WHITE PAPER

HMI/SCADA design fundamentals: Building for situational awareness

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Executive summary:

Manage the increasing volume of process data using the latest digital tools Discover a results-driven approach to HMI design with situational awareness as a cornerstone where operators can benefit from superior operational context to help streamline and optimize operations.

Introduction

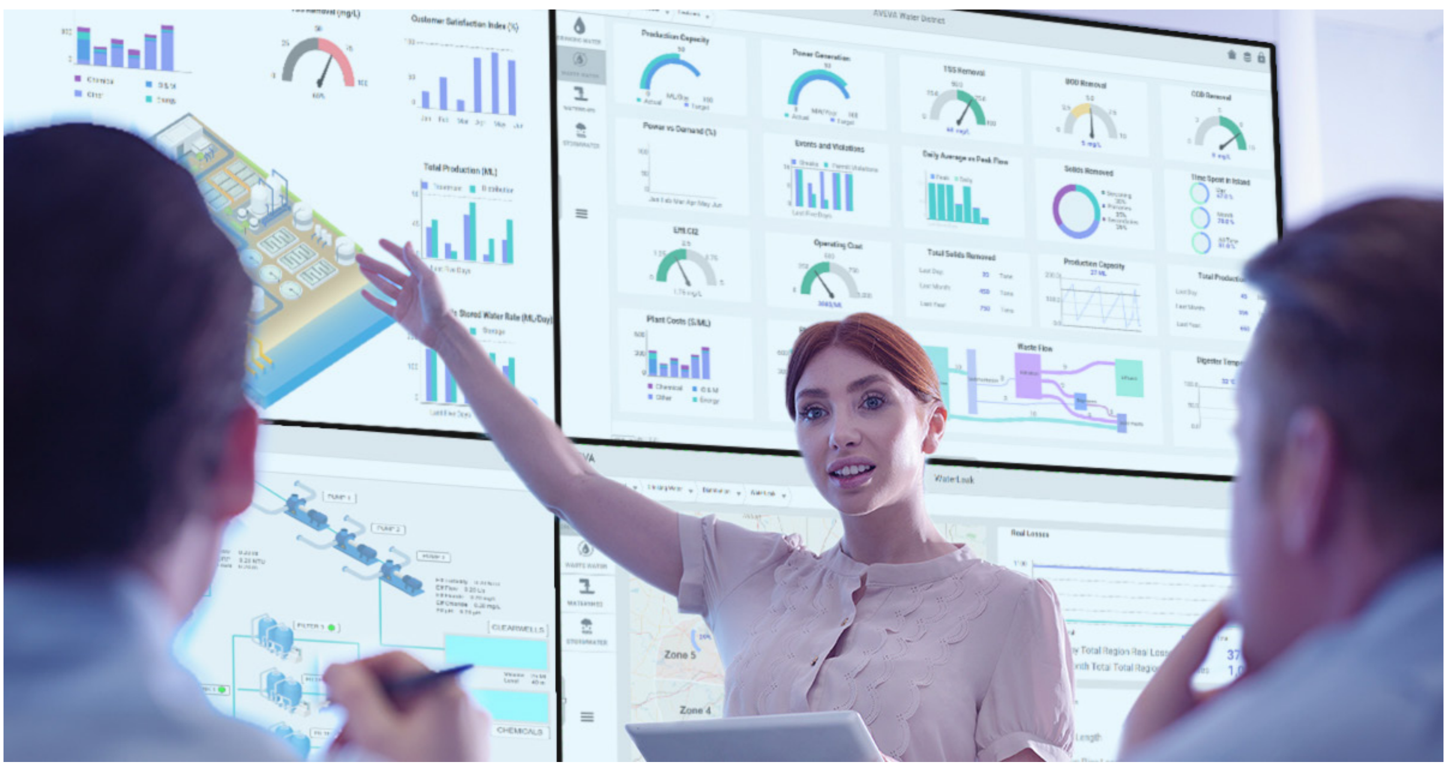
Organizations are always looking to improve their systems. One area where improvements can have significant impacts is quite literally staring users in the face: the human-machine interface (HMI) used to control and operate these systems.

By adding a diverse array of software tools used to control and operate industrial systems, operations teams can significantly improve both the business value and the safety of industrial systems with minimal cost investments.

Modern operations teams are using fewer resources to staff these systems, which increases the responsibilities of an operator. Moreover, the techniques to manage these systems lack standards and were not designed for managing an evolving volume of data and equipment.

The expense and reliability of networking systems continues to improve and, as a result, these integrated systems are commonplace today. Regardless of the business driver, the effect of these larger systems can easily overload the operator with much greater volumes of data than they can efficiently manage.

It's more imperative than ever that organizations work to build situational awareness into their operations control from the ground up. To do so, organizations should seek a suite of digital solutions that provides tools to reduce operator stress, automate manual or repetitious tasks, and drive a results-driven approach to operations control.



A results-driven approach

The cornerstone of improving the overall HMI design is to deliver situational awareness. Only by achieving situational awareness can the operations team make effective decisions that will deliver overall business success. Most HMI applications only assist the operations teams perceive information. HMI applications often only place a numerical value representing a current transmitter signal on the screen in a location that will orient the origin of the signal to the operator. How the operator processes this information will vary greatly based on their experience level.

The HMI should provide context that will help operators comprehend the information on their displays. In addition to the current value of the transmitter signal, the HMI should provide the operator with a clear indication of the expected value from the transmitter. Typically, the difference between experienced operators and inexperienced operators is that the experienced have memorized the system parameters and have familiarized themselves with the expected values.

By providing this information up front, you can empower an inexperienced operator to behave more like an experienced operator. However, even the most experienced operators will struggle to determine when to take action, let alone understand the consequence of that action or inaction. The good news is that there are tools and techniques available to improve the operations outcomes through goal-oriented design, effective window structure, effective color usage, actionable alarm management, and effective design elements.

Goal-oriented design

Achieving safety and economic goals are critical to delivering the expected business value. However, if the safety and economic goals of a process are not considered during the design of the control interface and implemented, then it is doubtful those goals will be achieved. To better achieve the benefits of an efficient system, safety and business objectives must be central to the initial design phase of the HMI application.

Effectively structuring information, using color and animation, and organizing alarms intuitively can provide much-needed role-specific context, allowing users to maximize their time and effort while reducing the possibility of operator error.

Effective window structure

An extremely common method of designing the window layouts of an industrial HMI is to simply replicate the piping and instrumentation diagrams (P&IDs) and then to provide navigational methods to each P&ID representation. By utilizing the P&IDs, the design effort is very low. However, P&IDs were not intended for the operations teams to use when achieving key business goals, and this design approach rarely achieves them.

Another common approach is to pack information as densely as possible. At first glance, this may seem logical, but this approach only serves to overload the operator. Research has shown that on average a person can only process about four chunks of data at a time.[3]

A solution should 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 in a Level 4 hierarchical nature as depicted in Figure 1. The windows and navigation in this structure will effectively orient the user to awareness, action, or details depending on the window level.

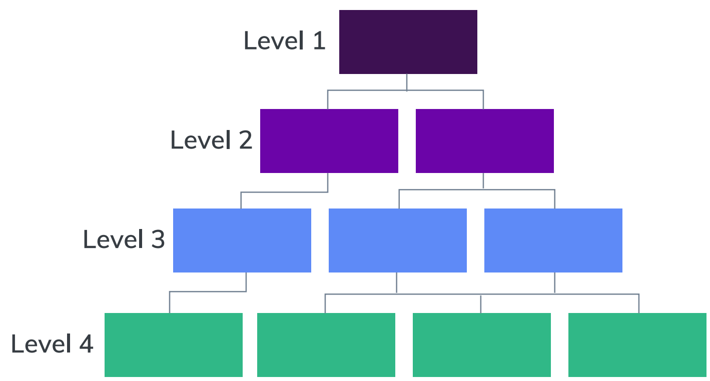


Figure 1: Effective HMI window structure

Level 1: Area-wide overviews

Level 1 windows should provide all of the key design elements that will communicate the information required for an operator to understand when to take action and an action's consequence.

Level 1 windows will very rarely look like the actual process but instead will more resemble an information dashboard as illustrated by the example in Figure 2. The most important aspect of the Level 1 windows is to drive operator awareness and facilitate a determination of when action or further investigation is required and guide access to the Level 2 windows.

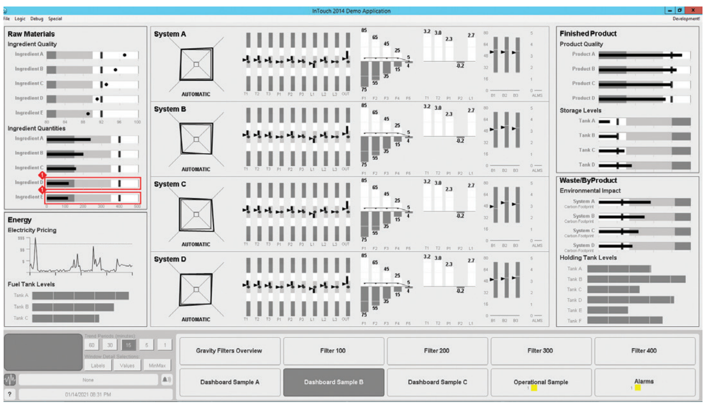


Figure 2: Level 1 Window example

Level 2: Facility-wide overviews

Once the Level 1 windows have created awareness of a need or prompted investigation, the next step is accessing the Level 2 window, which will enable the operations staff to execute the required action or perform the required investigation. Since the needs of HMI applications vary so widely, the division of awareness and action may be specific to the needs of your system.

A common technique is to design the Level 2 windows as the main operational windows. When designing the Level 2 windows, the operator's actions should be strongly considered. As shown in Figure 3, the Level 2 windows may contain elements that are recognized as process elements but are not expected to contain every detail. For example, if an operator is attempting to execute a system wide start-up procedure, then a specialty Level 2 window should be created that will consolidate the information and actions required during start-up on a single window.

Far too often the operator is required to move between many windows to execute a process, which can be slow and prone to error. This technique can dramatically improve the success and efficiency of extensive procedures. There may be more than one Level 2 display for each Level 1 window. When a more detailed analysis of the equipment state and detailed process values is required, the operator will have direct access to the Level 3 windows.

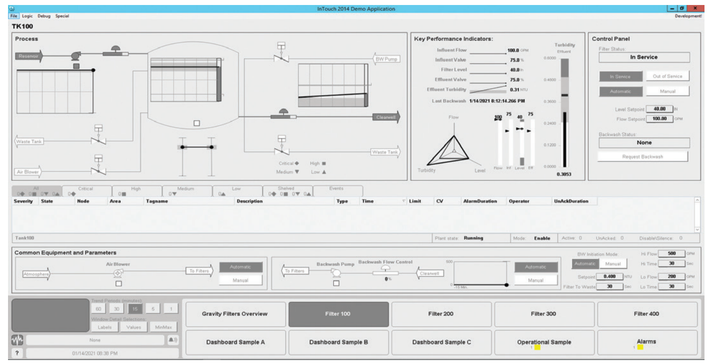


Figure 3: Level 2 window example

Level 3: Detailed operating information

The Level 3 windows are those that most closely resemble the P&IDs of most systems, and are the most likely to already be present for existing systems. An example of a Level 3 window is shown in Figure 4. Not every physical element (such as piping) needs to be included, as they rarely offer any valuable information.

These windows typically are used in support of the Level 2 displays. For example, if Level 2 displays are where process sequences are initiated, then the Level 3 display may be used to identify and clear process interlocks. The Level 3 windows will provide access to equipment status for all equipment in the scope of the associated Level 2 display. There may be more than one Level 3 display for each Level 2 display.

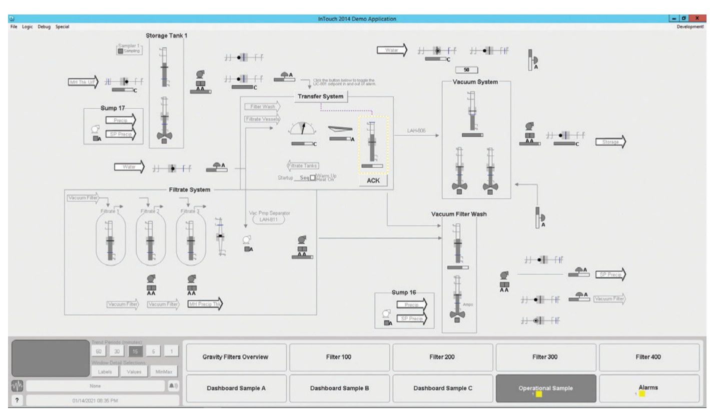


Figure 4: Level 3 window example

Level 4: Auxiliary information

There are a variety of activities that can be performed from the Level 3 Windows and the windows that provide the supporting information for those tasks are positioned at Level 4. Typically, these windows provide trend analysis, event analysis, alarm analysis, loop tuning, help/procedural information and a variety of other content.

In Figure 5, a Level 4 window example containing a combined Alarm Summary and Alarm History window is shown. There may be more than one Level 4 display for each Level 3 display.

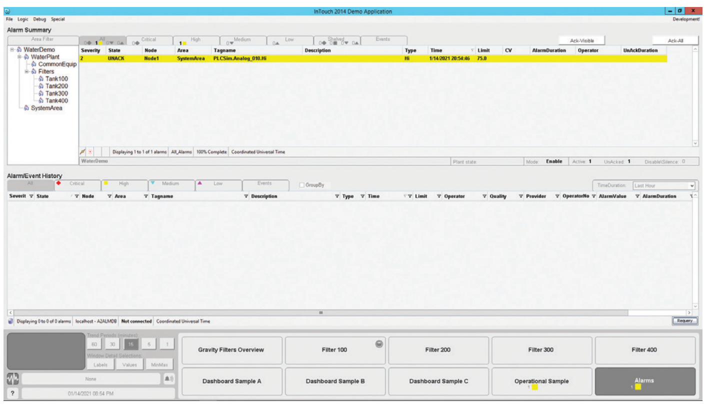


Figure 5: Level 4 window example

Color and animation usage

When computers were first put into use in industrial processes for the purpose of HMI they had only the most basic graphical capabilities. Eventually the computing systems gained graphical capability and HMI applications also began to leverage these improvements with little thought toward operator efficiency. It has become commonplace for HMI applications to act as a showpiece that emulates the process in a very visual manner, and often that visual presentation is used to justify the automation investment to key stakeholders.

However, these very elaborate visual approaches often impair the operator's ability to ascertain the current situation and ultimately make key decisions to maximize the business value of the application. In Figure 6 the process is displayed with three dimensional pipes and flanges that offer the operator no real information, gauges with artificial glare applied, use of the color red to represent several statuses, and a variety of other poor design practices.

The images shown previously in Figure 3, Figure 4, and Figure 5, demonstrate a much better use of color. There is a misconception that graphics designed for better situational awareness are not visually appealing. However, graphics that effectively communicate the state of the process to the operator are highly effective. A limited use of color draws operator attention to the point in the process that has deviated from a normal or expected state. When the system state is within expected norms, the process graphics should not emphasize and draw the operator's attention to these normal conditions, as that only serves to overload the operator's attention.

The utilization of animations should be with the deliberate intent of drawing the operator's attention and not just to make an impressive visualization. If operators are being distracted by spinning pumps or gradient shaded lights when they should be focusing on a process value drifting outside of operational limits, then the HMI is not likely to result in the improved ability to achieve the business goals or safe operation. While color should never be the only method used to communicate a value or state (up to 10% of people are colorblind) it can be a very effective tool for driving the user's attention. To ensure an optimal HMI design it is very important to establish and strictly utilize color standards.

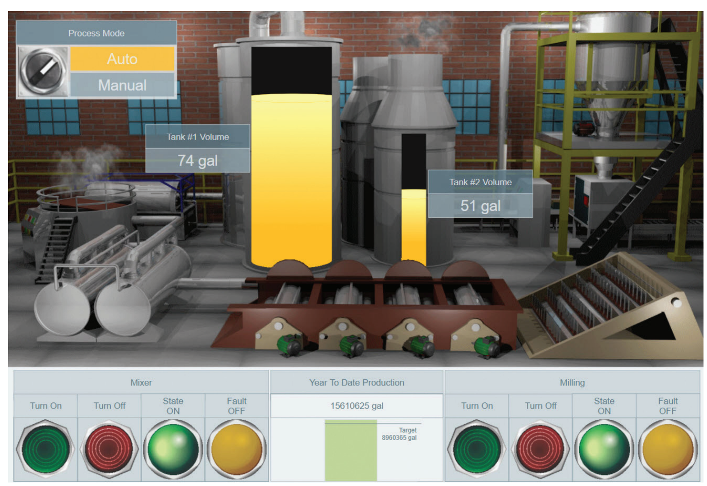


Figure 6: Example of poor color usage

Effective design elements

When designing and assembling an HMI that delivers effective situational awareness, it is important to begin with a standardized set of design elements that will be used throughout the application. These design elements can be symbols or displays that have been optimized for their ability to communicate key information to the operator with minimal training and cognitive load.

Trying to cover all the possible design elements is far too large a topic to address here. To illustrate the point, examples of meters with trends will be reviewed.

Meters with trends

The most common approach to industrial HMI design has been to draw a P&ID style process depiction and to adorn the graphic with numeric values to indicate the current value of transmitters in the field. These numeric values typically are accompanied with the tag name and units of the transmitter.

This method of presenting information has a large number of deficiencies that hinders an operator's ability to take that data and turn it into actionable information.

As shown in Figure 7, by indicating key alarm points, operational limits, optimal range limits, setpoints, and the current value in context, meters offer a great deal more information and are much more effective in increasing the operator's situational awareness.

With this representation the operator can identify at a glance if the value is abnormal. When combined with a trend element, not only can the current state be communicated but the directional movement with rate can allow the operator to project where that value will be in the future and determine if an action is appropriate.

Trends are one of the most effective methods of attaining the projection Level of situational awareness for a data value and should be used liberally in industrial HMI applications.

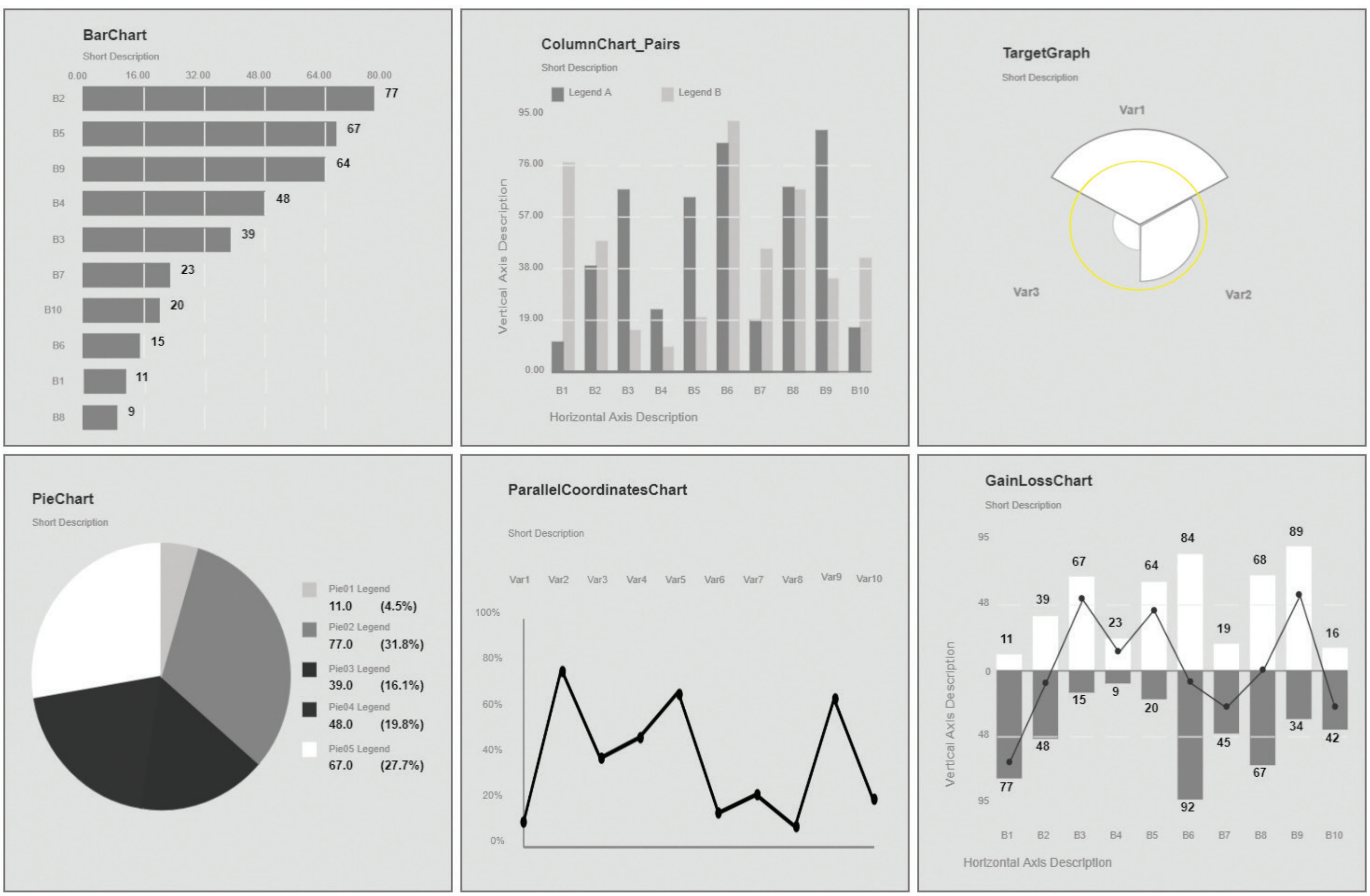


Figure 7: Attaining different situational awareness level with different design elements

Actionable alarm management

Alarms, by definition, are events that require an action. As such, alarms are a pivotal mechanism for driving operator actions. However, most systems generate a volume of alarms that simply cannot be handled by operators. In a recent survey 52% of respondents said they do not perform an analysis of their alarm systems to identify strengths and deficiencies.

From these results alone, it's clear that most systems have an opportunity to improve alarm management. To begin to address this issue, all configured alarms in the system need to be reviewed to evaluate the alarm's severity. While it has been commonplace to use a very large number of alarm priorities, this practice requires the operator to understand as many as thousands of alarm priorities, which is impractical. Under stressful conditions this lack of understanding can directly lead to errors in judgment.

The best practices in alarm management recommend the use of four severities at most; critical, high, medium, and low. These severities define the maximum response time for the alarms as five minutes, thirty minutes, sixty minutes, and one hundred and twenty minutes respectively, as shown in Figure 8. These times are a starting point and 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 to minimize the potential for nuisance alarms.

Alarm Severity	Expected Action Time Limit
Critical	5 Minutes
High	30 Minutes
Medium	60 Minutes
Low	120 Minutes

Figure 8: Alarm severities and expected action time limits

It may still be possible for the volume of alarms to be greater than can be processed by an operator, so methods must be used to allow an operator to identify which alarms must be actioned.

Alarm borders

To ease the process of determining which alarms to action, each of the severities will have a unique mechanism for visual display comprised of unique color, unique shape and a unique identifier. Figure 9 illustrates this concept as alarm borders. In the example of a critical alarm, it displays the color red (and red is used for no other reason), it displays a diamond shape, and it displays the number 1.

This triple coding ensures that the critical alarms are clearly recognized. These borders can be used around any graphical element to draw the operator attention. Since there may be multiple alarms associated with an element these alarm borders also summarize all alarm information on the associated element to identify the most urgent alarm state for that element.

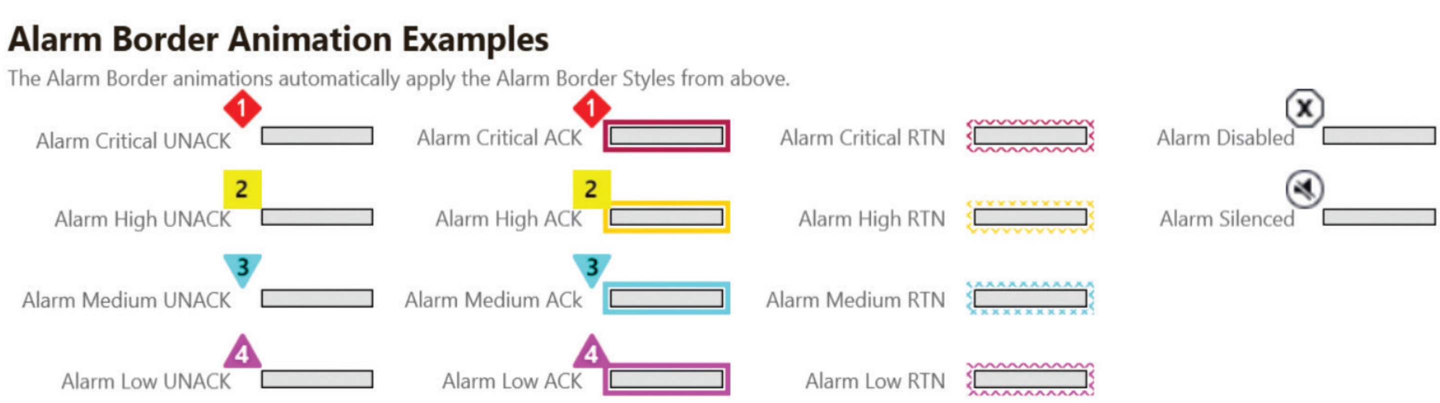


Figure 9: Alarm borders for each alarm severity

Alarm aggregation

A common practice in HMI design is to display an alarm banner to expose the current alarms to the operators but too often these alarm banners only show a handful of the alarms and alarms of a lesser severity can often obscure alarms of a higher severity.

By aggregating all of the alarms in a system in the same hierarchical manner as the navigation structure it is possible to visually display the overall alarm state as badges right on the navigation element as is illustrated in Figure 10. In this example, there are multiple alarms in the system and the operator can easily click on the desired button to navigate directly to the associated graphic to address the alarm.

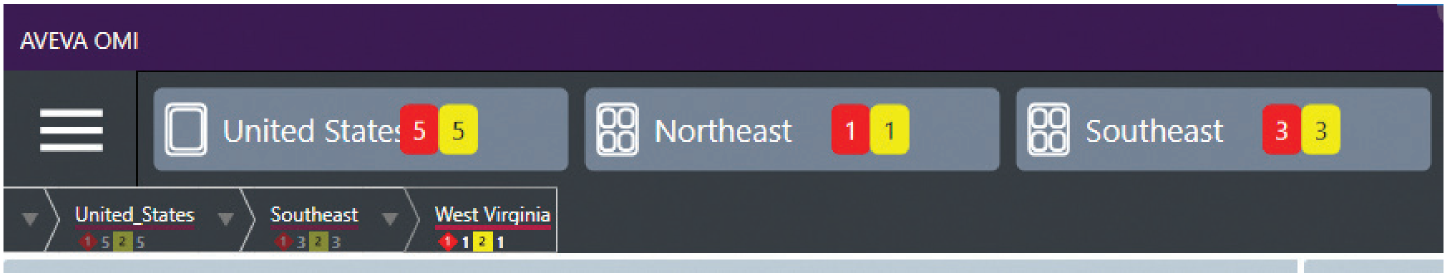


Figure 10: Alarm counts on navigation buttons

Alarm cause & response

With the increased levels of automation and rising prevalence of staffing issues, operator experience across all areas of the plant is increasingly difficult to achieve. An operator without the necessary expertise, or access to an experienced superior/peer, can be put under immense pressure when tasked with diagnosing and resolving situations they have never seen before.

Especially in cases of alarm floods, inexperienced operators can often focus their attention on the consequential alarms, rather than the root cause, further delaying the necessary steps required to resolve the situation and return the plant to normal operating condition.

By providing a quick-reference guide, as shown in Figure 11, to the potential alarm causes, recommended responses, expected response time, and possible consequences of their inaction, the operator is supported through unfamiliar scenarios so they can respond more effectively.

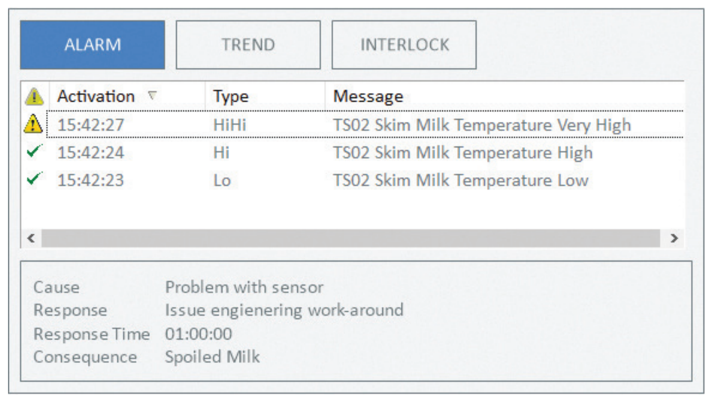


Figure 11: Alarm cause and response information

Alarm shelving

While regrettable, systems and instruments malfunction from time to time and require maintenance. A malfunctioning instrument often results in alarm conditions constantly being generated within the control system and acknowledging these repeated alarm incidents can quickly overload the operator, or worse, create undesirable learned behavior of automatically acknowledging the alarm.

Providing the ability to quickly shelve these nuisance alarms until they have been properly troubleshooted and fixed, as shown in Figure 12, is a mandatory requirement in alarming systems, and can be enhanced with support for shelving for a defined duration, as well as until a defined end date/time, rather than forcing the operator to separately calculate the shelving duration.

This should also be complemented with direct access to show all shelved alarms as shown in Figure 13, so these alarms can be individually restored after the necessary maintenance activity has been completed.

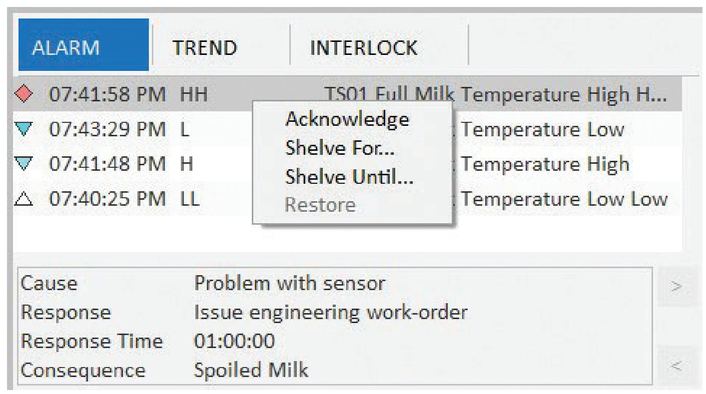


Figure 12: Alarm Shelving

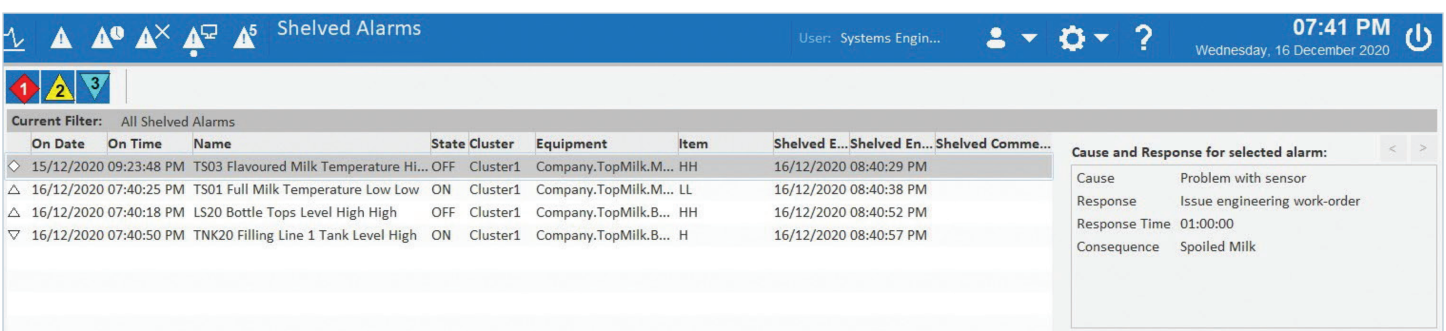


Figure 13: Display of all shelved alarms

Dashboard tools

One of the key challenges facing operators is how to take many values and quickly relate them to identify patterns or problems areas as well as associating them to business goals as they are changing in real time. In Figure 14, a table of numeric values is contrasted with the same data in various charts. The tabular form is very ineffective in exposing the key trends in the values. But, by using Dashboard Tools such as charts and graphs this information can readily be processed because the information can now be pre-attentively processed.

This means that instead of having to take in every value and perform mental calculations on the relationships, the relationships can be readily seen by even the least experienced staff member. In contrast, even the most experienced operators will rarely be able to discern this information with traditional HMI visualization techniques.

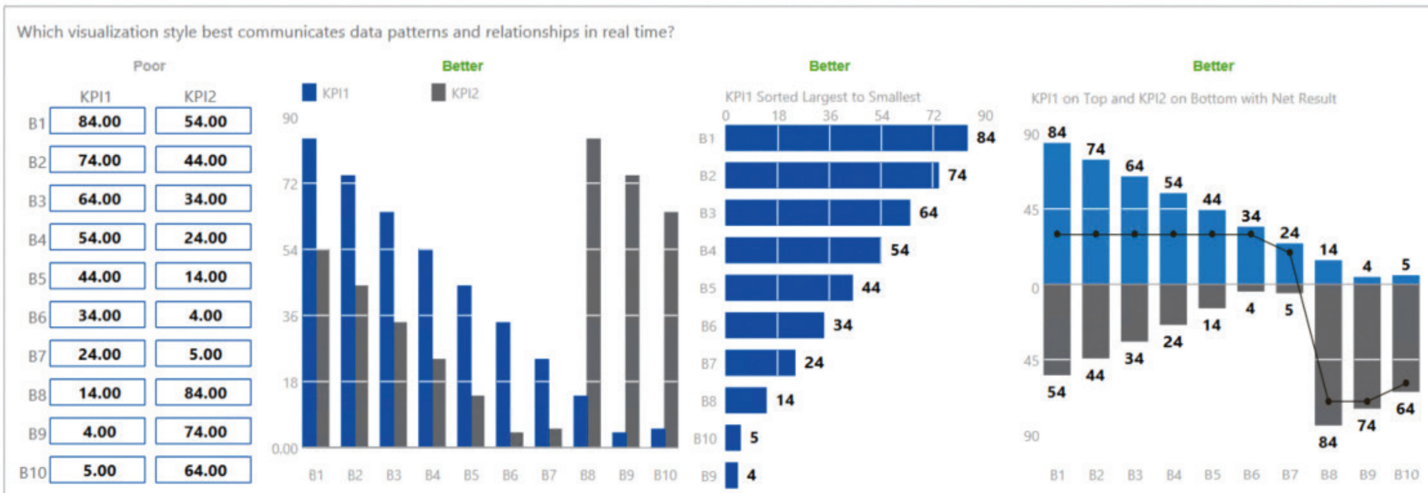


Figure 14: Exposing data relationships with a variety of design elements

Putting it all together

Modern industrial systems evolve, generate greater volumes of data, have increased levels of automation, suffer staffing issues, and are commonly operated from remote locations. These changes in the industry require a new approach to industrial process visualization.

A systematic approach to delivering situational awareness can greatly improve the likelihood of an industrial process achieving its business objective. Research studies have shown that these techniques make it 5 times more likely that an abnormal situation will be recognized before system availability is impacted than traditional techniques.

As industrial processes evolve, so will the design of the HMIs that are used to operate those processes. Figure 15 summarizes the key points of this evolution. Instead of asking the operators to focus on a large volume of process parameters, the data will be placed into context to deliver situational awareness.

Instead of viewing operations staff being viewed as labor resources they will be empowered as information craftspeople that will make key business decisions in real time. Instead of operating in a reactive mode the systems will be proactively managed to extract the maximum business value from those systems. And ultimately the focus of the operations teams will shift from merely operating the process to real time business management.

Past	Future
Process Parameters	Situational Awareness
Labor Resources	Information Craftsmen
Reactive Operations	Proactive Operations
Operating a Process	Real Time Business Management

Figure 15: Evolution of industrial process management

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John Krajewski, Sr. Director Product Management, John has 26+ years of experience in industrial automation and control systems. After acquiring a bachelor's degree in electrical engineering from the University of Delaware, John began his career working as a Control System Engineer in the potable water industry. Subsequently, John worked as an Application Engineer for a System Integrator who primarily focuses on the pharmaceutical and biotech industries.

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