How Human Machine Interface (HMI) Impacts Business Performance in Industrial Sites

by John Krajewski

Executive summary

Most Industrial system Human Machine Interfaces (HMI) in use today are outdated. Trends such as larger systems and greater volumes of data compound the problem by rendering the operator task more complex. As a result, business performance and safety are compromised. In fact, operator mistakes account for 42% of abnormal situations in industrial systems. This paper provides guidelines for designing HMIs that promote safety and enhance operator performance.
How Human Machine Interface (HMI) Impacts Business Performance in Industrial Sites

Many industrial Human Machine Interface (HMI) designs are now obsolete as a result of trends such as larger control systems, greater volumes of data, increased levels of automation, staffing proficiency issues, and expanded use of remote operations.

The unfortunate consequence is that overall operator performance is negatively impacted. Inefficiencies and interruptions to business are occurring as a result of human error. These operational mistakes account for 42% of abnormal situations in industrial systems.\(^1\) Human error, therefore, is leading to economic loss and also threatens workplace safety.

Since HMI design, in most cases, was never planned to accommodate new workplace realities, loss of system availability is costing industrial systems 3-8% of their capacity.\(^2\) Today it is both possible and prudent to plan HMI designs around the concept of “situational awareness”, a methodology of best practices that allows overwhelmed and undertrained industrial system operators to perform their jobs with a minimal amount of errors. In addition to reducing economic loss due to unanticipated machine downtime, proper HMI designs based on situational awareness concepts can also help to increase safety levels. This paper explains how an industrial HMI situational awareness design approach can be 5 times more effective at recognizing abnormal situations than are traditional techniques.\(^3\)

A key goal in all industrial environments is to maximize systems availability (so that product quality and quantity can be optimized) while minimizing the costs (raw materials, energy, and waste). Advances in technology (see Figure 1) now allow for the three pillars of a situational awareness design—perception, comprehension, and projection—to be implemented in a cost effective manner to help support this goal.

This paper points out common mistakes in HMI design which lead to confusion and poor performance. Best practices for addressing the key issues of system complexity, retirement of operational experts, and the unintended consequences of increased automation and remote operations are also highlighted.

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1. https://www.asmconsortium.net/defined/sources/Pages/default.aspx
As industrial systems increase in level of sophistication and functionality, user interfaces into these systems have not evolved at the same pace to handle the additional complexity. In addition, fewer resources are available to staff these systems while the span of control of one operator is growing. The typical machine operator deals with greater volumes of data than he can manage. The data density per piece of equipment continues to increase in magnitude.

The potential for bodily injury is always present in such environments, especially when heavy machinery is in operation. Investigation into industrial accidents reveals that HMI design is often cited as a contributing cause of the accident. One would think that advanced alarm notification systems would help to communicate potential safety issues. However, in a recent survey of industrial systems users, nearly 70% of respondents indicated that "alarm overload" impacts their ability to properly operate the production process.⁴

The way the industry is addressing these issues from an HMI perspective is inadequate. HMIs that are used to operate industrial processes today were designed to maintain a particular operational state rather than to optimize the performance of a business. Table 1 summarizes key mistakes that have been made and some of the consequences that result.

<table>
<thead>
<tr>
<th>Common mistakes</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and economic goals not part of the HMI design process</td>
<td>Expected business value not delivered</td>
</tr>
<tr>
<td>Replication of Piping and Instrumentation Diagrams (P&amp;ID) for designing HMI window layouts</td>
<td>Design does not align with business goals</td>
</tr>
<tr>
<td>Designers pack in screen content as densely as possible</td>
<td>Causes operator information overload</td>
</tr>
<tr>
<td>Operators need access to many windows to execute a process</td>
<td>Slow operator reaction time and higher likelihood of error</td>
</tr>
<tr>
<td>Every physical element (like pipes) is included in the display regardless of relevancy</td>
<td>Valuable information gets lost among information of secondary importance</td>
</tr>
<tr>
<td>Design using elaborate visual approaches and ambiguous use of color</td>
<td>Impairs the operator’s ability to make the best decision</td>
</tr>
<tr>
<td>Overabundance of system alarms</td>
<td>Impractical for operator managing daily tasks</td>
</tr>
<tr>
<td>Data presented in tabular formats</td>
<td>Ineffective in exposing key trends in the data</td>
</tr>
</tbody>
</table>

The “Situational Awareness” methodology serves as a cornerstone of sound HMI design in complex industrial environments. Figure 2 illustrates how situational awareness addresses the 3 levels of human operator / machine interaction: perception, comprehension, and projection.

⁴ [link](http://www.automationworld.com/operations/why-nuisance-alarms-just-wont-go-away)
Most HMI applications only assist the operations teams in achieving the perception level. As an example for how information gets processed at this level, a numerical value represents a transmitter signal on the screen in a location that will identify the origin of the signal to the operator. How the operator processes this information varies based on the experience level.

Following along with the same example, at the comprehension level, the current value of the transmitter signal provided by the HMI enables the operator to attain a clear indication of the expected value from the transmitter.

In the real world, experienced operators have memorized the system parameters and have familiarized themselves with the expected values. Inexperienced operators have not. By providing this information up front, the HMI empowers an inexperienced operator to behave more like an experienced operator.

However, even the most experienced operators will have difficulty achieving the highest level of situational awareness: projection. In order to reach projection, the system must facilitate the determination of whether an action is required and also communicate the consequences of that action or inaction.

Fortunately, tools and techniques are available today that allow development of a true situational awareness HMI design to improve business operations outcomes. These best practices include goal-oriented design, effective window structure, proper color usage, actionable alarm management, and effective design elements. All HMI design efforts should begin with a standardized set of design elements that will be used throughout an application. The goal of these standardized symbols or displays is to communicate key information to a minimally trained operator. The displays should be characterized by a low level of cognitive load. The following sections review how this goal can be achieved.

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Figure 2
Three levels of situational awareness

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5 http://en.wikipedia.org/wiki/Working_memory
Goal-oriented design

One approach that enables inclusion of safety and financial goals during the design of the HMI, called Goal Directed Task Analysis (GDTA)\textsuperscript{6}, begins by identifying the major business goals of the system. An example of a business goal would be the reduction of energy usage costs. From this major goal, system sub-goals are determined. The sub-goals are more specific. An example of a sub-goal would be the reduction of steam utilization during the cleaning process. The specific decision that the operator is being asked to make should be understood and then the HMI design should incorporate that decision-making capability. This allows the operator to be easily trained on how to execute a decision. Each sub-goal must be carefully analyzed to determine how the operator will attain Level 1 perception, Level 2 comprehension, and Level 3 projection (see Figure 2).

Effective window structure

A common method for designing industrial HMI window layouts is to simply replicate the Piping and Instrumentation Diagram (P&ID) layouts onto a screen and then to provide navigational methods to each P&ID representation. Under this scenario, the design effort is minimal but business goals are rarely achieved. This is because P&ID’s were not created with the intention of having the operations teams efficiently executing on key business goals. Another traditional approach is to pack as much content on the screen as possible. This only serves to overload the operator. Research has shown that, on average, a person can process only about four chunks of data at a time.\textsuperscript{7} Thus, an effective HMI design has to allow an operator to scan as few items as possible to determine if an action must be taken. To best achieve this, the system needs to be modeled using a four level hierarchical approach (described below). Such an approach orients the operator to the appropriate awareness, action, or details depending on the window level being observed.

- **Level 1 – Area-wide overviews**

  The Level 1 windows will communicate to the operator the information required to attain the projection level of situational awareness (developed via the Goal Oriented Design methodology). Level 1 windows rarely look like the actual process but instead resemble an information dashboard as illustrated by the example in Figure 3. Level 1 windows should drive the operator awareness and facilitate a determination of when action or further investigation is required.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{level1example.png}
\caption{Example of a “Level 1” HMI screen design}
\end{figure}


\textsuperscript{7} \url{http://en.wikipedia.org/wiki/Working_memory}
• **Level 2 – Facility-wide overviews**

Level 2 windows enable operations staff to execute the required action or to perform the required investigation. Level 2 windows should be designed as the main operational windows. At this level operator actions are emphasized. Level 2 windows contain elements that are recognized as process elements but these windows should not contain every detail (see Figure 4). If an operator is attempting to execute a system wide start-up procedure, then a specialty Level 2 window should be created that consolidates, on a single window only the information / actions required during start-up. In traditional environments, an operator is required to move between many windows to execute a process. As a result, the process is slow and error prone. The Level 2 technique improves the success and efficiency of operating complex procedures.

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**Figure 4**
The “Level 2” HMI serves as the main operational window

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• **Level 3 – Detailed operating information**

The Level 3 windows most closely resemble the P&IDs of most systems and therefore are most likely to already be present in existing systems. Not every physical element such as pipes needs to be included as they rarely offer any valuable information (see Figure 5). These windows typically are used in support of Level 2 displays. For example, if Level 2 is displaying the initiation of the process sequences, then the Level 3 display can be used to identify and clear process interlocks. The Level 3 windows will provide access to status of all equipment associated with the Level 2 display. There may be more than one Level 3 display for each Level 2 display.

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**Figure 5**
The “Level 3” HMI resembles the P&ID screens of existing systems
• **Level 4 – Auxiliary information**
  These windows provide the supporting information for those tasks outlined in the Level 3 windows. These Level 4 windows provide trend analysis, event analysis, alarm analysis, loop tuning, help/procedural information and a variety of other content. Figure 6 provides an example that displays alarm summary and alarm history information.

![Figure 6](image)

**Figure 6**
*Example of a “Level 4” HMI that provides alarming notification information*

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**Proper color and animation usage**

Many HMI designs have been burdened with very elaborate visual approaches which, although visually attractive to the general public, often impair the operator’s ability to assess the current situation in an accurate fashion. In some of these cases, screens appear with three dimensional pipes and flanges that offer the operator no real information, gauges are configured with artificial glare (to look more real), and the color red has several meanings. These are all bad practices that should be avoided. Such an approach compromises the ability of the operator to make key decisions and to maximize business value.

Effective use of color can take several forms. Within the HMI marketplace there are sometimes inconsistent guidelines. An HMI designed for better situational awareness can look boring to some. However, a less flashy interface often represents a pragmatic approach that enhances the productivity and safety of operations. Vendors in the marketplace, such as Schneider Electric, deliver design elements (called symbol wizards) that conform to user defined color standards (also called element styles). Through proper use of color, the operator’s immediate attention can be focused on a point that indicates a process under duress that has deviated from the normal or expected state. Figure 7 on the following page demonstrates an efficient use of color. Rules can be adapted to meet the needs of the particular business.

While color should never be the only method used to communicate a value or state it can be a very effective tool for driving the user’s attention. An efficient HMI design establishes and strictly enforces use of color standards. Ambiguous use of colors should be avoided. If the same color has multiple meanings then the operator becomes confused. Click [here](#) for a video demonstration of how color can enhance operator situational awareness.

A significant factor to consider when choosing colors is that color blindness affects as many as 8% of men and 0.5% of women. In order to compensate for possible color blindness, the variation of color saturation should be leveraged. While color blindness affects the hues of the color perceived by the user, a color blind person is still capable of discerning variations in color saturation. When choosing a color palette, one approach is to use only grays unless an
abnormal situation is to be communicated. It is important to ensure that the operator be able to readily distinguish a normal state from an alarm state with no ambiguity.

Figure 7
Simple and standardized use of colors and graphics helps to boost an operator’s clarity of decision and responsiveness.

Actionable alarm management

Most HMI systems generate a volume of alarms that simply cannot be handled by the operators. In a recent survey, 52% of respondents said they do not perform an analysis of their alarm systems to identify its strengths and deficiencies. While it has been commonplace to use a very large number of alarm priorities, this practice requires the operator to understand thousands of alarm priorities which is impractical. Under stressful conditions, this excess of unfiltered information leads to judgment errors.

A more efficient approach is to set up a system that defines four levels of severity: critical, high, medium, and low. Each severity should be defined in the confines of a maximum alarm response time. For example 5 minutes for critical, 30 minutes for high, 60 minutes for medium, and 120 minutes for low. Times can be adjusted to fit the needs of the process. If the event does not require an action in the time defined for the low alarm severity then it should be changed to an event and removed from the alarm list. The configuration of every alarm should be reviewed to ensure that the alarm is only triggered when an operator action is required. This will minimize the potential for nuisance alarms.

- **Alarm borders**

  The concept of alarm borders implies a mechanism that defines visual displays comprised of unique color, unique shape and unique identifier. The purpose of these alarm borders is to differentiate the various alarm severity levels. For example, a critical alarm will display in the color red (and red is used for no other reason) and it displays a diamond shape (denoting category of alarm), and it displays the number 1 (denoting highest priority). This triple coding ensures that the critical alarms are clearly recognized. These borders can be used around any graphical element to draw operator attention. Since there may be multiple alarms associated with an element, these alarm borders summarize all alarm information on the associated element and identify the most urgent alarm state for that element.

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• **Alarm aggregation**

Alarm banners, which are a common vehicle for displaying alarms, only show a handful of the alarms and the larger volume of alarms of lesser severity can obscure the alarms of higher severity. By aggregating all of the system alarms in the same hierarchical manner as the navigation, however, it is possible to display the overall alarm state as badges (symbols with unique shape, color and identifier) right on the navigation element. This allows the operator to click on the desired button or badge to navigate directly to the associated graphic in order for the alarm to be handled.

Design elements refer to a design standard that is consistently applied. The elements need to be designed to reduce the cognitive load on the operator and to empower them to make sense of the information being presented. Vendors such as Schneider Electric deliver a standard set of these design elements in their products. This helps users to reduce application development time and also avoids an inconsistency in quality of the resulting applications. Having in place a standard set of design elements eliminates the need for additional user financial investment and removes a barrier to entry for those organizations who wish to migrate to new, high performance HMI systems. Click [here](#) for a video demonstration of how design elements help to augment operator situational awareness.

**Leveraging meters and dashboards to identify data trends**

“Smart” meters can play an important role in enhancing an operator’s ability to take data and turn it into actionable information. They help to indicate key alarm points, operational limits, optimal range limits, setpoints, and the current value in context. This helps an operator to identify, at a glance if a value is abnormal. When combined with meter-driven trend elements, HMIs can communicate both the current state and the trending tendencies. This allows the operator to project where a particular operational value will be in the future and determines if a pre-emptive action is appropriate. Trends are one of the most effective methods of attaining the projection level (highest level) of situational awareness.

As mentioned before, the tabular format for presenting data is ineffective in allowing operators who rely on HMIs to identify key trends in the values. Dashboard tools such as charts and graphs, however, are much easier for operators to quickly process. Instead of having to take in every value and perform mental calculations regarding data relationships, even the most inexperienced operator can easily pick up on data trends. In contrast experienced operators will rarely be able to discern this information with traditional HMI visualization techniques.
Conclusion

As modern industrial systems continue to grow larger, generate greater volumes of data, and introduce higher levels of automation, operations staffs shrink and are often expected to work from remote locations. This separation from the equipment is presenting further challenges. The operations teams can no longer employ the same number of senses (sounds, vibrations, smells) as when they were physically located near the equipment. The most experienced operators are retiring and replacements need to be brought up to speed quickly.

These changes require a new, modern approach to industrial process visualization. Instead of asking operators to focus on a large volume of process parameters, the data can be presented in a way that enables operator situational awareness. Rather than being viewed as labor resources, operations staff will be empowered as information craftsmen that are capable of making key business decisions in real time. Operators can avoid working in a reactive mode and be able to proactively extract business value from their industrial systems. The proper HMI design allows operations teams to shift their focus from straight operations to real time business management. The ultimate benefit is higher safety and better economic performance for those organizations who embrace the modern approach.

About the author

John Krajewski is Director of HMI/SCADA Product Management in Schneider Electric’s Global Solutions organization. Prior to assuming this role, Mr. Krajewski spent 5 years at Invensys as a domain architect with responsibilities for architectural and functional definition of InTouch and ArchestrA technologies. He has also worked as an application engineer in the systems integration industry focusing on pharmaceutical and biotech businesses. He joined Invensys Wonderware in April 2000 as a Senior Application Developer in the Product Marketing Department.