or near areas frequented by field operators, such as the permitting area or field house?

- Provide non-operator personnel entering the control room (such as Operations supervision or engineering) an ability to see the “state of the world” without interrupting the console operator (Roth et al, 1998); Support the situation awareness of the [sic] operations team and “accurate” mental model of the plant process (Roth et al, 1998)

Would putting these large screens outside of the control room, perhaps at the doorway to the control room, better minimize the traffic and distraction to the console operators? Would designing a supervisor’s overview display that they can call up in their own office be a more effective means of supporting that user?

- Console operators have more mobility in the control room, because they can monitor their process area from other locations within the control room (Lyche, 1999)

This could a benefit of wall-mounted large screen technologies, assuming that legibility is not an issue from the various viewing distances. However, can such
**Conclusions**

Overall, HCS project experience suggests that answering such trade-off questions while iteratively evaluating control room layouts and alternative solutions that may (or may not) provide the same operational benefit for the systems-level requirements will improve the chances for design success. The decision to use wall-mounted large screen is potentially costly not only because of the investment in that hardware itself and its associated lifecycle costs but also because of the additional floor space that may be required. We have been in at least three control rooms recently designed wherein HCS was called in after the sites decided to install wall-mounted large screens before end users and their information requirements were identified, and as a result, sites’ operators were not using the large screen displays. There is a lost-opportunity cost associated with this situation as well in that (i) the investment was made rather than in other tools or expenditures and (ii) operators are potentially not as effective at controlling and optimizing the process because they were not using the large screens. Finally, each site is spending more money now to make the large screens useful enough that operators will look at those displays, rather than just focusing on their displays on their console.

In summary, successful design of a central control room involves employing a systematic process that begins with first establishing the design requirements driven by multiple factors. Among these requirements is supporting operator situation awareness, collaborations, and communications. In part, establishing these requirements includes defining an overall HMI philosophy. This philosophy would include how large screen technology will be used within the overall HMI strategy to address the target user’s interaction requirements. If large screen technology is to be used, it is important that the information displayed on the large screen(s) support the target user’s tasks and decision making. Therefore, a comprehensive requirements analysis should be undertaken to identify information display requirements, including what would be displayed on the large screens. The term ‘target user’, rather than ‘console operator’ is used here because the possibility exists that the large screens are better suited to the requirements of other personnel, rather than the requirements of console operators when compared to alternative solutions for the console operator. The implication then is that these large screens may not be best installed in the control room itself, but rather in other locations within the operations environment. Following that, it is important to design console and control room layouts based on the identified needs and requirements, while conforming to proper ergonomics. Finally, it is important—when large screens are to be used—to provide training and lifecycle technical support to ensure effective deployment.
References


