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Operator Situation Awareness & Delivering ASM-compliant High Performance HMIs: Failure Modes and Success Factors

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Operator Situation Awareness & Delivering ASM-compliant High Performance HMIs: Failure Modes and Success Factors

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Introduction

In the last few years, many basic process control system (BPCS)[1] vendors and system integrators have promoted solutions with terms such as "high performance HMI", "operator situation awareness", and "ASM-compliant displays". Operator situation awareness is foundational to moment-to-moment process safety, and the human-machine interface (HMI) to the various plant automation systems used by the console operator is critical to supporting strong situation awareness. The Abnormal Situation Management (ASM®) Consortium recently published a revision to their guidelines document *Effective Console Operator HMI Design* (Bullemer & Reising, 2013) in response to many of the myths, misunderstandings, and missed opportunities that Consortium members have seen since that document was first developed in 2001.

The ASM® Consortium is more than vendors and service providers peddling their wares. Rather, the Consortium includes operating companies from the hydrocarbon processing and oil & gas industries. Annually, in response to their respective plants' business needs and challenges, these operating companies direct the Consortium's research and solution development program. More recently, the Consortium funded two specific research projects to support more effective delivery of ASM-compliant high-performance HMIs for their members. The first focused on what a prototypical design specification might look like for BPCS HMI upgrade or greenfield design projects. The second recent project focused specifically on the best practices that the ASM member companies were using for the overall change management work process on such HMI design projects, resulting in a new ASM Guideline document specifically on change management practices. That document is currently under review by and available for deployment for ASM members. This AFPM paper reflects many years' experience and learning of the ASM members from HMI design projects, as well as these two more recent projects.

This paper discusses the relationship between operator situation awareness and ASM-compliant high-performance HMIs to help improve the delivery and end-product of future HMI projects. To that end, the paper focuses on challenges, failure modes, and success factors that Consortium members have witnessed while conducting HMI upgrade projects that were attempting to apply the ASM HMI design guidelines to deliver high-performance HMIs that improve operator situation awareness.

As a simple generalization for the number and depth of challenges with delivering ASM-compliant HMIs that support and improve operator situation awareness and ASM performance, this paper characterizes three over-arching challenges:

[1] This paper uses the generic term "basic process control system" to cover both distributed control systems (DCS) and supervisory control and data acquisition (SCADA) systems.

- Misunderstanding what operator situation awareness (SA) is and how the HMI supports situation awareness
- Misunderstanding what an ASM-compliant HMI is and how to design it
- Ineffective change management over the course of the HMI design project

The paper expands on each of these three challenges as well as discusses success factors that ASM members have seen work on their HMI redesign and upgrade projects.

HMI Support of Situation Awareness

Situation awareness (Endsley, 1995) has a very specific definition within the human factors engineering discipline which comes from years of research on pilot error and performance in military and commercial aviation. In particular, "operator situation awareness" involves three stages of awareness: perception, comprehension, and projection. Each stage has specific implications for HMI design requirements. To say that an HMI supports operator situation awareness means that the HMI supports all three stages equally well, not just – for example – perception of alarms through gray-scale color-coding of all non-alarm information. Delivering an ASM-compliant high performance HMI entails supporting these three stages of situation awareness.

The ASM guidelines aim to do precisely this through the recommended practices of:

- Using different display types, organized in a display hierarchy representing a correct mental model that also supports fast, intuitive, easily-accessible navigation
- Integrated use of trending tools for Level 1 overview displays as well as for Level 2 monitoring & control displays and Level 3 and 4 equipment and instrument detail displays, all of which can support multiple stages of operator situation awareness
- Using effective information presentation techniques that include: down-selecting to a small set of BPCS vendor HMI shapes, defining a small number of custom shapes; defining effective display layout and visual-coding practices
- Conducting requirements analysis of appropriate content and presentation for the expected operator tasks and activities to be supported

Delivering a HMI that supports operator situation awareness then requires understanding what an ASM-compliant HMI is and how to design it.

Designing an ASM-compliant HMI

To aid understanding of what an ASM-compliant HMI is and how to design it, it helps to understand what an ASM-complaint HMI is not. It is <u>not</u> simply applying a new gray-scale color palette to the existing BPCS displays. It is also <u>not</u> just replacing the piping & instrumentation drawing and subsequent numerical indicators in existing BPCS displays with 'dashboard display of high-performance shapes' for each of those existing displays. An ASM-compliant high-performance HMI does incorporate effective visual coding that includes both a well-designed

color palette for background and foreground display content as well as effective use of high-performance shapes.

The following sections provide additional details on characteristics of ASM-compliant high-performance HMI and the necessary work processes that deliver positive console operator performance outcomes. However, in general, an ASM-compliant HMI must also support the following (albeit incomplete) list of console operator performance-shaping factors:

- Having the correct mental model of the process and equipment in their scope of control
- Having a correct, accurate, and timely understanding of the situation for process and equipment in their scope of control
- Monitoring proactively their scope of control, rather than reacting as alarms occur
- Simultaneous viewing of both the overall big-picture situation (i.e., the 'forest') as well as the details of specific process and equipment areas (i.e., the individual 'trees')
- Being able to navigate intuitively, quickly and easily between the displays that need the operator's attention for the given situation
- Responding accurately and in time with the appropriate operator actions on the correct process control points for the situation
- Having increased console operator alertness and simultaneously reducing eye strain

Understanding how to design an ASM-compliant HMI requires that the design goes beyond picking and choosing the easy or 'convenient' ASM guideline design principles. Importantly, how to design an ASM-compliant HMI starts with the definition of the HMI requirements for the scope of the console operators' work activity. The HMI scope includes not only graphics that appear on BPCS operating displays, but all of the console hardware and software platforms including communication devices.

Effective Change Management for HMI Development

Delivering an ASM-compliant high-performance HMI that supports operator situation awareness as the end-product of a HMI design project requires defining and executing an effective change management plan. In 2012, the ASM Consortium members conducted a study to understand key challenges to achieving an ASM-compliant HMI solution. In a survey study, twenty-five individuals across the member companies were asked to describe their experiences in HMI development projects in terms of specific challenges and successes in achieving ASM-compliant solutions.

The study identified five types of challenges:

- Operator or Stakeholder[2] Preferences
- BPCS/Technical Capabilities

[2] "Stakeholder" is defined, for the purpose of this paper, as individual job positions that have a vested interest in the results of HMI design practices, including—but not limited to—operators, HMI developer, BPCS engineering or those that update and maintain the HMI, operations training, and operations management.

- Developer Knowledge and Skill
- Allocation of Resources
- Understanding Operator Requirements

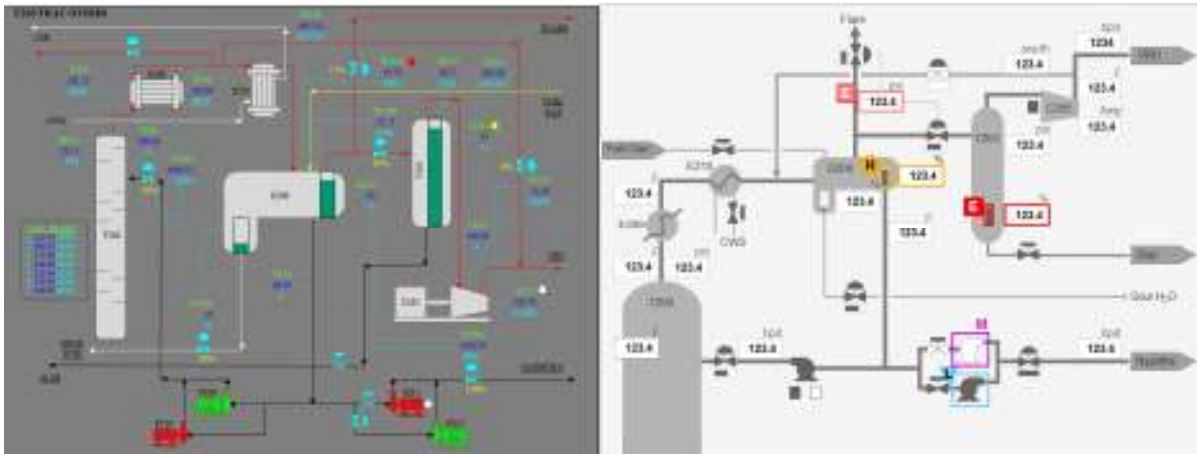
An additional challenge that ASM members identified in the subsequent HMI change management project that typically occurs before the other challenges in the overall HMI project sequence was

- Feasibility Stage HMI Design Definition

The remainder of this section describes each of these six challenges—approximately in the HMI project sequence in which they occur—as well as key elements of an effective change management plan that can lead to successful deployment of an ASM-compliant HMI solution.

Feasibility Stage HMI Design Definition

One of the most common failure modes in HMI upgrade projects is the fundamental assumption that like-for-like migration of existing displays is sufficient to achieve a high-performance ASM-compliant HMI. Typically, this failure is a result of assuming that changing the color palette of individual displays is sufficient to achieve an ASM-compliant HMI. However, the BPCS HMI design needs to consider how the whole set of BPCS monitors used by the console operator should be used together to deliver the desired high-performance ASM-compliant HMI (Reising & Bullemer, 2014). The difference between these two competing ideas is illustrated in Figures 1 and 2.



(A) (B)

Figure 1 (A) Existing display, prior to 'like-for-like' color palette migration project; **(B)** Migrated display, with basic ASM guideline color-coding and layout principles applied

Figure 1 illustrates the limited vision of a 'like-for-like' HMI upgrade project, where the assumption is that no other fundamental change in how the HMI design is evaluated or redesigned to achieve high-performance ASM-compliance is needed. In contrast, Figure 2 illustrates a 'holistic' evaluation of the console operator's situation awareness and interaction requirements, given the full complement of workstations and screens available.

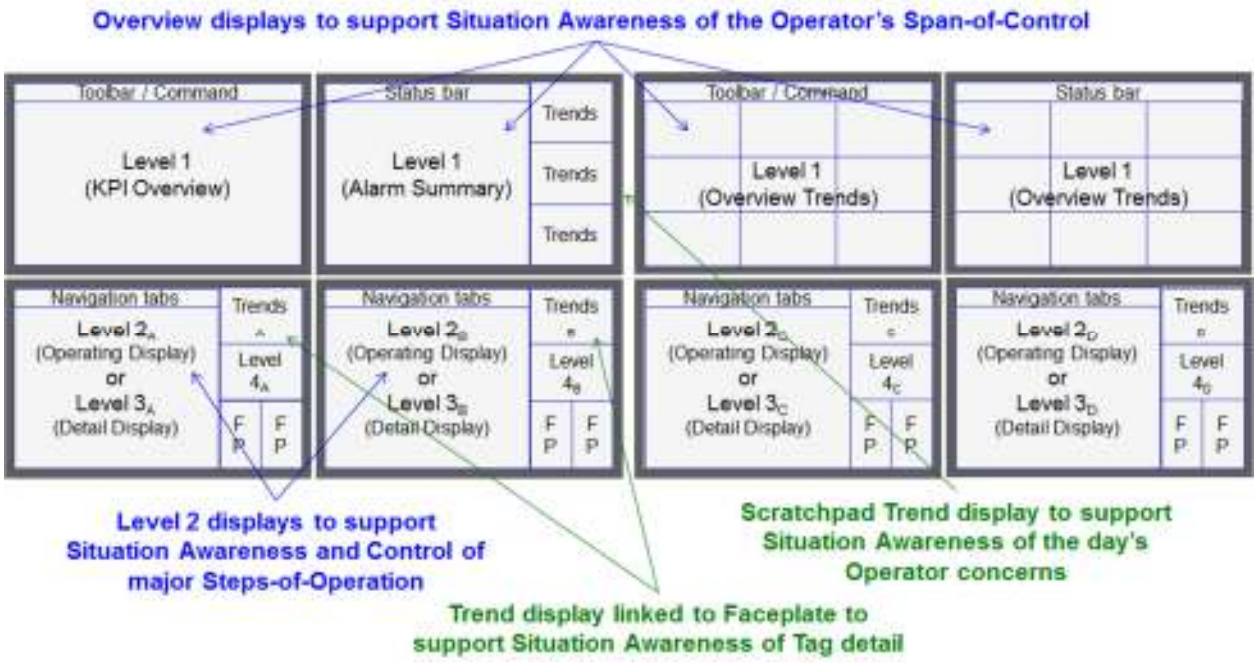


Figure 2 A conceptual illustration of an 'ASM-compliant' console operator HMI, and the simultaneous support for proactive operator situation awareness from 'big picture' to tag detail (in this case, with a drill-down navigation approach)

The ramifications for the failure mode of assuming like-for-like migration is that, typically, the HMI design definition outlined in the request for quote that is responded to by the main automation contractor (MAC) or engineering, procurement, and construction contractor (EPC) is too narrow and incomplete. The responding MAC or EPC will propose an effort that is not positioned to deliver a high-performance ASM-compliant HMI before the project essentially starts, resulting in ongoing struggles and change orders to go beyond the initial 'vision' defined in the request for quote.

Operator or Stakeholder Preferences

Survey respondents reported that often ASM-compliance is challenged because the stakeholder and/or operators prefer to keep their current design practices or because they believe their current design practices are better than the recommended ASM practice. The impact of this failure mode often leads to failure to implement the full recommended display hierarchy (i.e., Level 1 and Level 2 displays) and to the ineffective use of color as a visual coding technique.

To address this particular challenge, the change management plan for the development project should include a plan to engage all of the key stakeholders early in a project to agree on the vision and HMI philosophy. In addition, the development of the vision and philosophy should include a forum to educate the stakeholders on the human factors underlying the effective operator HMI design.

At the onset of a project, it is important to engage the key stakeholders so that they understand the human factors behind the recommendations on style, use of color, and use of text. Additionally, it is very important to make the operators and leadership teams aware of the operator performance benefits of the improved HMI design resulting from the ASM guidelines,

which are based on these human factors principles. Generally, when the stakeholders understand how these HMI design attributes influence human attention, perception, and cognition, they are more willing to embrace the recommendations in the operator interface philosophy. The leadership teams must be convinced and support the recommendations because, typically, operators will challenge the changes in the HMI design. Experience by ASM members indicates that the communication of human factors rationale behind the design requires that individuals formally trained in human factors engineering or psychology disciplines participate in that communication process, often in the form of on-boarding workshops.

The outcome of the vision and philosophy definition activity should be a HMI Philosophy and Design Style Guide document that defines the display types, screen use, navigation, alarm integration, BPCS shape selection, color palette, layout practices and HMI design work processes. As a result, the development decisions will be made on the agreed upon consensus solution rather than individual preferences of project team members.

BPCS/Technical Capabilities

Compliance with the ASM HMI design guidelines in this section is often challenged because of the technical capabilities of the BPCS or other platform elements. The challenges with respect to platform capabilities can be very specific to certain guidelines. Generally, the ASM guidelines that require more sophisticated technical capabilities are rated as priority 3 guidelines. However, to achieve an ASM-compliant HMI solution, one needs to be compliant with all priority 1 and 2 guidelines.

Achieving sufficient color contrast can be a challenge for a couple of reasons, most of which are technical. With respect to selection of colors for alarms, for example, some BPCS vendor platforms provide a limited selection of color choices, (e.g., limited to the eight system-color choices). These limited color choices may make it difficult to achieve optimal color contrast on the desired background color as well as for an overall foreground color palette beyond alarms, such as coding alerts, off-normal status, and other real-time information that requires operator attention.

Consequently, there will be design trade-offs between achieving compliance with both the ASM guideline on sufficient color contrast and the ASM guideline on use of color that maximizes readability and reduces unnecessary eye strain or fatigue. In addition, the hardware color settings on a set of monitors can vary within a console, which impacts the perception of contrast between colors in a color scheme. As a result, the HMI developer may need to spend effort on calibrating the console monitors. Also, as computer screens age, the quality of the color contrast can degrade over time. However, the developer has control over the color scheme used in the display shapes. The color attribute in the newer BPCS platform can often be defined as a global parameter, making it fairly easy to adjust the color scheme based on the actual appearances on the console screens.

Developer Knowledge and Skill

Compliance with the ASM HMI design guidelines is often challenged in this section because the HMI developer's knowledge and skills limit their ability to implement the recommended ASM practice, regardless of whether the HMI developer is a BPCS vendor employee or operating

company employee. In general, the developer's knowledge and skills can impact ability to achieve compliance with ASM guidelines. If the developer does not fully understand the intent and rationale underlying specific guideline recommendations, it is difficult to educate and convince the client or stakeholder of the value of the recommended practice. Beyond this general issue, there are some specific guidelines where HMI developer knowledge and skill may be the source of the challenge to achieve compliance.

For example, an ASM-compliant solution should include a structured navigation approach that provides direct access to primary displays and intuitive access to all other displays. Generally, the navigation scheme that is recommended by the HMI developer is comprised of the navigation techniques that either they are the most familiar with or are the 'default' techniques for the BPCS vendor platform. Failure to develop an on-screen, structured navigation scheme that supports the operators' mental model reflects a lack of knowledge on the part of the developer of effective techniques. Some developers' standard schemes involve pull-down menu structures and ad hoc use of onscreen navigation buttons. As a result, the implemented navigation structure depends on the developer's judgment as to where navigation buttons might be useful. The resulting displays end up with navigation buttons all over rather than in standard locations consistent with the mental model of the processes being monitored and controlled.

Allocation of Resources

The compliance with the ASM HMI design guidelines are often challenged in this section because of the initial allocation of resources to fund or support project development activities. Often management decides at the outset to migrate existing displays from the old platform to the new platform to minimize the cost of the project. Hence, as described above for the Feasibility Stage HMI Definition challenge, the project lacks the objective to try to improve on the display hierarchy, on additional display types (e.g., Level 2 displays), or on existing display content or layout. Migration projects generally do not include an evaluation on the number of displays or how they are structured or the content of display to support operator activities. The operating company simply provides a list of current displays to migrate to the new platform as part of a typical like-for-like migration.

Even when management decides to implement a new HMI framework, there can be issues with HMI developers getting access to key subject matter experts to ensure the content of the new operator interface meets the operators' requirements. The operating company organizations are often not willing—or not able after initial capital funding as a result of the Feasibility stage—to provide the budget to enable operator involvement in development activities and training programs. Often developers are expected to interact with operators while the operators are working on shift to obtain input or to train on the new HMI.

Hence, this challenge should be addressed in the change management plan similar to the first challenge. In the initial project feasibility phase, develop the HMI vision and philosophy with all key stakeholders, recognizing that high-performance ASM-compliant HMI requires more than a new color palette for existing displays. It is important to know where there is consensus on the vision and philosophy before the final request for funding.

Understanding Operator Requirements

The compliance with the ASM HMI design guidelines are often challenged because of the ineffective development of the operator requirements for the different console positions and the units that each respectively operates. The developer's approach to defining the operator requirements is important to achieving compliance with several ASM HMI design practices.

In many cases, the HMI developer simply does not attempt to determine the operator requirements beyond examining P&IDs and copying existing displays. In other cases, the developer fails to use effective methods to define the requirements such as asking operators what they would like to see in the display, rather than asking operators what the requirements are for different operational scenarios and tasks. For example, often as a result of this approach, the developer claims that there is a problem with developing effective console-wide process overview displays (i.e., Level 1 displays) or with developing effective monitoring-and-control displays (i.e., Level 2 displays). Without proper skills in requirements analysis, a HMI developer typically reports that operators want too much detail or data—or that they cannot agree on what should be included—in these new display types.

This challenge should be addressed with a change management plan to establish an effective interaction requirements methodology whereby the definition of requirements is based on an analysis of the operator decision making needs and operational activities rather than based on operator preferences, followed by an iterative review cycle with operations subject matter experts on the prioritized requirements and potential display mock-up layouts.

Conclusion

There may be many challenges and failure modes for a HMI design project. Some of the critical failure modes discussed or referred to above include;

- Defining the HMI project as like-for-like from the outset or failing to specify the design criteria for the desired high-performance ASM-compliant HMI and subsequent display types
- Relying exclusively on existing displays and/or P&IDs to drive display content during execution phase, rather than conducting operator interaction requirements analysis for the different display types
- Failing to conduct a gap analysis of the existing HMI against the ASM guidelines to identify both the gaps that should be addressed as well as the current good practices that should be retained in the new HMI specification (Note: preferences does not equal "good practice" in this case)
- Not conducting the appropriate consensus-building educational workshops that communicate the new proactive, situation awareness philosophy, the design rationale and the human performance science behind the HMI design with all relevant stakeholders, including – but not limited to – Operations management, Operations staff (e.g., console trainers, process specialists), console operators, BPCS support and control engineers, project manager(s), and HMI developers

- Allowing user preference to win out over high-performance ASM design principles, whether that preference is from management, engineering, operations, or some combination
- Not ensuring HMI developers are trained in the high-performance ASM design principles
- Not budgeting or scheduling for the necessary access to operations subject matter experts required for requirements analysis, display reviews, and for training prior to HMI commissioning

It is important to establish an effective change management plan early in the project to address these various potential failure modes and challenges for success. Some of the key success factors to address in the change management plan include a work process with the following elements:

- Educational visioning workshops on human factors in HMI design
- Consensus building on vision and philosophy before final budget allocation
- An early, clear definition of the HMI vision and expected design criteria to be delivered
- A HMI Style Guide document that communicates the consensus HMI vision and philosophy, including the critical elements such as display types, navigation, screen use, and visual coding and display layout practices
- Training for HMI developers as well as operators that are to use the HMI
- Requirements definition and design reviews with Operations input

Companies following such a work process improve their chances of delivering ASM-compliant high-performance HMIs that improve operator situation awareness and performance, and therefore improve the plant's process safety performance as well.

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