CONTROL ENGINEERING

Human Factors and the Impact on Plant Safety

Sponsor overview

The ABB Group

ABB is a global leader in power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact.

ABB Safety Systems

Over the past 30 years, ABB has successfully delivered and installed safety systems in more than 55 countries worldwide. We work hard with end-users to maintain and evolve existing installations, thereby maximizing customer value and ensuring safe plant operation throughout the safety system lifecycle.

The Power of Integration

The potential and the power of integra- tion lies in what can be achieved when information is made available, in context, to all of the devices, systems and individuals responsible for controlling, maintaining and managing production.

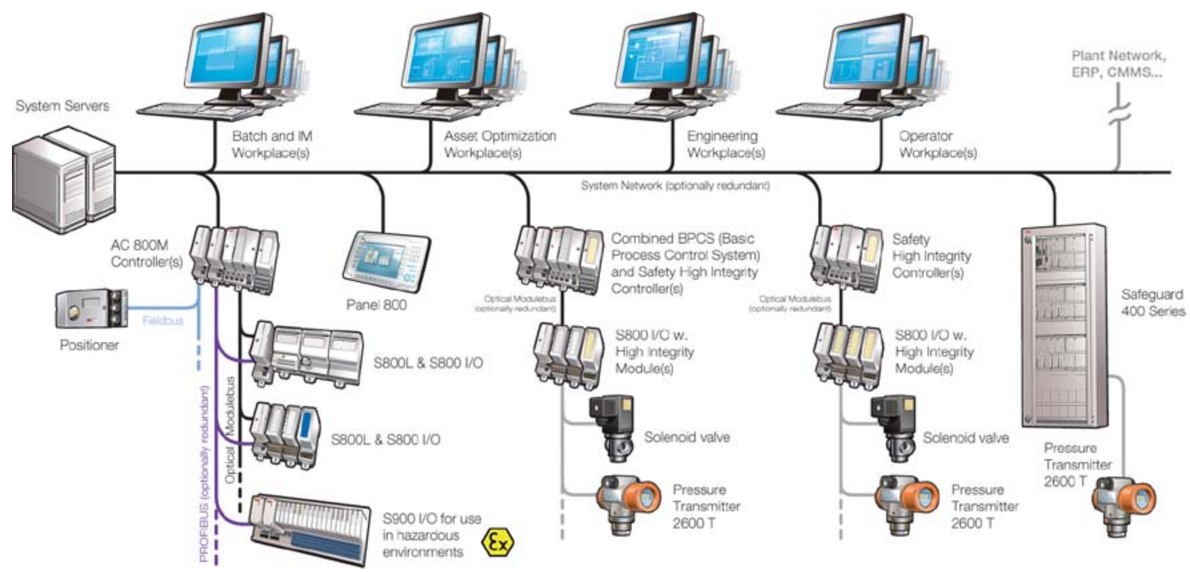
ABB's integrated approach to safety and control is yielding more cost effective safety system (SIS) implementations while delivering significant operational benefits. ABB's System 8 00xA architecture offers the flexibility of hosting both safety and process critical control applications in the same controller or on separate hardware if desired.

Either way, the user gains many of the same integration benefits, including common operator interface and engineering tools, plant-wide sequence-of-events (SOE) lists for consolidated root cause analysis, as well as centralized historian and data archiving.

Join the Discussion

Safety impacts many areas of plant operations including profitability, security, operator effectiveness and availability to name a few.

Visit ABB's Process Automation Insights blog to join the conversation at http://www.processautomationinsights.com/



Introduction

Operators: you have to live with them, because you can't run a plant without them.

For all our automation, people are still part of our processes. Like any other element, there are things you can do to improve performance and make sure human beings are not your weakest link.

While the exact percentage will depend on which study you want to cite, indications are that human beings are responsible for up to half the abnormal situations in process plants. Moreover, those studies suggest that process industries in the U.S. lose more than $20 billion annually as a result.

In spite of these statistics, most process plants depend heavily on operator intervention during critical operational phases (e.g., startup, shutdown) and when things start going wrong. A bad decision results when an inadequately trained individual doesn't know how to respond, or is misunderstanding the information he or she is getting from the control system.

Combine this dependence on human beings with the demographic shifts as experienced operators retire and it is easy to imagine a large and very costly problem hiding in the statistics.

The good news side of the situation is that many companies have worked at finding ways to improve human performance. Organizations that encompass users and suppliers are studying how people interact with control systems, how they absorb information, and how they make decisions. This growing knowledge combined with improvements in technology is rapidly building new ways to help recapture the economic losses.

The thought that cutting human-caused abnormal situations in half will save $5 billion each year is a powerful motivation. Companies like ABB that are leading the way can offer customers a tangible advantage as they look at ways to improve performance while welcoming a new generation of workers.

This eGuide contains a series of articles and videos that considers theoretical and practical; immediate needs and a look into the future. All aim at better processes through better people.

Developing people: Making operators more effective

Tools and methods for creating an industrial operator workplace ready for the needs of today and tomorrow. Improved situational awareness and better handling of abnormal conditions helps operators make better decisions and improve safety and process uptime.

Hongyu Pei Breivold, Martin Olausson, Susanne Timsjo, Magnus Larsson, Roy Tanner

Process industries globally lose around $20 billion annually due to process disruptions, which represents about 5% of total production. Studies suggest 80% of these losses are preventable, and of these preventable losses, 40% are primarily due to operator errors. This means that the total improvement potential—if a way can be found to help avoid mistakes—totals $6.4 billion. Operator effectiveness is a fundamental element for sustaining the economic value of process control and management.

One place to begin the process is by empowering operators through improved situational awareness and better handling of abnormal conditions. Operators can then make better decisions and so improve safety and process uptime.

The traditional versus a customized way of presenting data with different effects on situation awareness. Courtesy: ABB

Striving for operator effectiveness implies facing a number of significant challenges regarding both technology and management. For instance, managing and monitoring industrial processes is characterized by inevitable changes in technology, a diminishing knowledge base due to demographic changes in the workforce, and the ever-increasing complexity of operations. These factors may lead to huge cost escalations if operator effectiveness is not taken into account rigorously.

Developing an effective HMI (human machine interface) needs to look at the operator's workflow and requirements. A recent survey on operator effectiveness shows that this view is also shared by many of ABB's customers.

Four pillars of operator effectiveness

ABB's Extended Operator Workplace. The right combination of equipment and ergonomics creates an environment that lowers stress levels and allows operators to improve situational awareness. Courtesy: ABB

When designing an automation system, there are four main pillars affecting an operator's performance:

- Integrated operations
- Design for high-performance
- Attention to human factors, and
- Operator competence.

Integrated operations

An effective control system should provide customers with the means to consolidate and rationalize data from various sources seamlessly. It achieves collaboration between different computer programs and systems, supplying operators with all necessary information from any number of sources. Operators have intuitive access to actionable information and can manage views dynamically and effectively. These features reduce the time required to identify necessary actions.

Today, an operating plant may include multiple controller platforms including PLCs (programmable logic controllers), DCSs (distributed control systems), safety systems, FASs (facilities automation systems), and ECSs (electrical control systems) to name just a few. In addition, plant information systems such as CMMS (computerized maintenance management systems), ERP (enterprise resource planning), video monitoring systems, and data historians are also available and contain valuable information that can support operators in their decision making.

Design for high performance

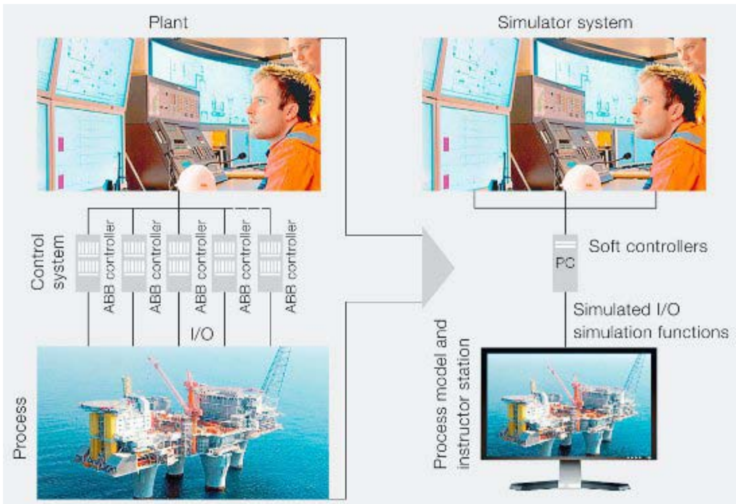
Many standards organizations and research institutes have made and continue to make valuable contributions to HMI philosophies. This knowledge has flowed into guidelines for interface design, ergonomics, situation awareness, and alarm management. Drawing on this as well as its own extensive expertise, ABB, along with other system designers, supports the establishment of good standards through its active participation in various technical committees, working groups, and scientific committees of standards-development organizations.

One key area affecting HMI development is the handling of abnormal situations. Abnormal situations are disturbances or incidents with which the control system is not able to cope of its own accord, and thus requires operator intervention. When implementing a control system project, it is critical to customize the workplace layout based on the end user's operational philosophy, and provide support for the implementation of high-performance alarm management strategies with features such as alarm shelving (operator-driven alarm suppression) and alarm hiding (condition-based alarm suppression). These features reduce the number of nuisance and noncritical alarms and so help end users meet or exceed current guidelines and standards such as EEMUA 191 and ISA SP18.2. Ian Nimmo, abnormal situation management expert and author of "High Performance HMI Handbook," believes that a driving factor of high-performance design for HMIs is situ-

Design for the layout of a control room. Effective facility design puts all the resources, operators, and production management needs within easy reach. Courtesy: ABB ation awareness. He says, "Having good situation awareness means the operator has an accurate perception of the current condition of process and equipment, and an accurate understanding of the meaning of various trends in the unit."

Some of the key concepts that situation awareness reflects are color definitions and use to maximize visibility of abnormal situations. The situation awareness concept is not new. It is, however, still a matter of debate between multiple organizations. One aspect being debated is the use of grayscale or cool process graphic schemes. In addition, navigation methodology, graphic-level definition for fast response under abnormal conditions, and presentation of information are used to seek to predict and avert abnormal situations completely.

One good example of situation awareness as described in the "High Performance HMI Handbook" mentioned above concerns two graphics that both embed the same information but



A System 800xA simulator providing a safe, yet realistic, environment for training. Courtesy: ABB

have totally different effects on situation awareness. A graphic with a black background and an abundance of colors leads to poor situation awareness even in normal situations, whereas the graphic with gray scales and the sharp color for alarm depiction represents good situation awareness.

Situation awareness can make a huge impact by:

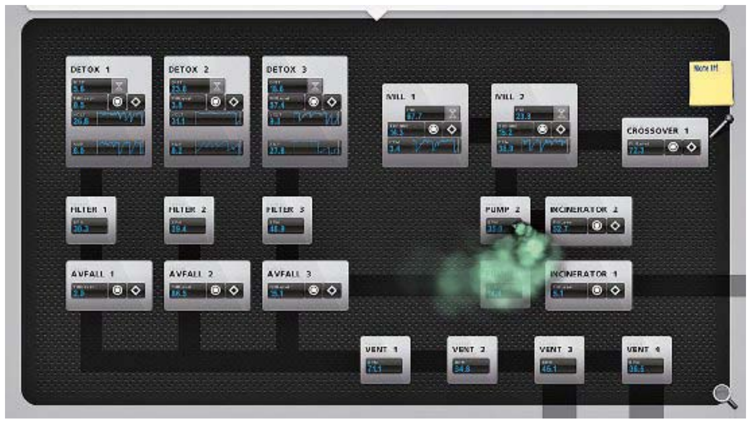
- Increasing the success rate in handling abnormal situations and returning to a normal mode of operation
- Reducing the time it takes plant operators to complete required tasks during an abnormal situation, and
- Raising the incidence rate of control room operators detecting an abnormal situation prior to alarms occurring.

Attention to human factors

System designers need to address attention explicitly to human factors. One main reason is that a skilled designer knows that a better working environment can reduce an operator's stress, which in turn substantially increases the operator's performance and effectiveness for handling abnormal situations, as well as reduces health issues and turnover of resources.

An effective operator workplace is equipped with advanced keyboards featuring hotkeys for multiclient handling, an operator desk system with motorized adjustable desk and monitor positioning, a directional sound system, and integrated dimmable lighting. Using such productive design concepts when creating control room environments has a major impact on the performance of operator teams. All these factors contribute to the enhancement of the operator environment and alertness level of control room operators.

Control room procedures are important to ensure consistency of operation. They can also support an operator in his or her activities that may be performed infrequently. An example of useful supporting mechanisms is the use of checklists to guide operators throughout the required procedures under specific circumstances.



A concept of a process display only viewed during abnormal situations. A collaboration board allows operators to communicate across shifts or with management. Courtesy: ABB

Clear definition of job roles and responsibilities is another vital element that characterizes successful operations. This means that all the tasks an operator needs to perform should be recognized and documented, including the tasks that go beyond operating in the normal mode.

In an effort to define a new standard for control rooms, or intelligent control centers, ABB and System 800xA have teamed with control-room furnisher CGM to create a demonstration project to emphasize an optimal control room layout with focus on human factors and ergonomics. The "Future Operations Center" in Borås, Sweden, is the place to visit to get the latest information about how to build the optimal control room. It covers, among others, such topics as sound, noise absorption, floor material, light control, and the color status of the process.

Operator competence

When operators interact with processes, their actions often have huge business consequences, especially when the process is in an exceptional situation and operators need to understand and manage complex operations to support recovery. New technologies using simulators for advanced training can recreate the exact operator environment, including graphics and control logic. The simulator provides a safe and realistic environment in which process operators and instrument technicians can learn how to master the process and increase their confidence.

In view of rapid technological evolution, generational shifts in workforces, and increasing complexity of operations, there is an explicit need to address operator effectiveness directly throughout the whole lifecycle of a process-control system. To leverage the four pillars of operator effectiveness, a number

Electronic desktop notes on the collaboration board. Courtesy: ABB of fundamental activities are continuously going on: user-centered design and an eye to the future.

User-centered design

Designing an effective HMI requires focusing on the control room operator's workflow and tasks. In order to achieve a good understanding of the workflow process and to obtain knowledge on how well the operator manages the significant number of operational tasks, the designer should perform operator task analyses together with operators through user studies. The methods for user study include interviews, field studies, and observations.

Interview questions are sent to the operators before a planned interview to ensure that the users have the right profile and knowledge, and that they are well-prepared. The interview questions may be structured or unstructured, both in the form they are asked and in the way they can be responded to.

Field studies and observations represent a way to identify and prioritize operators' goals and needs. By visiting users in their own working environment and observing how they perform operational tasks, firsthand information is acquired with respect to the operators' challenges and needs. This method is ideal for discovering incorrect or inefficient practices that the operators are not aware of. Operators' opinions should also be sought and direct feedback collected both for good practices and in areas with potential for improvement.

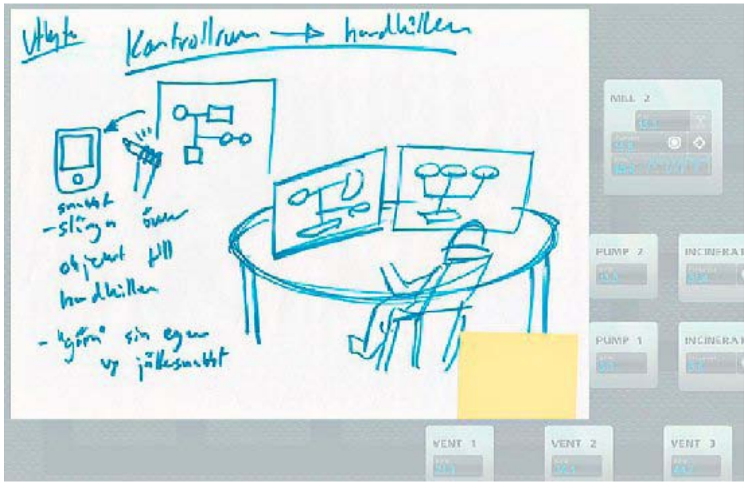
The collected data can then be analyzed and synthesized. The data synthesis process includes identification of the main concepts, indications from each user study, and analysis of how they relate to the improvement of operator effectiveness.

Another effective way to increase user focus is the establishment of a customer reference group (CRG) comprising customers from various domains. The purpose of the reference group is three-fold:

- Provide customers with firsthand information about ongoing and planned development projects
- Permit customers to actively influence the supplier's development of the system's operator interface, and
- Establish a forum for exchanging and testing ideas in user needs, trends, and future ventures in order to increase productivity and profits for customers.

Looking into the future

The continuous progress in software techniques related to user experience and interaction raises the need to permit existing human machine interfaces to evolve. As an example, ABB has a well-equipped user experience and interaction lab. The researchers look into the future, analyze the impact



Drop-down white board screen for discussions. Courtesy: ABB of emerging technologies, and explore efficient utilization and the reasonable combination of existing and emerging technologies. In particular, ABB has just created a new research area dedicated to operator effectiveness. One of its tasks is to look at new technologies in the market and their applications in industry domains. Examples include interaction, visualization, and design techniques.

Innovative ideas come from the viewpoint of centering operators' work process and tasks to develop an effective HMI. It is common knowledge that process operation is teamwork. Different shifts need to communicate and cooperate with each other. Accordingly, to assist operators in undertaking these activities, one innovative idea is a collaboration board, permitting operators to leave messages on real-time process displays, or using a drop-down whiteboard for sketching discussions. Such a collaboration function can serve various roles, including plant management, system management, managers, and maintenance and operation staff.

Operator effectiveness is a timeless characteristic and will always be important. Accordingly, in addition to improving operator effectiveness for the present generation of operators, it is critical to take future generations into account. Some customers are telling ABB that as the current workforce matures, operator expectations are evolving. Many operators being hired today grew up with computers and are "digital natives." For these new generations, visual learning is an ideal method to teach how the plant behaves. Studies of how such people operate the process show that they have more screens open than older crew members. They also ask for more customization of their screens. Newer operators tend to visualize the plant's behavior graphically, whereas older operators seek to understand the plant in a sequential manner. System designers should be actively monitoring and applying future technologies and design concepts to address younger generations whose operating skills are different from those of today.

The secret to operator effectiveness

Operator effectiveness is a challenging area. Any company hoping to excel in this area must take a leading role in facilitating the pillars of operator effectiveness by:

1. Leveraging an automation platform that can natively promote and provide the level of integration and centralization required to promote a collaborative environment.
2. Providing assistance to meet standards and design philosophies in situation awareness and abnormal condition handling, as well as leverage an automation system that has the flexibility to meet specific customer requirements.
3. Integrating human factors and best practices to provide the best in operator effectiveness.
4. Providing not only operator training but an environment that uses the most valuable assets and existing intellectual property to build operators' confidence and competence.

A process manufacturer intent on developing effective operators should create an environment that provides operator effectiveness, conduct continuous activities in user-centered design, and look into future technologies and their applications in the area of operator effectiveness. This can reduce the scope for errors through more efficient use of the operator's technological experience, quick access to relevant data in every operational situation, and assistance to operators in decision-making processes. All of these imply sustained economic value.

ABB has achieved considerable success in boosting operational excellence by focusing on operators and by providing process control interfaces that facilitate operators' ability to make the right decisions during all modes of operation. It is committed to remaining at the forefront of these developments through continued research and development, helping customers achieve operational excellence.

Hongyu Pei Breivold, Martin Olausson, Susanne Timsjö, and Magnus Larsson work for ABB Corporate Research, Västerås, Sweden. Roy Tanner is with ABB Inc., Wickliffe, Ohio.

Additional reading:

Atkinson, T., Hollender, M., 2010, Operator Effectiveness, Collaborative Process Automation Systems, ISBN 978-1-936007-10-3.

Hollifield, B., Oliver, D., Nimmo, I., Habibi, E., 2008, The High Performance HMI Handbook, ISBN-10: 0977896919, ISBN-13: 9780977896912, Plant Automation Services.

Methods and best practices to map displays to operator decisions

Produced using study results from The Center for Operator Performance.

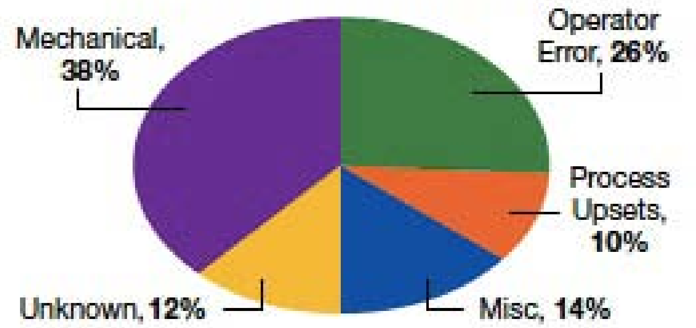
The critical nature of display design in process control system operator interfaces is highlighted by the fact that a high proportion of incidents are caused by operator errors. Currently, control operator display design is typically based on the P&ID drawings because this approach is fast and easy. The problem is that displays designed by this method do not necessarily provide the right information to the operator at the right time. A new approach organizes the display to provide information supporting decisions to operate the plant optimally and return the plant from abnormal situations back to normal conditions. The new display design process starts with analyzing the decisions operators have to make, maps available information to these decisions, and allocates information to the different levels of displays. The new approach has the potential to reduce the number of incidents by improving operator decision making.

Display design challenges

There is an increasing awareness of the role that operators play in the incident-free operation of a plant. A recent report by the Chemical Manufacturers' Association on the causes of incidents attributed 26% of the incidents to operator errors (see Figure 1). Some individual facilities have informally stated that they attribute a much higher proportion—even up to 66% of incidents—to operator errors. One of the most promising paths to reducing the number of operator errors is improving the operator interface, which consists of the set of graphic displays that allow the operators to view the process they are responsible for and take action as needed.

As a starting point, initial operator displays often mimic the process equipment shown on P&IDs. These initial displays include measurements, valves, other final elements, and control elements. They include enough of the process equipment and piping so that the process flow can be followed. Display navigation is added, allowing operators to follow the flow of the process quickly and drill into and out of detail as required. Over time additional related information from upstream and downstream processes is often added to the displays. The overall effectiveness of the system of displays depends greatly on the experience of the designers, the involvement of the operators, and the manner in which the graphic displays are structured.

Fig. 1: Causes of incidents



A new approach to display design

Clearly, the purpose of the display is to enable operators to make more effective decisions and, in particular, to eliminate operator errors as much as possible. To improve the overall effectiveness of operator graphics, the Center for Operator Performance (COP) is investigating a different approach to display design. Instead of following equipment layouts, the display design is based on the decisions that control room operators make. As part of this approach a systematic review and characterization of the decisions made by operators and others in process manufacturing is used. A rating and clustering technique is used to map the available information to the decisions. Information is then allocated to different display levels.

A typical first step is to identify the key operator decisions for each major section of the process. In an initial study, key decisions such as, "Why have I lost hydrogen?" and "Why are my separator levels changing?" were asked. The decisions that were selected require multiple data values from the underlying process model. For example, "Have I lost hydrogen?" requires only checking hydrogen measurement and should be alarmed. On the other hand, "Why have I lost hydrogen?" requires the analysis of multiple data points. Decisions involved in shift handoff, key upset systems, and typical daily instructions were also considered.

In a test case, the following decisions were selected for the hydrocracking unit:

- Why have I lost hydrogen?
- Why am I venting so much?
- Why has the recycle gas changed?
- Am I maximizing preheat?
- Am I operating inefficiently?
- Can I increase charge?
- Is my feed system set up to produce desired product?
- Is my recycle compressor operating near optimum?
- Am I at risk for a temperature runaway?
- Why has the reactor temperature taken off?
- Why don't I have enough feed?
- Are my reactors set up to produce desired product?
- Why am I not making the desired amount of light product?
- Why is the naphtha off spec?
- Why are my separator levels changing? and
- This should be displayed all of the time (cross-check).

What should be included?

One of the key challenges in designing a display is determining what information should be included in the display and how that information should be organized. There are thousands of data points in a typical unit, far too many to try to include on a display. A hydrocracker can have 3,000 tags, so it is important to define the ones that are most important. The procedure starts by dividing the unit into logical sections and then defining key data elements based on the process requirements and items that have important alarms and similar factors.

In many cases the data points must be combined to provide information that will aid the decision-making process. In this example, the number of tags was reduced from 3,000 to 120, with a total of 194 data elements. For example:

- **Front End-**High-pressure separator pressure PV
- **Back End-**Splitter top pressure output
- **Back End-**Splitter fuel gas pressure PV
- **Utilities-**Wash water flow PV
- **Back End-**Splitter top pressure PV
- **Front End-**Make-up compressor unit pressure mode
- **Front End-**Make-up compressor unit pressure output
- **Front End-**High-pressure separator pressure output
- **Front End-**Charge unit charge flow PV, and
- **Front End-**Furnace/heater (Both HT/HC RXS) fuel gas pressure PV

The next step is determining which among these data points are most important to the operators' decision-making process. For each of these decisions, experienced operators were asked to rate the importance of key data elements. The operators rated each data point on a scale of 1 to 5 based on its importance to each decision.

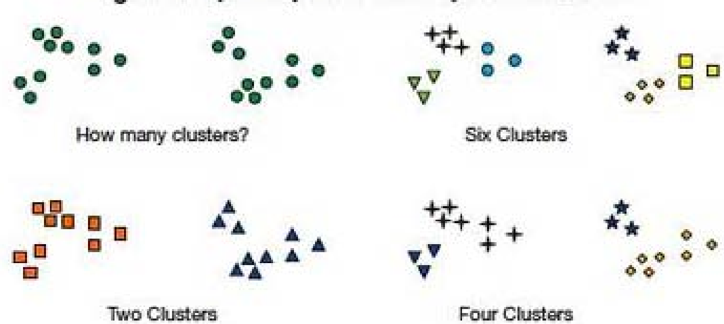
5 – Critical or extremely important
4 – Very Important
3 – Important
2 – Somewhat important
1 – Not at all important, and
0 – Doesn't exist on my unit

Cluster analysis

The responses from the operators were analyzed and each data element was assigned an average rating across operators for each decision. The results of the survey were then evaluated using a technique called cluster analysis to determine how the parameters should be organized. Cluster analysis sorts objects into groups where the objects in a group are similar to one another and different from the objects in other groups.

As shown in Figure 2, determining the number of clusters may require a few attempts to find the ideal number. As a general rule a good starting point is four or five clusters. The cluster groups are used to define the display hierarchy needed to move from high level situational awareness across multiple decisions down to individual data points on mimic displays.

Fig. 2: Multiple ways to divide objects into clusters



The following procedure is used to form five clusters:

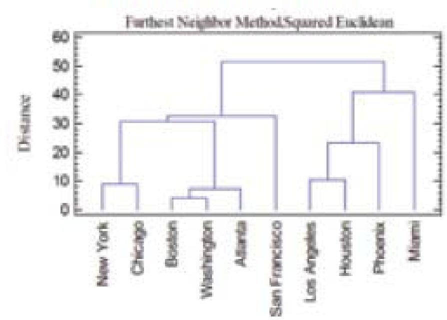
1. Each observation is in a separate group
2. Each two observations which are closest together are combined to form new groups
3. The distance between the remaining groups is calculated
4. The two groups then closest together are combined, and
5. This process repeats until only five groups remain.

Table 1: Dataset for cluster analysis example

City	Population	Percent female	Land area	Median age	Median income	Highest temperature
New York	8,008,278	52.6	303.3	34.2	38,293	76.9
Boston	589,141	51.9	48.4	31.1	39,629	72.9
Chicago	2,896,016	51.5	227.1	31.5	38,625	74.7
Washington	572,059	52.9	61.4	34.6	40,127	78.2
Atlanta	416,474	50.4	131.7	31.9	34,770	79.7
Los Angeles	3,694,820	50.2	469.1	31.6	36,687	72.0
San Francisco	776,733	49.2	46.7	36.5	55,221	63.7
Miami	362,470	50.3	35.7	37.7	23,483	84.3
Houston	1,953,613	50.1	579.4	30.9	36,616	53.0
Phoenix	1,321,045	49.1	474.9	30.7	41,207	90.7

To help explain cluster analysis, an example will be provided of how this method can be used to group cities based on demographic, economic, and environmental variables. The data set shown in Table 1 was used for this example.

Fig. 3: Dendogram



The data set above is shown in Figure 3 as a dendogram, a tree diagram frequently used to illustrate the arrangement of the clusters produced by hierarchical clustering. The bottom row of nodes in the dendogram represents individual observations, and the other nodes are used to define the clusters to which the data belong. The vertical distance from the common nodes to the bottom row is inversely proportional to the similarity of the members of the group. In other words when distance is small, the cities are more similar. For example, the dendogram shows that Boston and Washington are the most similar cities and that the most similar combination of three cities is those two plus Atlanta. The general shape of the dendogram suggests that the cities can be organized into two groups:

1. New York, Chicago, Boston, Washington, Atlanta, and San Francisco
2. Los Angeles, Houston, Phoenix, and Miami

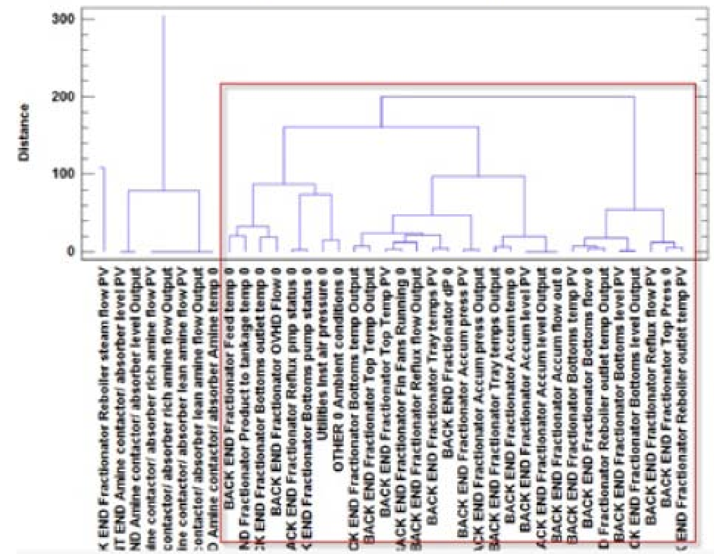
Since Group #2 contains cities that tend to be located in warmer areas, climate plays an important role in grouping the cities when the farthest neighbor method is used.

Applying cluster analysis to the hydrocracker example

The next step is to apply cluster analysis to the hydrocracker example mentioned earlier. Figure 4 shows the dendogram for the hydrocracker example.

The centroid is the average value of all members of the cluster on a particular variable. In the hydrocracker example, cluster 1 had an average response of 3.1 and cluster 2 had an average response of 1.8 to question 1 – Table 2. It is important to make decisions based on the patterns across the decisions and data instead of relying solely on the highest decision scores. For example, seven of the decisions had high decision scores

Fig. 4: Hydrocracker dendogram



in clusters 1 and 3, which both should play an important role in developing those decisions.

Cluster analysis separated the low impact data into clusters 2 and 4. The example below from cluster 4 suggests that these decisions can be separated out and handled on different overview or lower level displays.

Front End-Furnace/heater ID/FD fan status 0
Front End-Amine contactor/absorber level SP
Front End-Amine contactor/absorber level PV
Front End-Amine contactor/absorber level mode
Front End-Amine contactor/absorber level output
Back End-Fractionator reboiler steam flow SP
Back End-Fractionator reboiler steam flow PV
Back End-Fractionator reboiler steam flow mode
Back End-Fractionator reboiler steam flow output

Table 2: Centroids in hydrocracker example

Cluster	Can I increase charge?	Are my reactors set up to produce desired product?	Is my feed system set-up to produce desired product?
1	3.12459	2.64098	2.57705
2	1.84737	1.76842	1.80526
3	3.92308	3.74615	3.10769
4	0.575	0.5	0.466667
5	2.85667	2.59333	2.52333

Cluster	Am I at risk for a temperature runaway?	Is my recycle compressor operating near optimum?
1	2.78197	2.66721
2	1.77895	1.79474
3	4.10769	3.17692
4	0.391667	0.391667
5	2.26	1.86

Cluster	Why are my separator levels changing?	Am I maximizing pre-heat?	Am I operating efficiently?
1	2.68689	2.03115	2.93607
2	1.74737	1.64737	1.90526
3	3.33077	2.94615	3.52308
4	0.408333	0.433333	0.5
5	2.27	2.04	2.92667

Designing the display

Operators can be more effective when all of the related information they need is included on the same display. Data overload can be limited by defining the information that is needed and eliminating everything else. So it's important to determine what information should be at what level in the display hierarchy. The starting point is to determine what information is needed for high-level situational awareness. Display designers should also define what other displays operators need for direct access to related information. Information should be organized in terms of its value for high level overviews and its relevance in drilling down for more detailed information from the overview screens.

In the hydrocracker study, data was ranked across all decisions to determine the information for different display levels. Criteria were identified for determining which data elements should be included based on their ratio ranking as well as their average rating across all decisions. For example, in the COP study no more than 40 data elements are included in level 1 and all data elements in level 1 must have an average rating across all decisions of at least 3.0.

- Level 1—High-level overviews and alarms
- Level 2—Primary operation (unit-wide operation)
- Level 3—Secondary operation (task-oriented operation), and
- Level 4—Process detail or support graphic.

Once the parameters are organized into appropriate displays, the next step is to consider alternative ways to present the information, for example, graphical, textual, tabular, and auditory. Certain data is best visualized one way to support one task or set of tasks and better visualized a different way to support different tasks. As an example, consider the ways in which telephone numbers can be presented. If someone asks you to remember 1-800-677-4992, you'll probably have to work at it. However, once the number is situated in long-term memory, dialing the number is a simple task. Contrast that with trying to remember 1-800-MR-PIZZA. That representation of the same sequence of button pushes is easier to remember; however, it is harder to dial.

While low-level P&ID graphics based on plant layout and equipment are often easy to design, they may not provide the support needed for everyday supervisory control and situational awareness. The new method described here can help designers to consider the decisions operators are making, identify the content needed to support those decisions, and provide a systematic method to organize the content. The end result should be that the displays will help operators make better decisions and fewer errors.

Key concepts

- Most HMI designers create operator screens using the P&ID as the main design element. This works, but doesn't consider what information is most critical to operators.
- Operator decisions have a major effect on preventing up sets or making them worse, so delivering the right information quickly and clearly can minimize potential problems.
- Understanding basic decision making techniques can help an HMI designer create highly effective graphics.

Learn more:

- Find out more about Wright State University at www.wright.edu

- Watch an on-demand webcast about HMI design at www.controleng.com/media-library/webcasts.html

- The research in this article was conducted by the Center for Operator Performance, a diverse group of industry, vendor, and academic representatives addressing human capabilities and limitations with research , collaboration, and human factors engineering. Its mission is to raise the performance of operators and improve health, safety, and environmental awareness. Learn more at http://operatorperformance.org

A rational approach to alarm rationalization

While it may not be your favorite activity, thoughtful alarm rationalization pays major operational dividends in the long run and will keep your operators happier.

John E. Bogdan, Susan F. Booth

Alarm rationalization. Just the phrase is enough to cause managers to groan and potential rationalization team members to run for cover. Their reaction is not without merit. A typical alarm system is a morass of poorly thought-out alarms with little or no documentation, and the task of bringing such a system into alignment with a plant or pipeline's operating philosophy is a daunting one.

Why rationalize?

Most would agree that current alarm systems are broken, badly broken. There are far too many alarms in a typical system. Alarms are often in place simply because they came configured when the control system was installed. Some even came with arbitrary setpoints already designed. Does 90, 80, 20, 10 sound familiar? Setpoints, in general, are not related to realistic conditions. Priority has not been determined through a systematic analysis of consequences and time to respond. In most operations, about 80% of all alarms have been prioritized as high priority; clearly the alarm system is not close to the recommended alarm priority distribution. To top it all off, documentation is scarce and spotty.

For many, pressure to meet regulatory requirements is the driving force behind rationalization and the rest of alarm system redesign. For those who are not (yet) under the gun of new regulations, optimizing the alarm system will improve operator effectiveness and yield significant improvements in safety and productivity. Weighed against the cost of a potential incident, the cost of this effort can be readily justified.

What is rationalization?

Alarm rationalization, also called documentation and rationalization (D&R), is the procedure used to determine the optimum alarm set to be included in an alarm system. This is the set that will consistently deliver the right alarm to the right operator at the right time with the right importance and the right information to correct or mitigate the undesirable situation. During rationalization, a multidisciplinary team reviews and evaluates the operation and decides what possible undesirable circumstances could arise that would justify an alarm according to the criteria set forth in the alarm philosophy document (APD). The team also performs the preliminary design of each alarm, including the priority, setpoint, and other alarm attributes. They document all this information in a master alarm database (MADb).

(For more details on the basics of rationalization, please refer to Managing Alarms Using Rationalization, *Control Engineering*, March 10, 2011.)

Pitfalls of the common approach to rationalization

Rationalization is time-intensive and requires significant personnel resources, so attacking it with an effective strategy is imperative. A common approach is to start from the existing MADb and review every possible alarm made available by the control system, configured or not. Candidate alarms that meet the APD criteria are included in the optimized alarm system. This approach has the seeming advantage of giving the team a framework from which to start, but it has several drawbacks.

1. It is time-consuming. ISA suggests in its Alarm Management Class IC39C that 100 to 200 alarms per day is a good pace for rationalization, and 300 to 400 alarms per day are possible with good pre-work. Therefore, rationalization of a small to medium system containing about 10,000 alarms would require a minimum of 25 days. With ineffective techniques or staffing, rationalization has been known to drag on for months.

2. It is mind-numbing. The common practice has the team cloistered in a room staring at the existing MADb. Point-by-point (or group of points by group of points), the team runs through the same set of questions for each candidate alarm to determine if it is to be included in the new system. The sheer amount of garbage to cull through and the focus on details instead of the larger picture results in boredom, inattentiveness, and an occasional nap.

3. Most importantly, the result is often not the optimum system. It is possible, even likely, to miss necessary alarms. An inherent problem in a review process is that it is easy to overlook something that should be part of the system but was not part of the original design. If it is not there, it is not reviewed. Another drawback is that it can be tempting to accept original choices rather than take the time to evaluate whether better options might be available. Yet another is that elimination of unnecessary alarms may not be as thorough as possible. It can be tempting to retain alarms that are questionable rather than research more completely to be sure. The response, "It's only one alarm," happens more than once and can add up!

The review approach can work if the team keeps its focus on identifying potential undesirable situations, rather than on checking off alarms. However, the massive MADb is the framework, and we know it represents a broken system. Why start building a critical system from such a faulty foundation?

A more rational approach

An alternative to the common approach is one similar to that required for a new plant or operation in which no alarm system exists to be reviewed. This "clean slate" approach focuses on identifying undesirable situations (which is what we are really interested in), determining the best ways to detect them, and designing alarms to do the job. A general description of the procedure is:

Step 1. Divide the process into small, manageable units.
Step 2. Identify common or similar elements.
Step 3. For each unit, or group of common elements:

a. Identify events with undesirable or negative consequences.
b. Determine the best way to detect these.
c. Design the alarms.
d. Examine the interconnections between units to see if these boundaries introduce any events with undesirable consequences. If so, determine the best way to detect them and design the alarms for them.

The result upon completing these three steps for the entire process is the preliminary set of alarms. To this must be added any required alarms, those alarms required by an external agency (e.g., legal requirement, environmental permit, warranty), following procedures outlined in the APD.

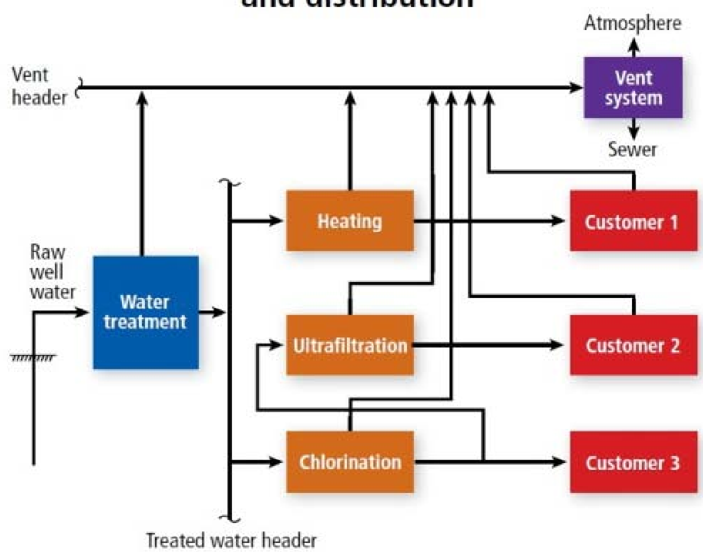
Step 4. Check the preliminary set of alarms against the existing MADb. There are four cases to be considered, the first three of which are readily resolved.

In Case 4, it is likely that the candidate alarm was unnecessary and should have been eliminated. However, it is possible that an undesirable event or required alarm was missed in the new rationalization. If so, the team should design the appro-

Table 1 – Comparison of new set of alarms vs. existing set in MADb

Case	Description	Outcome
1	The alarm was not configured either in the old system or during the current rationalization	No alarm
2	The alarm was configured both in the old system and during the current rationalization	Alarm
3	The alarm was not configured in the old system but was during the current rationalization	Alarm
4	The alarm was configured in the old system but not during the current rationalization	Discuss and resolve

Figure 1: Overview of water treatment and distribution



priate alarm and include it in the system, or add the required alarm.

The result upon completion of this procedure is the optimized set of alarms for the operation or process.

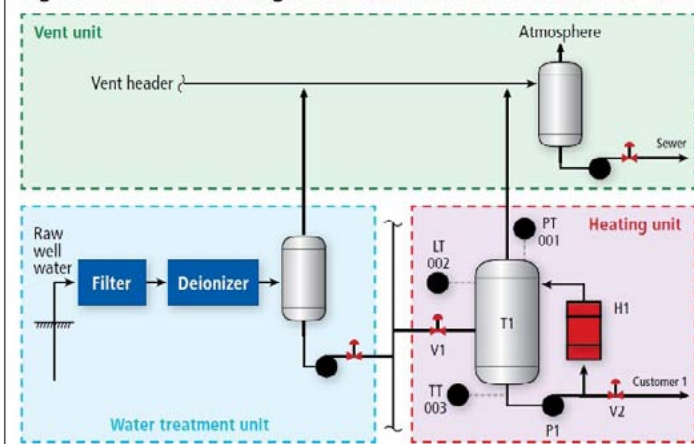
Example of rationalizing from a clean slate

The following example is deliberately simplified to illustrate the concepts. Figure 1 shows a water treatment and distribution process that treats raw water, further conditions it as necessary, and then distributes it to a number of customers.

This process is too large to be considered in its entirety and should be broken into manageable units. Most processes can be divided logically into workable units.

Following Step 1 in the rationalization procedure described above, three units were broken out from the example process and are detailed in Figure 2.

Figure 2: Detail of heating, water treatment, and vent header units



This example will focus on the heating unit and its connections to other units.

The heating unit takes treated water, heats it in a batch cycle, and then transfers it to a customer. The automated heating cycle is described in Table 2.

Table 2 – Description of batch cycle for heating sub-unit

Step	Description
Standby	All valves (V1 and V2) are closed Both heater H1 and pump P1 are off The cycle proceeds to the fill step by customer demand
Fill	Open valve V1 to fill the tank T1 to a desired level When the desired level is reached, close valve V1 and proceed to the heat step
Heat	Start pump P1 and heater H1 to circulate and heat the water in tank T1 to a desired temperature. When the desired temperature is reached, stop heater H1 and proceed to the drain step
Drain	Open valve V2 and pump the heated water to the customer. When the level in tank T1 reaches the minimum level, close valve V2, stop pump P1, and proceed to the standby step

In the existing design, the tank pressure and level are measured by PT001 and LT002 respectively. The water temperature is measured in the pump suction line by TT003.

Step 2 is to identify common or similar elements in the process. For example, just in Figure 2, there are multiple tanks and pumps, all in similar service. Therefore, you can expect them to be subject to similar events that might result in similar undesirable consequences. Using this commonality and applying the same line of reasoning to many elements at once can allow you to save significant time and effort.

Step 3 is to identify events in the heating unit with undesirable or negative consequences and design alarms to detect them. For this example, we will discuss two events:

- Loss of containment. The discussion reveals that there are two causes for this. They will be rationalized separately.
- Pump damage due to cavitation.

Tables 3 and 4 summarize the rationalization of the alarms associated with these two events.

Table 3 – Loss of containment rationalization

Undesirable event		Loss of containment in heating system
Cause 1		Overfilling tank T1
Alarm		High absolute alarm on tank T1 level (LT002.H)
Consequence		Overflow of water into the vent header system
Impact	Safety	No impact—the vent header system is designed to handle and contain entrained liquids
	Environment	No impact—the vent header system is designed to handle entrained liquids and properly dispose of them
	Financial	There is the financial loss associated with the lost water and the potential upset to the other units that share the vent header system
Corrective action		Any of the following: Close valve V1 Close manual valve in tank T1 fill line Close valve in water treatment system feeding common water header Open valve V2
Urgency		> 5 ≤ 15 minutes
Setpoint		Set to give the operator enough time to respond to the increasing level to prevent it from increasing above 98%

Confirmation/ Verification		None
Class		General
Design comments		This alarm is always active regardless of batch step or process condition
Cause 2		**Overpressure (plugged or restricted vent header system)**
Alarm		High absolute alarm on tank T1 pressure (PT001.H)
Consequence		Release of hot water through blown gaskets, seals, and/or ruptured piping or equipment
Impact	Safety	Personal injury—burn
	Environment	Release of hot water to ground and nearby area
	Financial	Cost to repair or replace damaged equipment, downtime and lost production, failure to meet contractual obligations to customer
Corrective action		Any of the following: Troubleshoot vent header system and resolve pluggage or restriction Close valve V1 Open valve V2
Urgency		≤ 5 minutes
Setpoint		Set to give the operator enough time to respond to the increasing pressure to prevent it from increasing above 100% of the minimum design pressure in the heating system
Confirmation/ Verification		None
Class		Safety related
Design comments		This alarm is always active regardless of batch step or process condition

Table 4 – Pump damage rationalization

Undesirable event		**Pump damage**
Cause		**Insufficient Net Positive Suction Pressure (NPSH)**
Alarm		Low absolute alarm on Pump P1 NPSH
Consequence		Pump damage due to cavitation
Impact	Safety	None
	Environment	None
	Financial	Cost to repair or replace damaged pump, downtime and lost production, failure to meet contractual obligations to customer
Corrective action		Shut down pump
Urgency		> 15 ≤ 30 minutes
Setpoint		Set to give the operator enough time to respond to the decreasing NPSH to prevent it from decreasing below 110% of the minimum required NPSH as determined by the pump manufacturer
Confirmation/ Verification		None
Class		General

<table>
<tr><td>Design comments</td><td>NPSH can be calculated by the following equation:
$NPSH = h_a + h_z + h_f + h_{vel} - h_{vp}$
<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>h_a</td><td>The absolute pressure on the surface of the liquid in the supply tank</td></tr>
<tr><td>h_z</td><td>The vertical distance the surface of the liquid in the supply tank is above the centerline of the pump</td></tr>
<tr><td>h_f</td><td>Friction losses in the suction piping</td></tr>
<tr><td>h_{vel}</td><td>Velocity head at the pump suction port</td></tr>
<tr><td>h_{vp}</td><td>Absolute vapor pressure of the liquid at the pumping temperature</td></tr>
<tr><td>Notes:</td><td>■ All heads are measured in feet of water @ 68 °F
■ Changes in water density as a function of temperature are significant and must be accounted for in the calculation of h_z
■ h_f and h_{vel} are insignificant and can be ignored
■ Changes in vapor pressure as a function of temperature are significant and must be accounted for in the calculation of hvp
(See Pump School - Net Positive Suction Head)</td></tr>
</table>
</td></tr>
<tr><td></td><td>This alarm is suppressed when the pump is not running</td></tr>
</table>

Next, step 3d requires examining the boundaries between units. This results in two more events that need to be discussed:

1. Product does not meet contractual temperature requirements. Discussion reveals that there are two causes for this. They will be rationalized separately.
2. Failure to deliver water on time.

Tables 5 and 6 summarize the rationalization of the alarms associated with these two events.

Table 5 – Out of spec product rationalization

Undesirable event		Product does not meet contractual temperature requirements
Cause 1		Temperature above specification limit
Alarm		High absolute alarm on tank T1 temperature (TT003.H)
Consequence		Failure to meet contractual obligations to customer
Impact	Safety	Personal injury – minor burn
	Environment	None
	Financial	Failure to meet contractual obligations to customer
Corrective action		Close valve V2 and allow the water to cool
Urgency		> 5 ≤ 15 minutes
Setpoint		Set to give the operator enough time to respond to the increasing temperature to prevent it from increasing to within 2 °F of the upper temperature specification limit
Confirmation/ Verification		None
Class		Required

Design comments		This alarm is suppressed except in the heat and drain steps with pump P1 running. If the pump is not running, the temperature measurement is in a stagnant section of piping
Cause 2		**Temperature below specification limit**
Alarm		Low absolute alarm on tank T1 temperature (TT003.L)
Consequence		Failure to meet contractual obligations to customer
Impact	Safety	None
	Environment	None
	Financial	Failure to meet contractual obligations to customer
Corrective action		Close valve V2 and circulate and heat water
Urgency		> 5 ≤ 15 minutes
Setpoint		Set to give the operator enough time to respond to the decreasing temperature to prevent it from decreasing to within 2.5 °F of the lower temperature specification limit
Confirmation/ Verification		None
Class		Required
Design comments		This alarm is suppressed except in the drain step with pump P1 running. If the pump is not running, the temperature measurement is in a stagnant section of piping

Table 6 – Failure to deliver product rationalization

Undesirable event		Failure to deliver water on time
Cause		**Batch sequence does not progress normally**
Alarm		Excessive time in step Note—the following alarms were considered but rejected because of their complexity: Low positive rate-of-change of tank level in the fill step Low positive rate-of-change of tank temperature in the heat step Low negative rate-of-change of tank level in the drain step
Consequence		Failure to deliver water on demand
Impact	Safety	None
	Environment	None
	Financial	Failure to meet contractual obligations to customer
Corrective action		Investigate and resolve the reason for the failure of the batch to progress normally. Notify customer
Urgency		> 15 ≤ 30 minutes
Setpoint		For each step, set at 110% of target step time
Confirmation/ Verification		None
Class		General
Design comments		This alarm is suppressed except in the fill, heat, and drain steps

The results of the above rationalization discussions are summarized in Table 7.

Table 7 – Summary of rationalization results

Tag	Alarm	Batch step			
		Standby	Fill	Heat	Drain
PT001	HH				
	H	✔– Always enabled regardless of batch step or process condition			
	L				
	LL				
LT002	HH				
	H	✔– Always enabled regardless of batch step or process condition			
	L				
TT003	HH				
	H			✔ (1)	✔ (1)
	L				✔ (1)
	LL				
NPSH	L	✔– Any time pump P1 is running			
Time in step	H		✔	✔	✔

1. Suppressed if pump P1 not running

Table 8 – Comparison of existing alarm configuration to rationalization results

Tag	Alarm	Batch step			
		Standby	Fill	Heat	Drain
PT001	HH		✔	✔	✔
	H		✔	✔	✔
	L				
	LL				
LT002	HH		✔	✔	✔
	H		✔	✔	✔
	L			✔	✔
TT003	HH		✔	✔	✔
	H		✔	✔	✔
	L				✔
	LL				
NPSH	L				
Time in step	H				

✔	The alarm is configured in the existing alarm system
	The alarm is configured in the existing alarm system but is not needed
	The alarm is configured in the existing alarm system but needs to be modified or replaced
	The alarm is missing from the existing alarm system but should be configured

There are significant differences between the existing alarm system and the rationalization results:

1. The high-high absolute alarms for PT001 and LT002 in the existing alarm system should be eliminated because they duplicate the respective high alarms.
2. The existing alarm system did not include an alarm on high pressure or level in standby mode, but should have.
3. The high absolute alarms for PT001 and LT002 were removed from the batch logic and placed in the continuous logic.
4. The low absolute alarm for LT002 in the existing alarm system, presumably for pump protection, should be eliminated and replaced by a new low absolute alarm on NPSH.
5. The high-high absolute alarm for TT03 in the existing alarm system should be eliminated because it is a duplicate of the high alarm.
6. The high absolute alarm for TT003 in the fill step in the existing alarm system should be eliminated because there is no required action and it is unnecessary.
7. The high and low absolute alarms for TT03 in the heat and drain steps were modified to be suppressed if the pump P1 was not running.
8. The existing alarm system did not include the NPSH or time-in-step alarms, but should have.

Conclusion

It may appear that this clean-slate approach to rationalization will be even more time-consuming than the commonly used review process since it also includes a check using the old alarm system. However, our experience shows that this approach actually ends up greatly reducing the time required. We have been able to rationalize an average of more than 500 alarms per day.

As in the review approach, significant gain is achieved by identifying similar elements and capitalizing on copying alarm design. We have found that it is easier to identify common elements when focusing on the big picture rather than the details, magnifying this gain. The largest time-saving, however, is achieved by avoiding dealing with thousands of candidate alarms that never should have been alarms in the first place. Comparing the results of the clean-slate rationalization against the old MADb is much faster than tackling thousands of poorly designed alarms. The wheat has already been separated; all that is left is to blow the chaff away. Not having to wade through mountains of chaff also reduces the mind-numbing aspects of rationalization. The team is more likely to be actively engaged in the process, which results in a more thoughtful analysis. The clean-slate approach can also reduce manpower demands because the work can be more easily divided, and therefore, meeting time can be reduced.

Most importantly, this approach is more likely to result in the optimum design for your alarm system. Why not take a rational approach to rationalization?

John Bogdan is principal consultant for J Bogdan Consulting. Reach him at john.bogdan@jbogdanconsulting.com. *Susan Booth is a consultant and technical writer for J Bogdan Consulting. Reach her at* susan.booth@jbogdanconsulting.com. www.jbogdanconsulting.com

Additional reading:

Managing Alarms Using Rationalization, *Control Engineering*, March 10, 2011, http://bit.ly/i1ytyF
ISA Alarm Management Class IC39C, www.isa.org
Pump School - Net Positive Suction Head, http://www.pumpschool.com/applications/NPSH.pdf

Automation future: Adaptable expertise for next-generation workforce

Human skills required include an understanding of the potential of automated technologies, how those technologies can be integrated, including with business and other systems, and skills in business analytics.

Tony Christian

Until recently, we had become used to dominance of the bandwagon that promoted the view that the future of developed countries depended on the transition from industrial into knowledge-driven service-based economies. It always seemed that the analyses that led to that conclusion were extremely light on understanding the interdependence of different economic sectors and on the sustainability of export markets for the different sectors. Following the financial crash in 2008, there now seems to be a consensus that, after all, manufacturing is the essential growth driver. So far, so good,

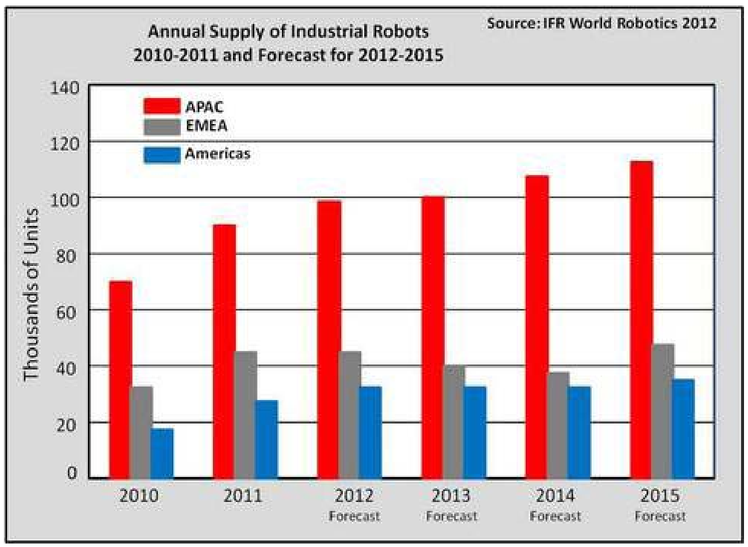


Figure 1: Graph shows sales of robots by region 2010-2015, according to IFR World Robotics Report 2012. Courtesy: Cambashi Observatory

but the question then is how can the developed countries, with their relatively high cost bases, compete in manufacturing? The answer has many components, but a significant factor is, of course, automation. Accordingly, the overall market for industrial automation software and equipment is predicted to growth at a healthy pace in 2013; the chart below shows the estimated volume of sales of robots in industry by region.

It's now over 50 years since the introduction of automation into manufacturing industries—the first robots and numerically controlled machine tools into factories, the development of the first computer-aided design technologies, and even the first computerized production planning and control systems. But an explosion in their capabilities has been enabled by the advances in communications technology over the last 20 years, transforming the structure of the industrial landscape profoundly. In most industries, a suitable mix of automation technology has delivered desired outcomes—the ability to produce more with fewer employees, reduced costs, faster time to market, and so on. Figure 2, extracted from Cambashi's Market Observatory datasets, shows the full scope of today's industrial automation technology set. But what has been the impact on the workers in terms of required skills and the nature of their activity; and what is the outlook?

Fewer routine tasks

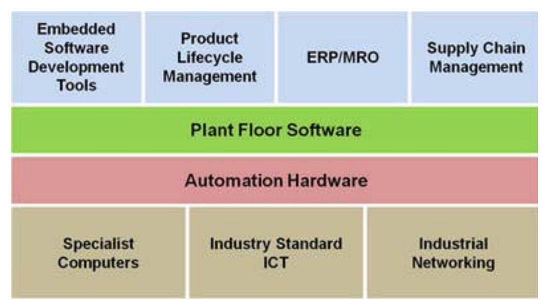


Figure 2: Key industrial automation component technologies include development tools, software, automation hardware and computers, information integration, and networking. Courtesy: Cambashi Observatory

The most obvious impact of automation is the elimination of routine tasks, be they manual production line activities or repetitive office processes. However, the ability to automate manual work has penetrated much further in the last 10 years, a good example being the extent to which even some aspects of design can be automated.

For specific, highly focused design tasks where the parameters and rules can be defined clearly—for example, routing of electrical/electronic circuits—a computer can certainly produce a viable design automatically. Similarly, for tasks like simulation and analysis, specialized expertise is no longer required to create the model in many cases, due to advances in technology that automate that pre-analysis modeling step.

Understand design principles

Does this mean that the design engineer can get away with lower levels of engineering expertise, a kind of "the calculator eliminates the need for mental arithmetic" effect? Or does engineering expertise need to be augmented by other skills? Today, the latter remains true for most situations. That is, the engineer will need to understand the principles underpinning a design to validate the outcomes of the automated aspects of the process. However, the reliability of automated design technology is improving all the time and in some areas—electronic circuit routing being a case in point—is well-established and produces reliable outcomes. This raises a lot of questions for the future. If the engineer no longer needs to validate the details of the design, what skills will be needed? Surely the detailed engineering expertise must reside somewhere, so is it with the software developer?

The answer is probably that it depends on the industry. But one aspect that is common to all is the point about communications technology. Coupled with dramatic improvements in both ease of use and integration between engineering applications, the ability to search, use, and share information has transformed work processes and the reach of individual engineers. This impacts all areas of the design process, from the ability to access existing options, through assessing more alternatives, to dealing with aspects, such as manufacturability, that might have previously required a hand-off to another engineer. The implication here is that each individual engineer will be in a position to take a broader view of the product development process. To exploit that potential will require a broader understanding of the engineering issues.

We have looked at the impact of automation on design, but what about the domain with which the term "automation" is most associated, the factory? Not only simple production tasks, but even those that may have required a high level of skill like welding complex geometries can be done to the required quality and to a high level of consistency by a robot. The automotive industry, along with the electronics industry, is the major exploiter of robotic technology; see the chart below.

Skill sets are changing

There is no doubt that factory automation results in fewer traditional factory workers; indeed, it's one of the main justifications for automating. So here again we have the question of the impact on the skills required of the workforce. For the factory, the skills shift is more significant than for other areas. The use of automation technology does not eliminate the traditional jobs altogether. In fact, understanding the manufacturing technologies and processes in the factory is a vital ingredient for process improvement. Nevertheless, the majority of roles will change in nature, at a minimum towards operating more complex computer-controlled equipment.

This trend will increase with the uptake of new technology

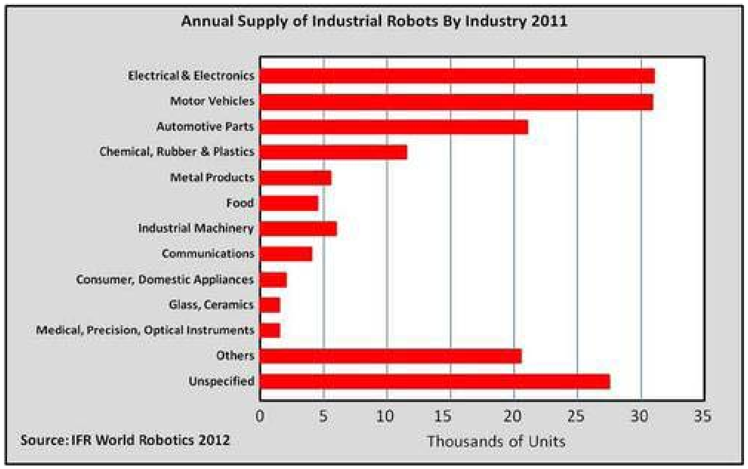


Figure 3: Current penetration of robots by industry shows leadership by electrical and electronics, motor vehicles, and automotive parts industries, according to IFR World Robotics Report 2012. Courtesy: Cambashi Observatory

that enables the "Internet of Things" and its exploitation for industrial Internets. This trend exploits the ability of machines and devices to exchange information over the Internet without human intervention. A recent example is GE's new advanced sodium-nickel battery plant in Schenectady, N.Y. The plant is peppered with sensors to measure all manner of manufacturing process data (cycle times, process parameters, material tracking, etc.), not only supporting a high degree of automation but also enabling comprehensive process analysis to identify opportunities for improvement. The human skills required are therefore an understanding of the potential for automated technologies, how those technologies can be integrated, including with business and other systems, and skills in business analytics.

The ability of devices to exchange information over the Internet without any human involvement also has major implications for higher-level factory and supply chain management activities. It will not be long before we see those activities having significant automated content as inputs like supply chain status, production status, quality information, and so on are fed automatically into a new planning run. Even the agent of much of the automation in industry, software, is experiencing substantial progress in the automation of its development, with technologies like model-based code generation gaining ground all the time.

Integrated digital factories

While, from an engineering perspective, the technologies that underpin digital factories are fascinating, any discussion of the impact of automation on the workforce should include a global perspective. This is a very large and broad-ranging topic, with no easy answers. While the developed countries see their future post-industrial economies involving high levels of automation, as shown in the chart in Figure 1, Asia is already the largest consumer of robot-based factory automation technology. So, while proponents of automation claim that it gives the high-cost countries the necessary productivity edge to compete in global markets, leadership in exploitation of the technologies is vital. A good example is achieving effective integration between the factory floor and the rest of the enterprise. This is a dynamic and evolving picture, requiring constant assessment of the opportunities for IT-enabled process change in the planning and execution of manufacturing activities. To achieve this requires a broad combination of IT and industry skills.

From this point of view, the developed countries should maintain the advantage for perhaps another decade; but over time, the approaches and methods will be adopted by emerging countries and the need to find other sources of advantage will be pressing. In the short term, it is true that the roles in manufacturing will not be as plentiful as in the past and that many of them will require more advanced skills. In fact, we must bear in mind that we may have reached the point where technology has become so pervasive that, despite the activities involved in its development, implementation, and maintenance, it is a net eliminator of jobs. The retail industry has suffered just this under the impact of Internet-based automation. Perhaps the most valuable skill of all will be adaptability!

Tony Christian, director, Cambashi, has a BSc degree (Mechanical Engineering) and MSc degree (Engineering Acoustics, Noise and Vibration) from the University of Nottingham. Cambashi delivers independent research and analysis on the business benefits of using IT in value-adding industries worldwide.

Edited by Mark T. Hoske, Content Manager, *CFE Media, Control Engineering* and *Plant Engineering,* mhoske@cfemedia.com

More Online
www.cambashi.com

Video: Making your plant performance reporting more interactive

What will tomorrow's "morning meeting" look like? ABB gives a preview of what's going on in the lab and what your future HMI may look like.

Peter Welander, Control Engineering

Most James Bond movies begin with a trip to the lab where Q shows off the latest gadgets, like a car with missiles or exploding watch. Attendees at ABB Automation and Power World last week got a similar treatment as the company showed what's cooking in the lab back in Sweden. One of the major questions that ABB has been puzzling over is how the next generation of process plant operators will respond to the typical HMI displays one finds supporting a process control system. It's probably hard to find someone who is pursuing a college education these days that has not grown up with computers and video games. The expectation is that anyone in his or her early 20s will be pretty bored with crude line drawings or eight-bit animation. At the same time, looking at the HMIs on display, it's clear that ABB has implemented graphics that certainly look like they have been influenced heavily by the recommendations of the Abnormal Situation Management Consortium.

ABB Simulator

ABB is exploring how you can create something that puts current graphic capabilities to work in a way that is actually useful in an industrial context. The Qs in this case are Martin Olausson and Susanne Timsjöe, who both work at ABB Labs outside of Stockholm. They were demonstrating some new platforms that interface with the 800xA system and are intended to provide useful and timely information to operators and maintenance people in a plant. I could try and describe the systems, but the attached video gives you a far better explanation. Even the video doesn't do the systems justice because there is no way you can see how much information is there. Suffice it to say if you're reviewing plant performance in your morning meeting, and you want to know what's happening in some corner of the process unit, the data is there and it's up to the minute.

These platforms are still prototypes, but as Olausson points out, the first one is working in the paper mill for which it was designed, and the operators use it every day. These systems aren't products yet, nor is there any assurance that they ever will be in their present form. ABB is still gathering input from users, which is why they were being displayed so openly at the event. It will be interesting to see the next round of developments.

www.abb.com

Read Gray backgrounds for DCS operating displays?

Peter Welander, pwelander@cfemedia.com

Video game or HMI?

Industrial HMI developers consider how video game technology can change the way operators work with control systems. Video: ABB demonstrates some interesting possibilities.

ABB adds new capabilities to its HMIs borrowing technology from video games.

Consider this situation: An operator has been trying to solve a problem in a dirty and dangerous part of the plant. He or she needs some information from the recent alarm list to help analyze the situation. It will only take a minute to get the data from the control room, but wearing dirty gloves and other PPE will not make it easy to use a conventional keyboard with the HMI. No problem. The operator stands in front of a large screen and simply looks at a process schematic, focusing on the key element. At the wave of a hand, the desired data pops up on the screen. Another wave, and the information is transferred to a smart phone or iPad. Everything is done without even removing a glove.

How does it work? The same technology that allows you to bowl or play tennis in your living room can be applied to your HMI. By tracking an operator's eyes and hand motions, the system can move a cursor and click without anybody touching anything. Video game technology meets an industrial HMI.

You might think it sounds great, or is a silly gimmick, but ABB is betting that this kind of capability will be increasingly important as companies depend more on control systems to facilitate collaboration across traditional departmental responsibilities, and engagement with younger (meaning more technology savvy) operators. ABB contends that a control system from 1989 may be adequate to keep the process going, but no operator born anywhere close to that year is going to want to run it. And as new operators become increasingly difficult to recruit, prospects will go where they expect to learn the most marketable skills.

At ABB's user group meeting one year ago in Orlando, the company demonstrated some sophisticated HMI capabilities. (See the video from the 2011 event.) Last week in Houston, we got to see what another year of work in the ABB corporate research group in Västerås, Sweden, has produced. Magnus Larsson and Isak Savo demonstrate the latest developments. See for yourself, and imagine ways you might find the technology useful. Maybe it's not for everybody, but it is getting closer.

www.abb.com

Peter Welander, pwelander@cfemedia.com

Human factors and the impact on plant safety

By Gregory Hale, Luis Duran

Start ups and shut downs remain the most tenuous time for any plant. The timing, technology, knowledge of technology, and adherence to procedures are vital.

Operating procedures should clearly lay down instructions for operation of the process plant. The procedure needs to represent a best practice that should occur at all times. Process operators should have guidance concerning the required operating philosophy to ensure they run the plant efficiently, comply with procedural requirements and properly identify abnormal conditions and respond accordingly. On top of that, adequate training should ensure operators are fully conversant with written procedures.

That is where people, process and technology all have to work in unison to make sure the plant starts or stops without incident. Yes, technology is always there to ensure the manufacturer has the correct tools and surely there is a process in place that earmarks the correct path. But what about the Human Factor? Just how does the human play into the impact on plant safety?

Technology is the key to any operation today, but humans factor into every aspect of the facility's lifecycle from design to operations and maintenance. But human factors analysis in the process industries found basic automated actions are reliable to one in several hundred thousand occurrences. To take it one step further, for certified safety systems the reliability is even higher at reliability levels approaching one failure in one million reoccurrences. But when it comes to manual actions, the reliability drops dramatically to 1 in 100 occurrences or less depending on environmental conditions such as mental stress during an abnormal event.

While through a concerted effort on process safety compliance via training, automation and enforcement there has been a dramatic drop in process safety incidents.

However, over the last five years, there has been a change. Incidents have not gone up, but rather there has been a plateau level where incidents remained low, but the infrequent incidents that do occur are more severe and costly. Root-cause analysis indicates in spite of the high degree of automation, operator training, and behavioral enforcement, error due to human judgment continues to be troubling.

These human failures are not the result of poor training, poor management systems, or unreliable machines or lack of information. In a large portion of the most recently reported process safety management incidents, these events occur with highly experienced operators. They just seem to make the one out of 100 errors in judgment which places them in the line of fire.

The question is, "If automation, training, knowledge and experience all in place, why is operator error most frequently identified as a significant contribution to the incident root cause?" One hypothesis is we have reached a saturation point between the operator, structured instruction and the automation systems. With saturation comes human overload. Add in additional environmental stress and you have a combination for failure.

Case in Point

To judge the importance of the human factor, take a look at the disaster at the BP plant in Texas City, TX, where 15 people died and 170 others suffered injuries in a massive explosion and fire during the start up of the isomerization process unit in March 2005.
Texas City had problems just about everywhere. They had antiquated equipment, corroded pipes about to burst, and safety alarms that didn't work. On top of that, there were three key pieces of instrumentation scheduled for repair, but it never happened. Add in the additional pressure to get the plant started up along with consistent lack of operating discipline, deviations from safe operating practices and complacency toward serious process safety risks.

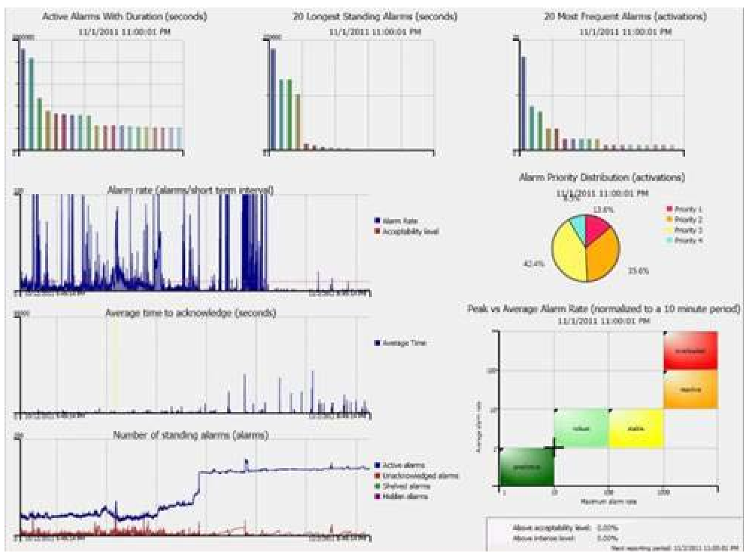
While Texas City is a text book case of how technology, process and humans were not working on the same page, the idea that people could have prevented that catastrophe screams out beyond the headlines.

While well known, a little background shows that on March 23, 2005, a hydrocarbon vapor cloud explosion destroyed BP's


Courtesy of the CSB

isomerization process unit. The Texas City Refinery was the second-largest oil refinery in the state, and the third-largest in the United States with an input capacity of 437,000 barrels per day. Reports suggest the direct cause of the accident was "heavier–than-air hydrocarbon vapors combusting after coming into contact with an ignition source. The hydrocarbons originated from liquid overflow from the F-20 blowdown stack following the operation of the raffinate splitter overpressure protection system caused by overfilling and overheating of the tower contents."

BP and the Chemical Safety and Hazard Investigation Board (CSB) identified technical and organizational problems at the refinery and within corporate BP. Organizational failings contributed to the human factor in the incident with corporate cost-cutting, a failure to invest in the plant infrastructure, a lack of corporate oversight on the safety culture and major accident prevention programs, a focus on occupational safety and not process safety, a defective management of change process, the inadequate training of operators, a lack of competent supervision for start-up operations, poor communications between individuals and departments and the use of outdated and ineffective work procedures which were often not followed. There were technical failings as well, including a blowdown drum that was of insufficient size (which would have been identified in the HAZOP procedure), a lack of preventive maintenance on safety critical systems, inoperative alarms and level sensors in the ISOM process unit and the continued use of an outdated blowdown drum and stack technology when replacement with the safer flare option had been a feasible alternative for many years.



There is no doubt Texas City was a combination of human factors, but that disaster was an end point that started long before that fateful day. Other organizations in the industry face that same scenario every day where features and procedures that operators should follow to properly run the system ended up bypassed – not out of negligence, but out of expediency. With the proper systems in place reinforcing a solid safety culture, you could most likely erase one disaster from the record books.

It would be possible for humans to eliminate errors by keeping a vigilant eye toward asset optimization where the user could right click and get access to procedures and configuration guidelines. In addition, through an integrated control and safety system it would be likely to catch alarm failures and the lack of adequate safeguards and use of outdated process design.

In addition, a warning or event indication would be able to alert the operator or maintenance workers if there was a recirculation automated level control valve left closed during start-up or if there were failures or breakdowns not attended where a work order ended up closed without job the completed.

Humans are Fallible

Hardware and software systems have improved immensely over the past 30 or 40 years through the use of automated procedures, proper audit trails, management of change process, alarm management, situation-based displays, human-centered HMIs and control room design, but with humans still in the loop either in the design, operation or maintenance there has to be an understanding that mistakes will happen. Humans are fallible and they make high degree of errors and that has to be taken into account which means there has to be a very robust system.

That is where process safety and integrity management can come together. Process safety is the prevention of unplanned and uncontrolled loss of containment from plant and process equipment that might cause harm to people or the environment. That definition works hand in hand with integrity management which is the assurance that plant and equipment are fit and ready to go by establishing competent people, effective systems and dependable assets.

Benefits from integrated safety and integrity management include:

- Being in control, resulting in improved health, safety and environmental performance; full regulatory compliance, and business performance benefits, including higher plant availability, improved output and more reliable customer provision
- Reduced costs, including maintenance costs
- Compliance with the ability to reliably meet ever more demanding regulatory requirements
- Technology backbone to a culture that ensures safety and integrity are integral parts of day to day operations.
- Delivery of performance which means a more proactive approach and managing improved performance sustainably

Risk Reduction

In an industrial facility, it is all about reducing risk and to do that a manufacturer has to design in inherently safe processes. Industrial processes have a built in danger and that means accidents should always be at the forefront of everyone's mind. But with a strong safety culture, the potential for accidents can significantly lower through a constant assessment of the significance of safety events and issues to ensure each receives the appropriate level of attention.

Part of those assessments will include the idea that system design must follow safety standards that include an ongoing continuous improvement cycle based on periodic Hazard Analysis or HAZOP.

Also, asset management systems must undergo regular testing and maintenance in accordance with safety procedures. Proper asset management must include an alarm management strategy with warning or event indication to alert the operator and maintenance when maintenance is due.

Integrated safety systems to plant automation are an important technology trend across the industry seamlessly displaying critical information or alarms. Utilizing common reporting tools for safety and basic process control systems (BPCS) creates an environment for consistent analysis and breeds familiarity with safety systems for the operator.

Operator effectiveness needs to be taken into account. Effective operator ergonomics will improve the work environment which will have a positive impact on alertness, which removes the potential to miss critical information due to fatigue. With extended operator workplaces with interactive personal large display, the operator has a greater overview of the complete process; better working height and viewing angle; increased sitting comfort and legroom; better ambient lighting; reduced noise level and traffic, and console proximity to communications and collaboration.

Even with multiple technology protective layers, manufacturers need to enforce a strong safety culture that reaches every level -- and it has to start at the top.

Technology and Training

Systems can undergo a design to react properly to an incident, but it can't just stop there. Operators will need proper training. The system cannot prevent every little discrepancy, but the right problem solvers in the right culture with the right technology will solve problems before they escalate.

One way to ensure a safe environment is to implement lifecycle management that will not only allow the user to work with

Addressing the Human Factor

Technology does go a long way toward handling safety issues that can arise, but humans do remain the vital part of a safety solution.

The following are some recommendations to keep everyone tuned into plant safety:

- Use check lists: Create a check list and then have a co-worker verify the checklist. With tablets becoming more commonplace, that will be a big assist.
- Foolproofing: Recognize some operations are highly critical and sit down and make sure everyone understands that and then find the answer to the question of how can we make this foolproof in the human interaction.
- Flag changes: Operators and maintenance users get a flag that tells them when systems end up moved off automatic and into manual. Flagging should make workers aware when others make changes and what that means to the safety of the plant.
- Communication: Workers need to cross check and talk through an issue; create a collaboration table where people can have a look at the plant digitally where they can cross check and look at diagrams and understand the ramifications behind any decisions.

issues that are known today, but also tackle those that appear down the road.

When looking at the human factors, think about the entire lifecycle. When the designers created the system, did they understand the risks? Did they use reasonable levels of probability? How about the consequences? Did they mitigate those factors?

Equipment will continue working for years, but other factors intervene. Just how sure is everyone that valves that have been in place for 20 years or so will open or close as they should during an emergency situation? Have they been tested and how do you know they will work?

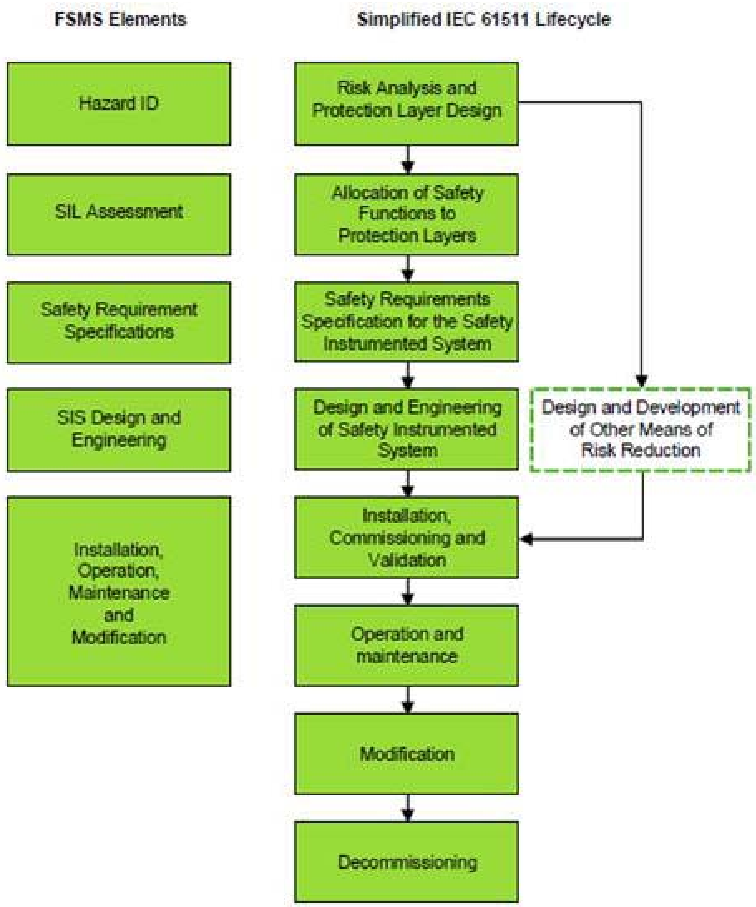
Technology will not fix a problem unless the right processes and the right best practices are in place. Technology will help enable people to make the right decision. But the culture has to be there to enforce them to make the decision in the first place.

Human Factor Squeeze

One idea where technology may advance to the point where manufacturers may be able to tighten up the human factor is using a combination of software and wireless to improve manual operations.

This is where the manufacturer can eliminate human interfacing in a manual safety setting by using computer integration techniques to combine manual procedures with automated equipment.

One example would be the frequent case of loading or offloading a truck with a chemical at a facility. In that procedure



there are a number of valves and pumps and not all of them are automated. In most cases users do not have automation on the valves that line up equipment from one tank to another and from one line to another, so that ends up being a manual procedure to "lock this" and "turn on that" to control the actions. What if the workflow to those manual actions used mobile technology and checklists? In this case, the operator does his manual task by checking the box in the mobile device and that sends a signal back to the control system which provides interlocks to the flow control and pumps and switches so it assures the operational state or readiness. It integrates the manual task with the automated action.

This future technology shift error proofs the manual action that does not have I/O and still needs the human to initiate the task. It automates the workflow and allows the completion of the workflow with the automation system.

Near Misses

One area manufacturers need to focus on is not just reacting to a problem, but also assessing near misses. All factors should come into play in a true safety lifecycle management program. A cycle for continuous improvement in safety performance also should be in place to track any near misses, analyze them for root causes, and use the results to further improve safety system performance. This is another area where technology (such ICSs) can help an operator track the right KPIs that plant management already established.

In the case of Texas City, not calibrating the instruments properly may seem like a small issue, but after a period of time of ignoring a seemingly small issue, that may have caused a slight performance blip which ended up starting the countdown to a disaster.

Proper management of the safety lifecycle requires trained and certified workers. Along those lines, maintenance of safety-related equipment often goes overlooked and that means operations and maintenance personnel need training and certification in testing safety systems.

Better adherence to maintenance practices is a must. Asset integrity management systems can help bring about a more proactive maintenance strategy and can even reduce maintenance costs.

Standards Set the Tone

In short, safety often relies upon adhering to a company's standards or the industry standards like IEC's 61508 and 61511 standards. What is interesting to note, and something most manufacturers should keep a vigilant eye on, is just about 66 percent of safety instrumented systems in use today predate these standards.

And while the U.S. implementation of IEC 61511, or ANSI/ISA 84, includes a "grandfather clause" for older systems, its insistence that operating companies ensure safety systems end up "designed, maintained, inspected, tested, and operating in a safe manner" leaves no room for less-than-rigorous safety system discipline.

While the IEC Safety Instrumented Systems (SIS) standards are not legal requirements such as in the United States, their growing acceptance as descriptors of industry best practices means that non-compliance may have very real liability implications in the event of an incident. And in some regions and industries, compliance already carries the force of law like in the United Kingdom, Germany and Australia. One economic plus is if manufacturers can prove compliance, it may help operating companies reduce insurance premiums.

Purposely non-prescriptive in nature, the IEC safety standards outline a holistic methodology for managing every stage of a safety systems' lifecycle — from risk analysis and design engineering through operations, management of change and decommissioning.

Elements relevant to safety systems performance assessment include adherence to accepted risk evaluation and mitigation methodologies such as process hazards analysis (PHA), hazards and operability (HAZOP) analysis, and layers of protection analysis (LOPA).

Risky Business Means Accidents

Even when precautions are in place to reduce the risk of accidents, they will happen. Nearly 3 million nonfatal workplace injuries and illnesses ended up reported by private industry employers in 2011, resulting in an incidence rate of 3.5 cases per 100 equivalent full-time workers, according to the U.S. Bureau of Labor Statistics.

In addition, there were 4,693 fatal work injuries recorded in the U.S. alone in 2011, compared to 4,690 fatal work injuries in 2010, according to the Occupational Safety and Health Administration (OSHA).

A majority of the industrial accidents that occur every year are a result of human error. Those incidents occur as a result of improper training of personnel. Systems can have the right design to react properly to an incident, but manufacturers need properly trained workers to ensure the safe handling of a problem.

Manufacturers need to have an action plan of best practices to ensure a safe environment. They need to:

- Set up procedures for reducing incidents that include proactive asset management and written standard operating procedures.
- Perform comprehensive hazard assessment after every incident or accident to ensure equipment meets baseline pro tection levels at minimum.
- Manage process safety as an all-inclusive effort where all parties (including third-party contractors) possess appropriate process safety knowledge and expertise. Root cause analysis of incidents leverages lessons learned and adds to the overall body of knowledge.
- Consider an integrity management system to gain more knowledge of the current state of all plant equipment as it relates to safe operations.
- Do retrospective HazOp implementing "what if" scenarios. If the plant has been running 10 to 15 years, every five years the plant should do a HazOp test to make sure everything is working.
- Layers of protection analysis (LOPA). This is to overcome human factors where plants undergo changes over the years. People have modifications like add ons or close offs. This type of analysis would inform what was working and what was not.
- Asset integrity management. This is for the mechanical items on a production plant. Make sure the control valves, the emergency relief valves, piping and pressure vessels, etc. undergo inspections at defined frequencies.
- Alarm management. A root cause of the Three Mile Island nuclear plant incident was the operators ended up swamped with alarms. Operators had dozens of flashing lights and they couldn't tell the wood from the trees. Alarms need to be put into context. Now there are emergent stand ards coming out that allows for a certain amount of alarms in 10 minutes.

Safety goes beyond just ensuring processes remain stable. By having a solid plant and ensuring a strong safety culture where all users remain involved at all times, safety does have a direct link to increases in production and decreases in incidents. The issue is not enough manufacturers are looking at the big picture and realizing just what a strong safety program brings to the bottom line.

As Trevor Kletz, an adjunct professor of the Texas A&M University Artie McFerrin Department of Chemical Engineering, said during the CSB investigation of the Texas City Disaster, "If you think safety is expensive, try an accident. Accidents cost a lot of money; not only in the damage to a plant and in claims of injury, but also in the company's reputation."

Luis Duran is the product marketing manager safety systems for ABB.

Gregory Hale is the editor and founder of Industrial Safety and Security Source (ISSSource.com).

Sources:

www.CSB.gov
http://www.cbsnews.com/8301-18560_162-2126509.html
http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/SP/STAGING/local_assets/assets/pdfs/Baker_panel_report.pdf
http://www.bls.gov/news.release/pdf/osh.pdf
http://www.bls.gov/news.release/cfoi.nr0.htm
ABB Control supplement
Interview with Luis Duran, ABB
Interview with Tony Conning, ABB
Interview with Mike Williams, Dow