Situational Awareness – The Next Leap in Industrial Human Machine Interface Design

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Executive summary

Wonderware® InTouch® has been the world's number one Human Machine Interface (HMI) for over 25 years and offers legendary ease of use, market leading innovation, unequalled investment protection, brilliant graphics, unsurpassed connectivity, the industry's best support and the broadest partner ecosystem.

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Introduction

The end users of modern industrial systems are constantly searching for methods of improving the availability and maximizing the efficiency of those systems without compromising the quality of their offerings or safety of their operations teams. One of the areas where improvements can have significant impacts in this pursuit is quite literally staring them in the face; the human machine interface used to control and operate these systems. By implementing improvements in the mechanisms used to control and operate industrial systems, operations teams can significantly improve both the business value and the safety of their industrial systems.

Continual Evolution

Over the past several decades the way people have interacted with industrial systems has changed dramatically as depicted in **Figure 1**. These changes were driven by the needs of the operations staff to improve the way that they use, manage, and maintain those systems coupled with advances in technology that facilitated those improvements. Changes like this will continue to naturally occur over the coming decades and will be driven by market needs coupled with advances in technology that address those needs and provide further opportunities for improvements. There are several trends in the current implementations of industrial automation human machine interface (HMI) systems that are driven by the current market needs. The trends that are currently driving the needs of industrial HMI application design are larger systems, greater volumes of data, increased levels of automation, staffing proficiency issues, and expanded use of remote operations. Each of these industry trends poses new challenges that can severely impact the ability for an operations team to achieve optimal business performance of their systems and safe operations.

Figure 1

An Illustration of Industrial Operator Interface Evolution

Larger Systems and the Increased Span of Control

The number of pieces of equipment used in modern industrial systems is continuing to grow as the cost of connected devices continues to fall, the capabilities of control systems to handle more equipment rises, the reliability and bandwidth of networks grows, and the demands of industrial systems are driven by the business needs of larger global markets. While the technology has enabled more and more pieces of equipment to be connected into an integrated system, the user interfaces into these systems have not evolved at the same pace to effectively handle this increase. Modern operations teams are using fewer resources to staff these systems and the span of control of an operator is growing while the techniques he utilizes to manage his system were not designed for such volumes of equipment.

Another key factor in the growth of systems has been the integration of much larger geographic areas into single systems than was possible or practical in the past. These larger systems allow users to make key operational decisions in real time, such as determining which production facility can produce a service or product at the least cost. The costs and reliability of networking such systems together continues to improve and in result these types of systems are commonplace today. Whatever the business driver, the end result of these larger systems is an overload of the operator with much greater volumes of data than they can effectively manage.

Greater Volumes of Data and the Increased Operator Load

Even as the number of pieces of equipment grows, the equipment itself is generating more data. In the past, a single transmitter may have generated only a single value connected into the monitoring system, but modern transmitters have additional diagnostics, onboard control, and many tuning parameters all of which have increased the data density per piece of equipment by multiple orders of magnitude. In many cases the user interfaces that contain this data have not been designed to optimize the operator interpretation of this data and further compounds the operator overload described in the previous section.

Increased Levels of Automation and the Unintended Consequences

In an effort to reduce the variability that human operators can introduce, more and more of the functions performed in industrial automation systems are automated by control loops and process sequences. These control loops and process sequences do offer the operator some relief from the factors already discussed that increase their workload but also have unintended side effects. As the operations teams are rarely involved in the design and implementation of such systems they have little understanding of the actions being taken by the control system and they become disconnected from the process. This can lead to an over-dependency on the system to drive operator behaviors through mechanisms like alarms or process interlocks. It is very common to hear that operations teams are reduced to either resolving interlocks or reacting to process alarms. In this type of environment the operator is performing reactively and cannot prevent disruptions but instead can only react to them when they occur.

Staffing Issues and the Impact on Proficiency

As these systems evolve, and the user interface design techniques are kept mostly the same as has been done prior to these evolutions, it has driven up the amount of time that it takes to bring a new resource on board and make them proficient in utilizing these systems. It is common to hear that it will take about 2 years for an operator to become proficient on a system. This extended period of time is required because the operators need to become experts on the system to make up for deficiencies in the system design. However, other conditions in the market are shortening the length of employment terms. Operations staff have more freedom to seek employment elsewhere, advance through their organizations and a variety of other causes that result in the average term of employment being near 2 years. This means that the operations teams are rarely at maximum proficiency. Another common concern in nearly every market is the impending retirement of the people who best understand the systems and the need to replace these experts and bring those replacements up to speed quickly. Something must be done to reduce the amount of time taken to achieve both operator proficiency and the variability in the quality of the process from one resource to another.

Remote Operations and the Challenge of Distance

With advances in networking technologies and reduction in costs for these technologies it is becoming more commonplace to remove the operator from the location where the process is actually taking place. This can often be driven by needs such as safety, optimizing staff utilization through increased span of control, or a need to locate the operations where subject matter experts are available. Whatever the reasoning, this separation is presenting further challenges to the operations teams as they can no longer employ the same number of senses as they could when they were located near the actual equipment. Many operators have described being able to understand the equipment and process status through sensing sounds, vibrations and smells alone. When the operations are remote and these additional senses are no longer able to be used, the operations team becomes even more dependent on the effectiveness of the HMI in communicating the state of the system or process. But too often the user interface has been implemented by recreating and animating the Piping and Instrumentation Diagrams (P&ID). But these P&ID's were never designed to overcome these challenges and as such this results in operators that poorly understand their systems and how to properly manage them.

The Impact of Human Error

With the above trends pushing the limits of operations teams, a common result is interruptions and inefficiencies in the process due to human error. These errors, or mistakes, account for 42% of abnormal situations in industrial systems.[1] These abnormal situations have a direct correlation to economic losses and safety concerns.

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[1] https://www.asmconsortium.net/defined/sources/Pages/default.aspx

Economic Losses

Abnormal situations in industrial processes directly result in economic loss due to a total or partial loss of the system availability, a reduced efficiency of the industrial process, or a reduced quality of the resulting product or service. Studies indicate that loss of system availability costs industrial systems 3-8 percent of capacity.[2] When summed up over the operational lifetime of a system the losses experienced due to process inefficiencies are likely much higher due to a reduced capacity or a reduction in the quality of product or service produced. These inefficiencies can result in a great deal of economic loss over the lifetime of a system. These losses can be prevented, and if an approach to improve HMI design is not taken, it is highly likely that the amount of loss will continue to increase. Far too often the business value of a process is poorly understood by the operations teams and completely ignored in the development of the HMI design.

Safety Risk

In many industrial processes there is significant potential for bodily injury or loss of life. There are multiple factors to consider for the overall system safety including, but not limited to, alarm management, control loop performance and the HMI design. In this document we will limit the discussion to the HMI aspects of safety while recognizing it is a much broader topic. In the investigation of many industrial accidents the HMI design has been cited as a contributing cause. One of the most common ways that HMIs communicate potential safety issues is through alarm notifications. However, in a recent survey of industrial systems users, nearly 70 percent of respondents indicated that alarm overload impacts their ability to properly operate the production process.[3] The techniques for alarm communication that are commonly employed in HMI design do a poor job of facilitating an operator to quickly assess the severity of many alarms and decide on the appropriate action. Without an improvement in how this critical information is being communicated and processed, the overall safety of the system is being compromised.

Business Value Model

In just about any industrial process there is a simple model than can be used to describe the business value of the process as depicted in **Figure 2**. While many processes vary in terms of the product or service they produce, just about any process has raw material and energy inputs and product/service and waste outputs. The key goal for the process itself is to maximize its availability while minimizing the costs (raw materials, energy, and waste) and maximizing the quality and quantity of the products and/or services provided by the process. Unfortunately however, the HMIs that are used to operate most of the industrial processes in the world were designed with the main purpose of achieving or maintaining a certain operational state rather than optimizing the performance of the business. In order to best drive the business value of these systems the design of the system must take the business values into account. The process needs to be analyzed to determine which decisions the operator should

Figure 2
Generic Industrial Process Business Value Model

be making in order to drive the desired business value. Once the decisions that the operations team should be making are known then the user interface should be designed in a manner that facilitates those decisions and drives the operator to the desired action.
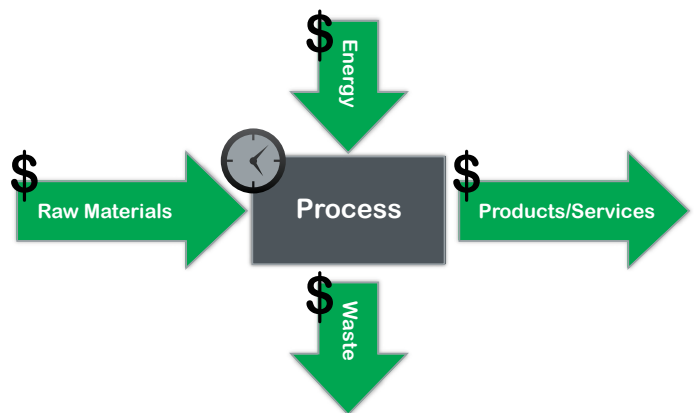
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[2] http://www.asmconsortium.net/Documents/2007%20ASM%20Overview%20--%20MKO%20Symposium.pdf
[3] http://www.automationworld.com/operations/why-nuisance-alarms-just-wont-go-away

A Results-Driven Approach

The cornerstone of improving the overall HMI design is to deliver Situational Awareness (SA). Only by achieving the proper Situational Awareness can the operations team make effective decisions that will deliver overall business success. In **Figure 3** situational awareness has been broken into 3 Levels; perception, comprehension, and projection. Most HMI applications only assist the operations teams in achieving the first Level; perception.[4] HMI applications far too often will 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 the experience Level. The HMI can provide information that will facilitate attaining the second Level of situational awareness; comprehension. In addition to the current value of the transmitter signal the HMI can provide the operator with a clear indication of the expected value from the transmitter. Typically the difference between the experience operators and the inexperienced operators is that the experienced operators have memorized the system parameters and have familiarized themselves with the expected values. By providing this information up front it is possible to empower an inexperienced operator to behave more like an experienced operator. But in most cases even the most experienced operators will inconsistently achieve the highest level of situational awareness; projection. In order to reach projection the system must facilitate determining if an action is required and 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.

Figure 3
Three Levels of Situational Awareness
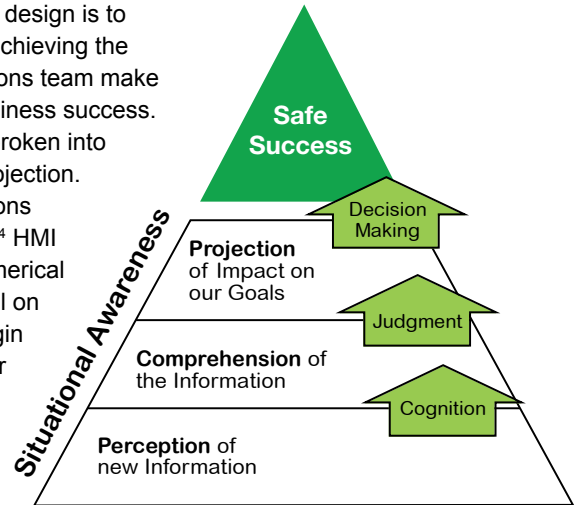
Goal-Oriented Design

Above we described the needs of achieving safety and economic goals in order to deliver the expected business value. However, if the safety and economic goals of a process are not considered during the design of the interfaces by which the system will be controlled and operated then it is doubtful those goals will be achieved. To better achieve these goals, they must be strongly taken into consideration during the design of the HMI application. One method for assisting in designing and identifying the goals of an application is called Goal Directed Task Analysis (GDTA)[5]. As depicted in **Figure 4**, the GDTA process begins with the major business goals of the system. An example of a business could be to minimize the cost associated with energy usage. From these major goals an analysis of the system will be performed to determine the sub-goals. The sub goals will be more specific goals that are directly related to the process such as minimizing steam utilization during the cleaning process. These sub-goals need to be actionable. It must be understood what decision the operator is being asked to make and then design the HMI so that an operator can be easily trained on how to make that decision and ultimately achieve the original goal. For each sub-goal it must be considered how the operator will attain Level 1 perception, Level 2 comprehension, and ultimately Level 3 projection. Only once the business goals of a system are clearly understood can the system itself be designed to achieve them.

Figure 4
Goal-Decision-SA Requirement Structure
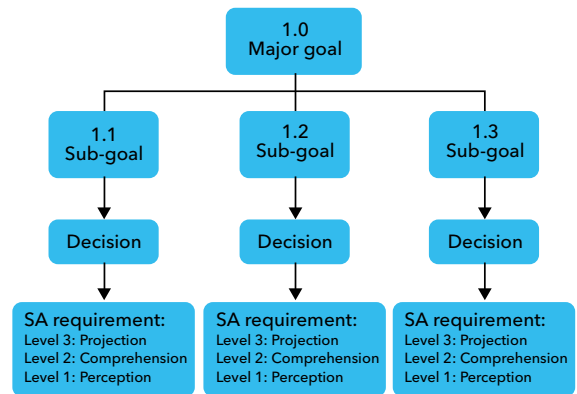
[4] http://en.wikipedia.org/wiki/Working_memory
[5] Mica R. Endsley, Designing for Situation Awareness: An Approach to User-Centered Design, 2nd Edition, pg. 65

Effective Window Structure

An extremely common method of designing the window layouts of an industrial HMI is to simply replicate the P&ID's and then to provide navigational methods to each P&ID representation. By utilizing the P&ID's the design effort is very low but the issue with this approach is that the P&ID's were not created with the intention of the operations teams achieving the key business goals and as such this design approach rarely does achieve them. Another common approach taken when there is a great deal of information contained within a system it to pack in the content as densely as possible. At first glance this may seem logical but in actuality this approach really 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.[6] With this in mind we must use an approach that will 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 4 Level hierarchical nature as depicted in **Figure 5**. The windows in this structure will effectively orient the user to awareness, action, or details depending on the window Level being observed.
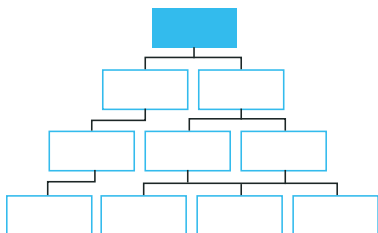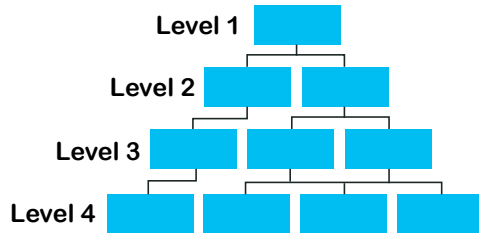
Level 1 – Area-Wide Overviews

The top of the structure or Level 1 windows will provide all of the key design elements that will communicate to the operator the information required to attain the projection Level of situational awareness for the key sub-goals identified in the GDTA (performed as part of the Goal-Oriented Design). 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 6**. The most important aspect of the Level 1 windows is to drive the operator awareness and facilitate a determination of when action or further investigation is required and facilitate access to the Level 2 windows.
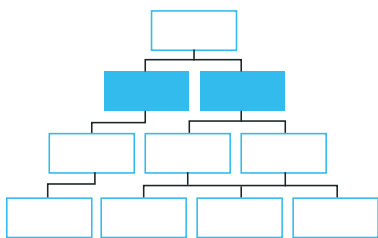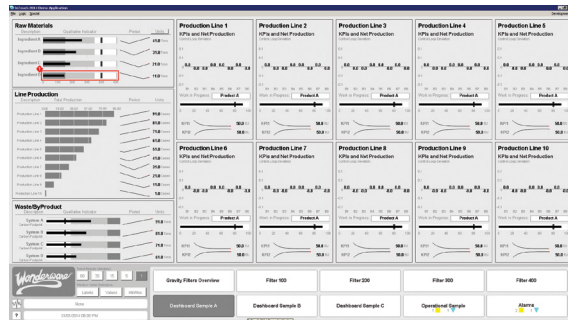
Level 2 – Facility-Wide Overviews

Once the Level 1 windows have created the awareness of a need or investigation to occur the next step is to access 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 actions should be strongly considered. As shown in **Figure 7**, 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 all of 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

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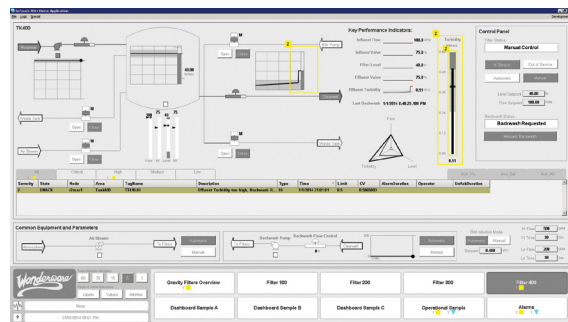
[6] http://en.wikipedia.org/wiki/Working_memory

slow and error prone. 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.
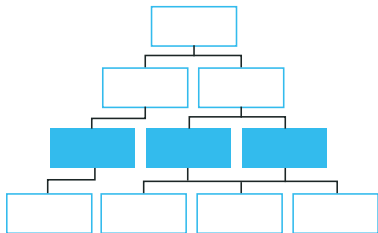
Level 3 – Detailed Operating Information

The Level 3 windows are those that most closely resemble the P&IDs of most systems and therefore the most likely to already be present for existing systems. An example of a Level 3 window is shown in **Figure 8** and from there it can be seen that not every physical element such

Figure 8
Level 3 Window Example

as pipes 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 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 of the equipment in the scope of the associated Level 2 display. There may be more than one Level 3 display for each Level 2 display.
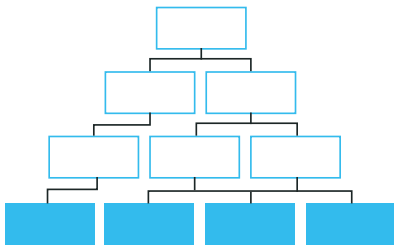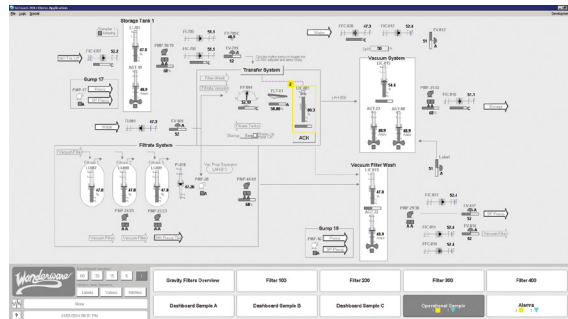
Level 4 – Auxiliary Information

There are a variety of activities that can be performed from the Level 3 Windows and the windows

Figure 9
Level 4 Window Example

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 9** 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. Level 3 – Detailed Operating Information.
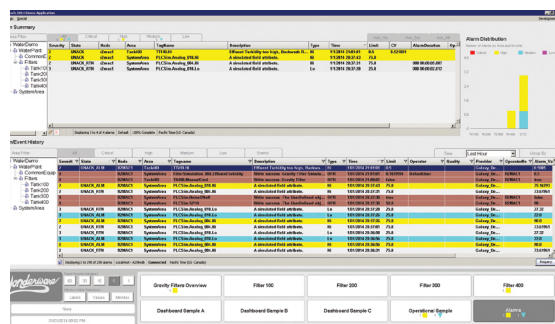
Color and Animation Usage

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 more and more graphical capability and the HMI applications also began to leverage these improvements with little thought of whether that was the right choice to make. It has become commonplace for the HMI applications to become a show piece 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

Figure 10
Example of Poor Color Usage

impair the operator's ability to ascertain the current situation and ultimately make key decisions to maximize the business value of the application. In the **Figure 10** the process is displayed with three
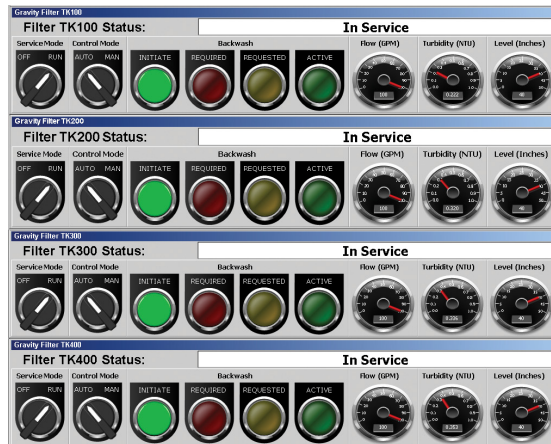
Figure 11

*Example of Better
Color Usage*

dimensional pipes and flanges that offer the operator no real information, gauges with artificial glare applied, the color red has several meanings, and a variety of other bad practices. In the version of that same graphic shown in **Figure 11**, there is a much better use of color. Often people will comment that the graphic designed for better situational awareness is boring and the truth of the matter is that graphics that effectively communicate the state of the process to the operator are boring. Through a limited use of color the operator's attention can be driven to the point in the process that has deviated from a normal or expected state.
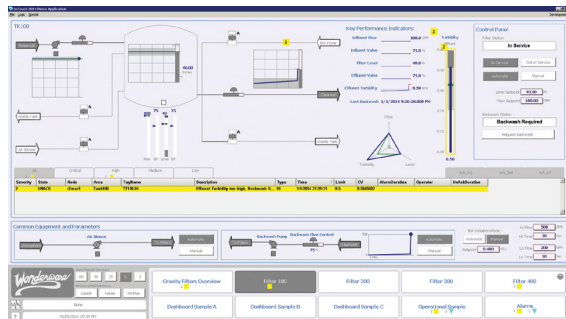
When the system state is completely within expected norms the process graphics should not emphasize and draw the operator's attention to these normal conditions as that only serves to overload the operators attention. The utilization of animations should be with the deliberate intent of drawing the operator's 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 of achieving the business goals or safe operation. 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. To ensure an optimal HMI design it is very important to establish and strictly utilize color standards.

When designing the color standards that will be used in the HMI application it is very important to prevent an ambiguous use of colors. If the same color has multiple meanings then the operator will often become confused about the information that is being communicated. A significant concern when choosing colors is that color blindness affects as many as 8 percent of men and 0.5 percent of women. A very effective method for combating color blindness is to leverage a variation of color saturation. While color blindness affects the hues of the color perceived by the user these people are 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 possible to use alternate colors in the palette as in shown in **Figure 12** but it is very important to ensure that the operator be able to readily distinguish a normal state from an alarm state with no ambiguity. There is no one color palette that is universally correct for all applications but by following these simple recommendations you can ensure that your color palette is working for you, instead of against you.

Figure 12
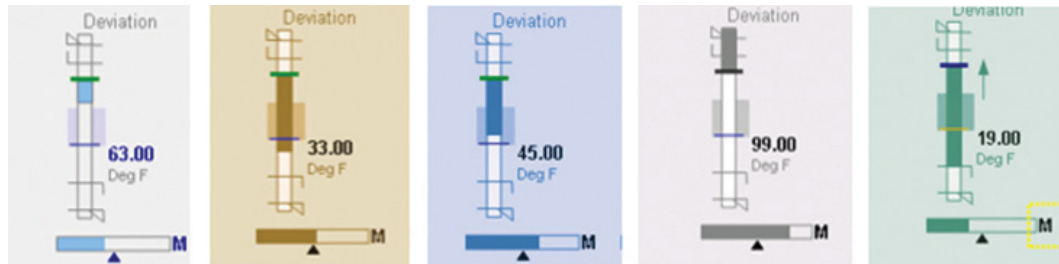
*Alternate Effective
Color Palettes*

Actionable Alarm Management

Alarms by definition are events that require an action and 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 the operators. In

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

a recent survey 52% of respondents said they do not perform an analysis of their alarm systems to identify its strengths and deficiencies.[7] It is clear that something needs to be done to improve alarm management. To begin to address this issue, all configured alarms in the system need to be reviewed to evaluate the alarms 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. And under stressful conditions this lack of understanding can directly lead to errors in judgment.

The best practices in alarm management recommend the use of at most four severities; critical, high medium and low. These severities define the maximum response time for the alarms as 5 minutes, 30 minutes, 60 minutes, and 120 minutes respectively as shown in **Figure 13**. 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 and minimize the potential for nuisance alarms. It may still be possible for the volumes 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 14** 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.
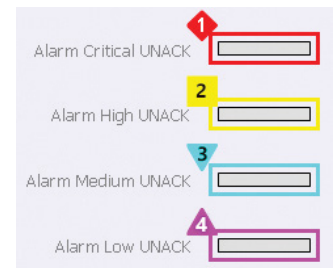
Alarm Aggregation

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 was structured it is possible to visually display the overall alarm state as badges right on the navigation element as is illustrated in **Figure 15**. In this image there are 3 buttons; one for the Gravity Filters Overview, one for Filter 100 and one for Filter 200. In this example it can be seen that there are 2 alarms in the system; one critical severity and one high severity. The critical severity alarm originated from Filter 100 and the high severity alarm originated from Filter 200. The operator can easily click on the desired button to navigate directly to the associated graphic for the alarm to be handled.

Gravity Filters Overview	Filter 100	Filter 200

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[7] http://www.automationworld.com/alarm-management-opinions
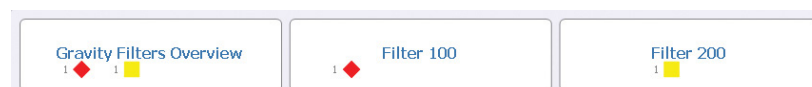
Effective Design Elements

When designing and assembling an HMI that delivers the best 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. These design elements will be optimized to achieve the appropriate Level of Situational Awareness (perception, comprehension, or projection) to manage the associated process. Trying to cover all of the possible design elements is far too large a topic to address here. To illustrate the point, examples of meters with trends and dashboard tools 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 Tagname and units of the transmitter. This method of presenting information has a large number of deficiencies that hampers an operator's ability to take that data and turn it into actionable information. As shown in **Figure 16**, 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.
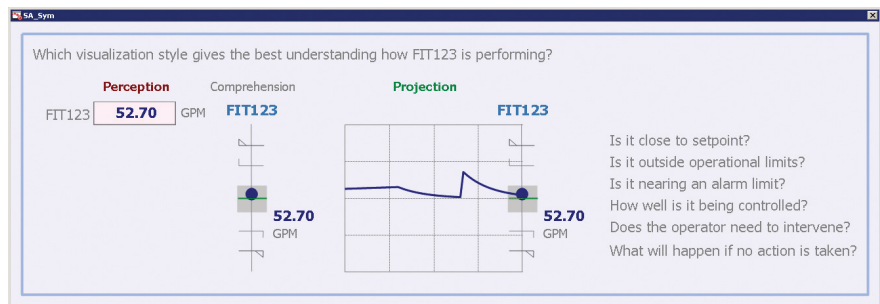
Figure 16

*Attaining Different
Situational
Awareness Levels
with Different
Design Elements*

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 associated them to business goals as they are changing in real time. In **Figure 17** 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.
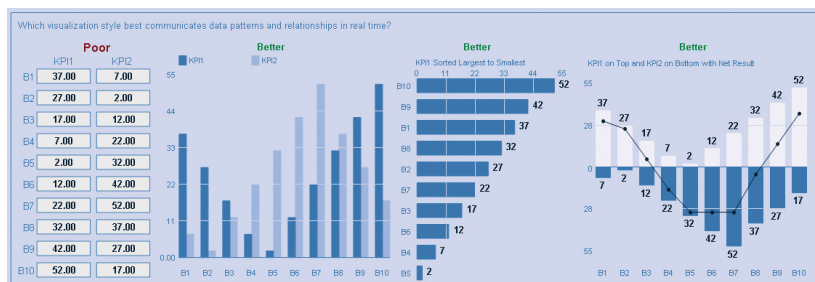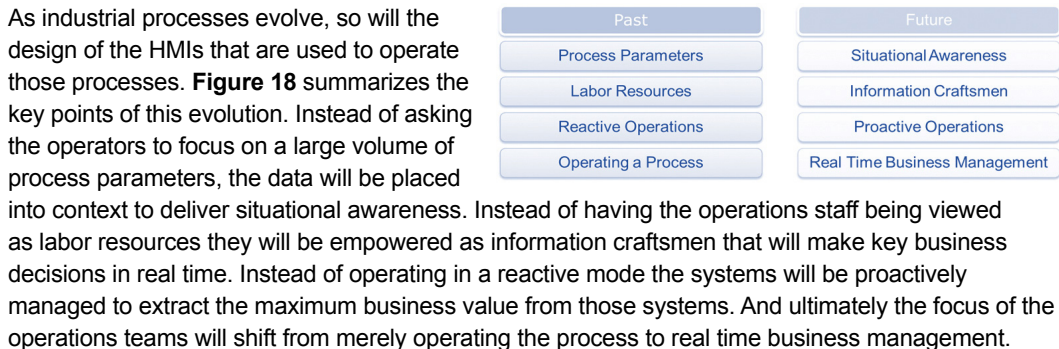
Figure 17

*Exposing Data
Relationships with
a Variety of Design
Elements*

Putting it All Together

The modern industrial systems continue to get larger, 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 as a whole 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 goals. 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.8 By identifying and addressing abnormal situations prior to experiencing the process impacts of those abnormal situations the industrial processes will yield an overall higher business value and will be operated more safely.

Figure 18
Evolution of Industrial Process Management

As industrial processes evolve, so will the design of the HMIs that are used to operate those processes. **Figure 18** 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

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

into context to deliver situational awareness. Instead of having the operations staff being viewed as labor resources they will be empowered as information craftsmen 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.

Beginning with the release of InTouch 2014 HMI and Wonderware System Platform 2014 supervisory control software all of the techniques described in this document are available out of the box in a very easy to use product set. These methodologies can be integrated into existing systems or used on the design of new systems. Where an existing system already has P&ID type windows it can be simply augmented with the appropriate Level 1 and Level 2 windows to facilitate achieving improved

Wonderware System Platform and InTouch

Figure 19
Example of a Level 1 Window Leveraging Situational Awareness Techniques

Situational Awareness on any budget. Through the use of Situational Awareness Techniques provided by InTouch HMI and Wonderware System Platform supervisory control software any business can experience world class industrial system performance with minimal cost and fast return on investment.

✎ About the author

John Krajewski has 19+ years experience in industrial automation and control systems. 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. He joined Invensys Wonderware in April 2000 as a Senior Application Developer in the Product Marketing Department. Shortly thereafter, John assumed the role of Product Marketing's Functional Manager of Infrastructure. John Spent 5 years as a Domain Architect with responsibilities for architectural and functional definition of InTouch and ArchestrA technologies. For the past 5 years John has served in multiple Product Management roles for Invensys HMI/Supervisory Control products.

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