

The

High Performance

HMI

Handbook

A Comprehensive Guide to Designing,
Implementing and Maintaining
Effective **HMIs** for
Industrial Plant Operations

By Bill Hollifield, Dana Oliver,
Ian Nimmo, & Eddie Habibi

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First Edition

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Dedications

*For my parents, Joe and Leona, who provided me
with a wonderful, living example of
the benefits of love and hard work.*

- Bill

*For my wife and children, Elizabeth, David,
and Katelyn. Thanks for allowing me to sometimes
get too involved in my work but always remember
that what I love most is you guys.*

- Dana

*For Barbara, my best friend and life partner,
who has supported me in all my undertakings
and has been faithful and patient
as I have traveled the world - Ian*

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to read and write themselves, but instilled in their
eleven children the need for an education, a thirst
for knowledge, a strong work ethic,
and above all kindness.*

- Eddie

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PART II: Fundamentals of HMI Design and Best Practices

The concepts and practices of proper HMI design are examined in detail. Good and bad practices are illustrated. Assessment methods for existing systems are provided. Methods for providing proper process overview, graphic hierarchy, and progressive exposure of detail are introduced, along with detailed design principles and examples. Proper physical console layout and other factors are covered in detail.

PART III: Design and Implementation of a High Performance HMI

A straightforward methodology is provided for the development, implementation, and maintenance of a High Performance HMI. The methodology is useful for either new applications or for the improvement of existing HMIs.

PART IV: Control Rooms, Abnormal Situation Management, and the Future of the Industrial HMI

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Foreword

Time for a Paradigm Shift in Industrial Operations

...

“We cannot solve our problems with the same thinking we used when we created them.”

- Albert Einstein

...

Today's control room console operator is responsible for operating a process manufacturing facility safely, securely, and efficiently. This critical task is intended to ensure that the millions, or even billions of dollars invested in these facilities are providing optimum returns. To accomplish this task, the operator views the process through “glass.”

The degree of success of the plant is determined by the degree of success of this control room console operator. The “glass” is the operator's Human Machine Interface (HMI), and whether petroleum refinery, chemical processing unit, or power plant, is the window on the operation – providing the second-to-second and minute-to-minute pulse of equipment performance, process integrity, product quality and operational effectiveness.

This important window has historically been neglected. The HMI has received little attention in plant studies or in industry literature. Poor HMIs have been specifically cited time and time again in major industrial accidents. They are contributing factors to on-going poor performance. In many cases, the HMI impedes rather than assists an operator in handling a process upset or abnormal condition.

Attractive justifications for operator HMI improvement include safety and loss prevention. The best way to put a value on such an initiative is to assess

cumulative losses over time that can be traced to operator error. Unfortunately, abnormal situations, upsets, and shutdowns are not even tracked in many companies, and in those that do the root causes are often obscured and many times ignored.

Although the HMI is seen as a key component of operational success, it has not generally been developed with the control room console operator's work process or tasks in mind. Any effective HMI must incorporate such a viewpoint.

So, why the lack of proper HMI development? Even in new control systems and projects implemented today, the design of the HMI usually embodies concepts and techniques that originated in relatively primitive digital systems. Those paradigms have become deeply ingrained; they have remained with us even though today's technology can now support vastly improved HMIs. In fact, while many control systems have gone through multiple generations of technological improvement, the original poorly designed and operationally inefficient HMIs have often been simply migrated.

Things are changing.

The combination of changing work process, technology and people is driving the HMI to a new level of performance. Companies are beginning to recognize the need for HMI improvements. The operator's HMI is becoming a core element of an overall plant operations and situation awareness strategy – an element that is key to safe and reliable plant operations.

The next generation HMI must transform the mounds of raw operational data traditionally provided to the operator into actionable information that is in proper context – because *data is not information*.

With the publication of this handbook, the principles for creating a High Performance HMI have been captured in one place. A *High Performance HMI* enables an operator to safely and effectively monitor and manage a processing plant. It is based on best practice principles of human factors engineering and ergonomics design. It is designed to actively assist the operator in effectively managing both normal and abnormal conditions by substantially enhancing “in the moment” situation awareness. The authors believe safety related best practices should be shared and made accessible to all. If your role relates to

process plant operations, automation, safety, or reliability, then read on.

The High Performance HMI Handbook is an engaging compendium detailing the planning and implementation of a high performance HMI solution. Through the use of illustrations and examples, this book clearly explains how to justify investment in HMI improvements, the guidelines for developing an HMI philosophy, the methodology for HMI performance assessment, and the principles for creating high performance graphical interfaces.

The migration of our existing HMIs will be a big challenge. Many of our paradigms and thoughts about HMIs have strong roots and exert a powerful hold on us. But the time has come to re-examine the “old” – and to consider re-design with field-proven best practices that are much more safe, much more effective, and hold the promise of greater profitability.

- Kevyn Renner
Senior Technology Consultant for Chevron Global Manufacturing



Kevyn Renner currently drives innovative application of Control & Information Systems technology for Chevron Global Manufacturing. He has 25+ years combined experience in Process Design, Operations, and Advanced Control with companies including PetroCorp, Mobil Oil, Foxboro, Emerson and Sun Microsystems. Kevyn is widely published on automation and information systems topics. He graduated from the University of Canterbury, New Zealand with an honors degree in Engineering, with majors in Chemical Engineering and Chemistry.

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Industrial Plant Operations**

Part 1:

The History and Current Status of the Industrial HMI

We begin with the origin and evolution of the industrial HMI. The positive and negative issues posed by the introduction of the Distributed Control System (DCS) are covered. The current status of industrial HMIs is characterized, along with clear justification for significant improvement.

Chapter 1

Introduction

Chapter 2

The State of Industrial HMIs and Operator Graphics

Chapter 3

The Justification for HMI Change

Chapter 4

HMI Best Practices – A Managerial Overview

Chapter One

Introduction

...

“A picture is worth a thousand words. An interface is worth a thousand pictures.”

- Ben Shneiderman

...

Every process controlled by a modern Distributed Control System (DCS) utilizes an HMI (Human – Machine Interface), which is the collection of both hardware in the form of physical screens and input devices, as well as software in the content of the displays designed to represent real-time plant operations and enable the user (operator) to monitor and manage the process. The overall HMI includes a collection of “built-in” (unchangeable) displays provided by the DCS manufacturer, custom graphic displays designed and used by the owner/operator, navigation methods to access the information, and several other similar hardware and software items. Every system’s HMI becomes a customized implementation – there is no “standard” HMI to adequately represent every process. The result is a high variation in the quality of HMIs.

Most operator control of a process is done through the HMI. A properly designed HMI will support smooth, stable operations, optimum situation awareness, and optimum response to abnormal situations. A poorly designed one can degrade safety, production, quality, and profitability.

The authors have examined hundreds of industrial HMIs and, unfortunately, most only remotely follow the fundamental design principles contained in this book.

Poorly-designed HMIs are common. They:

- encourage various poor operating techniques, such as “running by alarms.”
- actively impede in proper situation awareness.
- result in increased process variation and poorer quality.
- contribute to higher numbers of avoidable upsets.
- increase the likelihood of sub-optimum response to abnormal situations.
- have been identified as significant contributing factors to major industrial accidents.

The HMI exists so the process can be run as safely and profitably as possible. This book puts forward the principles for designing a ***High-Performance HMI*** and compares it to what is referred to as a “Traditional HMI.” Studies have proven (see Chapter 3) that large improvements in operator performance and effectiveness come from the creation and use of High Performance HMIs. Poor HMIs result in lower profitability.

Reading this book will very likely make many engineers and managers uncomfortable. People are generally proud of their Traditional HMIs (since they are usually designed “in-house”) and are often unaware of their deficiencies. They are certainly “used to them” and any change will be resisted. Pointing out deficiencies can bring out a very defensive emotional response. Engineers are passionate about their HMIs because a lot of time and effort is usually put into their creation. This is particularly true about custom graphics, which are a major focus of this book. Realizing that effort may have been counterproductive is a bitter pill to swallow.

However, that should not be the case. This book discusses an evolutionary application of new technology to improve the control system. Changing an HMI to take advantage of new capabilities is not an admission that the old systems were designed poorly. The fact that aircraft now use jet engines does not mean the designers of 1940s era turbocharged piston engines were poor engineers! It means the aircraft engineers were not reluctant to take advantage of new knowledge, materials, research, and capabilities for improved performance.

1.1 Why This Book Was Written

In November 2006, Automation World published an article beginning with:

“If you’re seeking best-practices standards for designing graphical operator-interface displays, you won’t find them.”

The purpose of this book is to capture in one volume the current body of best practices knowledge for improving and optimizing the performance of a modern DCSs HMI, tailored specifically to the solution of the problem.

There is a widespread need for the information in this book. It is not provided by the DCS manufacturers. In fact, the DCS manufacturers usually demonstrate their graphic capabilities using example displays violating almost every good practice for HMIs! There are a few industrial magazine articles on the topic from different sources and these vary widely in their content. There are good principles and practices known to consulting companies and other organizations which have been closely held and have required substantial fees for access.

In many ways, the situation is similar to that of Alarm Management, prior to the 2006 publication of *The Alarm Management Handbook*. That book provided a comprehensive guide to solving alarm problems, presented in a straightforward, usable way. This book is another comprehensive guide dedicated to solving widespread problems with HMIs.

This book focuses on practical advice and techniques to significantly improve the performance of existing HMIs and turn them into High Performance HMIs. The principles herein can also enable new systems to be initially implemented correctly and not require expensive re-design after problems later become apparent.

PAS has well over a decade of extensive experience in designing DCS HMIs and implementing advanced automation solutions for companies all over the world. User Centered Design Services (UCDS) has vast experience and proven global expertise in automation, HMI, and control room design. This book is based upon this extensive worldwide, multi-industry experience, along with a thorough knowledge of all of the guidelines, articles, reference works, and other materials

on the subject.

The book contains actual examples of good practices and poor practices. The various problems of Traditional HMIs are covered, with guidance on how they came about and how to effectively correct them. Since most operating companies are limited in time, money, and resources, the focus is on straightforward and practical solutions.

1.2 Is This Book For You?

This book specifically targets HMI design for modern control systems using custom graphic screens in the HMI (such as DCSs and SCADA systems). These flexible and capable systems are used throughout various industries, including oil and gas, refining, chemical, petrochemical, pulp and paper, pharmaceuticals, power generation, minerals processing, discrete manufacturing, and others. The most common scenario this book addresses is a processing facility – continuous or batch – with one or more operators using a modern DCS. If you have such a facility, you will find this book valuable.

The contents include:

- the detailed characteristics of a High Performance HMI.
- methods for assessing an existing HMI against High Performance principles.
- HMI factors leading to proper situation awareness and response to abnormal situations.
- step by step guidance on implementing and maintaining a best-practice High Performance HMI to support optimum process control.

1.3 A Word of Warning!

The discussion and criticism of graphic displays is quite a touchy subject. There are paradigms involved in current graphic displays that have grown deep roots, despite their clear ineffectiveness.

This book directly and intentionally examines many such paradigms and clearly points out deficiencies and opportunities for improvement. The recommendations are not absolute – there is room for adaptation to particular situations.

Every single illustration in this book can be a source of debate. Every principle and example put forth can evoke the response, “Well, we’ve done it just the opposite way for 15 years and that’s better for us.” Resistance to change in this area is very high. When reading, concentrate on the validity of the principles and do not get lost in the details. Consider ways to apply the proper principles to

your own control situation.

No book can provide examples of detailed graphics covering all processes. Diagrams are provided to illustrate common display situations in generic ways. The printed examples may appear different than the same examples shown on computer screens.

It is the responsibility of industrial process owners, operators, and of automation suppliers to create HMIs maximizing safety, productivity, and profitability. The principles needed to do so are now known. Correcting existing deficient systems requires the knowledge and the will to question many strongly rooted paradigms, but the result of doing so will be highly rewarding.

Disturbing Moments in Cinematic Human-Machine Interfacing:

Master Control Program (MCP): <*disgustedly*> “*This is what I get for using humans.*”

Indignant high-tech company CEO: “*Now wait a minute, I wrote you!*”

MCP: “*I’ve gotten 2,415 times smarter since then.*”

Tron

Chapter Two

The State of Industrial HMIs and Operator Graphics

...

“It is impossible to design a system so perfect that no one needs to be good.”

- T.S. Eliot (1888 – 1965)

...

2.1 In the Beginning – the Control Panel

Control rooms date back to the earliest days of manufacturing plants. By the 1930s – 1940s, it was typical to have a small separate room near the process where most of the instruments (typically pneumatic) were grouped. Control panel arrangements received a lot of thought, and instruments were logically grouped. Sometimes a pictorial representation of the plant was used as a background onto which the instruments were placed in their appropriate positions. Many readings were represented on paper strip-chart or circular chart recorders. Alarms consisted of separate “lightbox” annunciator panels.

Such installations had many advantages. The process condition could be determined at a glance. Trends of important readings were always in view – all the operator had to do was look at them. The alarms were carefully selected and various different upsets would often produce repeatable patterns on the annunciator, besides the individual alarm indications. With a simple walk through the control room, experienced operators, engineers, and managers could quickly see the overall state and health of the process – it was easy to get “the big picture.” These “control walls” persisted into the 1960s and 1970s, although stand-alone electronic instruments began to replace pneumatics.

There were many disadvantages with this arrangement as well. The addition of new instruments or alarms might require moving several other instruments to keep a logical arrangement. This was expensive, and thus often was not followed, leading the logical pictorial arrangement to become out-of-date over time. Pneumatic instruments were difficult to combine into complex or advanced control schemes. The instruments took up a lot of room, and the space behind the panel was often a dirty, cramped maze of tubing and wiring. Communication of the control system to “anything else” was generally impractical.



Figure 2-1: A Typical Pre-DCS Control Panel

2.2 The Arrival of the Distributed Control System (DCS)

The frustrations associated with the Control Panel were addressed with the arrival of the Distributed Control System (DCS), in which process signals were monitored by a computerized structure and physical instruments were replaced with software displays. The business advantages of a DCS are huge! It is easy to reconfigure control strategies and programmatically alter the behavior of the system. In addition, almost everything in the system is changeable without much trouble. (The astute reader will also realize that the ease of such changes is also the source of major problem areas in administering a DCS!)

So, over a couple of decades, DCSs have predominated and most older-style control systems have been converted. The advantages of a DCS have far outweighed some well known DCS deficiencies, such as dealing with the thousands of alarms the systems are able to generate (See Appendix 4).

The earliest DCS implementations did not have “custom graphics.” Instruments and readings were displayed in “group displays.” Shown in Figure 2-2 is a group display in which 8 separate control elements are shown. (The actual display has a black background and colored text, which does not print well in a book, so the figure is reversed.) Hundreds of these groups would be configured to display all of the controls and measurements available to the operator. The issues around black display backgrounds will be discussed later in the book.

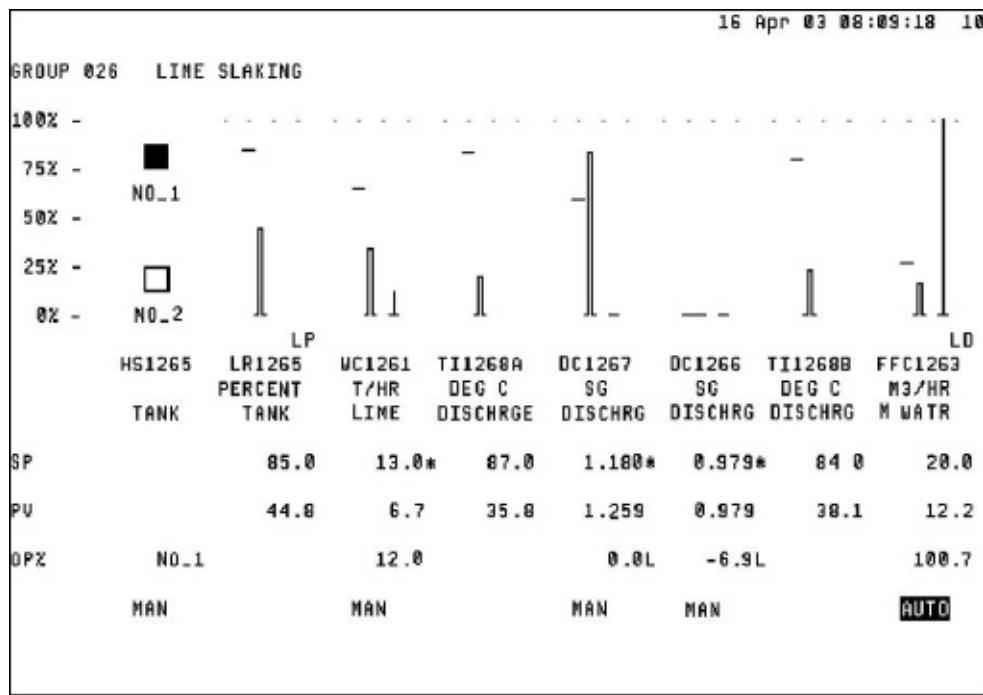


Figure 2-2: A Typical Pre-Graphic “Group” Display

The CRT-display workstations used to display these groups were expensive – around \$50,000 each in the 1970-80s! Thus systems were installed with the minimum possible number of such screens and the operator’s “big picture” view of the process collapsed to a “peek through the keyhole” view. With the big picture gone, the practice began of configuring more and more alarms. The alarms notified the operator about changing conditions “outside their keyhole” which used to be able to be seen at a glance. The DCS made this quite easy –

alarms were “free” and could be created with a few keystrokes. A single operating position had about 50 alarms in the control panel days; the typical DCS operating position is now configured with over 3,000! This is the origin of the DCS Alarm Management problem.

DCSs quickly evolved to allowing for the creation of custom graphics. A schematic-type picture could be built showing process vessels, piping, equipment, and live process values. A limited palette of colors and intensities was available for use (and misuse). Screen elements could be built to change shape, color, or functionality based on process values. Trends could be created and displayed.

However, as in so many things, our ability to design and create new products and capabilities works much faster than our ability to understand how to use them effectively. With little research or guidelines as to how to effectively design and use a screen-based control display, engineers and operators (with the best of intentions) implemented whatever they thought was good – or at least usable.

Resistance and Inertia

It is interesting to note there was typically very high resistance on the part of the operators in changing from “groups” to “graphics.” For all of their deficiencies, operators were familiar with using the group displays and had adapted to run with them. Groups typically display faster than graphics and operators often have the access codes to the groups memorized. This same phenomenon of resistance has been and will be experienced when changing from whatever type of graphics are currently in use to the high-performance graphics as described in this book. Expect it.

2.3 Early and Current HMIs

The most common use of the initial DCS graphics capability was simple and straightforward. A P&ID-like depiction of the process was created and live process values were “sprinkled” all over it. While easy to create, this is not very effective. Even given 20+ years of significant advance in DCS display capabilities, the vast majority of all operator graphics follow this paradigm and have improved little since the 1980s in real capability and effectiveness.

However, now the colors used may be more varied, the process vessels rendered in 3-D shading and animated flames used to represent burners – all of which are counterproductive, poor practices.

DCS vendors have now provided the capability of creating HMIs with extremely high sophistication, power, and usefulness. Unfortunately, this capability is usually unused, misused, or abused. The basic principles of effective displays are often not known or followed. Large amounts of process data are provided on graphics, but little information. Information is “data in context made useful.” In many cases, the DCS buyer will proceed to design and implement graphics based on the flashy examples (Figure 2-3) created to sell the systems – unaware from a usability and effectiveness point of view, they are *terrible*. Such graphics contain:

- equipment depiction with excessive, distracting detail.
- hard-to-read numbers and status information.
- inconsistent process flow and navigation.
- poor and inconsistent color choices.
- a lack of hierarchical content (the progressive display of detail).
- an almost total lack of trend or status information.
- improper alarm depiction.
- a lack of display methodologies showing the operator the state of the process compared to the desired conditions.

One DCS vendor has actually advocated taking a digital photograph of different parts of your process, using it as a display background, then adding “live values” of flow, pressure, and temperature on top of it. There could actually be few worse displays for operating a process than this idea.

Here is a quote from the website of a popular vendor of HMI software tools. It notes they include with their software a “*comprehensive library of pre-built, eye-popping graphical symbols and faceplates.*” “Eye-popping” is exactly what is not desired!

2.4 HMI-Related Problems Arise

There have been multiple examples of major industrial accidents where a poor HMI was cited as a contributing factor. The 1994 Texaco Pembroke (UK)

explosion is one of the well-researched and most cited cases. In this event, overflow of flammables into a flare header not designed for liquids led to a rupture and vapor cloud explosion. The HMI-related contributory factors were determined to be improper alarm management and the lack of the DCS HMI to provide the operators with an overview of the process conditions. It was determined the displays provided were inadequately designed and configured to help operators control the process. Had a proper overview display been provided depicting volumetric or mass balance information, the accident might well have been avoided.

In an eerily similar accident 21 years later, the BP Amoco Texas City plant overfilled a tower for many hours, and then overflowed flammables from it to a blowdown drum, and from there to the ground, causing a vapor cloud and explosion that killed 15 people and injured many more. There were both alarm-related and HMI-related contributory factors. Once again, there was no overview display allowing for a proper depiction of the state of the process. The existing displays did not provide volumetric or mass balance information which would have clearly indicated the situation.

This problem is not unique to the process industries. In the 1980s, the software user interface (the HMI) of the Therac-25 radiation therapy machine was implicated in several patient deaths due to radiation overdose. There have been more recent medical journal reports documenting how poorly-designed HMIs for specifying and ordering medicine have contributed to the death of patients. That's something to think about the next time you are in the hospital.

2.5 How Did This Happen?

Why are industrial HMIs implemented so poorly? This situation came about mainly as a result of two factors: knowledge and money. Early DCSs had limited graphics capability. When panel instruments were migrated to a DCS, funding for the graphic development was often not included (or minimized) in the overall funding for the conversion project. When it was included, often the system integrator had little expertise or experience in graphics. Late in the project (with funds running out), the issue had to be addressed:

Typical DCS Conversion Project Manager circa 1985-1995: “*Graphics? You mean pictures? You want pictures of the process on these fancy screens? Don’t*

you know we only have a few weeks until cutover? Hmmm – what do we have laying around here...OK! See that stack of P&IDs? Those are pictures, right? Use them and get it done quickly and don't bother me about this anymore. I've got a budget review meeting."

The unfortunate thing is P&IDs are tools for designing a process which is a very different thing than a user interface for controlling a process. Yet the fact they look like pictures and were convenient, began the current, widespread paradigm that an HMI should look like a P&ID with “live values” sprinkled on it. It is “the easy way out.”

Without specific funding or guidance, the graphics were developed in a variety of ways. In many cases, it was left to the production department to take care of the HMI. Sometimes the engineers did them, who, even with the best of intentions, were not knowledgeable in effective graphic design. Knowledgeable guidelines were not available.



Figure 2-3: A typical vendor graphic more appropriate for selling systems than operating a process!

Luckily you are spared the animation...

It was also very common to deal with the problem by saying, “Lets make the operators responsible for doing the graphics. After all, they’ll be using them.” Then, an operator would be chosen for the job and sent to a DCS graphic training class. (While the DCS manufacturer could certainly teach how to create graphics on their system, this did not mean they knew or taught how to create effective graphics.) The frequent result was what we like to refer to as a “Chapter 3 Graphics Implementation.” That is, the operator would then create the graphics using the techniques and information covered in the DCS graphics building manual up to about chapter three. More complex or advanced techniques went unused. The emphasis would be on display of values, perhaps some condition-based colors, but certainly not of such desirable things as embedded trends.

In some cases, a third party integrator or engineering firm might be charged with creating the graphics as part of a large upgrade. The tendency would be to economically (for them) reuse the simplistic practices of past projects.

With few reference works available on the subject, and the lack of a comprehensive HMI Philosophy with a Style Guide, the resulting graphics would (in hindsight) embody many of what we now know to be poor practices and inconsistencies.

Over the ensuing years, DCS hardware and software upgrades would be released, greatly enhancing the potential graphic capabilities. However, when these enhancements would be issued, the DCS owner would already have a large existing inventory of graphics “everyone was used to.” The reaction to DCS upgrades was usually not “Great! Now we can redo our HMI, and add embedded auto-ranging trends and multi-state conditional elements!” No, it was instead, “Do you have a migration utility to convert my *existing* graphics so they will continue to work unchanged in the new system?” Often, there has not been enough time, money, and knowledge to properly take advantage of advanced graphic capabilities in the real-world industrial environment.

Do It Yourself

We would think it strange if Boeing sold jetliners with empty cockpits, devoid of instruments logically and consistently arranged for use by the pilot. Imagine if they suggested, “Just get your pilots together and let them design their own

panel. After all, they'll be using it."

Imagine if your car came with a blank display screen and a manual on how to create lines, colors, and shapes so you could build your own speedometer. While this might actually appeal to the technical audience of this book, the rest of the world would think it strange and unacceptable. And, could you operate your car by using the "Doom" display motif created by your teenage son?

This do-it-yourself approach, without consistent guidance, is the general case with industrial graphics and is a major reason the results are often poorly conceived, inconsistent, and generally of low quality and performance.

2.6 The Answer to the Problem

This book contains detailed information for the design, implementation, and maintenance of a High Performance HMI. The solution involves understanding:

- Principles and best practices for an effective HMI
- Proper display hierarchy, content, and navigation
 - Level 1 process overview displays
 - Level 2 process control displays
 - Level 3 process detail displays
 - Level 4 process support and diagnostic displays
- Effective operator console design

The creation of a High Performance HMI is accomplished using a straightforward, seven step methodology. In later chapters, each step will be discussed in detail.

- Step 1: Adopt a high performance HMI philosophy and style guide
- Step 2: Assess and benchmark existing graphics against the HMI philosophy
- Step 3: Determine specific performance and goal objectives for the control of the process, for all modes of operation
- Step 4: Perform task analysis to determine the control manipulations needed to achieve the performance and goal objectives
- Step 5: Design high performance graphics, using the design principles in the HMI philosophy and elements from the style guide to address the identified tasks

Step 6: Install, commission, and provide training on the new HMI

Step 7: Control, maintain, and periodically reassess the HMI performance

2.7 Conclusion

The Bad News	The Good News
Sophisticated, capable, computer-based control systems are operated via poorly functioning HMIs designed with inadequate knowledge.	The functionality and effectiveness of these systems can be greatly enhanced if some redesign in accordance with proper principles is made. A <i>High Performance HMI</i> is practical and achievable.

Disturbing Moments in Cinematic Human-Machine Interfacing:

NORAD Computer to unaware teenage hacker:

“Would you like to play a game?” <displays list>

David: *“Sure. How about Global Thermonuclear War?”*

Wargames

Chapter Three

The Justification for HMI Change

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“The problem is never how to get new, innovative thoughts into your mind, but how to get old ones out. Every mind is a building filled with archaic furniture. Clean out a corner of your mind and creativity will instantly fill it.

- *Dee Hock (1929 -)*

...

A Tale of Two HMIs

In the air...

You've saved all your overtime money you make as a DCS board operator and used it for flying lessons! You've learned to fly in a modern small single-engine aircraft. It utilizes a glass panel – the instrument functions are shown on two large LCD screens. These screens and the information embedded in them and accessible by them comprise a highly sophisticated HMI. For several years now, the old "steam gauge" type of instruments have been replaced with such modern avionics, even in simple trainer aircraft.

As you began your flight, the HMI assisted you through a comprehensive pre-flight checklist, engine start (with diagnostics), communications with Air Traffic Control (ATC), and even displayed an airport taxi diagram as a moving map showing your position.

An hour into your solo cross-country flight, the HMIs moving map shows you at the proper altitude and on-course. Even small deviations are quite easy to detect and correct. Real-time satellite weather is depicted and you have chosen a course

keeping you away from a cold front.

Shortly after changing from the left wing fuel tank to the right (and in a highly unlikely and rare case) you experience a total loss of power from the engine. During this highly stressful Abnormal Situation, the HMI comes to your aid in several important ways. It is designed to be useful in an abnormal situation.

1. Your first priority is to maintain control of the aircraft and maximize your options. Your primary flight display immediately indicates your targeted best engine-out gliding airspeed, in case you had forgotten because of the stress! You immediately begin decelerating to this speed by gaining altitude, which will maximize your available gliding distance.
2. There is no need to begin a frantic search of your paper charts. Your moving map display shows all of the nearest airports with their distances and directions. A circle is calculated and depicted around your current position. It indicates your maximum gliding range based upon your current altitude, your current and best glide speed, and even the direction and magnitude of the winds in the area. You note you have several miles of gliding distance available and there are 3 airports within range.
3. You select the nearest airport, hit 2 buttons, and the autopilot turns to take you straight in that direction while holding your best glide speed. This is a great assistance while you proceed with the engine restart checklist.
4. You do not have to fumble around for the Emergency Operations chapter and checklists in the aircraft flight manual. You do not have to rely on your memory of those procedures. The HMIs Emergency Page shows an engine restart checklist designed for your specific engine, with the steps to recover from the most common problems.
5. You quickly execute the steps displayed. Changing back to the original fuel tank restores full engine power. This was one of the first things on the emergency checklist. Knowing there is either bad fuel or a mechanical problem with the right fuel tank, you proceed to the nearest airport you selected for a precautionary landing. All of the information about the airport is now displayed on your screen – runway lengths, directions, radio frequencies, and availability of maintenance.
6. You were already in contact with ATC, but if you had not been, their proper radio frequency is selectable based on your current GPS-derived location. Additionally, the universal emergency frequency, 121.5, is a single button-

press away, as is the 7700 emergency transponder code. You call ATC and request a destination change for a precautionary landing and inform them of your situation.

7. You make an uneventful landing. You know maintenance services are available at this airport, because it was shown on the HMI. If they weren't, you could have diverted to another airport still within a safe distance.



Figure 3-1: Garmin ® G1000 Dual-Screen Integrated Avionics in a Small Aircraft

Once on the ground, you have some coffee in the pilot's lounge. You are something of a student of aviation history and you know aircraft instrumentation has come a long way in the past decade. Amazing functionality is available, even in small planes, that not even the most expensive airliners had a few years ago. The HMI of your plane was pre-programmed to actually help you in the stressful situation when you needed it the most, with the right information, portrayed in the right manner, and with the right automation.

On the ground...

The next week, you return to your job on the DCS board, using a multimillion dollar DCS to control a half-billion dollar chemical process. All is well, but then there is a recycle compressor trip. Dozens of alarms begin sounding simultaneously. The alarm display becomes a useless, distracting, scrolling list. The pressure on the upstream and downstream units swings wildly. Unless you handle this situation quickly and correctly, a total shutdown will occur and production loss will easily exceed \$100,000.

1. Your process control HMI was created when the DCS was installed 20 years ago. It was hurriedly designed and hasn't changed much throughout its life. Your control displays are essentially little more than P&IDs with a bunch of live numbers sprinkled on them (similar to Figure 3-2).
2. The procedure for handling a recycle compressor trip is contained somewhere in a six-foot set of books in the next room. You don't bother to go try to find it – there isn't time. You know it hasn't been updated and projects have changed the recycle system anyway.
3. Luckily you have many years of experience and have handled this upset before. You know the controls you need to manipulate are spread out on eight different displays. There are no displays at all designed to specifically help you in this situation.
4. You have confidence you can handle this upset. As you begin your response, you have a fleeting thought, wondering what the outcome would be if this upset happened on the next shift – when the new guy is on duty.

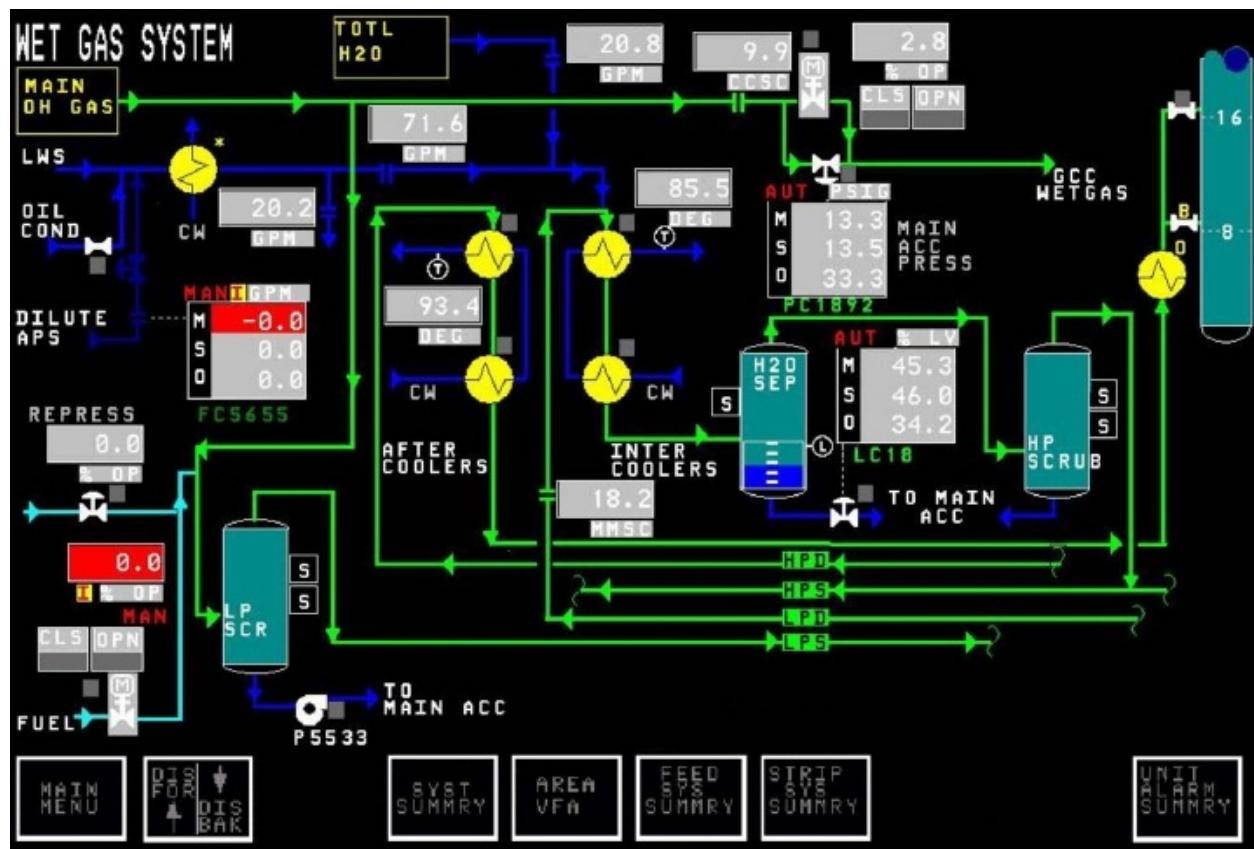


Figure 3-2: Typical Process Industry Graphic

You successfully handled the upset and avoided a total shutdown. You reflect on

how different the situation was in the airplane and here at work. You have a lot of ideas for improving the DCSs HMI, but you know the person who knew how to modify the graphics left two years ago. Besides, there's never time or money around here to improve things like this.

The next week a different upset happens while the new guy is on shift. The resulting total unit shutdown costs \$320,000 of lost production.

...

There is no question that industrial HMI improvement is possible, and needed. The issue is always, “What’s the payback?” Management has been reluctant to pay for re-design of the alarm management system and the HMI as they felt they had already paid for the design once and could not see justification in paying again. Even so, management generally knows bad design has impacted operator performance and thus production.

However, another fair question to ask is, “Where was the dollar justification to install a poor HMI?” Is it a good idea to run a multimillion dollar facility with an operator interface that often impedes proper operation? Do you drive with your parking brake on? Of course not.

“If you think safety is expensive, try having an accident.”

Industry adage

A good HMI will facilitate proper operating techniques and a poor one will impede them. Many HMIs encourage “operating by alarms.” The operator monitors – to a varying extent – what is going on in the process, but most of the attention is based upon checking the almost continuous string of alarms coming in and adjusting the process in response to them.

Imagine you are on an airliner. The pilot heads in a general direction towards the destination. When the “Left-of-Course” alarm goes off, he turns to the right. Then, the “Too-High” alarm comes on and he begins a descent. When the “Right-of-Course” alarm comes on, he turns back to the left. This is followed by the “Too-Low” alarm and he pulls up. Would this provide for a smooth,

economical ride? Would you fly this airline again? Doubtful. Yet many processes are operated in just this fashion – running by alarms.

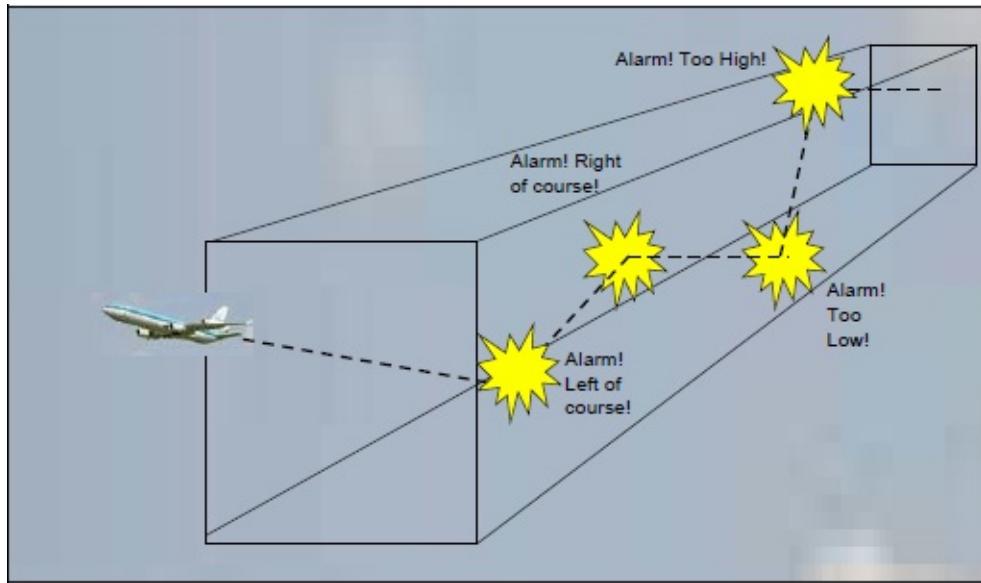


Figure 3-3: “Operating By Alarm”

This is certainly not the paradigm in modern aviation. The pilot is continually monitoring course, speed, and altitude and making small adjustments to minimize the deviation long before any alarm would come in. The modern HMI (See Figure 3-1) is specifically structured to aid in situation awareness by these sorts of features:

- Moving-map GPS technology showing exact aircraft location, course, and speed relative to airspace boundaries, navigational aids, depicted roads, towns, lakes, airports, and other terrain features.
- Displays clearly showing and warning of proximity to rising terrain, obstacles, and other nearby aircraft, including voice alerts.
- Flight path deviations are continuously and clearly depicted. “Synthetic Vision” shows a generated view of the nearby terrain and course progress, even when the aircraft is embedded in clouds and the pilot has no outside visual references.
- Continuously-received satellite weather information (including lightning) can be overlaid on the mapping display.
- At-a-glance monitoring graphics for engine function are provided, along with interactive checklists for normal operation and emergencies.
- Access is provided to an embedded, detailed, and updated support

information database about destinations, with information on runway arrangement, radio frequencies, fuel and maintenance facilities, and even the local restaurants.

- Analog and digital information is carefully chosen and each type is used and displayed where appropriate.

Alarms in the cockpit are quite infrequent. This type of instrumentation and HMI is now common on newer small, single-engine aircraft where the entire airplane costs much less than a single industrial DCS. The situation awareness of the pilot has been multiplied many times by these advances, making the aircraft more reliable, effective, and safe. Industrial HMIs lag far behind the aviation industry.

Buttons, Complexity, and Crashes

Aviation HMI technology has had its own technological growing pains. Early, numeric-entry-and-display-based Flight Management Systems (without graphic displays) were complex to program and read and this complexity helped lead to accidents.

An FMS input error led to American Airlines Flight 965 to collide with a mountain in South America. Korean Airlines flights KAL 902 (in 1978) and KAL 007 (in 1983) were both shot down by the Soviets, when navigational errors led to airspace violation. There are many other examples.

The phrase “lack of situation awareness” is common in fatal aircraft accident reports. However, the aviation industry is generally much better at collectively learning from safety-related mistakes than the process industries.

There is now recent and process-industry-specific data as to the significant potential for improved operation based on proper HMIs. A study was performed by the Abnormal Situation Management (ASM) Consortium ® and Nova Chemicals.

In this study, twenty-one experienced operators were tested using traditional graphics vs. graphics designed in accordance with many of the principles in this book. Using a sophisticated simulator, operators had to detect and respond to identical malfunction and upset scenarios. The results were clear. Using a High Performance HMI, more operators were able to consistently detect abnormal

situations well in advance of alarms. The events were dealt with in far less time and with a much higher success rate.

Task	With Traditional HMI	With High Performance HMI	Result
Detecting abnormal situations before alarms occur	10% of the time	48% of the time	A 5X increase
Success rate in handling abnormal situation	70%	96%	37% over base case
Time to complete abnormal situation tasks	18.1 min	10.6 min	41% reduction

Figure 3-4: High Performance HMI Benefits

Based on historical incident and upset rates, the anticipated annual savings by switching to a High Performance HMI were determined to be \$800,000/year for one ethylene plant. There is clearly a financial return on investment for such efforts, along with a step change in the potential capability to avoid incidents and accidents (See the References section for the study information).

The ASM® Consortium estimates abnormal situations account for more than 20 billion dollars per year lost in just the U.S. economy. From 3% to 8% of industrial capacity is lost to such situations. It is estimated that 20% - 25% of this loss can be recovered with proper implementation of High Performance HMIs (and thus better situation awareness) and proper alarm management methods. These areas are linked and best results are obtained when both are addressed.

The processing industries in general make investments where the ROI is quantifiable and predictable, as exemplified by widespread investments in advanced process control. When it comes to investments related to mitigation of loss, the industry is historically slower to move, with a good example being the area of alarm management. Alarm management was recognized as a clear operational and safety issue as early as 1994 by industry leaders. However, it is only since 2003 that alarm management improvement has become an industry-wide best practice initiative.

The improvement of HMIs seems to be tracking the same timeline. It will be unfortunate if ten more years are required to widely recognize the influence of poor HMIs as a contributing factor to safety and operational mishaps.

The purpose of a High Performance HMI is to enable you to run smoothly and efficiently, as well as help you detect, diagnose, and respond to abnormal situations at the earliest possible moment and with minimum adverse consequences.

So, does your HMI embody concepts and abilities resembling the modern avionics shown earlier? Does it consistently and logically provide the operator all of the information needed for optimum process operation or is it closer to providing the much poorer “situation awareness” of the HMI for this other flying machine?

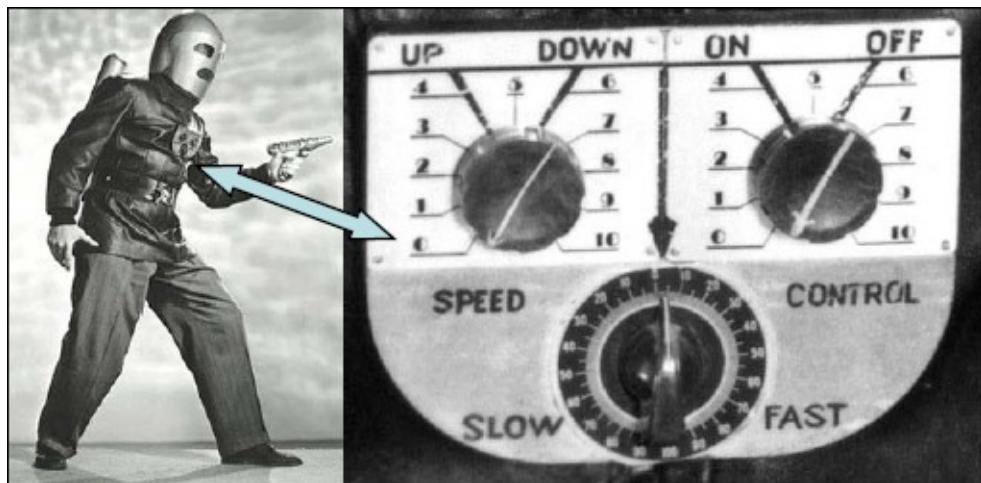


Figure 3-5: Commando Cody HMI (Poor HMI or not, wouldn't you want one of these?)

Chapter Four

HMI Best Practices – A Managerial Overview

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“Human beings, who are almost unique in having the ability to learn from the experience of others, are also remarkable for their apparent disinclination to do so.”

- Douglas Adams (1952 – 2001)

...

A High Performance HMI enables an operator to safely and effectively monitor and manage a processing plant. It is based upon best practices for the display of information conforming to known human factors issues and the proper principles for abnormal situation management. The HMI is the operator's window to the process and is a critical element for operations effectiveness.

Several specific practices exist to make a High Performance HMI possible. These are covered thoroughly in the later parts of this book. This chapter is a high level overview of the principles and work processes.

4.1 Bring Back the Big Picture

With the older control walls, experienced operators could use pattern recognition techniques to quickly ascertain the overall health of the process. Most values were trended. Abnormal event detection could be quite fast. During a major upset, everyone in the control room could easily see the status of the plant in one view by examining the wall-mounted instrument panel.

With the DCS, managers, engineers, and outside operators often have to question the console operator to learn the plant status (or worse, “take over” some of the

screens and begin calling up other displays). During abnormal situations, this is an unnecessary distraction which only adds stress to an already stressful situation.

An optimal solution for all is the introduction of large, off-workstation Process Overview displays, configured to show a proper summary view of the process. Situation awareness is greatly increased by the usage of such overview displays. With these, the entire operating team always has a clear view of key process conditions. Typically, 50 inch and larger computer video displays are used, with larger sizes becoming more practical and less expensive. However, such possible large sizes as shown in Figure 4-1 are not necessary.,



Figure 4-1: An “Over-the-Top” Overview Display

Projection Display System picture courtesy of BARCO, www.barco.com

4.2 Create Hierarchical, Scenario-Based Displays to Improve Situation Awareness and Response

Situation Awareness is an accurate and timely understanding of the condition and behavior of the process. Proper display design should support situation awareness and encourage proper operating practices.

Four distinct levels of displays should be used, incorporating the principle of progressive exposure of detailed data. These are:

- Level 1 – Process Area Overview (for situation awareness)
- Level 2 – Process Unit Control (for ongoing process manipulation)
- Level 3 – Process Unit Detail (for close, detailed examination)
- Level 4 – Process Unit Support and Diagnostic Displays (for troubleshooting)

When P&IDs are used as the simplistic basis for graphic design, a proper graphic hierarchy will not result. P&IDs are a totally “flat” form of depicting the process. For control purposes and proper abnormal situation handling, the displays should enable “drill-down” for increased level of detail.

Proper displays for running a process in a normal situation will likely not contain the right information for handling an abnormal situation. Additionally, there should be displays specifically designed to address upset conditions, as well as certain routine activities such as mode or product transitions.

4.3 Redesign Displays to Emphasize the Most Important Information

Display design and style has a significant impact on the speed and accuracy of operators’ interactions with a display. Meaningless (yet common) misuse of color, animation, and flashing lights are an impediment to easy and early recognition of a significant event. Our knowledge of human factors has increased greatly since the introduction of the DCS, yet display design has not generally incorporated this knowledge.

Proper design schemes increase the ability of operators to distinguish different conditions, recognize important information, and respond to abnormal plant conditions. Improper design slows response times and contributes to errors in perception and comprehension.

Traditional displays are usually far too cluttered and covered with numeric data. The operator needs information (data in context made useful) to operate in a high performance manner. Proper presentation of information in innovative ways will significantly enhance the operator’s situation awareness and ability to deal

with abnormal situations.

Some characteristics and contents of High Performance displays are as follows:

- Gray backgrounds are used to minimize glare, along with a generally low-contrast depiction.
- No gratuitous animation, such as spinning agitators or pumps, moving conveyors, and splashing liquids and sprayers. Animation should be limited and only used to highlight abnormal situations.
- Depiction of process values is made in the context of information, rather than as simple numbers on a screen.
- Important information and key performance indicators have embedded trends.
- There is very limited use of color. Alarm colors are used only to display alarms and nothing else.
- Equipment is depicted in a simple 2-D low-contrast manner, rather than brightly colored 3-D vessels with shadowing.
- Layout is generally consistent with the operator's mental model of the process.
- Navigation methods are logical and consistent.
- A hierarchical structure supports progressive exposure of detailed information.
- Display access requires a minimum number of operator keystroke actions.
- Techniques are used to minimize the possibility of operator mistakes, as well as provide validation and security measures.
- Display elements have consistent visual and color coding.

4.4 Employ Proper Control Room and Physical Console Design

It is a common situation to find especially poor design of the operator's workspace. The quantity of physical screens, their layout, and the correct access to communication tools greatly affects the ability of the operator to function effectively. Imagine if an aircraft pilot had to leave his seat to use the radio! Equivalent situations are not uncommon for process operators.

Proper design of the control room and the operator console is essential to operator alertness and situation awareness. Factors to be considered in control room and console design are detailed in later chapters. They include:

- Comfort factors, such as lighting, temperature, noise, and traffic
- Number, type, and arrangement of screens and keyboards per specific console
- Console heights, adjacency, and similar ergonomic factors
- Support equipment (radio, intercom, phone, switches, etc.)

4.5 Minimize Distractions in the Control Room

Console operators need an environment free of distractions, especially at times when the unit is in a transition or an abnormal situation. For example, maintenance scheduling and management activities should not share the control room.

It is a poor practice to see engineers, supervisors, managers, and maintenance technicians accumulating behind the console and calling up various displays. Distractions are a major problem for operators.

Control and production engineers should have their own workstation, clearly distinct from the console operators. By policy or by control room design, maintain a separation between the console operator and everyone else during unit upsets. Give engineers and managers access to information through large screen displays, separate workstations, or a situation/conference room located just off the control room. With support people close by, the operator can ask for help if needed and still maintain a sense of control over the work environment – an important stress management technique.

4.6 Seven Steps for Creating a High Performance HMI

The following steps are optimum for transforming a traditional HMI into a High Performance HMI. They are also easily adaptable for creation of a new HMI for an entirely new facility.

Step 1: Adopt a High Performance HMI Philosophy and Style Guide

Step 2: Assess and benchmark existing graphics against the HMI Philosophy

Step 3: Determine specific performance and goal objectives for the control of the process, for all modes of operation

Perform task analysis to determine the control manipulations

Step 4: needed to achieve the performance and goal objectives

Step 5: Design and build high performance graphics, using the design principles in the HMI Philosophy and elements from the Style Guide, to address the identified tasks

Step 6: Install, commission, and provide training on the new HMI

Step 7: Control, maintain, and periodically reassess the HMI performance

Each of these steps will be covered thoroughly in later chapters.

PART II:

Fundamentals of HMI Design and Best Practices

Chapter 5
Assessing HMI Performance

Chapter 6
The Development of a High Performance HMI Philosophy

Chapter 7
Basic Principles for High Performance HMIs

Chapter 8
Detailed Design of High Performance Displays

Chapter Five

Assessing HMI Performance

...

“Your call may be monitored for quality purposes. Our menu options have recently changed. Please listen carefully to the entire list before making your selection...”

- Every Annoying Voicemail HMI in the World

...

To begin an improvement effort, an existing HMI should be assessed against High Performance HMI best practices. The assessment of HMI performance is much more of an evaluation process, “Does my HMI meet all of these various criteria?” than a numeric or statistical analysis process, “What percentage of the surface area of my displays is blank space?” For us engineers, subjective evaluation is usually more difficult than recording data and processing formulas. While there are some measurable quantities factoring in to an HMI assessment, they do not dominate the assessment as they do when evaluating an alarm system’s performance.

Even so, there is a logical process to follow for HMI assessment. The determination is primarily based on observation of operators, discussion, questionnaires, and checklists. Herein, we have adapted a method put forward by the United Kingdom’s Health and Safety Executive (HSE). In using it, you will arrive at one of 5 grades (A, B, C, D, or F), a system which is familiar to most. Here is an overview of the method (Appendix 2 contains the full details and checklists to use).

Methodology Overview:

Beginning Score: F

Satisfy Criteria 1, 2, and 3

New Score: D

Satisfy Criteria 4

New Score: C

Satisfy Criteria 5

New Score: B

Satisfy Criteria 6

New Score: A

5.1 HMI Evaluation Methodology

A final performance grade is determined by starting at the bottom grade and working upwards. To advance to the next higher grade, defined criteria must be met. If all of the criteria are not met, the grade is established.

For each grade level, there are certain best practices the HMI must follow. These include HMI design, certain aspects of console design, the control room environment, and control room operating and managerial practices. These are determined by comparison to the detailed checklist in Appendix 2.

5.2 A Failing Grade: “F”

“No more TV or video games or hanging out with your friends for you anymore, young man! You’re going to study every night until your grades come up!”

All of these first three criteria must be satisfied to move beyond an “F”.

Criteria One: Operators find it easy to keep track of the process in normal conditions. Potential problem areas which must be addressed to achieve this include:

- insufficient process information
- unreliability of sensors or displays
- other tasks operators are required to perform
- distractions, such as maintenance permit writing and telephone calls

Criteria Two: Information about the process and plant condition is adequate for operators to be confident they can effectively monitor abnormal or upset conditions. The critical measure of an operator information system is how well it performs when the demands are greatest – in an abnormal situation.

Criteria Three: During an abnormal, upset, or emergency condition, the operators can keep track of the process using only the HMI, without a burdensome and distracting need to gather relevant information from multiple control room displays, logbooks, procedure manuals, etc.

It is quite common to see operators working from multiple screens or consoles, or paging through several displays or manuals to gather and analyze information, and then take action and monitor results on yet other displays. Remembering to return to a particular display to check on one critical point can be cognitively demanding, especially when under the added pressure of an abnormal situation.

5.3 Not Quite Failing – a “D”

“Do you think this is acceptable? Is this the best you can do? We expect far better from you than this! And for now, you’re still grounded!”

A “D” is thus achieved if the operators are always presented the proper information to monitor the condition of the plant in a timely, accurate, and reliable manner – regardless of upset or emergency conditions. To move to a “C” requires more.

The focus now shifts to providing a distraction-free environment. The ultimate goal is a high level of situation awareness (an accurate understanding of the condition and behavior of the plant), which can only happen in a distraction-free environment. To achieve a “C” level, the following must be true.

Criteria Four: During abnormal situations, the unit’s managers, engineers, and supervisors must not interrupt the operator by manipulating the operator’s displays, or even worse, making their own adjustments to the process.

5.4 Still Not Good Enough – a “C”

“You got a ‘C’? How do you possibly expect to get into college? Or get a

scholarship? Do you think you can live here with us forever when you finish school? Well, you've got another think coming! I want to examine your homework every night and no TV until it's done!"

A “C” is thus achieved when, in upset and emergency conditions, all relevant operators and supervisors can accurately and reliably assess the condition and behavior of the plant within the available time without disturbing each other or blocking each other’s access to information. To achieve a “B” level, the following must be true.

Criteria Five: Non-operating tasks are not required of the operator during upset or abnormal conditions. Whenever there are critical process activities demanding the operator’s attention, there must be no unnecessary tasks, duties, or disturbances.

Once again, the most frequent distraction we find is the telephone, which clearly rings most often during a unit upset. When the surgeon is in the middle of your heart operation, you don’t want him leaving every 5 minutes to discuss his progress with your in-laws!

5.5 Finally – a “B”

“Well, that’s more like it! Now you have a chance for a decent future! You’re not grounded anymore. Keep applying yourself because we know you can do even better!”

A “B” grade is thus earned only if the operators have absolutely no responsibility other than monitoring the process during times of abnormal or unusual conditions. This also applies to startups and shutdowns, if the process is normally a continuous one and they are infrequent. There must be a high level of continuity in the operator’s tasks during critical process events. Operators are not required to perform tasks that significantly disrupt their concentration on the process and they are able to delay other activities to minimize distractions.

To achieve an “A” requires the following.

Criteria Six: The HMI must meet all of the major criteria contained in the assessment checklist in Appendix 2 regarding:

- General graphic factors
- Navigation factors
- Workstation factors
- Control room and work practice factors
- Alarm management factors

5.6 All Right! An “A”

“Great going! You know, we’ve been thinking that maybe you’ve been showing enough responsibility that we can talk about getting you that car...”

The “A” grade is reserved for those units with sound operator information strategies for routine as well as abnormal situations, a distraction-free environment, and minimal disruptions from the primary task of monitoring the process unit. The principles of a High Performance HMI are adopted, yielding an HMI specifically designed for effectiveness in both normal and abnormal situations.

5.7 Periodic Reassessment

A High Performance HMI is part of a continuous improvement program. Even with high knowledge, diligent effort, and skill, every situation cannot be anticipated. There should be an on-going system of operator feedback on HMI effectiveness and recommended enhancements. The HMI should be under appropriate Management-of-Change (MOC) control so all changes are in accordance with the HMI philosophy.

At most companies, production upsets, incidents, and accidents receive an internal review. Part of the review of such events should be to assess the effectiveness of the HMI during the event.

Disturbing Moments in Cinematic Human-Machine Interfacing:

Young John Connor: *“You can’t just go around killing people!”*

Model T-800 Terminator: *“Why?”*

Terminator 2: Judgment Day

Chapter Six

The Development of a High Performance HMI Philosophy and Style Guide

...

“No matter how cool your interface is, less of it would be better.”

- Alan Cooper

...

It is necessary to create a comprehensive, detailed guideline outlining the principles to be followed in designing a High Performance HMI. Such a document must meet the needs of different roles, has several important components, and a variety of uses.

Ideally the contents of the document would be treated as a mandatory standard. In most companies, there is such a large investment in traditional displays, the transformation to High Performance HMIs must be phased in over time and overcome much operational inertia.

6.1 A First Principle: Users of HMIs

One DCS manufacturer gives the following poor advice in their user manual for building displays.

“A (graphics design) hierarchy should suit the needs of various users, including managers, MIS groups, engineers, supervisors, and operators.”

This is bad advice because the primary purpose of the HMI is to exist for the use of the operator. While other roles and functions have interest in the data displayed, the operating displays should not be designed for them and proper

design should not be compromised based on the needs of other roles. The operator uses the HMI continuously as the main tool for accomplishing their job – the monitoring and control of production. Use by other roles is significantly less frequent and definitely less important.

We have often seen DCS alarms configured to provide an event record for other functional groups than the operator. This is a misuse and abuse of the alarm system, but is done because the alarm system is easy to use for such tasks. Similarly, DCS graphic displays are easy to use (and abuse) to satisfy the needs of other groups and this can result in displays not optimum for use by the operator in actually controlling the process. There are many other and more proper methods to provide real-time process information to managers and other groups.

As another example, the maintenance function may use the displays in troubleshooting and instrument repair. They are less familiar with the process, but the displays should not be designed to enhance maintenance's process understanding at the expense of the most effective display practices for the operator.

Engineers and managers must also monitor how the process is running. As will be later discussed, a properly designed Process Overview Display summarizes the operation relative to several Key Performance Indicators.

6.2 The HMI Philosophy Document and Style Guide – Overview

The principles embodied in a High Performance HMI are communicated in the Philosophy document. The HMI Philosophy document is intended to be generic and apply to multiple types of DCSs. Although several different DCS systems may be in use at a single site (or even in a single control room), it is desirable to make the HMI similar on them all.

There are aspects of an HMI which are very specific to the abilities and paradigms embedded in a particular DCS. The HMI Style Guide is a detailed document specific to a particular type of DCS. It covers the exact methodologies by which the principles contained in the High Performance HMI Philosophy are embodied within the capabilities of the subject DCS. Separate Style Guide sections are needed for each type of DCS.

It is not recommended for a single operator to use multiple types of DCS systems. However, a site's evolution and capital constraints may have resulted in this situation. In such cases, the HMI designer should bring commonality to the systems to minimize confusion; this scenario is a high risk for human error.

The combination of the HMI Philosophy and Style Guide should embody all of the principles contained in this book. Full examples of the Table of Contents of both a High Performance HMI Philosophy Document and a Style Guide are shown in Appendix 1.

6.3 Purpose and Use of a High Performance HMI Philosophy Document

Simply put, the HMI Philosophy document covers how to properly create a High Performance HMI. It is a guide to doing it right. Without such guidance, engineers and operators with the best of intentions will do whatever is thought best and expedient at the time. It will be based on whatever knowledge (good or bad) those involved have picked up over the years. The results will typically be the poor HMIs prevalent throughout industry.

The philosophy document should cover the life cycle of the HMI, including design, implementation, performance monitoring, ongoing modification, and management of change. It is for both in-house use and for the use of contractors hired to work on the system.

6.4 Development of a High Performance HMI Philosophy Document

Development of an HMI Philosophy should follow a proper process, particularly if the desire is to overhaul an existing HMI. There will be a tremendous amount of resistance to changing the current HMI. You cannot expect to just hand out this book and say, "This is how we will do our HMI."

The involvement and buy-in of management, operations technical staff, and operators themselves is needed to develop the Philosophy which will result in the successful adoption of a High Performance HMI. Without this involvement, the change may well be doomed from the start.

6.5 HMI Style Guides

The style guide is a highly detailed document. All of the proper principles for HMI design are used in developing the style guide. All aspects of display design are covered – layout, hierarchy, backgrounds, lines, text, objects, trends, navigation, and so forth. Since the style guide is specific to a certain DCS, it specifically documents the exact methods by which proper HMI principles are executed given the DCS capabilities and limitations.

6.6 HMI Objects and Object Libraries

The style guide has two major components:

- Text descriptions and documentation
- Software code and behavior documentation for all objects

The style guide will depict and document the various screen elements to be used in creating displays. As an adjunct, the actual source code and objects themselves are part of a DCS-specific Object Library saved in the software code format of the DCS. Standardized elements are created with specific functionality and included in this library. From this library, the elements are chosen and used in the displays.

It is essential to perform proper Management-of-Change practices on the library elements themselves and their documentation. The elements should not be individually modified in the process of being incorporated in individual displays. This is because it may become desirable to make an alteration in a particular library element and then push out the altered version to all of the displays using that element.

Make sure to create offsite backups. There are horror stories about lost HMI source code.

Disturbing Moments in Cinematic Human-Machine Interfacing:

Bowman: "*Hal, open the pod bay doors.*"

Hal 9000: "*I'm sorry Dave, I'm afraid I can't do that.*"

2001 – A Space Odyssey

Chapter Seven

Basic Principles for High Performance HMIs

...

“Those are my principles, and if you don't like them... well, I have others.”

- *Groucho Marx (1890 - 1977)*

...

7.1 Overview

Much has been learned over the last 20 years regarding good and bad industrial HMI design practices. What we now know to be good design practices have come from a variety of sources, including:

- HMI deficiencies made apparent by accidents, with resulting in-depth analysis
- Information from academic research.
- Information from research by other industries such as aviation and computer programming.
- Advances in technology and new capabilities of modern HMI systems.

In this chapter, we distill these learnings down to a fundamental set of principles which, when put into practice, provide for the design of High Performance HMIs. These principles become the rules which guide the development of all aspects of the operator HMI, from the various types and overall layout of the graphics in the operator's console to the way a PID controller is represented on each type of graphic, as well as how the operator interacts with the graphic to make process changes.

In Chapter 8, we will take the principles learned here and apply them to create

the various components which make up the operator graphic. The three primary principles are:

Clarity

- Graphics are easy to read and intuitively understandable.
- Graphics show the process state and conditions clearly.
- Graphic elements used to manipulate the process are clearly distinguishable and consistently implemented.
- Graphics do not contain unnecessary detail and clutter.
- Graphics convey relevant information, not just data.
- Information has prominence based upon relative importance.
- Alarms and indications of abnormal situations are clear, prominent, and consistently distinguishable.

Consistency

- Graphic functions are standardized, intuitive, straightforward, and involve minimum keystrokes or pointer manipulations.
- The HMI is set up for navigation in a logical, hierarchical, and performance-oriented manner.

Feedback

- Graphic elements and controls (objects) must behave and function consistently in all graphics and all situations.
- Important actions with significant consequences will have confirmation mechanisms to avoid inadvertent activation.
- Design principles will be used to minimize user fatigue, since operations personnel use the graphics constantly.

The goal is to provide the operators the information they need in a clear and intuitive format and in such a way minimizing the possibility of mistakes. Following these three principles will deliver this goal.

The following sections will take the primary principles of clarity, consistency, and feedback to develop design rules, which will result in graphics with the following attributes:

- The operator's attention is drawn to the most critical information.
- Confusion and mistakes are eliminated by designing the HMI in a consistent, easy to read, intuitive manner with proper feedback.
- Reaction time is optimized by providing the operator information needed in a simple, logically progressive, performance-oriented HMI display structure.

High Performance graphics are designed in a hierarchy for progressive disclosure of further detail and to handle specific tasks. It is far too common for HMIs to be “flat” and without hierarchy, which produces cluttered displays poorly suited to either normal or abnormal operations. A proper hierarchy for graphics is:

- Level 1 – Process Area Overview
- Level 2 – Process Unit Control
- Level 3 – Process Unit Detail
- Level 4 – Process Unit Support and Diagnostic Displays

7.2 The Process Pictorial – An Overused, Low-Performance Paradigm

Industrial projects have long used P&IDs as process design tools, which is their purpose. They pre-date display screens by many decades. A P&ID was never designed nor intended to be the basis for an HMI. They have no hierarchy, intentionally being a “flat” view of every element of the process, rather than supporting “drill-down” for additional information.

However, because of their availability, convenience, and visual nature, most of the displays now used throughout the process industries are little more than P&IDs with “live values” sprinkled on them.

This “process pictorial” paradigm is extremely widespread and tens of thousands of operators throughout the world use such displays every day. In many cases, they have been in use for almost two decades essentially unchanged. Entirely new displays following this old paradigm are being created every day and the people doing so believe they are doing a good thing. It has become the “default”. The result is sub-optimum performance.

We are not advocating the elimination of the process pictorial as an element of a high performance HMI. When done well (unfortunately all too rare an occurrence), it is a display element having a proper place and uses. However, it has severe deficiencies in many areas and there are more effective methods of displaying information to the operator.

A High Performance HMI cannot be achieved by replicating P&IDs on a display screen.

“You'd be surprised how much it costs to look this cheap.”

Dolly Parton

7.3 Recognizing Good and Bad Graphics at a Glance:

High Performance Graphics should look boring!

A graphic optimally designed for running a process and handling abnormal conditions effectively will, in fact, look boring. Here are some examples of what we mean. This is where some readers will begin squirming in their seats...

Poor Graphics have:

- No trends.
- Big flashing flames showing when a burner is on.
- Brightly colored process vessels rendered with 3-D shadowing, as well as 3D process lines and pumps.
- Spinning agitators and pumps, moving conveyors, splashing liquids and sprayers, and other such animation elements.
- Detailed depiction of non-changing internal elements of equipment.
- Attempted color coding of process piping with their contents.
- Measurement units (psig, gpm, etc.) spelled out in big, bright text.
- Liquid levels in vessels displayed in bright colors the full width of the vessel.
- An exact representation of the P&ID with minor connections and valves.
- Lots of crossing lines.
- Process flow from left to right, right to left, top to bottom, and bottom to top. There are a very few countries where right-to-left process flow

depiction is used, matching the written language practices. However, this is not uniform.

- Alarm-related colors used for non-alarm related elements.
- Limited, haphazard navigation from screen to screen.
- Inconsistent color coding of various elements.

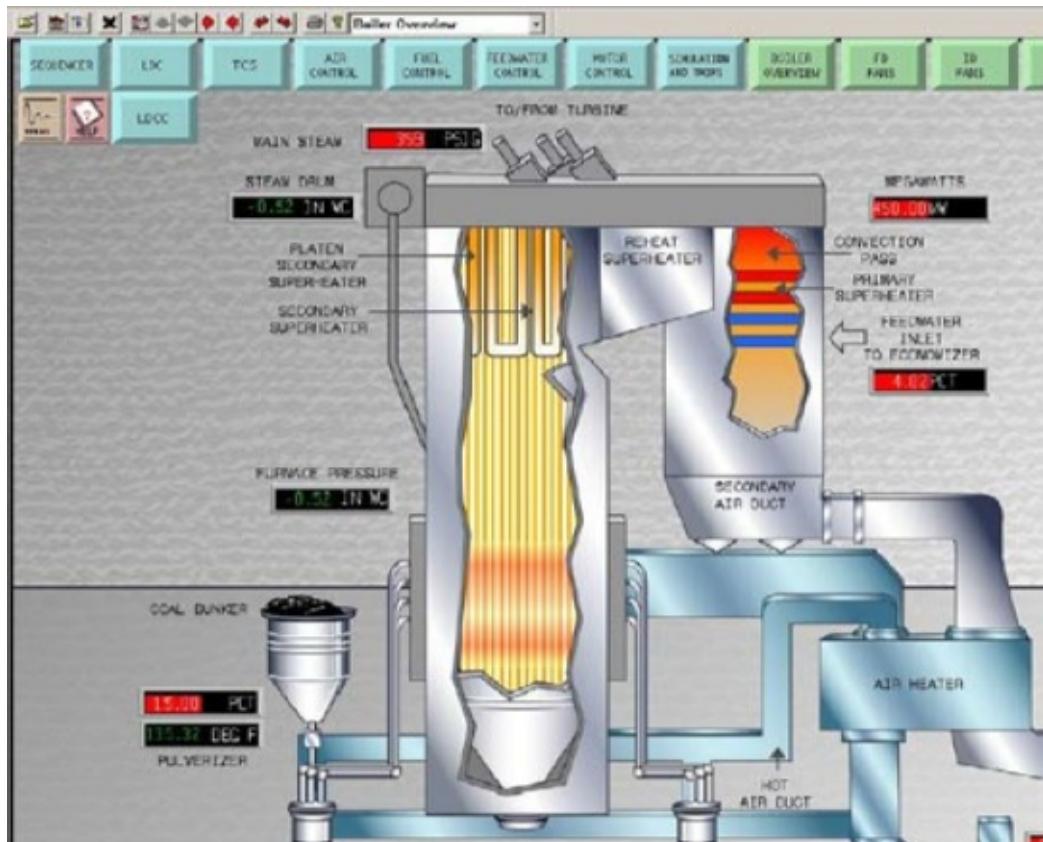


Figure 7-1: An example graphic violating many of the principles for a High Performance HMI

When looking at Figure 7-1, you can see it is quite flashy in appearance and devotes much detail to the depiction and labeling of non-changing, internal elements of the boiler. The room's floor and wall have different textures and the boiler even has a shadow. The ductwork is highly polished. However, the process values used to control and monitor the boiler are depicted as small text with contrast problems. There are no trends or performance information of any sort. Possible control manipulations are not apparent. Color is used inconsistently and improperly. Much work may have gone into the creation of this graphic.; that work has been wasted. Previously shown Figures 2-3 and 3-2 are similar examples of poor design.

Graphics like these might look great and impress the children visiting the control room on career day, but the operators using them every day are being provided a very poor set of tools to accomplish their primary job – operating the process safely and profitably.

High Performance Graphics have these characteristics:

- Depiction of process status and values are made in the context of information rather than as simple numbers on a screen.
- Important information and Key Performance Indicators have embedded trends.
- There is no gratuitous animation, which includes no spinning agitators or pumps, moving conveyors, splashing liquids and sprayers, *etc.* Limited animation is used only to highlight abnormal situations.
- Gray backgrounds are used to minimize glare, along with a generally a low-contrast depiction.
- There is very limited use of color and alarm colors are used only to display alarms and nothing else. If yellow is an alarm color, then yellow is never used as a text label, line color, border, or any other non-alarm-related element.
- Equipment is depicted in a simple 2-D low-contrast manner, rather than brightly colored 3-D vessels with shadowing.
- Layout is generally consistent with the operator's mental model of the process.
- Logical and consistent navigation methods utilize a hierarchy for the progressive exposure of process detail.
- Display access requires a minimum of operator keystroke actions.
- Techniques are used to minimize the possibility of operator mistakes, as well as provide validation and security measures.
- Display elements have consistent visual and color coding.
- Gray process lines are used, with major lines shown slightly thicker.
- A layout wherein the process flow is from left to right whenever possible. Gas should flow up and liquids flow down. Proper layout minimizes crossing lines.
- A layout consistent with the operators' mental model of the process. The operators may relate better to the physical plant layout than the layout as shown on a P&ID. They may always enter the process from the south, so an

equipment layout as perceived from the south might be optimum.

- Techniques are used to minimize the possibility of operator data entry mistakes and provide validation and security measures. For example, a graphic element pushbutton to initiate an infrequent shutdown action should include a step to confirm the operator intentions and allow for cancellation.
- Measurement units should be shown in low contrast lettering, if used at all (the operators generally know the units of measurement.)

“Same mule, different saddle”

Old saying

Don't think the examples shown are the worst possible displays. We have seen a case where an early model "Brand X" DCS was installed in the 1980s. It could display little more than numbers on a screen. In the early 1990s, it was replaced by a "Brand Y" DCS with significantly enhanced graphics capability. This capability was used to exactly duplicate the more primitive "Brand X" displays. They remain in use, essentially unchanged, to this day. Inertia is a powerful force in HMI design!

7.4 Data is Not Information!

“Data is not information, Information is not knowledge, Knowledge is not understanding, Understanding is not wisdom.”

- Cliff Stoll & Gary Schubert

There is a big difference between data and information. Most poorly constructed operator displays show a great amount of data, but little information. We have seen displays consisting of little more than the presentation of well over a hundred numeric values on a single screen. A display element, such as in Figure 7-2, is a typical "bad example." The element shown is, unfortunately, a common example of process displays worldwide.

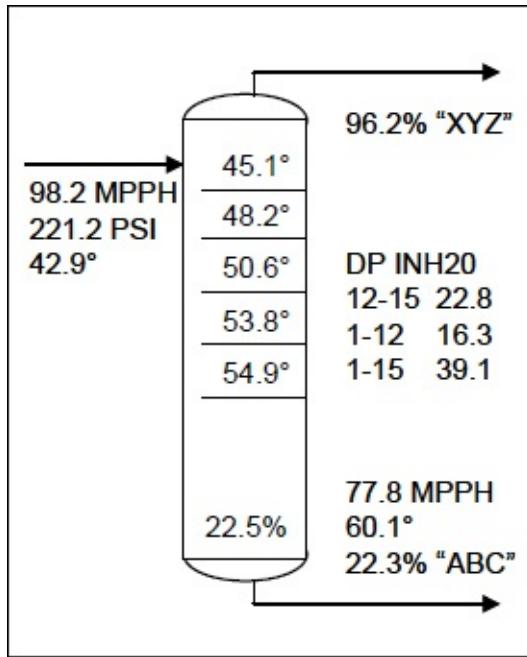


Figure 7-2: Displaying Lots of Data

Let's illustrate the difference between data and information. Here are the results of a blood analysis of Fluffy, a pet cat. What can be determined from this information? Is Fluffy sick?

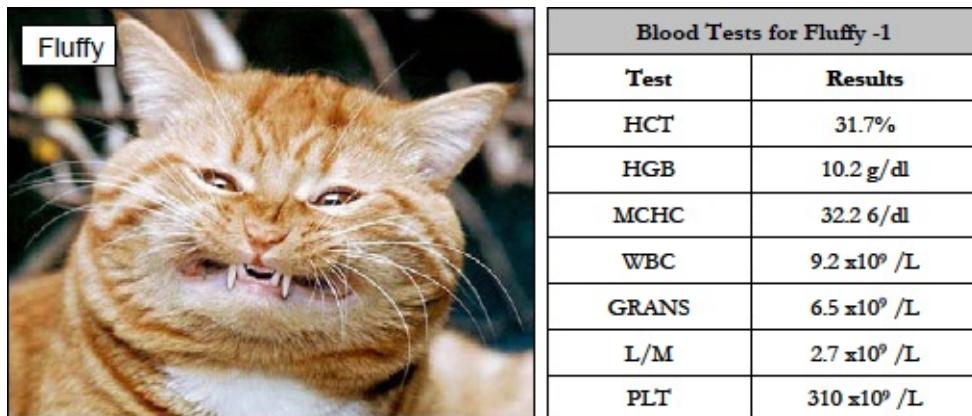


Figure 7-3: Fluffy's Blood Test

The answer is, unless you are a veterinarian, you have no idea! Here is the same data, with a slight improvement:

Blood Tests for Fluffy - 2		
Test	Results	Range
HCT	31.7%	24.0 – 45.0
HGB	10.2 g/dl	8.0 – 15.0
MCHC	32.26/dl	30.0 – 36.9
WBC	9.2 x10 ⁹ /L	5.0 – 18.9
GRANS	6.5 x10 ⁹ /L	2.5 – 12.5
L/M	2.7 x10 ⁹ /L	1.5 – 7.8
PLT	310 x10 ⁹ /L	175 – 500

Figure 7-4: Fluffy's Blood Test – View 2

By carefully (and tediously) examining the above, you can get a slight idea as to whether each number is “good” or “bad” based on the position within the range – even without knowing what the individual values mean to feline physiology.

A much better presentation is as follows – where far less time is needed to understand the numbers:

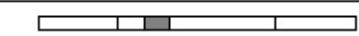
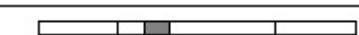
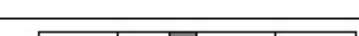
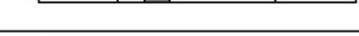
Blood Tests for Fluffy - 3			
Test	Results	Range	Indicator Low – Normal – High
HCT	31.7%	24.0 – 45.0	
HGB	10.2 g/dl	8.0 – 15.0	
MCHC	32.26/dl	30.0 – 36.9	
WBC	9.2 x10 ⁹ /L	5.0 – 18.9	
GRANS	6.5 x10 ⁹ /L	2.5 – 12.5	
L/M	2.7 x10 ⁹ /L	1.5 – 7.8	
PLT	310 x10 ⁹ /L	175 – 500	

Figure 7-5: Fluffy's Blood Test – View 3

The graphical indicators give the information at-a-glance that Fluffy is OK. In fact, this depiction can be flashed on a screen for less than one second and people will clearly understand it. Information is *data in context made useful*. The individual numbers are not even needed as long as the indicators are in the proper range. A proper use of this technique “lines up” the indicators when everything is normal, which is a common practice for aviation engine instruments.

7.5 Analog is Often Better

The Douglas Adams novel, *The Hitchhiker's Guide to the Galaxy*, refers to Earth as “an utterly insignificant little blue-green planet whose life forms are so amazingly primitive that they still think digital watches are a pretty neat idea.” (Great novel. Good British TV series. Terrible movie!)

Humans are analog beings. The world we live in is an analog world – all the way down to the quantum level. We understand many things most effectively when presented properly in an analog fashion. Some readers will remember when digital watches were first introduced. How cool they were! What excitement! Then the fad died down quite quickly because people actually *do not care what time it is*. What we care about is usually *how much time we have between now and some other event*. Your next meeting is at two o'clock. You make a split-second glance at your watch. Can you make the meeting?



Figure 7-6: Can You Make the Meeting?

The analog watch (even the cool but “distracting” one shown) is much more suited to the human ability to quickly interpret analog values. A conventional watch can show, in literally a small fraction-of-a second glance, “I have about 10 minutes until the meeting.” Interpreting a digital display of 1:48:58 takes longer and requires more mental effort.

The **Bulova Accutron** electronic tuning-fork-movement watch (1960-1977) was the height of pre-quartz watch technology. Transistors drove the coil (containing almost 300 feet of wire) at 360 hz (musically, F sharp – you could

tune your saxophone to it.) Advertised as accurate to “one minute a month”, it became hugely popular. The see-through “Spaceview” was not designed for purchase, but as a jeweler’s model to explain the technology. Many customers wanted to buy it instead and it became the most popular version. If you are old enough to have seen the original run of *The Man from U.N.C.L.E.*, you have seen many Accutron commercials – and some are still on YouTube. An Accutron movement regulated an experimental module left on the moon’s surface by Apollo 11. These watches are now highly collectible; the 1971 model shown (\$180 originally) was an author’s high school graduation present – and still runs perfectly.

The rare **Hewlett-Packard HP-01** electronic wristwatch (1977-1980, originally \$650 to \$850) was a technological marvel in 1977, but a business failure. It was not only an LED chronometer, alarm, and calculator, but could also perform dozens of dynamic calculations based upon changing time, such as displaying the accumulating cost of a long-distance phone call (expensive in 1977). The younger readers of this book may not know early LED watches did not display continuously due to their high power drain; pressing a button was required to show the time. The HP01 had three batteries, two of which drove the display. The buttons were manipulated using a small stylus included in the wristband.

The HP-01 suffers from a poor HMI. Advanced functions require the buttons to be pressed in certain memorized sequences and the display feedback is highly limited. Similar situations are found when conventional 12-button telephones are equipped with advanced features via multiple “codes” and “switchhook manipulations” that often frustrate the user.

Only 50,000 HP-01s were made and many were sold at steep discounts to HP employees. The ultimate in geek chic, these are also now highly collectable.

Hollywood movies consistently have major failings in the accurate depiction of technical information. However, the film industry is masterful at coming up with visual techniques to display crucial information, in literally a split-second of on-screen time. Here is an example many of us are familiar with – the sickbay medical readout from the classic 1960’s *Star Trek*:

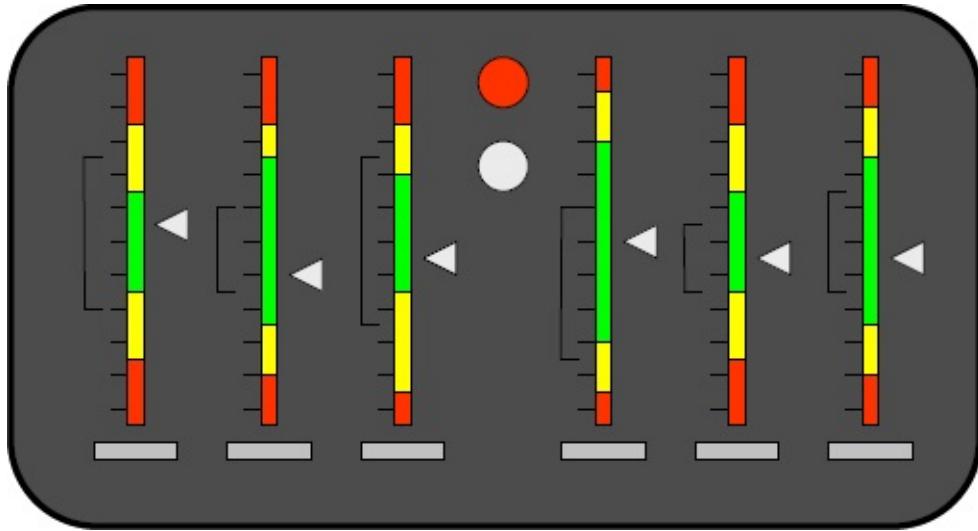


Figure 7-7: “He’s not dead, Jim.”

This graphic panel could be displayed for only a second or two on screen, yet the viewer understood immediately the health of the patient via the moving triangular indicators. The small text did not have to be readable. The display was coupled with alarm sounds for out-of-proper-range values and the bars were color-coded with the healthy ranges. When the red-shirted crewman inevitably died, the indicators would sink slowly and sadly to the bottom. (It is rumored that one of the in-joke indicators was labeled “Remaining Medical Insurance.”)

Translated to an industrial situation, consider these alternative compressor display elements. These might be a piece of a larger graphic. The desire is to understand the nature of the operating performance at a single glance.

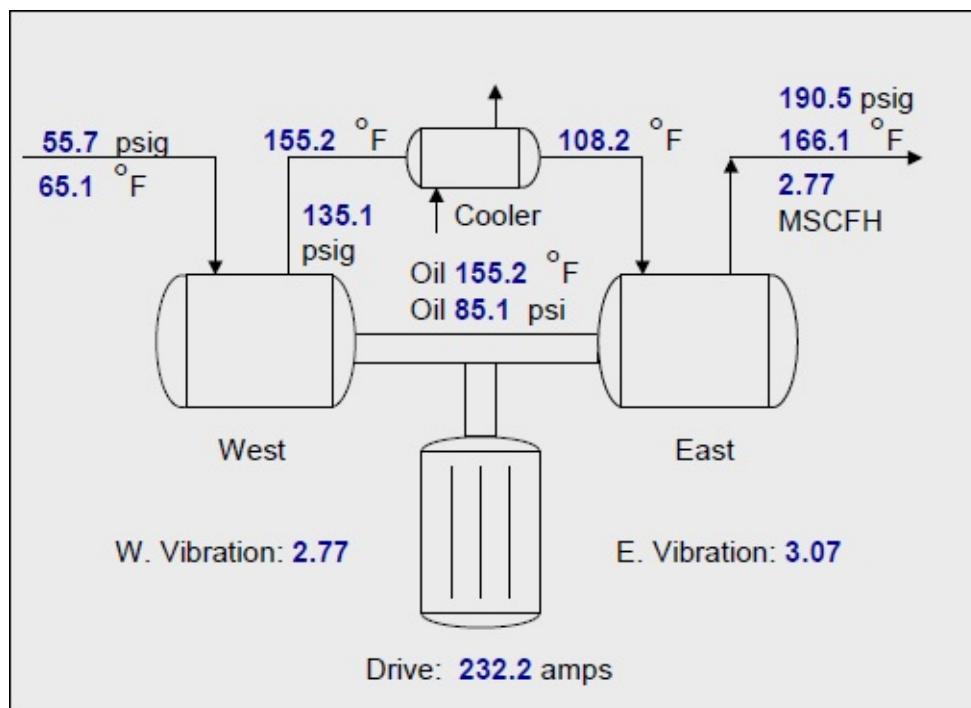


Figure 7-8: A Process Pictorial View of a Compressor

Compare the above traditional depiction to the following High Performance display element.

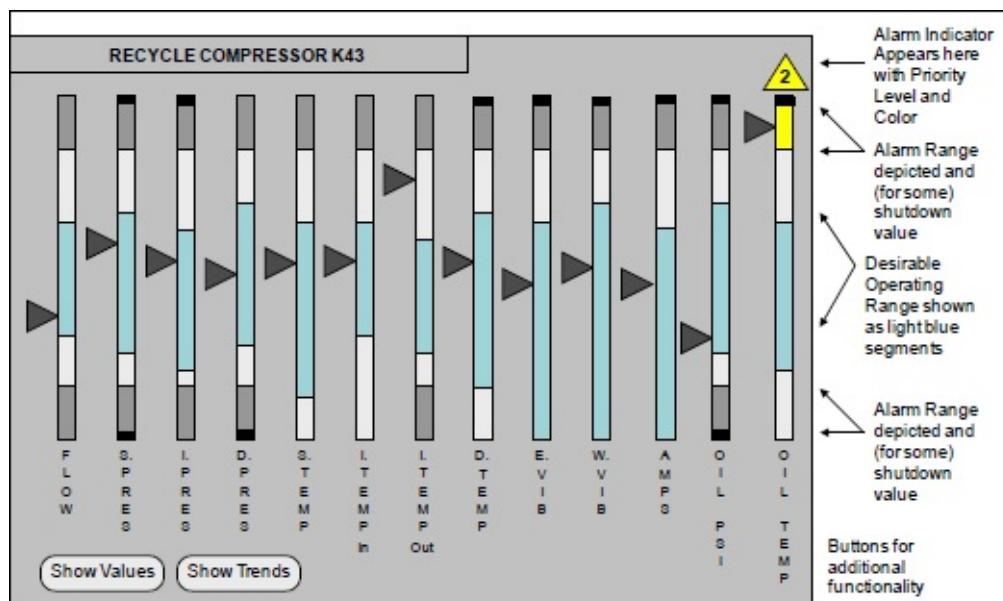


Figure 7-9: A High Performance View of a Compressor

7.6 Moving Analog Indicators

Figure 7-9 depicts moving analog indicators. With these, the operating status is visible at a single glance of a second or two. If all the indicators are inside the light blue bands indicating normal range, then there is no need to look at the compressor any further. The operator can proceed to survey the rest of the process for anomalies. In the element shown, two values have left the normal range, but not so far as to activate their alarms. This is clearly shown and assists in the desired aspect of detecting abnormal situations at early stages before alarms occur. The use of bar graphs instead of moving indicators may be easier to accomplish on some DCSs, but there are disadvantages to this method; when the values are low, the bars cease to show. Moving indicators are preferred.

Note also that the individual indicators show whether alarm ranges exist (for example, the vibration indicators have only high value alarms, not low alarms) and whether the measurement acts as an interlock initiator (the solid black rectangles at some of the endpoints).

Dynamic scaling of indicators like these can be used for different plant states, such as different feedstocks, products, or modes. Additional indication (Figure 7-10) can be made to show the value, direction, and magnitude of indicator movement for a defined time period.

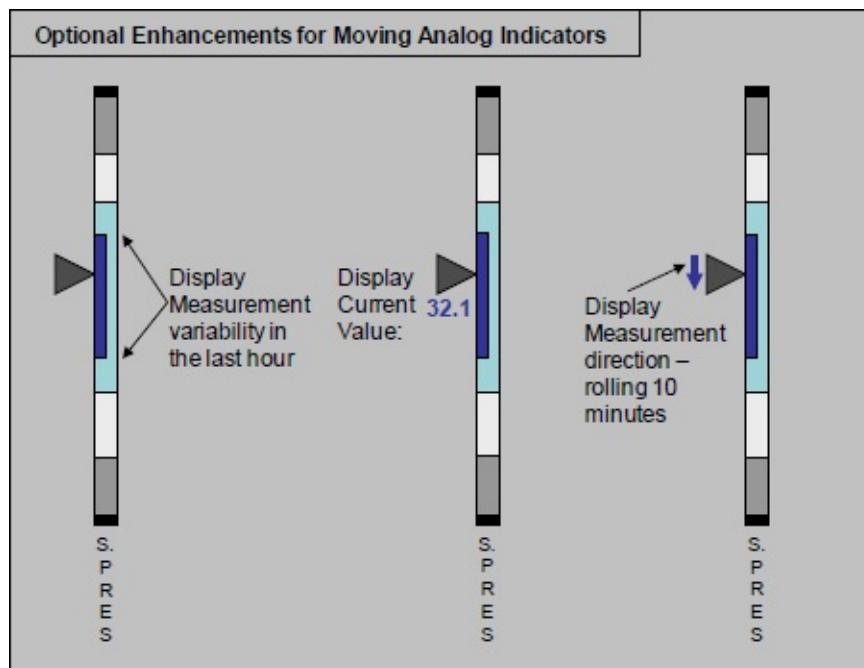


Figure 7-10: Moving Analog Indicator Enhancements

Digital Controls

Imagine if instead of guiding your car with a steering wheel, you would instead type in a number from 0 to 360 degrees for each desired wheel position. Would you buy such a car? (Or more tellingly, would you insure one?) Analog is not old, obsolete, or out-of-date. Analog neatly matches human abilities and is very powerful!

7.7 Other Analog Depiction

As another example, consider these alternative distillation column temperature profile displays. The desire is to understand the nature of the profile at a single glance.

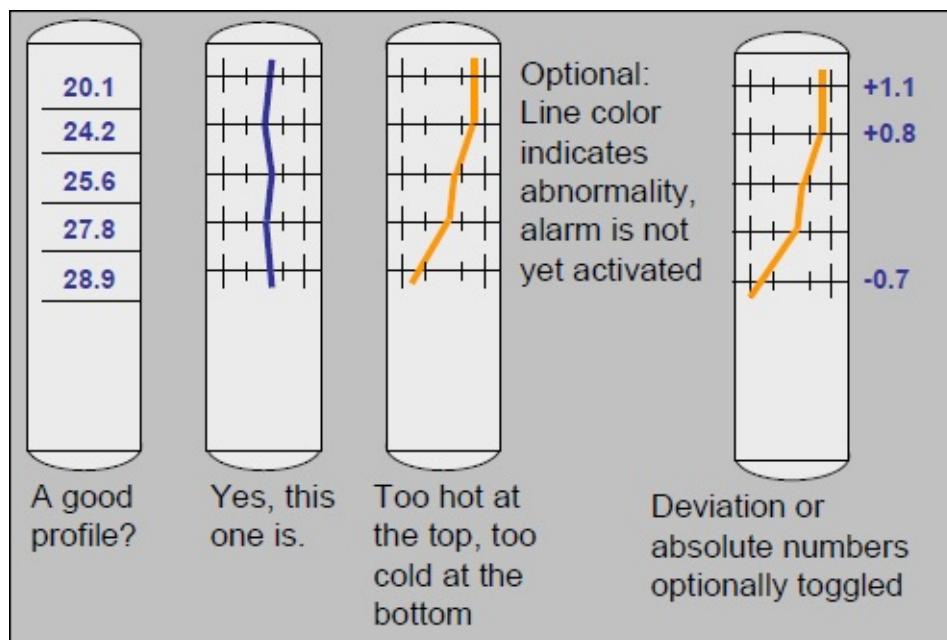


Figure 7-11: At-A-Glance Indicators – Column Temperatures

A correct profile can be seen at a glance as a straight line. Temperature values or deviation numbers can be programmed to appear/disappear with a toggle-type click. Digital numbers are displayed when accuracy is paramount.

All of the books in the world contain no more information than is broadcast as video in a single large American city in a single year. Not all bits have equal value.

-Carl Sagan (1934 - 1996)

7.8 The Importance of Trends

None of the examples above deal with a highly important aspect of operator displays – namely, trends. Trends are far underutilized in industrial displays. However, they are essential for properly presenting important data. Consider the following examples:

Current Pressure	Alarm Limit	Shutdown Actuation
235.2 psig	250 psig	300 psig
		

Figure 7-12: Data Needing a Trend

The display of the current value only shows “where I am now.” Even when coupled with the graphical indicator, the information is not optimal for managing many situations. Note how the trends below convey much more information about the nature of the process.

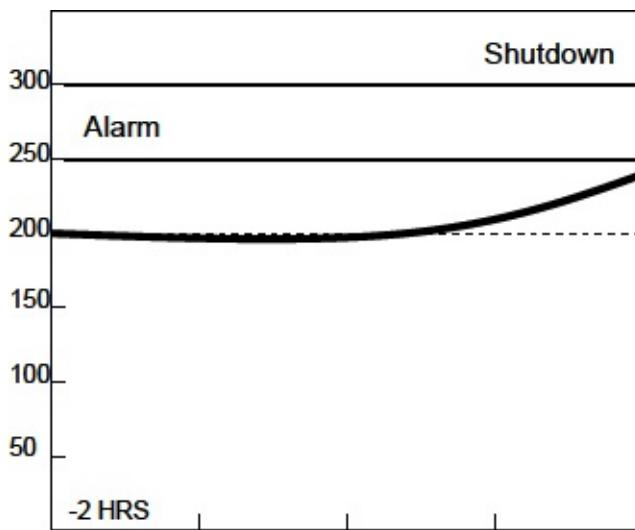


Figure 7-13: Trend Showing Slow Increase

The pressure had been stable at the desired 200 psig (dotted line), but began to rise at an even rate an hour ago. If this continues, it will reach the alarm point in a few minutes.

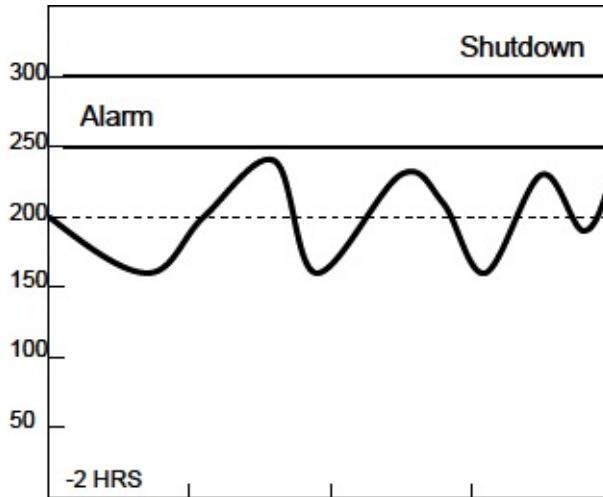


Figure 7-14: Trend Showing Oscillation

Here, the pressure has been oscillating around the desired value at about a 30 minute rate, but not getting up to the alarm point.

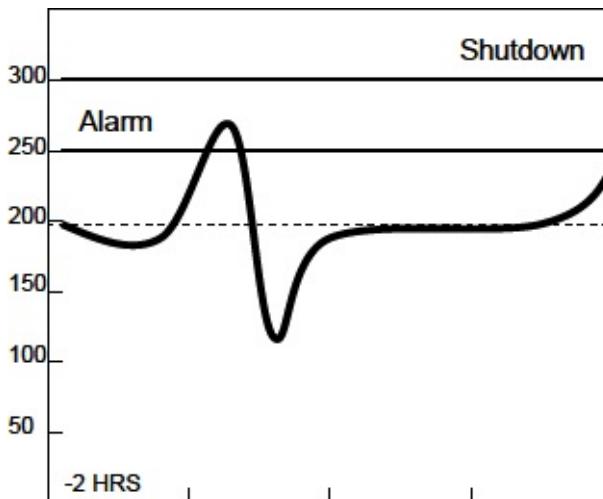


Figure 7-15: Trend Showing Prior Upset

Here, an upset about 90 minutes ago was over-corrected after the alarm. Now it looks like something similar might be beginning to happen again. A simple static display value would not convey any of this important information.

It pays to be obvious, especially if you have a reputation for subtlety.

- Isaac Asimov

7.9 Proper Implementation of Trends

Trends are essential. Use lots and lots of trends!

Important values should be trended!. Now you may say, “But my DCS has the ability to pick any point and trend it if the operator wants to. Just select the value and hit the TREND button.” You would be right, they can. But they won’t though, not if it takes 10 or 20 keystrokes and mouse clicks to generate them. The actual series of keystrokes is often to hit the TREND button, and then select the proper scale, and then select the proper timebase, and then pick a color for the trace, and figure out what other things would be useful if displayed on that same trend, then decide if a multiple Y-Axis is needed because of different ranges, and then give the trend a cryptic name and save it, having forgotten that the same trend was built a month ago, and other operators on other shifts have built similar ones with other cryptic names and forgotten about them as well. Now this one trend is taking up an entire screen and the operator needs to look at something else

In theory, theory and practice are the same, but in practice, they’re not.

John Rummel, NASA astrobiologist

Operators have different skill levels with the DCS functions and it’s our job to make sure the right tools are on the system so *every* operator can run the process effectively.

A much better solution than trending on-the-fly is to ensure every Level 1 and Level 2 graphic has, embedded in it, at least one trend of the important values associated with the operation. Multiple embedded trends are sometimes desirable. The information content of trends is far more valuable than the depiction of many typical “P&ID” elements on graphics.

Trends should be implemented with these capabilities and characteristics:

- When the graphic is called up, the trend’s Y-Axis span should automatically range itself to a predetermined scale or a predetermined amount relative to the current value of the reading, such as +/- 2% or +/- 5 engineering units. The scale should rarely be the full scale of the value. It

should be a tight scale where meaningful change of the value is immediately detectable. The scale span values should be shown and adjustable.

- The trend should come up with a default timebase appropriate for the process condition (for example, to show the last 10 minutes, 2 hours, or the last 24 hours). This choice will vary based upon the particular process value being trended.
- Normal process bounds, quality limits, or desirable operating range should be indicated based on the state of the process.
- Manual alteration by the operator of the ranges and timebase should be possible and should persist to the next invocation of the display. A “Retrend” button should allow for the trend to return to the automatically-calculated values if the manually adjusted ones are no longer appropriate.
- The operator should not have to manipulate any keys to make the trend usable.
- The display of multiple traces should be consistently implemented.
- Trends with either the y or x axis size at less than around 2 inches (perceived at arm’s length from the screen) are very likely too small to be effective.

Dedicated Level 2 displays consisting of only trends and faceplate access buttons to controllers associated with those trends should be provided for each process operation. The very best, most experienced operators will often run the process using primarily such displays. They do not need pictures of the distillation column showing each tray.

A proper trend of a controller will show process value, setpoint, and controller output. (As a good practice, the controller output trace should be available via toggle.) Such trends are highly useful for diagnosing controller problems and, particularly, valve problems. Studies have shown, unfortunately, on average :

- More than 50% of all control valves are incorrectly designed with a nonlinear installed valve characteristic and/or incorrect sizing for the application.
- More than 50% of all control valves have mechanical problems of hysteresis or stiction.
- Almost 20% of control strategies can be improved upon.
- 10% to 20% of industrial control loops are run in manual.

- About 33% of controllers produce more variability in auto than in manual (Bialkowski 1993; Debborough & Miller 2001; Desborough et al 2001; Ender 1993; Smuts 1999).

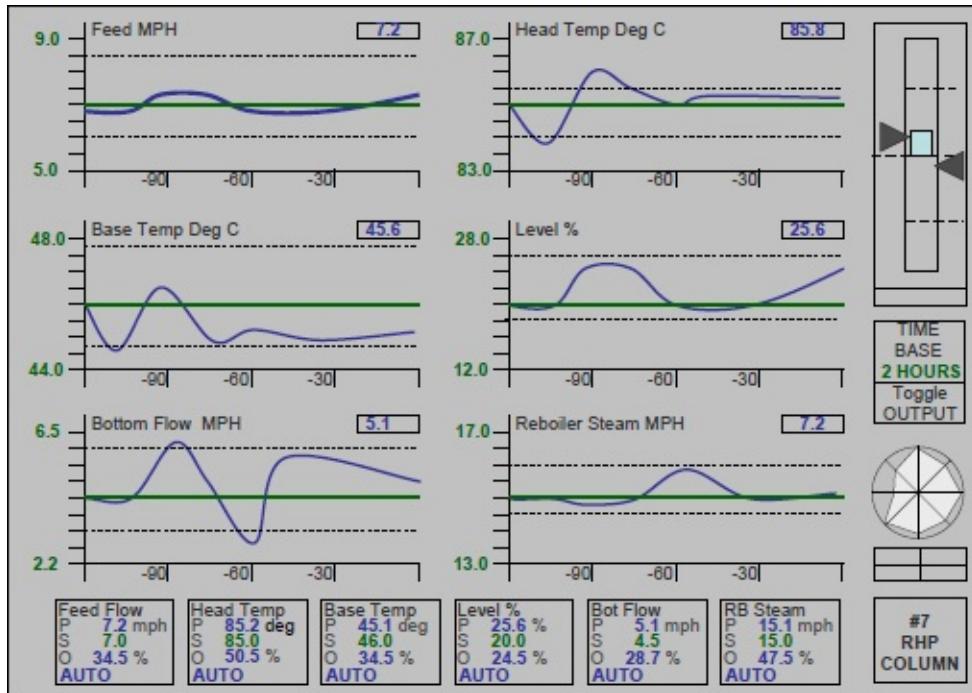
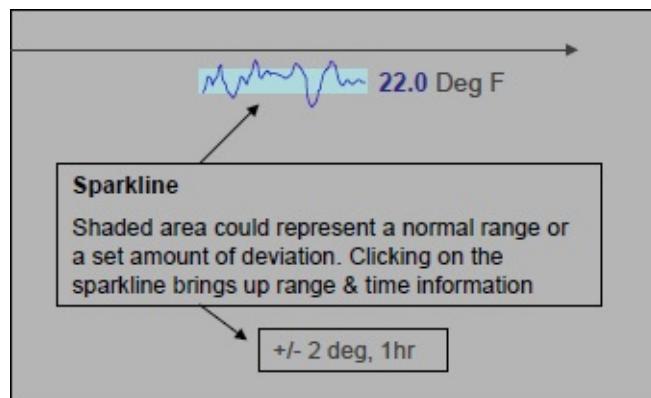


Figure 7-16: An “All-Trend” Level 2 Display with Access to the Relevant Process Controllers

Sparklines

Edward Tufte (2001) describes very small and limited trend depiction for certain uses. When precision is not essential and simple direction, magnitude, and amount of change are desirable, a small unlabeled trend can be beneficial next to a depicted process value.



Some DCSs may be unable to accomplish this depiction.

7.10 General Considerations for Displays

There are many graphic design principles common to all displays, regardless of their level in the hierarchy. These common principles are covered in the following sections with examples. In the next chapters, the detailed considerations for content of each display hierarchy are covered.

7.11 Use of Color

Color perception is a highly complex topic, about which thousands of pages of research have been written. In industrial HMIs, color is often highly overused and improperly used. For a High Performance HMI, color usage is restricted for very specific reasons having to do with consistency and with drawing attention to important situations. Color choices and usage must be applied consistently throughout the entire graphics hierarchy. Color should never be the sole differentiator of important factors. Color differences should be combined with other distinguishing characteristics such as shape.

Proper use of color is a factor in making graphics easy to use and comprehend. Misuse of color will significantly hinder the operator's ability to quickly and accurately detect an abnormal situation.

Background Color

It has long been thought that proper display contrast is achieved by a light or dark background, but not in-between. This advice was partially correct, and was influenced by display hardware limitations in the early days of DCS graphics. However, contrast is not everything. High-contrast, bright figures on black backgrounds are fatiguing and uncomfortable to the eye. If that was an effective mechanism for people, then books would have light text on dark paper. It isn't and they don't.

The correct guidance is for the background color of a display should be a light gray. This most effectively addresses the problems of glare, contrast, color interference, and fatigue. Control rooms should be brightly lighted (as discussed in a later chapter) and displays should mimic the ease of reading paper

documents, rather than being made of brightly glowing lines, objects, and text on dark backgrounds.

Glass CRTs have more problems with glare than LCDs and are rapidly being replaced in control room applications. In addition, the same graphic shown on different hardware may look significantly different.

Color and the Brain

In human perception, color is a special attribute. Color is processed “pre-attentively” meaning there is circuitry deep in our brains picking out color differences. Our attention is automatically drawn to something having color contrast with its background. This is known as the “pop-out” effect. Strongly contrasting color is a powerful tool for directing the operator’s attention – which is why it should be reserved for abnormal situations (such as alarms).

Experimentation with different levels of gray backgrounds and foreground objects in the actual control room and on the correct display hardware can be used to decide upon specific values. Figure 7-17 is an example illustrating the typical 16 gray-level contrast. A Gray 3 (RGB 221, 221, 221) or Gray 4 (RGB 192, 192, 192) is often a good background choice since they work well with other selections for foreground objects. Gray backgrounds have minimum interference with other color choices.

A screen element, such as Figure 7-17, can be used to test choices in your actual conditions and by the people who will use the displays. Since printed output differs considerably from screen appearance, it is unreliable for making choices.

Foreground Colors

A minimum number of colors should be used and quite sparingly. HMI graphics are different from other graphic pictures we interact with daily. For example, internet web pages are usually very colorful and animated. This is for a reason; they are competing with all the other web pages for our attention. Typically most of the information on a web page is static, has equal importance, and there are only minor consequences if you overlook a piece of information. This is not the case with DCS graphics.

Process lines and the outlines of vessels and equipment should be dark gray or black, not colored. Emphasis is provided via differences in line thickness, not color.

Color should not be used in an attempt to indicate the type of material (i.e. white is steam, green is demineralized water, pale blue is ethylene, etc.) as it usually cannot be consistently achieved in actual practice (or memorized by the operators) and proves to be a distraction.

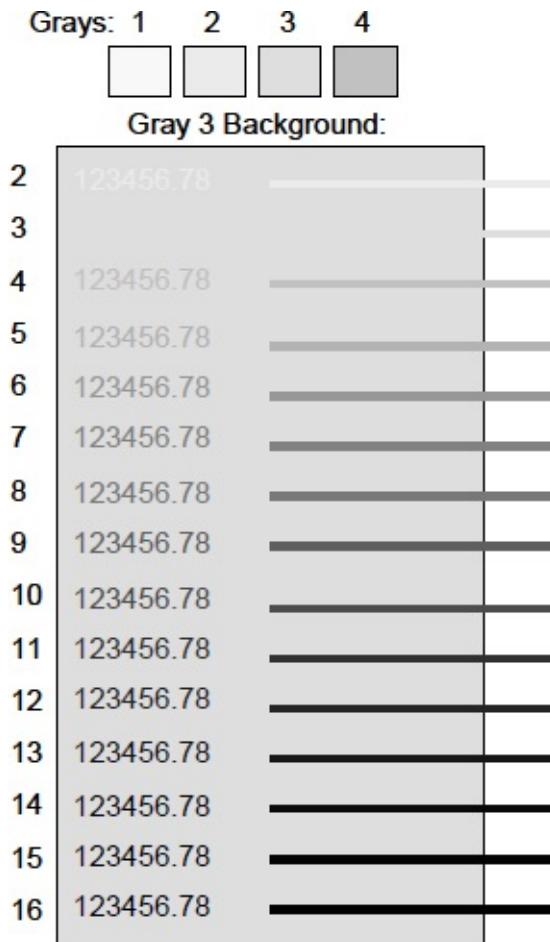


Figure 7-17: Shades of Gray and Contrast

Bright, intense (saturated) color is used only for quickly drawing the operator's attention to abnormal conditions and alarms. If the process is running correctly, the screen should display little to no color. All use of color must be standardized and rigorously followed.

Color is perceived poorly in human peripheral vision. Since multiple monitors

are normally installed in an operating console, never assume a color change alone will draw an operator's attention. A graphic behavior, such as blinking, is highly detectable by peripheral vision, but should not be overused. Many control rooms have screens full of constantly blinking data.

Color Blindness

Color-blindness is a common phenomenon and there are several varieties. For this reason, an object's color is never the only method used to convey important information. The most problematic color pairs are red-green, green-yellow, and white-cyan. The saturation and brightness choices of the specific shades chosen can be adjusted to achieve differentiation on the chosen gray background.

Color is used in conjunction with text, shape, filled/unfilled status, texture, or a similar aspect. This redundant coding of information is one of the primary methods by which color-blindness is addressed.

7.12 Standards and Color Conflict

There are a variety of standards (ISO, IEC, ANSI, ISA, API, etc.) applicable to various industries. Some of these standards contain color coding guidance, though not necessarily for screen displays. The unfortunate truth of the matter is the writers of these standards were not necessarily experts in HMI design. Various standards specify totally different uses for the same colors, particularly red and yellow. The purpose of these standards was not to provide guidance on HMI display design for high performance.

Therefore, attempts to design displays reflecting the content of such standards will not produce high-performance results, but instead can result in inconsistency and confusion.

7.13 Depicting Lines, Vessels and Static Equipment

While the process pictorial elements are typically overused, it is important to design them correctly when they are used.

Process Lines

- Process lines should be dark gray or black.

- Thickness, not color, is used to differentiate their significance.
- Main process lines should be 3 pixels in width; secondary process lines should be 1 pixel. Use arrows sparingly to indicate flow direction on primary lines.
- There should be no more than two or three line types (such as solid, dotted, dashed) and a similar number of line thicknesses.

Process Vessels

The tendency in the past has been to create life like graphics with 3D vessel and a great amount of detail around static data. This is counterproductive.

- Vessels should be depicted as 2 dimensional, not 3 dimensional.
- The interior of the vessel should be uniformly shaded, without gradients, and be the same as the background color.
- The vessel should be outlined in a thin line of black or dark gray.
- The vessel's representative shape shall be shown, but without much detail.
- The size of the vessel shall be relative to the process importance of the vessel and also relate to its physical size (when practical).
- There should be no animation associated with vessel internals.
- Vessels should not be shown as cut-away drawings showing detailed unchanging internals.

Process Flow

- Process flow should be depicted consistently.
- Flow should generally be from left to right.
- Vapors generally flow up and liquids down, although compressors and pumps affect this depiction.
- Process lines should enter and leave the screen in consistent ways. Entry and exit points which are also navigation targets should be consistently presented and differentiated from non-navigation link labels (See Figure 7-18)..

Some places have carried the gray-scale principle too far and created extremely low-contrast graphics (Figure 7-19). Such “blob graphics” are not recommended. The key is to provide easy visibility of elements, but to reserve emphasis for abnormal situations.

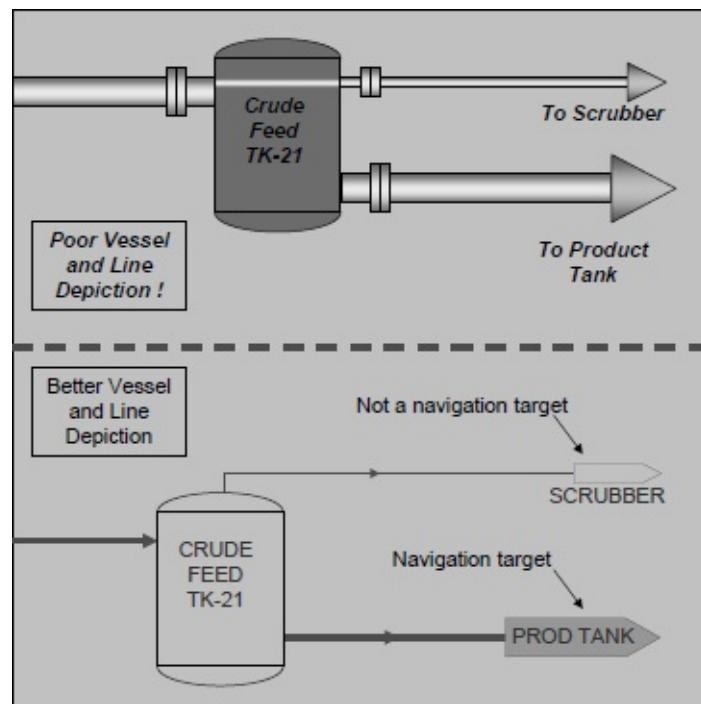


Figure 7-18: 3D vs. 2D Vessels and Lines

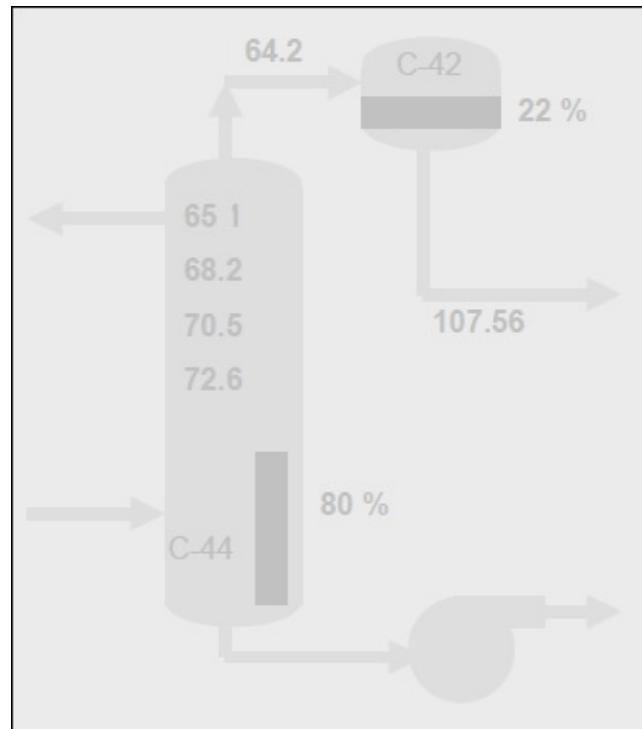


Figure 7-19: Low-Contrast “Blob Graphic” Elements

7.14 Depicting Text

The display of static text on-screen should follow several principles:

- The amount of text should be minimized, but not eliminated. A graphic screen is not an instruction manual or a training document. Nor should it be a puzzle. Use text to identify different items when their placement or shape does not make their identity obvious.
- Text should generally be a dark gray, not black.
- All display screen lettering should be in non-serif fonts. We know, printed books and magazines use serif fonts (such as you are reading now) because they make reading easier and faster. However, books and magazines typically have at least four times the resolution of a CRT or LCD screen display. Depicting serif fonts on such displays actually makes the text less readable.
- Use larger, highly visible text to identify duplicated equipment, such as multiple reactors, furnaces, compressors, and so forth. When a screen shows only one furnace out of several, it is extremely important to be clear on which furnace is being depicted.
- For isolated words, titles, short labels, and equipment designations (particularly for a “non-word” term like HYDRO SEP), all uppercase lettering is preferred. For other uses, mixed-case lettering is much more legible.
- Ensure consistency with abbreviations; make sure to maintain a master list and glossary of them.
- There are many formulae and calculation methodologies for determining the proper size of text based on screen size, angle, placement, pixel density, and other factors. From a typical viewing distance of 24 inches, ANSI recommends text heights of a minimum 2.8mm, nominal of 3.5mm, with a maximum of 4.1mm. As in so many things, simpler is better. As a check to these values, create some mockup graphics with various sizes of text, and insure your operators (particularly your “more experienced” ones) can read them.
- Operators like to have all the information in front of them. In response, many existing graphics have sacrificed clarity and reduced text size too much in order to cram more data (not necessarily *information!*) onto a single display.

7.15 Depicting Values

The display of live values on the screen should be shown in a different way than static text.

- The choice of a bold, dark blue is a good choice for the gray background and differentiates live values from static text (see Figure 7-20).
- Leading zeros are not displayed, except on fractional values (e.g., 0.27). Values are shown only to the precision needed by the operator.
- In tables, align numbers on the decimal point.. In a High Performance display, tables of numbers are not generally recommended.
- When needed, the units of measurement are displayed in lower contrast text adjacent to or near the value.
- Tagnames should not be shown on the screen by default. It should never be necessary for an operator to have to type in a tagname in the entire HMI. It is a typical DCS functionality that the selection of a live value provides access to a faceplate-type mechanism where many further details of the reading (including the tagname) are provided. In some cases, it may be desirable to provide a toggle command by which the values on the screen have their tagnames appear and disappear. This is not advisable as a default because it can pose significant layout problems.
- When items are “selected”, that status should be indicated. Surrounding the selected item with a white outline is a good practice.
- Action or status messages should be short, simple, and specific. For example:
 - “Backwash complete. Filter cycle is restarted.”
 - “Open Valve 16A for batch to proceed.”
 - “Quality Parameter <xxx> exceeded in current analysis.”

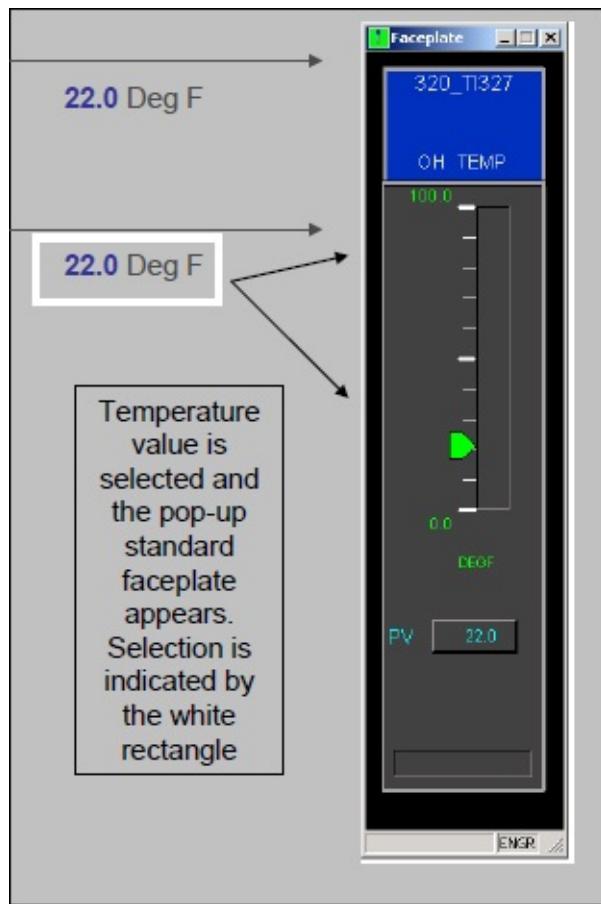


Figure 7-20: Values and Faceplate Pop-ups

7.16 Depicting Vessel Levels

There are several methods for analog indication of vessel levels. The object is to depict the level without undue emphasis or distraction. Indication of any alarm limits is also recommended, such as with the small marks on the rightmost example in Figure 7-21. The overall height of the level bar depicted should correspond with the physical range of the instrument as installed on the vessel.

Moving analog indicator-type elements can also be used for tank level indication. For some equipment, a trend line is the best method for depicting levels.

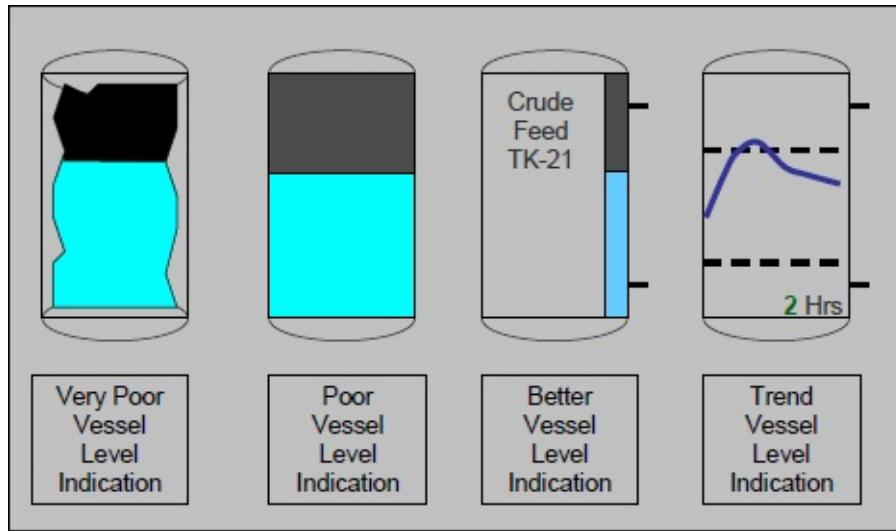


Figure 7-21: Example Practices for Vessel Levels

7.18 Depicting Alarm Behavior

Any value in alarm must be shown clearly and consistently. There are a variety of methods, some clearly better than others. The following principles apply:

- Color is related to alarm priority. Every alarm priority has its own color which is used for nothing else, on any graphic, than to depict alarm-related behavior.
- Unacknowledged alarms should be distinguished from acknowledged alarms. The most common method is the flashing of the alarm indicator for the unacknowledged condition.
- If more than one alarm is in effect on a value, the highest priority alarm should be indicated.

Graphics should not be “hard-coded” with alarm behavior for points; the behavior should be consistent based on the current configuration of a point’s alarm and should change if the configuration changes.

7.19 Alarm Priorities

It is a well-known best practice for process alarms to utilize a primarily three-priority system. For full details on the proper selection and distribution of alarm priority, see the references section for *The Alarm Management Handbook*.

If possible, diagnostic-type alarms should be segregated from the primary three priorities. Diagnostic alarms are those indicating instrument malfunctions not solvable by the operator and generally requiring maintenance attention. If the DCS is capable of a fourth annunciated priority, then diagnostic alarms for which the only operator response is the writing of a maintenance work order should be segregated into the fourth priority.

Suggested colors for a recommended 4-priority system are:

- Priority 1 – (Highest); Red
- Priority 2 – (2nd Highest); Yellow
- Priority 3 – (3rd Highest); Orange
- Priority 4 – (Reserved for Diagnostic Alarms); Magenta

Via prototype testing, ensure the colors chosen are easily distinguishable on your particular display hardware. Printouts will appear different than LCDs or CRTs.

7.20 Alarm Indication Methods

The following figures show several alarm indication methods with their advantages and disadvantages. The third method is the one recommended.

Method 1:

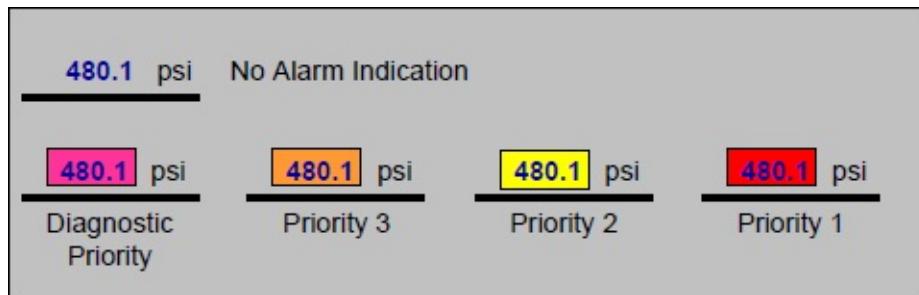


Figure 7-22: Method 1 – Solid Color Blocks Behind the Process Value (Not Recommended)

Advantages:

- The color stands out and draws attention to the value in alarm.
- For the unacknowledged condition, flashing of the solid block and not the value ensures the value is always visible.

Disadvantages:

- Color combinations can be problematic – consider the red-blue combination for Priority 1.
- The alarm priority is shown only by color and is not redundantly coded, thus the color-blindness issue is involved.

Method 2:



Figure 7-23: Method 2 – Color Outlines Around the Process Value (Not Recommended)

Advantages:

- The color stands out and draws attention to the value in alarm, although the decreased area of colored space provides a lesser effect.
- For the unacknowledged condition, flashing of the Outline block and not the value, ensures the value is always visible.
- The color combination problem in the method #1 is addressed.

Disadvantages:

The alarm priority is still shown only by color and is not redundantly coded, thus the color-blindness issue is still unsolved.

Method 3:

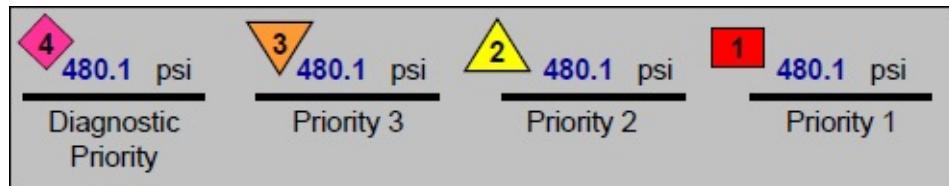


Figure 7-24: Method 3 (*Recommended*) – The Separate Alarm Indicator Element

In this method, a new alarm indication element appears and disappears with the

activation of the alarm condition..

Advantages:

- The color stands out and draws attention to the value in alarm with adequate visibility.
- For the unacknowledged condition, flashing of the entire element does not affect the visibility of the process value.
- There is no color combination problem.
- Placement of the indicator is flexible and can be anywhere near the value (although a consistent placement is preferred).
- The priority of the alarm is redundantly coded by alarm indicator shape, color, and priority number.

Disadvantages:

- All these methods share one disadvantage: the specific type of alarm is not shown. Unless it is obvious from the operator's inspection of the process variable, a click to bring up the faceplate may be needed to determine the specific alarm.



Figure 7-25: Alarm Suppression Indicator

It is also recommended for any alarm suppression in effect on a point be shown on the graphic as well. The above method works well.

Method 4:

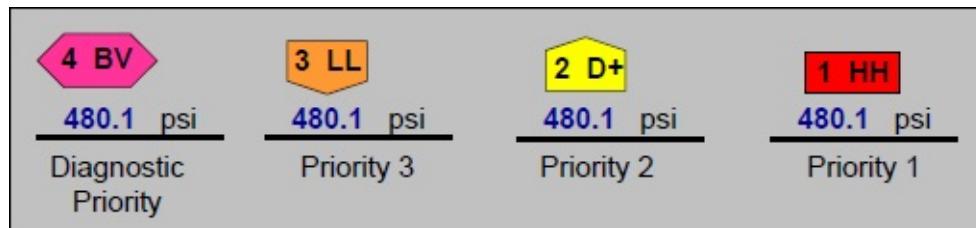


Figure 7-26: Method 4 – The Separate Alarm Indicator Element with Alarm Type (Not

Recommended)

In this method, an attempt is made to code alarm type into the separate alarm indication element. This method seems acceptable, but has significant problems in actual practice.

Advantages:

- Includes the addition of alarm type display. Alarm types can include:
 - High Value HI-HI Value HI-HI-HI Value
 - Low Value LO-LO Value LO-LO-LO Value
 - Rate of Change Positive Rate of Change Negative
 - Deviation Above Setpoint Deviation Below Setpoint
 - High Controller Output Low Controller Output
 - Bad Value Diagnostic Range Diagnostic
- This has all the same advantages as method #3 as well.

Disadvantages:

- For any given value, a dozen or more alarm types may be available on a typical DCS. (This is part of the overall problem of alarm management.) The coding of these types can begin to occupy a lot of space. Attempts to save space can yield very cryptic abbreviations for alarm type. It is additionally possible for a value to have more than one type of alarm in effect at the same time (for instance, high value, plus high rate of change). Attempts to show these multiple alarms or to arrange the depiction in some sort of hierarchy pose significant practical difficulties.

There is simply far too much information available in a DCS, even about a single value or alarm, to attempt to show it all on a single graphic indication. Many attempts have been made and they generally result in over-crowded and confusing displays. The principle of disclosing progressive amounts of detail, as needed, addresses the issue in an improved way.

It is never recommended for the color of the value itself to change based upon an alarm. While often the “easiest” path, this is a poor practice.

7.21 Alarm Access

A High Performance HMI is designed to minimize the number of keystrokes required to identify, verify, assess, and respond to an alarm.

Every point with a configured alarm should have an associated Level 2 or 3 graphic display on the DCS. This associated display should aid the operator in the proper diagnosis and mitigation of the event causing the alarm. Methods by which the operator is quickly directed with a single keystroke or button-click (i.e. one-touch access) to the associated display should be used. Most DCSs have this capability, but it must be configured.

A more sophisticated implementation is possible once you are at the appropriate Level 2 or 3 display. When an item comes into alarm, the display can be configured to show not only which value is in alarm, but to also highlight predetermined items associated with the alarm, which should be the ones needed to respond.

A single alarm interface should be used, namely, the DCS. If alarms can come from sources nominally “outside” of the DCS, those should be brought into the DCS if it is used in any way to respond to the alarm. All alarms should be acknowledged only once; it should never be required to acknowledge the same alarm using more than one methodology.

A process graphic must visually and consistently identify tags in alarm, whether the alarm is acknowledged, and the priority of the alarm.

7.22 Audible Alarm Indication

Every alarm priority chosen should have its own unique alarm sound. In a control room with several operating positions and consoles, this could pose a difficulty. If closely adjacent consoles have the same sounds, then the operator cannot use sound to detect a new alarm on their own console.

The solution is each console can use its own “family” of sounds for priority. It is also possible to use lights; we have seen consoles topped by a small stacked cylinder of three or four lights, with colors matching the alarm priority colors. These lights activate either instead of or along with the appropriate sound. In this way, if the sound volume is kept down and if one operator is having a discussion with another operator at their console, the lights help indicate the presence and

location of a new alarm.

Guidelines for the effective use of sound are:

- Sound level should be enough for easy detection, but should not startle the operator. A value of 15dBA above background noise is about right, but should not exceed 80 dBA. A sound starting at a lower level then rising in pitch and intensity can be very effective. Most DCSs are no longer constrained to hardware “beepers” for alarms, but can utilize any sound file saved on the computer – even voice.
- People vary in their hearing ability. Some have hearing loss specific to certain frequency ranges. Ensure, via testing, the sounds and the volumes work with the operators.
- Small, wireless earpieces or lightweight headphones are a fairly recent development and can be used to send sounds only to a specific operator. (Covering only one ear is preferred.) Frequent testing of the devices is necessary (consider the batteries). A hardwired light can be substituted for the external alarm sound to indicate the presence of a new alarm and this should be used as backup, since the earpiece is a single point of failure. It is never desirable for an operator to miss an alarm.
- It should be possible to turn off the alarm sound for the lowest alarm priority during periods of high alarm loads. The operator doesn’t want or need a continuing distraction from the low priority alarm sound during a major upset. Visual notification should remain in place. This practice must NOT be left in effect all the time. It should have a timeout feature after a few minutes.
- The preceding principles assume proper alarm management practices have produced a rationalized, meaningful, and effective alarm system. If a system is generating 500 (or 20,000+) alarms per day, sound becomes a nuisance distraction.

We often see these basic principles violated. We see “alarm colors” used for all kinds of different graphic elements and single alarm sounds assigned to multiple priorities. Even worse, we see priorities with no sound at all – making it much less likely an operator will initially see such an alarm. The result of such configuration decisions will be an alarm system HMI which is less effective in helping the operator to properly detect, identify, and respond to alarms.

Be careful who you listen to!

It is surprising to learn some people claiming expertise in HMI design advise to use only a single alarm sound for all alarm priorities. They say, “With more sounds, the operator will get confused!” Well, would you want your telephone, pager, cell phone, alarm clock, doorbell, and microwave oven to share the exact same sound? No. An important purpose of sound is to differentiate. It would be easy to test this misguided advice. Imagine if you select 100 different sounds from various events, television shows, and movies, such as:

The first four whistled notes from *The Andy Griffith Show*

The static-filled scratchy spoken sentence beginning

“*That’s one small step...*”

R2D2 “speaks” in *Star Wars*

The opening orchestral notes from *I Love Lucy*

The tick of the stopwatch used in *60 Minutes* (or the one in *24*)

The sound effect of the *Star Trek* transporter or communicator

The first 4 notes from the opening of *The Twilight Zone*

As you read these, you probably imagined the sounds. (Many people can sing all the verses from *Gilligan’s Island* – an ability they never specifically sought.) You could play these sounds for a variety of test subjects and the recognition score would be quite high. This is true even though the exposure to these sounds is far less than will be encountered by a trained operator working with a console for 12-hour stretches. People readily remember and associate sounds and have little confusion doing so. Use sound effectively!

Voice Rather than Sound?

DCSs may have the capability of using voice (usually via .wav file) rather than simple sounds for alarm annunciation. (Fighter aircraft use this capability and a female voice was chosen after extensive ergonomic and audibility study. Pilots, however, have a derogatory name for this system, one that we shall not repeat here.)

The use of voice capability must be approached carefully. Consider a 3 priority

system with 3 well differentiated "beeps" indicating a new alarm of the corresponding priority. This is a very fast and low-distraction notification of a new alarm and its priority. To use voice instead, there must be some additional benefit justifying the extra time and "interruptive" nature of a voiced alarm.

To use voice, it is also necessary to have your alarm system under control and have low alarm rates.

If the 3 beeps were replaced with a voice saying either

"Priority 1 alarm" or "Priority 2 alarm" or "Priority 3 alarm"

then little value has been added. If the alarm rates are high, then a very annoying distraction has been created.

However, if voice can be used to differentiate something like:

"Compressor Priority 2 alarm" or

"Heater Priority 3 alarm" or

"Raffinate Priority 1 alarm" then extra information possibly yielding more benefit has been added. But, this may be difficult to implement. Voice should not read out each individual alarm, as in "EFF CEE One four zero one dash one five Splitter Inlet Flow Hi Rate Alarm Priority 2," because that message is more quickly read than heard.

Additionally, there is the whole issue to deal with about the voice repeating until alarm acknowledgement. Reading from the display can be done at the operator's discretion since the message will stay there. The operator can finish typing in a setpoint change and then read the alarm. Listening, however, has to be done when the speaking is occurring, and is thus more of an interruption.

Therefore, the use of voice rather than sound for alarm annunciation needs considerable thought to be done correctly.

7.23 Objects and Symbols

Develop standard shapes and sizes for vessels, instrumentation, pumps, heaters, heat exchangers, interlock symbols, etc. Make use of pattern recognition so objects can be identified at a glance.

Proper labeling should not be intrusive or of high visibility. Use consistent methods for labeling vessels, pumps, motors, navigation targets, and similar items. Note, every item does not require a label; identification by context is often adequate. In particular, tagnames or point IDs should not be routinely displayed on a graphic; they merely add unnecessary visual clutter.

The examples shown throughout this section incorporate depictions consistent with these guidelines.

7.24 Process Controllers

There is much variety in the depiction of a process controller. Many people equate a controller with a valve and associate the controller information (setpoint, process value, output value, mode, etc) right next to, and often indistinguishable from, a controlled valve. This is a poor practice.

A controller should be thought of and depicted as a physical entity, similar to a pump or heat exchanger. (We know it is only a software construct in the DCS, but in thinking about the process, the operator's mental model should represent it as a separate "thing." Proper graphics should promote proper mental models.) Controllers do not just control a single valve but also multiple elements and even other controllers. By depicting a controller separately, proper information about its operation, status, and connectivity can be clearly shown. If it is part of a larger control scheme, perhaps involving cascades and programmatic elements, a more complete depiction of the control scheme can be designed, yet be consistent with the depiction of simpler schemes. Linking controllers conceptually to control valves is far too limiting.

The depiction of controller elements poses a significant problem in "where to stop." The DCS construct of a controller may involve several dozen different parameters, as shown in Figure 7-27.

To depict a controller on a process pictorial therefore involves some substantial editing. An effective depiction will show only four items, with more detail available via the faceplate-type display. These items are:

- Controller Process Value (PV or P) – The current reading of the process value being controlled, generally in Engineering Units.

- Controller Setpoint (SP or S) – expressed in the Engineering Units of the PV.
- Controller Output (OP or O) – expressed as a Percentage, generally within -7% to +107%.
- Controller Mode – generally Automatic (AUTO), Manual (MAN), Cascade (CAS), or a few other specialty modes in some DCSs.

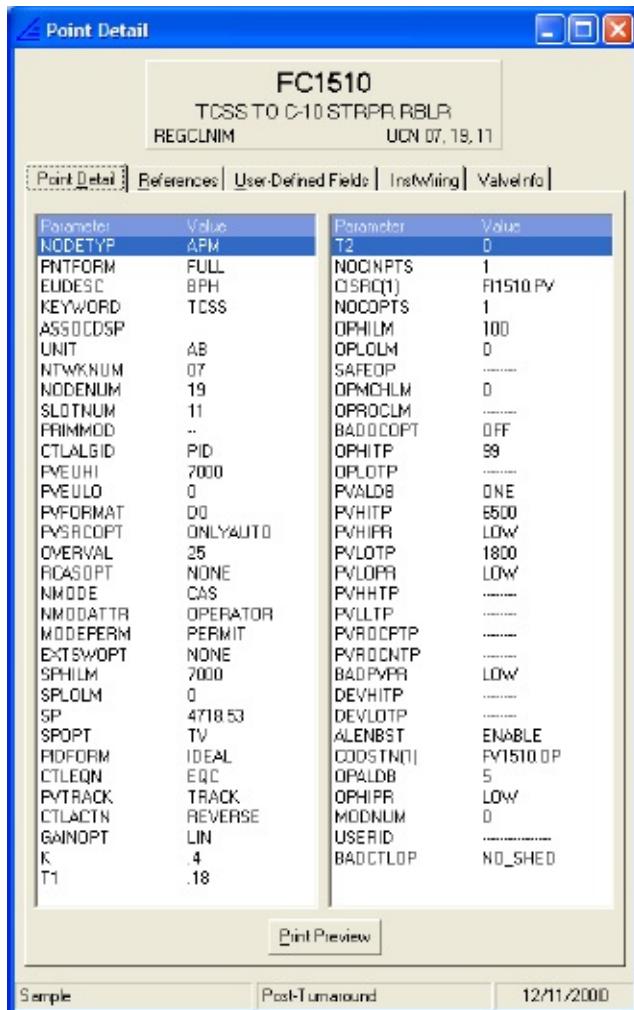


Figure 7-27: A Typical DCS Controller With More Than 80 Parameters

The depiction should be simple, straightforward, and consistent. Hundreds of different options are available, but the tendency to try to cram too much information via tiny symbols and cryptic abbreviations must be resisted. Figure 7-28 is a good example.

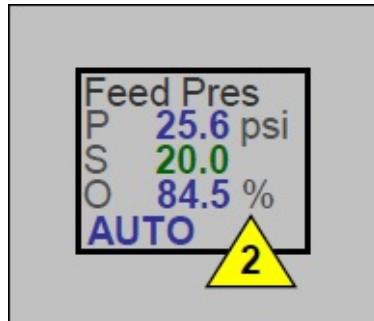


Figure 7-28: A Simplified Controller Element for Graphics

In Figure 7-28, the four main controller elements are shown, along with an alarm indication and a space for a short, descriptive title. (Do not use the title area for only a meaningless tagname.) The units of measure are shown. The presentation is compact. “Live” values of PV and OP are shown and the Setpoint is subtly distinguished in a dark green. Attempting to incorporate a tiny analog scale in conjunction with a controller depiction, such as this, is generally futile. The scale is just too small.

The slight color difference for Setpoint is not very significant – it is more important that the relative placements be consistent. The intent of the color difference is to distinguish between measurements sensed by the system and operator-changeable values. This difference should be consistent across other types of control elements as well.

Simplicity is the ultimate sophistication.

Amy B. Smith (MIT) quoting Leonardo da Vinci

A click of the simplified controller element should bring up a faceplate as shown in Figure 7-29. The faceplate has more detail and the ability to alter setpoint, mode, output, and other operator-adjustable parameters. Graphic faceplate elements for all DCS point types are usually provided from the manufacturer. It may or may not be possible to alter them and they may not follow other principles in your high performance displays. Improper use of color is a common fault in vendor faceplate elements. Rebuilding or replicating dozens of standard faceplates from scratch to correct minor consistency issues may not be worth the effort since future vendor software upgrades may override the work. Moving analog indicators modified to show the additional controller functionality are

also practical for many uses.

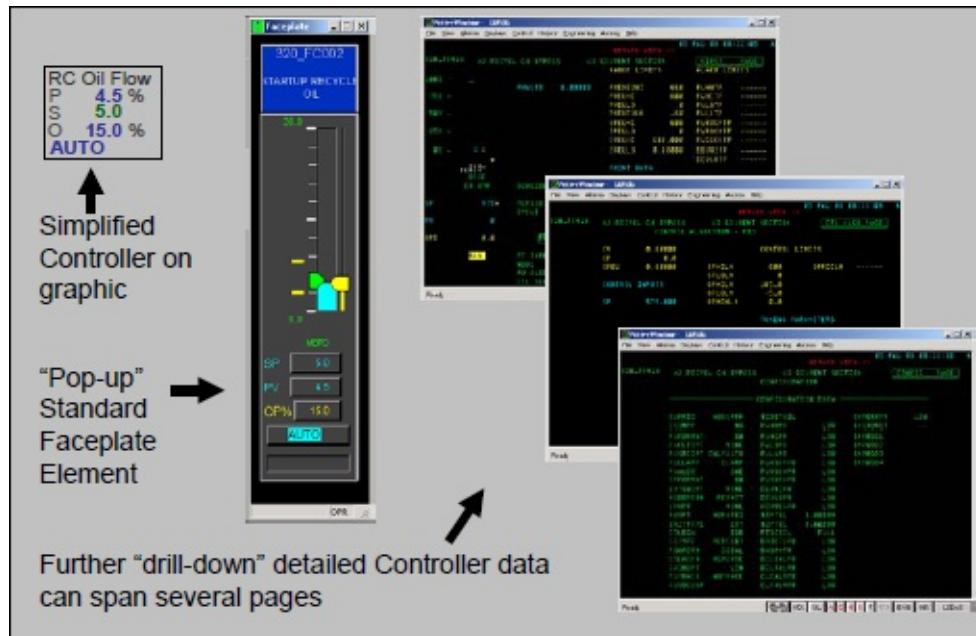


Figure 7-29: Progressive Exposure of Controller Detailed Functionality

7.25 Control Valves and Shutoff Valves

There is also much variety in the depiction of valves. Again, the tendency is to cram too much data into a small space. Avoid tiny scales to show output percentage, variable shading or color depending on valve condition, and other such efforts. Make consistent decisions as to what controller output is a “closed” vs. an “open” valve. One-click access to the controller or valve faceplate will reveal this type of information when needed by the operator.

In a few cases, a single controller affects multiple valves via split-range techniques. In such cases, numerically showing the open percentage next to each valve may be useful. This appears to contradict the principle that raw numbers should be avoided, but a percentage number is very easily and quickly interpreted, and other solutions to this issue are usually far too complex. Figure 7-31 illustrates this.

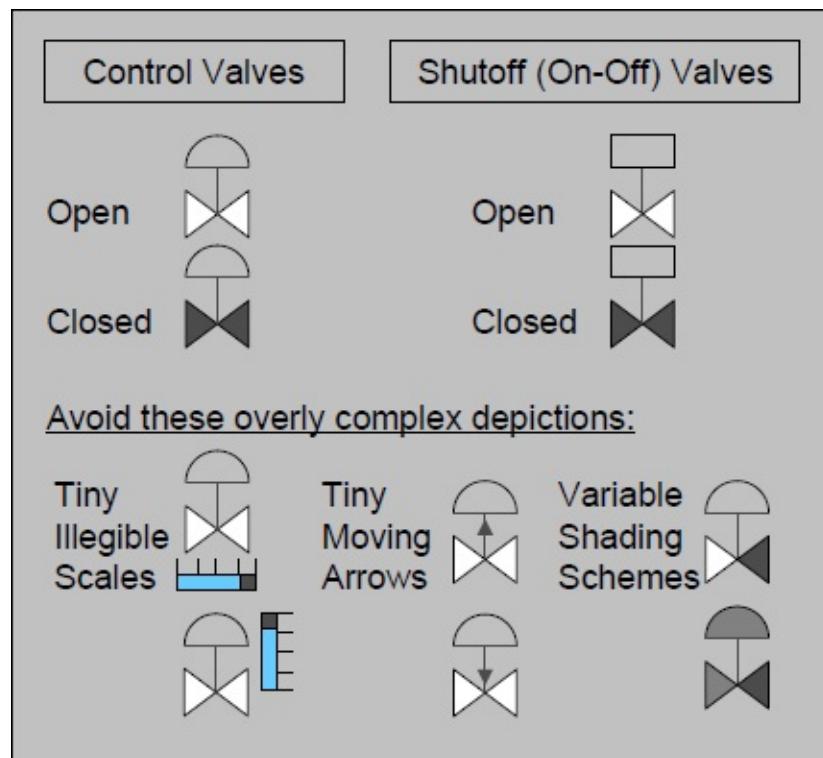


Figure 7-30: Simple Valve Depiction

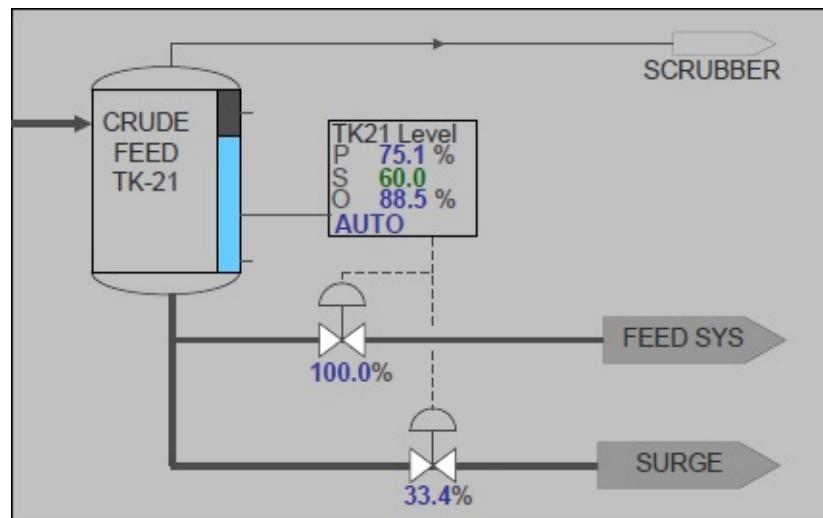


Figure 7-31: One Controller with Multiple Valves

7.26 Instrument Lines

The process connection to a controller should be shown as a one-pixel, solid, dark gray line. The connection from a controller to its final control element(s) should be a one pixel dashed dark gray line, when this is practical. Do not clutter

a display with instrument lines – an HMI is not a P&ID. It is useful to show the connection between controllers when a cascade loop is in effect.

7.27 Depicting Dynamic Equipment

It is important to properly show the current condition of equipment that can have multiple operational states. State depiction should not depend on color, but upon fill status, shape, or even simple text. The depiction must differentiate between equipment whose state is signaled to the DCS versus similar equipment not so equipped. The depiction of pumps is a common issue illustrating all of these factors.

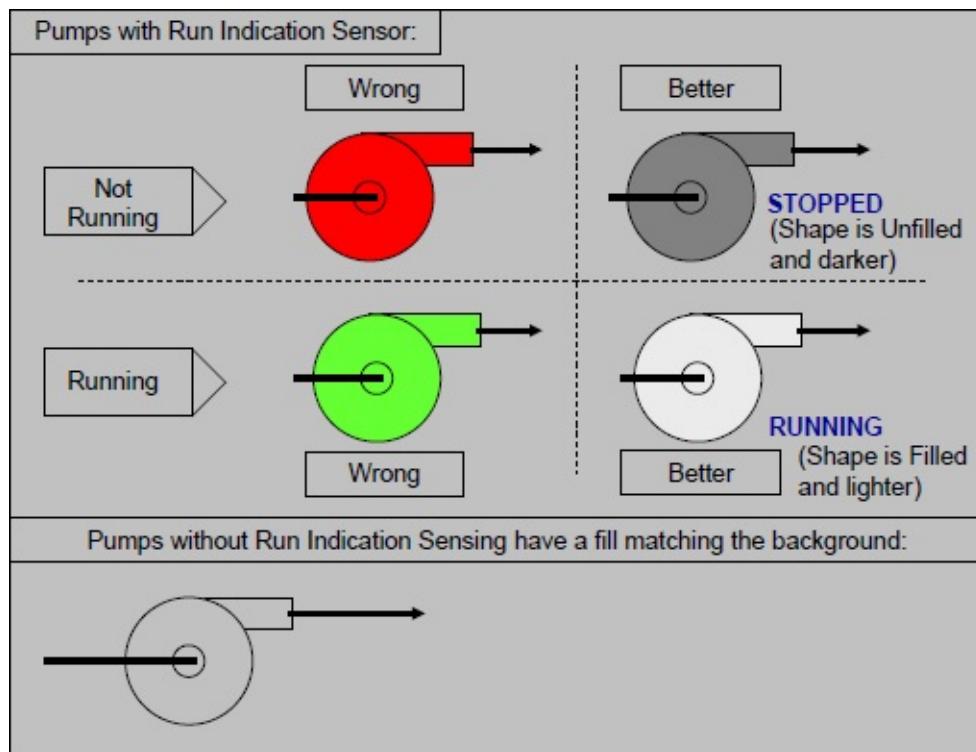


Figure 7-32: Pump Run Status Depiction

It is also possible to depict state with a simple text string next to the pump of “RUNNING” or “STOPPED”, as shown. The running pump should not be shown as “green” and the stopped pump should not be shown as “red.” Color is used to bring attention to abnormal situations. There is nothing inherently abnormal about a pump either running or not running.

Indeed, there should never be an alarm on a pump simply because it is not

running. There should possibly be an alarm if the pump is not running *when it is supposed to be running*. This is a logical alarm design differing from the usual, poorly implemented “Off-Normal” type of alarm.

Selecting the pump should bring up the command possibilities via the faceplate.

7.28 Depicting Equipment Commands

When DCS points are built that indicate equipment state, the control engineer can usually decide what words should be displayed to represent the current state. The choices they make are often poor. The most common example is “RUN” and “STOP.” Do these represent the equipment’s status or a command to it? “RUNNING” and “STOPPED” are much better status indication words. “STOP” and “START” are commands, not statuses. Similarly, the graphics need to clearly differentiate between status indications and command possibilities.

7.29 Display Layout

Displays need a consistent “look and feel.” Different DCSs have unique embedded structures and paradigms around the location and type of navigation abilities, faceplaces, “change zones,” programmable keys, etc. These features should be implemented in such a way as to comply with the principles of High Performance displays.

It is important to use these built-in abilities to their maximum potential. It is inadvisable to attempt to make a “Brand XYZ” DCS look like a “Brand ABC” – the results will usually be far from optimum. This is true even if you are migrating from one DCS type to another; learn the new paradigms embedded in the new DCS rather than trying to custom-build your old DCS structures on top of the new system.

Displays should be clean and uncluttered. Build and use standard display layout templates showing common items for each type and level of display.

7.30 Navigation

Multiple methods of navigation should be provided. The operator should be able to go up and down through the hierarchy, side to side through the process, and

call related details, trends, and shutdown status displays from any graphic. This navigation capability should work with all available methods provided for navigation by the DCS vendor – mouse or touch screen target selections, keyboard keystrokes, context sensitive menus, etc.

The system and graphics should be configured so it is never necessary for the operator to type in a point name or graphic name. The ability to get to any graphic without knowing the hierarchy should be available for maintenance and engineering users of the system; this may include an overall menu or direct entry of graphic names displayed/printed with the graphic.

Most DCSs have arrays of programmable keys, which can be assigned to call up certain displays or combinations of displays. Such key arrays should be arranged logically and match the hierarchy of the HMI. Preferably, all Level 2 displays should each have a dedicated key. The most commonly used Level 3 and 4 displays should get the remainder.

Create a standard naming convention for graphic files and embedded display files. Use clear, descriptive names identifying the process and hierarchy. However, it should never be necessary to type filenames to navigate. Show the graphic name on the display unobtrusively.

7.31 Yoking

Yoking is a display arrangement concept. The intent is to create an optimal arrangement of graphic displays on multiple physical screens for a particular situation. This arrangement is saved and made recallable with minimum keystrokes. It is of great use in dealing with time-sensitive abnormal situations.

7.32 Shutdown Actuation

Operators must generally be able to manually and quickly shut down operating equipment. However, when an important action with significant consequences is based upon operator input, the input should have a confirmation mechanism that avoids inadvertent activation. The “cancellation” option should be consistently implemented.

It should never be possible to make a single selection on a screen that results in

an inadvertent shutdown. A “Shutdown button” should call up at least one and perhaps two layers of confirmation before it is possible to actually cause such a significant event.

The “defaults” of such mechanisms should be on the safe option. Always consider what an inadvertent “ENTER” will do and label screen items with full clarity.

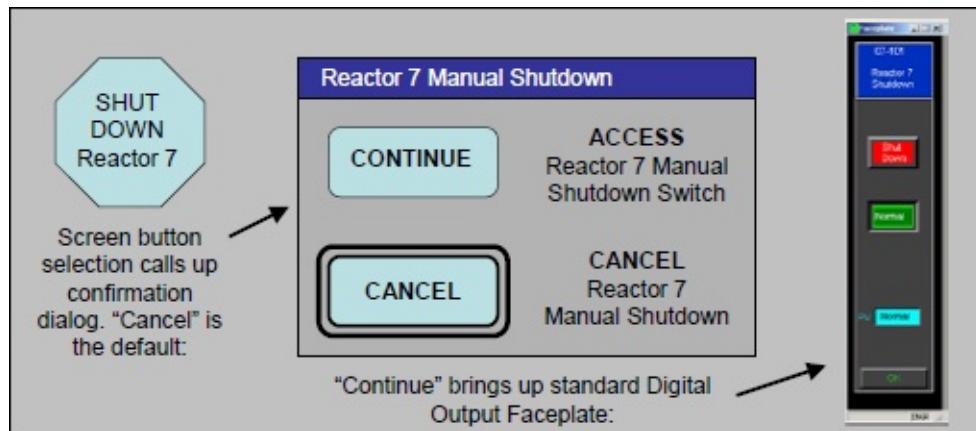


Figure 7-33: Layers of Confirmation

Major process upsets have occurred by mistyping an input (for example, opening a slide valve to 47% instead of 4.7%). DCSs using membrane keyboards are particularly susceptible to this type of error. Error checking methods should be used to require confirmation of numerical entries that seem inappropriate.

7.33 Call-Up Speed and Performance Expectations

Graphics used for operational purposes should display quite quickly when called up. Graphics taking longer than 3 to 5 seconds to appear become frustrating. However, since almost all high-performance graphics should have certain trend information, this may be a challenging goal, as trends often take a few seconds to populate. There are methods by which the simpler content can be displayed first and then the trends, which will somewhat alleviate the “blank screen” frustration.

Screen updating of depicted values should relate to the speed at which the process is capable of change. The need is to avoid excessively high update rates. These can be distracting and also generate unnecessarily high bandwidth

utilization on the DCS network.

An update rate of up to twice the rate of significant process change is the maximum recommended. For most typical industrial processes, an update rate of every 2 to 4 seconds works out fine, with one-second updates chosen for particular things by exception. Sub-second update rates are not very usable by the operator; a screen displaying jittery numbers is a distraction, not a help. This is particularly true if the changes are only in the fourth and fifth decimal places of the value, which is a separate issue previously addressed.

DCS Bandwidth, Loading, and Errors

Many DCSs are surprisingly low-bandwidth devices. This arises from the legacy nature of their network architectures and the need for backwards compatibility. Many engineers carry a cell phone having much higher bandwidth than their multi-million dollar DCS. The DCS designers have to allocate limited bandwidth to various system tasks.

Alarms are one of the high-priority users of bandwidth. DCSs are capable of generating and saving hundreds of thousands of alarm events per day. In some cases, we have seen bandwidth maxed out by alarms that have been suppressed and not shown to the operator, and thus not presenting a visible symptom of the problem.

A variety of problems can begin to appear when bandwidth utilization approaches the maximum capacity. Lower priority engineering-related tasks, such as program operation and compilation, data extraction, and calculations may begin to fail in unanticipated and unrepeatable ways. This can produce obscure and inconsistent errors and data gaps. If you are experiencing such problems, check your DCS bandwidth utilization.

7.34 Depicting Material Balance

There have been at least two major process accidents where large amounts of flammable materials flowed from the process into systems not designed to handle them. These large flows went undetected by the operators for many hours. A properly implemented mass balance or volumetric material balance calculation could have detected these situations and should be part of an

overview display and relevant Level 2 displays. Figure 7-34 shows two examples with explanatory labeling. These could be made more compact in actual practice.

The more compact example on the right incorporates a bar growing upwards or downwards from a center zero based upon the accumulated positive or negative difference. An alarm indication is shown based upon the calculated difference exceeding a value representative of equipment capacity. Number display could be toggled via another button.

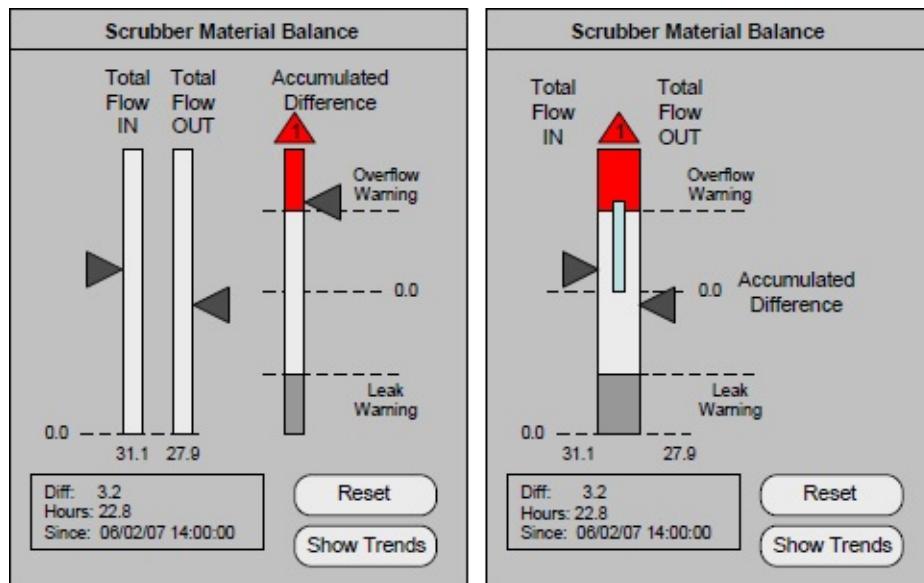


Figure 7-34: Mass Balance Indicators

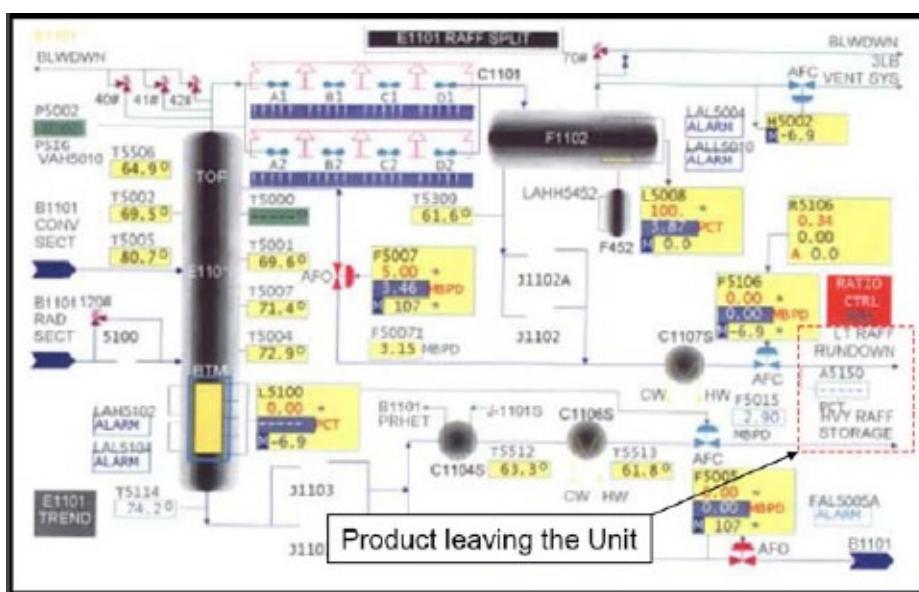


Figure 7-35: The ISOM unit graphic. This image is from the CSB's Final Report on the 2005 BP Texas City Explosion and Fire.

Figure 7-34 is the actual graphic used in control of the BP ISOM unit which exploded in 2005. The Chemical Safety and Hazard Investigation Board's report on this accident is recommended reading for everyone in the process industry. The CSB indicated a contributing factor to the accident was the graphic depicting the ISOM unit. The flow out of the splitter was shown, but the flow in was shown on another graphic. No balance computation or comparison was made. This graphic is unfortunately typical – being little more than a segment of a P&ID with “live values” sprinkled on it. There are no trends and no condition indicators. Tagnames clutter up the screen. Color is used inconsistently. There are several other poor practices. The graphic obviously did not provide good situation awareness to the operator.

It is generally much simpler to expend time and energy fighting problems caused by a faulty paradigm than it is to change the paradigm.

Joel Salatin

Disturbing Moments in Cinematic Human-Machine Interfacing:

Lt. Ripley to *Nostromo*'s command computer, “Mother”:

What is Special Order 937?

Mother:

Nostromo rerouted to new co-ordinates.

Investigate life form. Gather specimen.

Priority One: Insure return of organism for analysis.

All other considerations secondary.

Crew expendable.

Alien

Chapter Eight

Detailed Design of High Performance Displays

...

“If you put tomfoolery into a computer, nothing comes out of it but tomfoolery. But this tomfoolery, having passed through a very expensive machine, is somehow ennobled and no-one dares criticize it.”

- Pierre Galloisign

...

This chapter contains detailed design information for each level and type of a High Performance display.

Many example depictions are shown conceptually and schematically because there is such wide variation in the display capabilities, characteristics, and arrangement paradigms of specific DCSs. There are major differences between DCSs regarding such commonplace things as controller faceplate access and display. It is the concepts and principles that are important, which are then applied to your particular process and within your particular DCS capabilities.

8.1 Display Hierarchy

A concept of hierarchy (Levels) should be followed in constructing DCS displays. The primary purpose of these levels is to provide different amounts of operating detail to aid the operator in performing different tasks. A secondary purpose of these levels is to allow easier navigation. Four levels are optimum. They are:

- Level 1 – Process Area Overview Displays

- Level 2 – Process Unit Control Displays
- Level 3 – Process Unit Detail Displays
- Level 4 – Process Unit Support Displays

The four levels of displays represent increasing levels of complexity and/or detail – “zooming in” on the process. The hierarchy operates like a tree structure or computer folder structure wherein lower-level displays are associated with specific higher-level displays.

The majority of operator actions should be taken in Level 2 and Level 3 graphics, as shown in Figure 8-1.

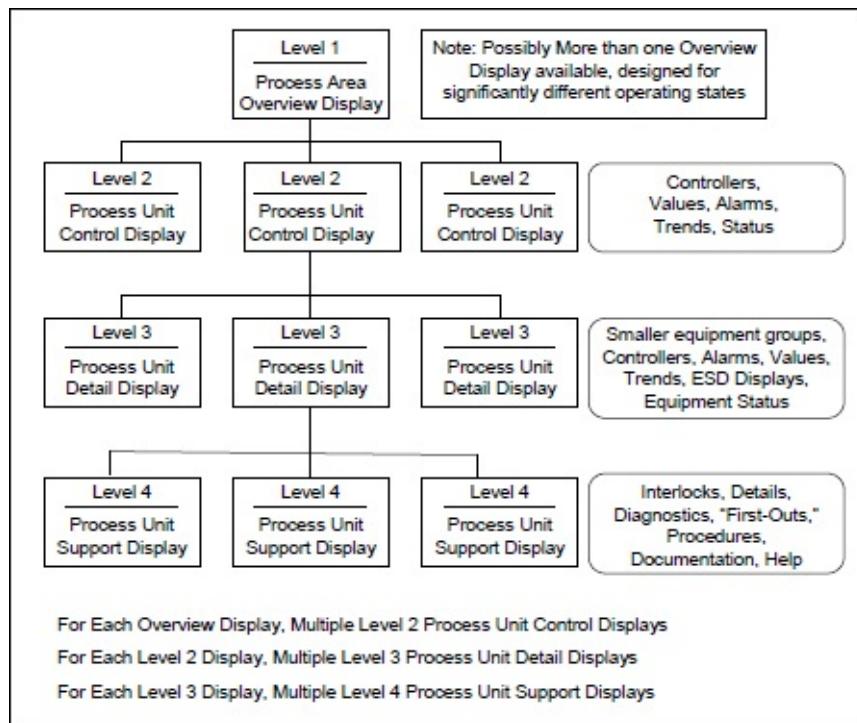


Figure 8-1: High Performance HMI Display Hierarchy

8.2 Designing Level 1 Process Overview Displays

Now, just because a console already has a giant display does not mean the display is being used effectively. In fact, many control rooms have installed large screens with little actual thought or consistency as to what to show on them. There has been little available in the way of guidance – a shortcoming we will rectify here.

The Overview display will show the broadest available view of the facilities under a single operator's control. It is a "big picture" at-a-glance view of the process unit. It provides clear indication of the current performance of the process by tracking the Key Performance Indications.

It should also be possible to call up the overview display on one of the console screens when there is a problem with the large display (or if one is not yet installed).

The Overview depicts elements and features, such as:

- High level Key Performance Indicators such as safety, environmental, production, efficiency, and quality
- Values, trends, and deviations of Key Performance Indicators
- Alarms of the top 2 of 3 highest priorities, including acknowledgement status
- Key process controllers
- Important calculated parameters and conditions, such as mass balance
- Important information from upstream and downstream units
- Advanced control mechanisms performance and status
- Major equipment status
- Appropriate trends of important process parameters
- Indications of abnormal situations, denoting severity

Consider an operator responsible for two reactors, two hydrogenation systems, and some support systems. Here is a conceptual arrangement of a High Performance Level 1 Overview Display for such a position.

Figure 8-3 shows how high performance graphic elements can be assembled into an overview display.

In Figure 8-3, the overview graphic does not embody the "process pictorial" paradigm. Instead, embedded trends, moving analog indicators and radar plots are incorporated. Radar indicators are so capable, versatile, and underused that Appendix 3 is devoted to them. Important KPIs are calculated and trended along the right, along with other system status information.

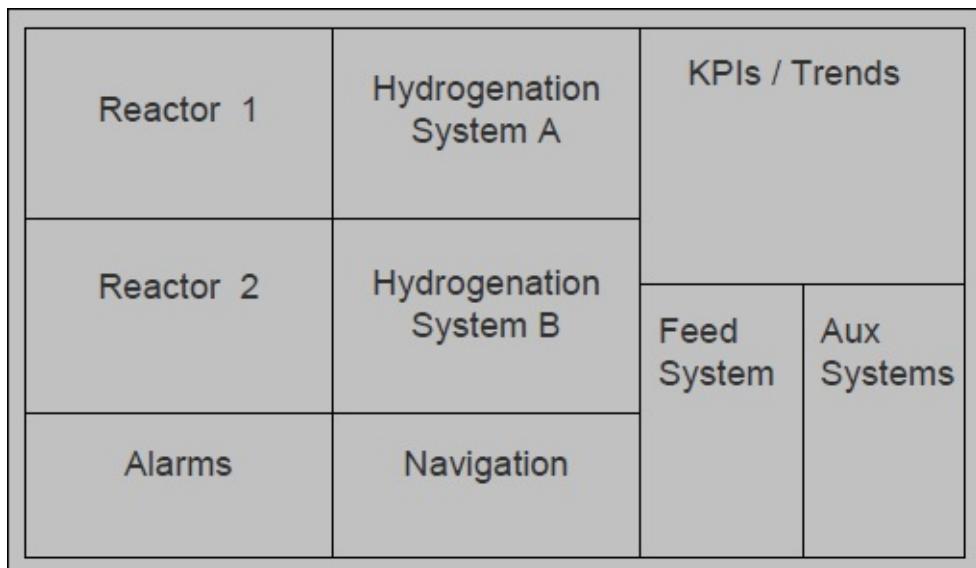


Figure 8-2: Logical Arrangement of a Process Overview Display

The overview display is often properly placed on a large screen off of the workstation or on a video wall depending on the display's audience. In many facilities, operating areas are closely coupled through feed and product streams, heat integration, and dependant utilities, so the overview of any given area may be useful to adjacent operators running other areas. The overviews are also useful for supervisors, engineers and managers.

Usually only one overview display is designed for a specific operating position. In some cases, the process makes different products, uses different feedstocks, or operates in significantly different states. In such cases, alternative overview displays can be created and used at the proper time.

The overview display should not be the first display designed. It is most practical to design Level 2 displays first and develop the Overview display afterwards.

More High Performance Display Examples at the PAS Website

This book has illustrative examples of the elements and types of high-performance displays. Many more such examples are available at the PAS website, www.pas.com. From the main page, select the **High Performance HMI** link to then access the images.

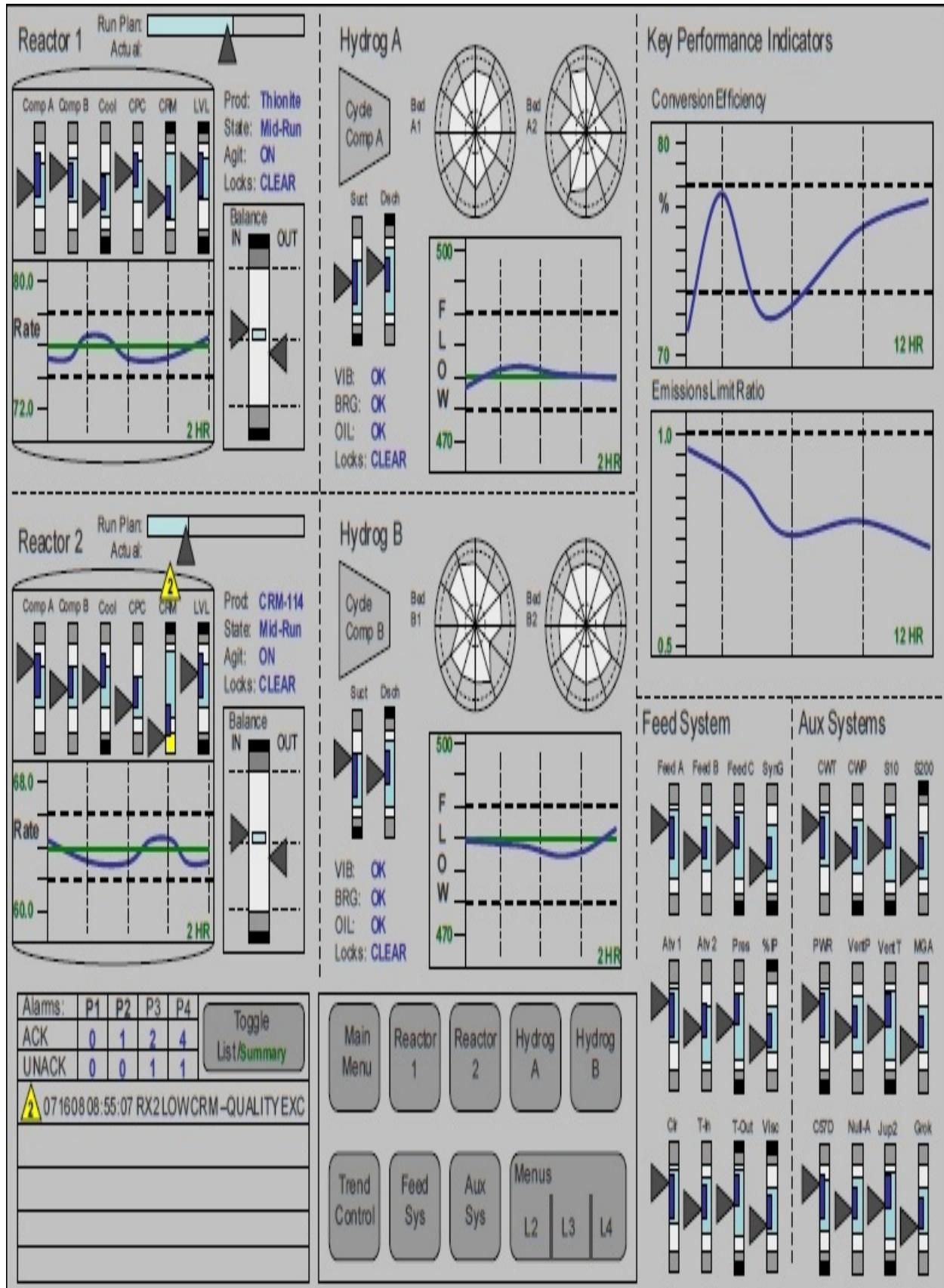


Figure 8-3: Example Contents of a Process Overview Display

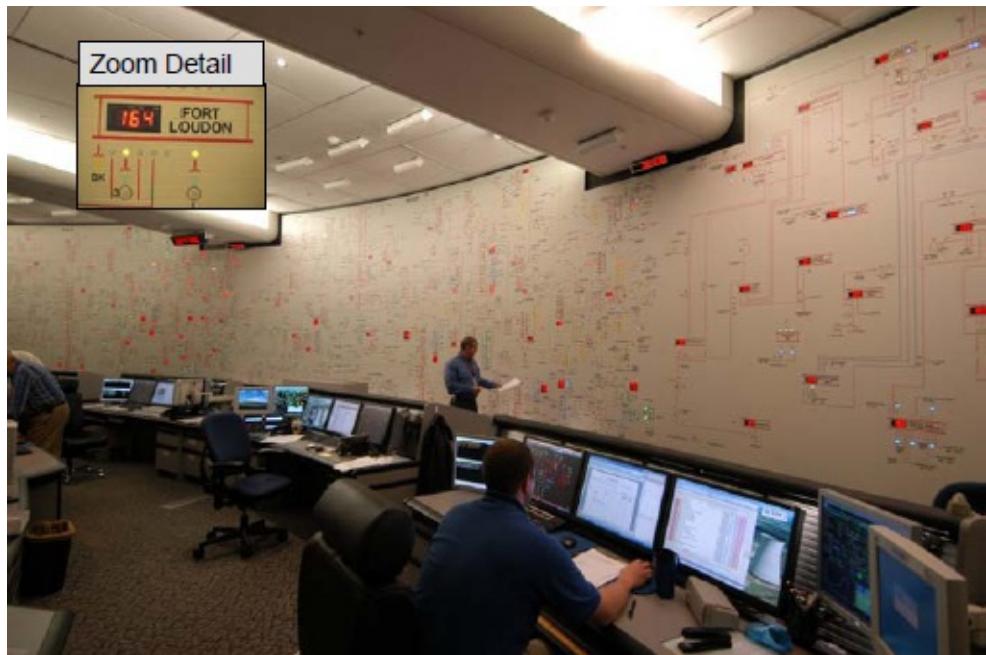


Figure 8-4: A Non-Projection Technology Overview Display

Figure 8-4 is a picture courtesy of the Tennessee Valley Authority System Operation Center in Chattanooga, Tennessee. This is an extremely large, complex example of a control wall and is a stunning feat of pre-computer projection technology. It continues to provide an overview of multiple power plants.

This control wall is 125 feet wide and 14 feet tall. It is comprised of 252,000 individual replaceable 1 inch x 1 inch elements mounted in a grid structure. If represented by a computer screen, the equivalent would be 24,000 pixels wide by 2,688 pixels tall. This is the equivalent of 82 projection screens at 1024x768 pixel resolution!

8.3 Designing Level 2 Process Control Displays

The Level 2 graphic should contain all the information and controls required to perform most operator tasks associated with a specific plant unit, from a single graphic. Both routine changes and some abnormal situation interventions should be possible.

In the design process, Level 2 displays should be created first. The development requires the contribution of process engineers, production engineers, and operators. A major intent of Level 2 development is to ascertain and verify the operator's mental model of the process.

- It is important to model the entire span of control responsibility for the operating position. Use a geographic plant plot plan and P&IDs to define the scope.
- While P&IDs are a tool in this process, the result should not look like a P&ID.
- The overall plant mental model is divided into logical standalone sections, usually along the lines of major subsystems, such as a reactor, furnace, or distillation column.
- Determine the various performance KPIs, controls, and control depictions to be placed on each Level 2 graphic. This will be further discussed in Chapter 9.

Figure 8-5 depicts these principles. All controllers and important indicators are shown on the various Level 2 displays. The displays are used for routine tasks such as manipulating controllers, operating pumps, starting blowers, opening valves, etc. All alarms of the top 2 of 3 priorities relevant to the depicted process are displayed. In some cases, it may be possible to depict all alarms. If not, the display should indicate there are Priority 3 alarms in effect and provide navigation access so they can be evaluated.

- For some controllers, the setpoint and process value are trended. Output can be added via a right-click action. Output is always scaled at 0% to 100% with a right-side axis.
- It is possible to rescale trends individually and to set different time spans for them either individually or altogether (via the “Trend Control” button at the bottom.)
- For two controllers (pressure and level), full-size embedded trends are not needed and sparklines are used.
- Analog indicators are used, as previously described, to give at-a-glance knowledge of any significant deviation from proper values.
- Access to important reactor safety controls (Shutdown, Freeze, and Isolate) are provided and given prominence.
- A material balance indicator is included.

- The reactor has redundant level indication showing two bars, indicating any deviation between their values.
- In this example depiction, only one alarm is in effect – a diagnostic problem with the spare pump. (This situation would be shown in detail on the Level 3 graphic.) Other alarms would be depicted similarly. The fact pump 2 is stopped does not generate an alarm because only one pump is specified as needing to be running.
- Navigation and other control feature buttons are shown along the bottom of the display. This tends to be a DCS-specific choice and can take the form of tabbed displays or other mechanisms or placements. The intent is to provide one-click navigation to the most likely displays the operator may need to consult from this display.
- Access to a Level 3 graphic is provided to show in detail the various interlock inputs, outputs, and diagnostics. However, the activation of any interlock causes elements to appear on the Level 2 graphic to depict the situation. For details, see section 8.5.
- Buttons are provided labeled “Startup Overlay” and “Sequence Overlay.” Some DCS graphics have mechanisms to swap out sections of the display with other purpose-designed sections. For example, different trends and progress indicators would be useful during startup compared to steady-state operation. If overlays are not supported or their implementation is too complex, different graphics can be provided for such situations.

As noted and shown before, Level 2 displays consisting of nothing but predefined, important trends, as well as access to the right controllers, can be highly effective for process control by experienced operators.

8.4 Startup, Shutdown, and Abnormal Situation Level 2 Displays

Multiple Type 2 displays may be needed to cover the same equipment. These would be purpose-built for specific situations such as startup, normal operation, state or product transitions, and shutdown. (In some DCSs, previously mentioned graphic “overlay” methodologies might be adaptable to this purpose.) The task analysis for the abnormal situations will likely require information on the screen not useful for the normal operations case and would only be distracting or cause visual clutter. In complex situations, checklists should be

displayed to help guide the operator through the proper response.

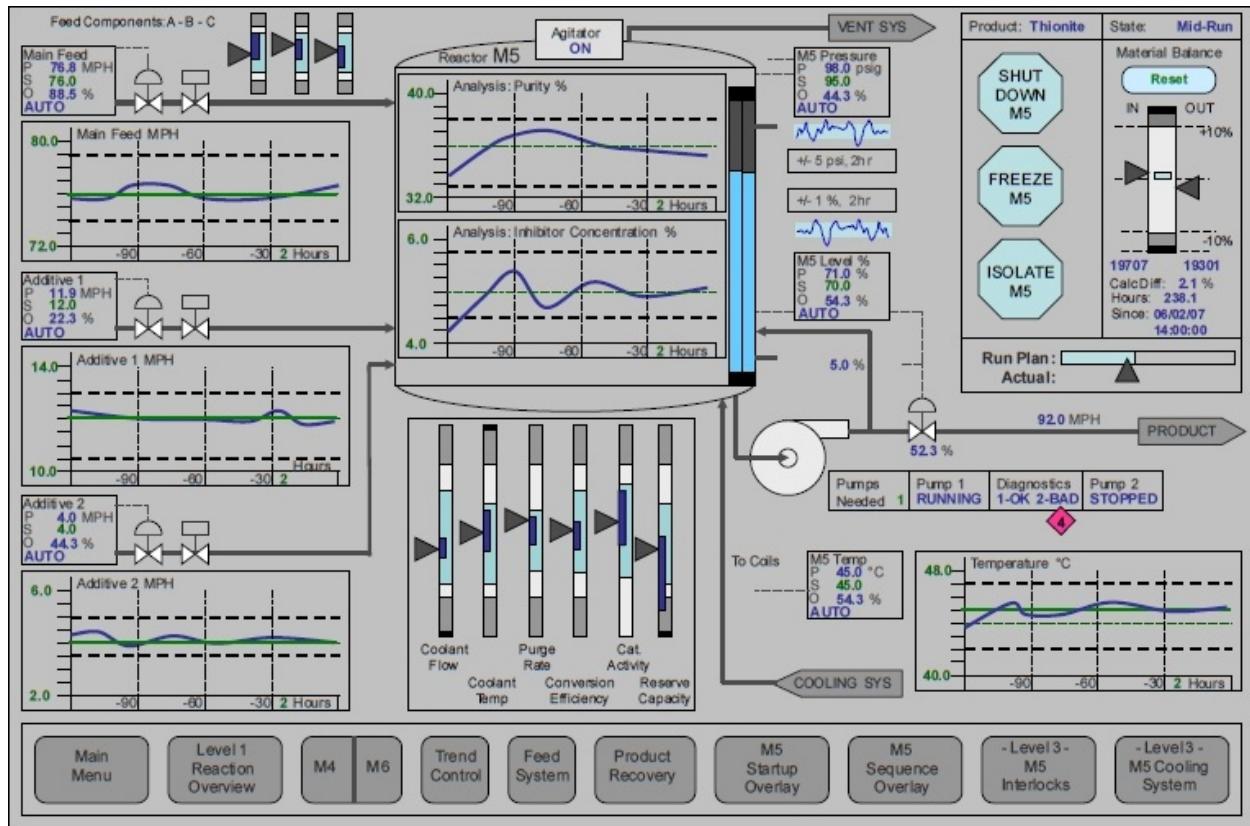


Figure 8-5: Example of a Level 2 Display

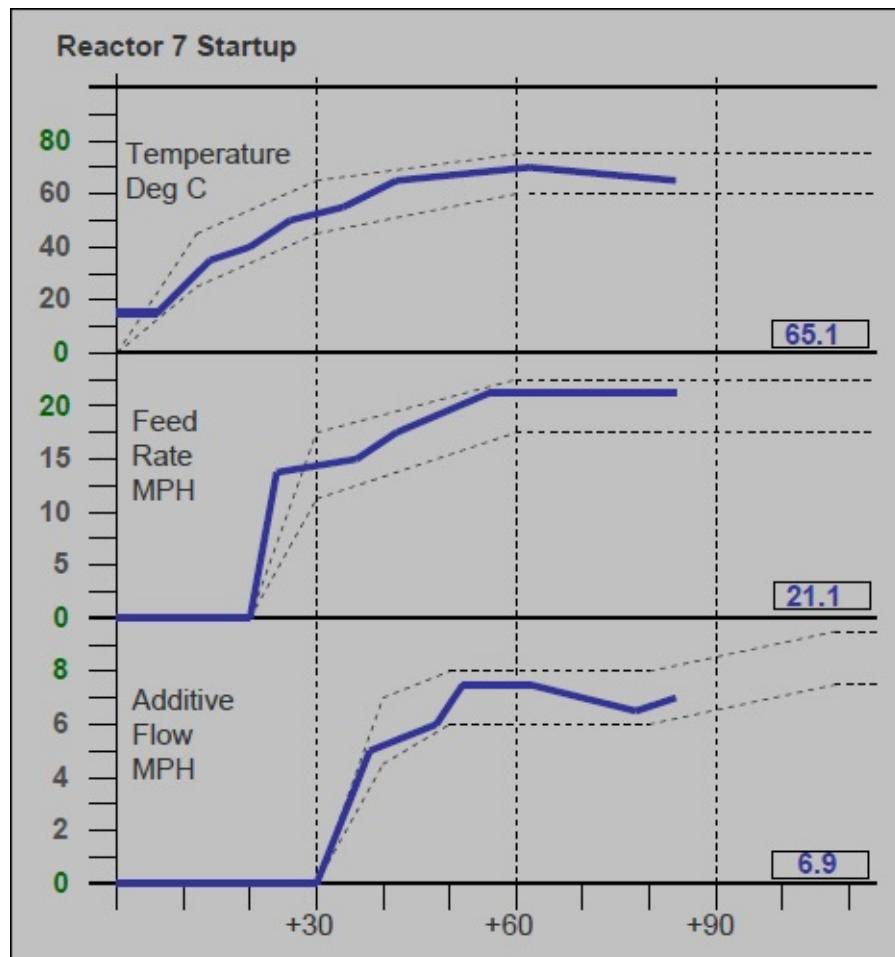


Figure 8-6: An Example of a High Performance Display Element Used for Startup

Consider the principle illustrated by Figure 8-6. The “roadmap” for a proper startup is clearly depicted and progress is visible. The structure gives the operator proper situation awareness and shows not only what has happened, but what is coming up next. A picture of a P&ID sprinkled with live values can do none of this, yet startup graphic elements like this are extremely rare. People may say, “But it costs money to design screens like this!” Yes, but we don’t save money by not painting lane divider lines in our roads. A single poorly-executed startup often costs more than proper HMI development. How many such startups have you had in the last decade?

These types of graphic elements are applicable to startups, shutdowns, grade transitions, product transitions, and similar mode changes. Automated Startup/Shutdown checklists and progress indications (such as in Figure 8-7) are also valuable aids to assist the operator in making the right adjustments at the

right time and keeping the process on track. Poor startups and shutdowns cost money and typically make large, avoidable quantities of off-spec material.

Reactor 7 Startup Sequence	Started	Completed	Step	Elapsed
<input checked="" type="checkbox"/> Step 1: <Description Here>	14:00	14:21	21	21
<input checked="" type="checkbox"/> Step 2: <Description Here>	14:23	14:37	14	37
<input checked="" type="checkbox"/> Step 3: <Description Here>	14:50	15:15	25	75
<input checked="" type="checkbox"/> Step 4: <Description Here>	15:20	15:48	28	108
<input type="checkbox"/> Step 5: <Description Here>	16:05	--:--	--	--
<input type="checkbox"/> Step 6: <Description Here>	--:--	--:--	--	--
<input type="checkbox"/> Step 7: <Description Here>	--:--	--:--	--	--
<input type="checkbox"/> Step 8: <Description Here>	--:--	--:--	--	--

Progress Plan:  Actual: 

Figure 8-7: Another Example Element of a High Performance Display Element Used for Startup

Comparative 30-Year Progress...

Starting a Jet Engine in the 1970s

It is the early 1970s and you are a commercial pilot starting the engine of a small business jet. The starting process requires you to use an auxiliary power unit to get the engine spinning, then the careful introduction and control of fuel rate, while simultaneously monitoring the engine speed and temperatures carefully. There are several ways in which the start process can go wrong and it is not uncommon to experience a “hot start.” In a “hot start”, inadequate engine intake air flow provides inadequate cooling and the turbine section rapidly overheats. The result? Shut everything down, call the aircraft owners, and tell them the engine must be removed, disassembled, inspected and (hopefully) repaired. Just the inspection task will cost over ten thousand dollars and jet engine parts for repair can be several times that.

Starting a Jet Engine in the 2000s

Turn the Engine switch to “Start.”

The Full Authority Digital Engine Control (FADEC) unit monitors and adjusts

all engine starting parameters 70 times a second to ensure a safe and uneventful engine start.

Compare to the process industry...

Starting an Ethylene Plant in the 1970s

<75+ page procedure omitted for brevity> From cold start to full-rate on-spec production can take several days.

Starting an Ethylene Plant in the 2000s

See “Starting an Ethylene Plant in the 1970s.”

That is, unless you work for the “EPX” Chemical company, who long ago automated the startup procedure and can be up and on-spec in a few hours.

Does your control system and HMI take advantage of automation technology that has been around for 20+ years? How much lost production and money has a “No” answer cost you?

8.5 Displaying Interlock Functionality on Level 2 and Level 3 Displays

Interlocks are functions whereby normal control actions are overridden by predetermined process conditions. An example would be to override a steam valve to the closed position if the equipment temperature or pressure is too high. There are several HMI-related issues to be addressed for interlocks and these must be handled regardless as to if the interlock is implemented in the DCS or in a separate Safety Instrumented System.

Interlocks are implemented using logic structures – usually “blocks” or “points” or “ladders.” These are usually complicated and cryptic to understand when displayed using the native capabilities of the DCS. They may activate infrequently since they are usually designed to protect against an abnormal situation. Due to this, the operator may not encounter them for months. When they activate, the operator may not remember being told about “the new column interlock” implemented a year ago and have no idea why he cannot start feed to the column. If this occurs at 2AM on a Saturday night, then the engineer is

(deservedly) likely to get a phone call and production may be delayed.

Therefore, every interlock, when activated, needs to indicate the activation on the appropriate Level 2 & 3 display. The strategy may be different for those displays.

For Level 2 displays, an interlock sequence depiction, such as the graphic “piece” shown below, works well if there is room on the display. If room is limited, a simplified depiction can be made with full information in the Level 3. In this example, high pressure on the vessel will first activate a Priority 2 alarm at 180 psi and will then activate an interlock at 200 psi. The interlock will close the Main Feed valves.

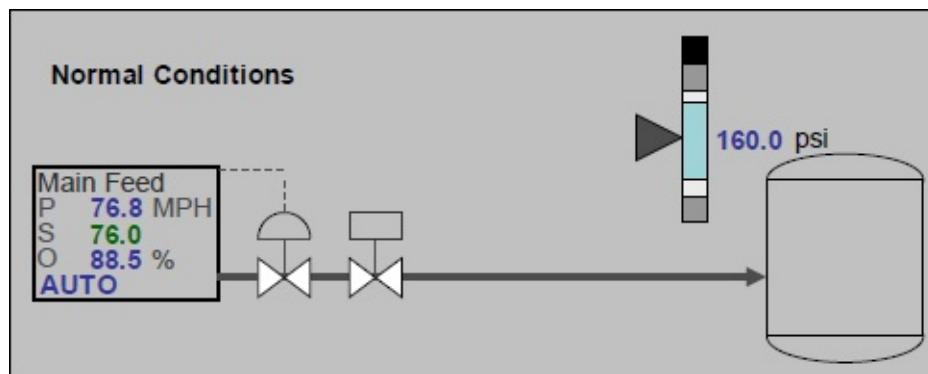


Figure 8-8: Interlock Depiction Part 1

Figure 8-8 shows the normal operating condition with no alarms and no interlock activation. The pressure signal is shown using an analog depiction. If a value is important enough to trigger an interlock, it should not be shown merely as a number. This analog depiction has the black section at the top, but not the bottom. This indicates an interlock will activate at high pressure but not also at low pressure.

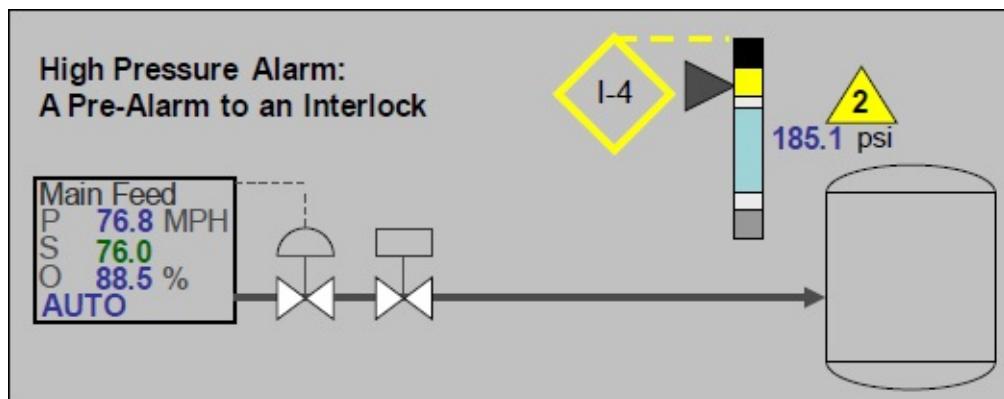


Figure 8-9: Interlock Depiction Part 2

Figure 8-9 shows the pressure has exceeded the high alarm limit and a priority 2 alarm has activated. Both valves remain open. Since this alarm is a precursor to an interlock, the interlock diamond (designated I-4) has appeared as well, but is not connected to anything. This is an optional depiction, but is useful since in many systems the interlocks activate only rarely. It draws the operator's attention to determine what could happen if the pressure is not reduced. Clearly in looking at this portion of the display, something unusual is going on. The operator can see the pressure must be reduced or an interlock action will occur.

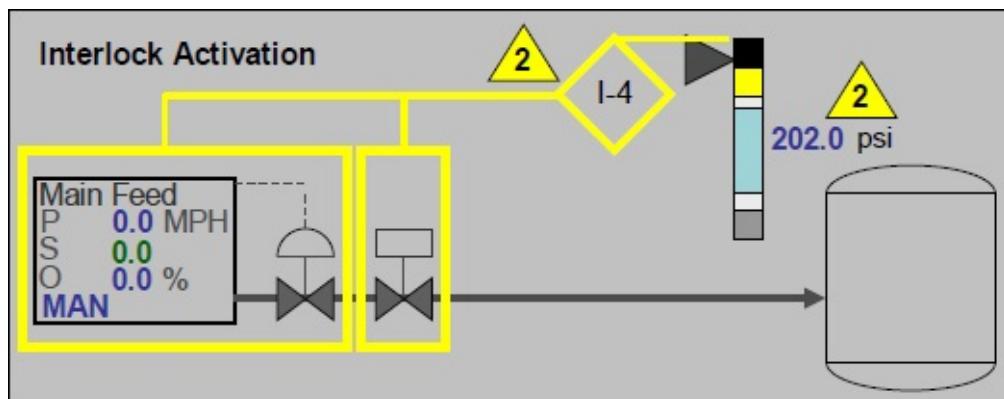


Figure 8-10: Interlock Depiction Part 3

Figure 8-10 shows that the high pressure was not resolved soon enough and rose into the interlock activation range. The following things happened and are shown:

- An additional priority 2 alarm came into being as the interlock activated. This is not a “high-high” alarm on the pressure signal; it is a “Trip Notification” alarm from the interlock function itself.

- The on-off valve closest to the vessel has closed as a result of the interlock. This state is shown and the color yellow matches the priority of the interlock alarm.
- The yellow interlock box includes the controller and control valve as well. In most cases, an interlock will not just shut a separate on-off valve but will override the separate control valve as well, generally via the solenoid on the valve. In the case above, the interlock not only does that but also commands the flow controller to go to manual with zero output. This is a “belt & suspenders and another belt” approach.

The display is thus indicating, at a glance, something is very wrong with the main feed and the pressure. A quick look at this display would draw your attention to the situation.

Interlock Alarm Priority

Proper alarm management might have chosen a different alarm priority for the interlock than for the pre-alarm. This is because alarm priority should relate to the avoidable consequences if the correct operator response is not made. For the pre-alarm, the avoidable consequences include the entire upset occurring from the interlock activation. For the interlock activation alarm, those consequences are no longer avoidable; the avoidable consequences at that point have only to do with the optimum management of the upset condition. The “Trip Notification” alarm may properly be a lower priority than the pre-trip alarm.

For Level 3 displays, an interlock diagnostic element must be created clearly showing the possible initiators and possible actions taken by the interlock. This does not have to be complicated; a table such as the following can often suffice.

Column 41 Feed & Steam Interlock			
Initiators		Action	
Pressure > 95 AND	X	Feed Valve Closed	
Temp < 80			
OR			
Temp > 225 OR		Steam Valve Closed	
Recycle Compressor OFF	X	Feed Valve Closed Steam Valve Closed	X

Figure 8-11: Interlock Diagnostic Table

The operator can easily understand the logic when depicted in this way, even with multiple cases of ANDs and ORs. It is clear why there is no feed flow and no steam flow, as well as what to do to restore them. Indeed, the table element, when looked at, acts to remind the operator of the other interlocks possible on the system. This diagnostic element can “pop up” on the Level 2 or 3 graphic or be combined with several other interlock elements on a Level 3 or 4 Detail or Diagnostic display.

In the case of an interlock which shuts down some equipment, a first-out indication is desirable since some of the other initiators may activate after the shutdown trip occurs. Here is a simple example of a Shutdown “First Out” Table:

Compressor 43 Shutdown Initiators		
Overspeed		OK
West VIB >25	X	1.5 First Out
West Bearing Temp >220		160.3
East VIB >25		1.3
East Bearing Temp >220		155.3
Suction Pressure <20	X	12.3
Discharge Temp >240		148.7
Oil Pressure <10	X	3.3

Figure 8-12: Shutdown Initiator Table with First Out

Shortly after the compressor shuts down due to high vibration, the oil pressure also drops, which produces another shutdown initiator. As a result of equipment isolation, the suction pressure may also drop sufficiently to activate another shutdown initiator. Thus by the time the diagnostic graphic is consulted, three separate shutdown causes are present and the question is – which is the original culprit? Two are a consequence of the immediately prior shutdown and the actual cause of the shutdown is shown via the “First Out.” The vibration reading depicted is “currently” much less than the shutdown limit (since it quits shaking after the shutdown), thus the high vibration indication (the “X”) needs to be latched until reset. Embedded trends of the vibration readings can show what actually happened. Alternately, the shutdown initiator reading can be “frozen” at the value at the time of the shutdown. The objective is to speed up the diagnosis of the problem and eventual restart.

This is a simple example, which could be implemented on existing graphics quickly and cheaply. Even better would be a Level 3 Display for the various diagnostics and shutdown initiators shown in at-a-glance analog fashion, such as prior Figure 7-7. This could even be included on the Level 2 Display of the compressor, if space is available.

Note to control engineers: In the creation of interlocks and shutdowns, it is often overlooked as to what the interlock will do if one of the initiating sensors malfunctions into a “Bad Measurement” state. It depends upon the DCS and how the specific interlock is built. The interlock table should show such conditions.

8.6 Designing Level 3 Process Detail Displays

Level 3 displays contain all control loops (controllers, indicators, alarms, status switches, etc.) They are also used for detailed investigations and interventions that are not time-critical.

Level 3 displays include the following:

- Detailed views of sub-units, individual equipment items, components, and their related controls and indications
- Custom pre-built trend displays for specific diagnostics
- Shutdown System diagnostic displays
- Interlock Diagnostics and similar troubleshooting displays

These detailed displays are mainly intended for troubleshooting or manipulating items not accessible from the Level 2 displays. All indicators, controllers, and alarms of all priority levels are shown on these screens. There may be several Level 3 displays for each Level 2.

For example, imagine an operator controls a reaction system, a recovery system, and a compression system. The compression system contains 3 compressors, which are on or off depending on a variety of factors. A “Compression System” Level 2 display should exist and show summary information and provide functional control of all three compressors. A Level 3 display for each compressor (Figure 8-13) then provides drill-down detail.

In some cases, the information is shown both in an analog manner (for fast comprehension and problem recognition) and on the process pictorial for more concentrated analysis and visualization.

8.7 Designing Level 4 Process Support and Diagnostic Displays

Level 4 displays provide the most detail of subsystems, individual sensors, or components. They show the most detailed possible diagnostic or miscellaneous information. The dividing line between Level 3 and Level 4 display can be somewhat gray.

Level 4 Support displays include the following:

- “Common Alarm” displays with details of individual sensor status
- Detailed information about equipment and instrumentation
- Detailed status of Advanced Process Control (APC) functionality
- System-supplied displays such as point detail, system diagnostics, alarm summary, *etc.*
- Help displays

Other displays at Level 4 not associated with the display of live process information can include the integration of:

- Operating procedures
- Alarm documentation and response guidance
- Abnormal situation response guidance

- APC documentation and operational procedures
- Other program-related documentation and operational procedures

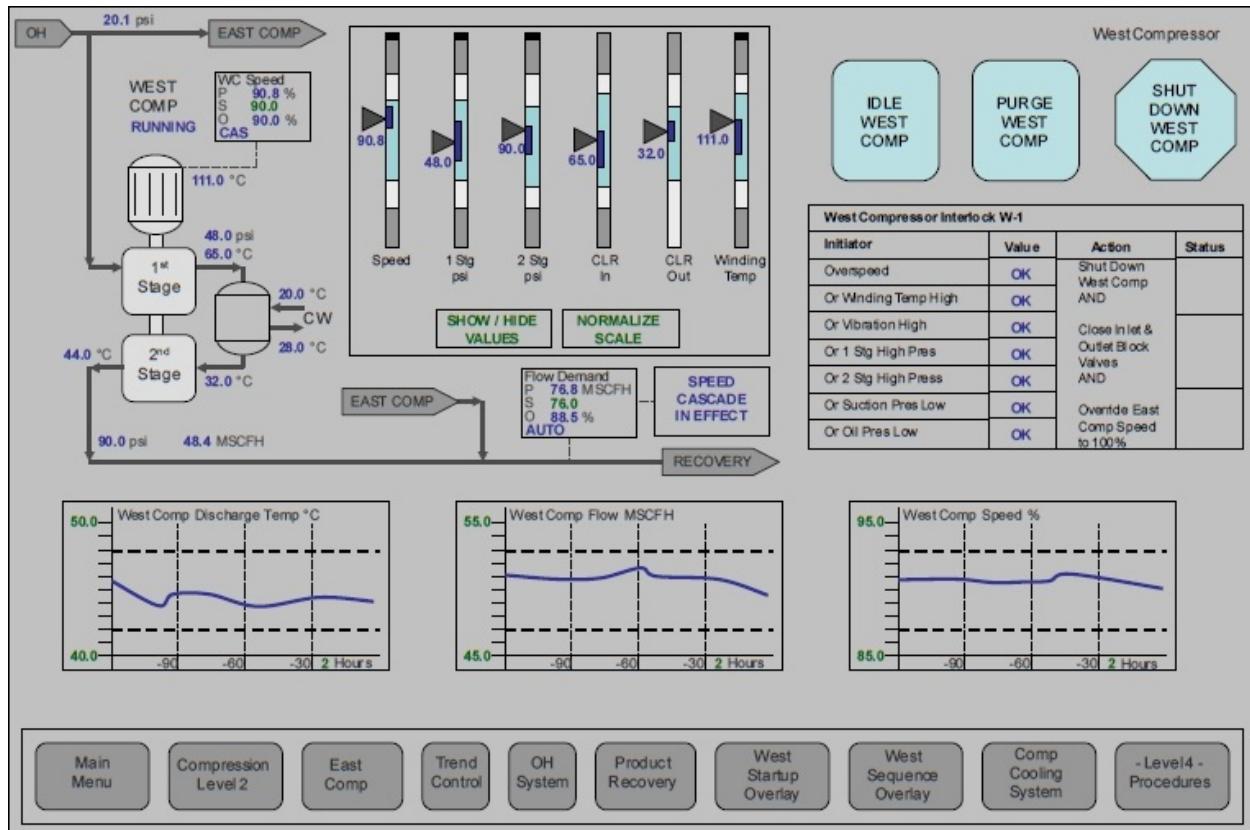


Figure 8-13: Schematic Example of a Level 3 Compressor Display

TI-468-02 Column Overhead Temperature		
Alarm: PVHI	Setting: 120 deg C	Priority: 3
Class: Minor Financial	Response Time: <15 min	
Alarm Consequences:	Alarm Causes:	Corrective Actions:
Off-spec Production	Excess steam	Adjust base steam rate
Lowered efficiency	Pressure excursion	Check pressure and feed parameters vs. <u>SOP 468-1</u>
	Insufficient reflux	Adjust reflux per computation; check controller for cascade mode
	Feed composition variance	Check feed composition

Figure 8-14: Example of Alarm Rationalization Information

Information about each alarm should be available to the operator. If possible, “popup” information via a right-click action inside the operator’s HMI is preferred. This is more effective than searching through documentation or searching a database separate from the operator’s HMI. Access to operating procedures via embedded links can be incorporated.

Disturbing Moments in Cinematic Human-Machine Interfacing:

U.S. Defense Supercomputer Colossus, referring to a communication link with a Soviet supercomputer counterpart:

“Restore communication immediately or action will be taken.”

Project Director Forbin:

“By order of the President of the United States, communication will not be restored.

Colossus:

“Missile launched. Impact in 607 seconds.”

Colossus: The Forbin Project

PART III:

Design and Implementation of a High Performance HMI

- Step 1:** Adopt a High Performance HMI Philosophy and Style Guide
- Step 2:** Assess and Benchmark existing graphics against the HMI Philosophy
- Step 3:** Determine specific Performance and Goal objectives for the control of the process, for all modes of operation
- Step 4:** Perform Task Analysis to determine the Control Manipulations needed to achieve the Performance and Goal objectives
- Step 5:** Design and build High Performance Graphics, using the design principles in the HMI Philosophy and elements from the Style Guide, to address the identified tasks
- Step 6:** Install, commission, and provide training on the new HMI
- Step 7:** Control, maintain, and periodically reassess the HMI performance

Chapter 9

The Design and Implementation of High Performance HMI Displays

Chapter 10

Physical Screens and Layout of an Operator Console

Chapter Nine

The Design and Implementation of High Performance HMI Displays

...

“Design can be art. Design can be aesthetics. Design is so simple, that's why it is so complicated.”

- Paul Rand

...

9.1 Overview

The following straightforward steps make up the design methodology for designing, implementing, and maintaining an effective High Performance HMI.

- Step 1: Adopt a High Performance HMI Philosophy and Style Guide
- Step 2: Assess and benchmark existing graphics against the HMI Philosophy
- Step 3: Determine specific performance and goal objectives for the control of the process, for all modes of operation
- Step 4: Perform Task Analysis to determine the Control Manipulations needed to achieve the Performance and Goal objectives
- Step 5: Design and build High Performance Graphics, using the design principles in the HMI Philosophy and elements from the Style Guide, to address the identified tasks
- Step 6: Install, commission, and provide training on the new HMI
- Step 7: Control, maintain, and periodically reassess the HMI performance

Prior chapters covered steps one and two. In this section, we concentrate on the remainder.

9.2 Step 3: Determine specific Performance and Goal objectives for the control of the process, for all modes of operation

Steps three and four are key steps with several important parts. High Performance displays require a thorough understanding of the process and the necessary operator actions in controlling it in various scenarios. The process engineer, control engineer, operations engineer, and operators should be involved in defining information to be used by the HMI designer.

Performance and goal objectives should be determined for factors such as:

- Safety
- Production Rate
- Efficiency
- Run length
- Equipment health
- Environmental (i.e. Emission control)
- Production Cost
- Quality
- Catalyst life
- Reliability

It is important to document these, along with their goals and targets. This is rarely done and is one reason for the poor state of most HMIs.

As an example, it is common for managers to be concerned with production efficiency and energy usage. This may be a frequent discussion topic at meetings with the operators. Yet, you can examine every graphic and not find a single depiction of an efficiency number or trend! How concerned is the operator supposed to be with something that is not depicted on the controls? How concerned are you with the temperature of your automobile wheel bearings?

Many of the performance goals will have different values depending upon the process mode. Most processes have different possible operating modes. Each of these must be defined. Examples of modes of operation include:

- Starting Up
- Normal Operation

- Partial Rate Operation
- Shutting Down
- Producing Alternative Products
- Utilizing Alternative Feedstocks
- Expected Abnormal Situations
- Operation after the Activation of a Safety Shutdown Systems

Example: Refining System Modes of Operation
Full Rates Product “A”
Full Rates Product “B”
End-of-Run Cleanup
Empty - Standby

Figure 9-1: Example Modes of Operation

For each of the identified modes of operation, determine the specific control performance goals in each category. For example, a certain important Quality Parameter “A” is to be maintained between values of X and Y. The method to achieve this control may involve the observation and/or manipulation of several different process variables, which must be identified and any associated performance goals for those variables determined.

Mode: Full Rates Product “A” – Example Performance & Goal Objectives
Overhead Purity >99.2%
Production rate 36,000 lb/hr average on a daily basis
Energy usage <42 MMBTU/Hr
Overhead Pressure between 220 psig and 230 psig
Vent to flare: zero flow
Recycle compressor vibration and bearing temperatures within limits
Overall column tray differential pressure < 62 in.H2O
Sidedraw purity > 88%

Figure 9-2: Example Performance and Goal Objectives for One Mode

These goals for each mode are documented for the overall process (the subject of the Overview Display) and for each subsystem the operator controls, which will generally constitute a Level 2 display each.

9.3 Step 4: Perform Task Analysis to Determine Control Manipulations Needed to Achieve the Performance and Goal Objectives

The creation of a High Performance HMI requires an understanding of the necessary tasks to accomplish the operating performance goals. This is called task analysis.

We can hear the loud groans from the practical-minded engineers now! You are thinking, *“Here is another consultant boondoggle. We’ll pay a lot of money to conduct interviews, procedure reviews, and make observations. Eventually we will get a report filled with the blindingly obvious, except it will be presented with a lot of buzzwords and unfamiliar terminology. There will be lots of confusing tables, charts, and graphs. One of the conclusions will be that more study is required.”*

In fact, several of the reference works we studied in writing this book gave us the exact same impression. However, we authors have considerable real-world experience and we know how to separate out the useful information from the generalities and buzzwords.

Task analysis is important – but it can be simple and straightforward. You do not need industrial psychologists or human factors “experts” to conduct it. It requires you to think through process scenarios and answer some straightforward questions.

From the Tables produced in step 3, with the identified goals and variables involved, determine the operator tasks necessary to accomplish effective control. Typical tasks include:

- Controller setpoint and mode manipulation
- Digital (on-off) point manipulation (pumps, fin-fan banks, compressor loading, valve switching, etc.)
- Activation and monitoring of advanced control schemes or programmatic controls
- Observation of lab results
- Direction of outside operators to perform non-automated tasks
- Interaction with daily production planning goals & changes

- Troubleshooting
- Abnormal Situation response

Control manipulation begins with Level 2 graphics. For each Level 2 subsystem and for each mode, list all of the control system elements that must be manipulated by the operator in order to perform the tasks. List the elements to be observed and trended to meet the performance & goal objectives.

Full Rates Product “A” – Necessary Level 2 Display Control Indications & Manipulations	Indicator Type (from Style Guide)	Range
Overhead Analyzer Product Purity	Main Display Trend #1	Desired purity range is 98% - 100%. Default time scale 2 hrs.
Production rate	Main Display Trend #1	Scale 30,000 to 40,000 lb/hr.
Calculated hourly energy usage in MMBTU/Hr.	Vertical Scale	Good: 40 to 42. Poor: 42 to 50.
Overhead Pressure	Vertical Scale	220 psig to 230 psig. Shutdown at 300.
Vent to flare	Vertical Scale	Zero flow is normal. Scale to 5,000 lb/hr with auto-rescale when exceeded
Recycle compressor vibration & bearing temperatures	Vertical scale multiple module	See equipment spec 15-A for limits.
Overall Column tray differential pressure	Main Display Trend #2	30 to 70 in.H2O, alarm above 62. Default time scale 2 hrs.
Sidedraw purity > 18%	Main Display Trend #2	10% to 25% range, bad below 18%. Time scale 2 hrs.
Column Pressure Controller PC2011-1	Standard Controller block	
Column Level Controller LC-2011-2	Standard Level depiction	
Reflux pump Start/Stop HS-2011-3	Standard Digital Controller	
Base pump Start/Stop HS-2011-4	Standard Digital Controller	
Recycle compressor function	Radar plot of multiple items	See separate list in the compressor specification
Sidedraw sep. level	Std. Level depiction	

Figure 9-3: Observation and Control Elements for a Level 2 Display

Figures 9-1, 9-2, and 9-3 were created to illustrate the principle of task analysis. In actual practice, tables of instrument listings would be used, with columns to indicate the named displays each instrument should appear on and their method for depiction. This should be a collaborative effort of the process engineer, control engineer, operations engineer, HMI designer, and experienced

operator(s).

9.4 Step 5: Design And Build High Performance Graphics, Using The Design Principles In The HMI Philosophy And Elements From The Style Guide, To Address The Identified Tasks

Ensure the graphics facilitate both the observation of the performance goal variables and provide access to all of the system manipulations associated with control of those variables. Perform proper grouping so control is not spread out across several graphics.

For example, if a certain important quality parameter is to be maintained between values of X and Y, then the graphics should show the parameter, a properly scaled and time-spanned trend of it, and the associated part of the process and manipulation controls used to affect the parameter. When graphics are produced based on P&IDs as the starting point, often the result will not provide the proper controls on the right graphic.

Participation in this step should include the same people as in the preceding steps, although the DCS HMI designer (in-house or outside services) will be doing most of the work at this point.

Perform testing of the prototype graphics, preferably using a process simulator if you have one. Allow more users than those assigned to the design effort to review and participate in the testing. A final testing check should be made to ensure the changes have not affected important functionality. Graphics can contain complex code interactions and modal operations; there have been cases where improper coding has made safety functions (such as shutdown actuation) unavailable when needed most.

Ideally, the tests should involve certain key simulated situations with the operators performing relevant tasks. This will uncover issues with the interface that might not be detected in a casual examination. The cohesiveness of the HMI as a whole should be assessed, and any necessary adjustments to the graphics are determined.

9.5 Step 6. Install, Commission, And Provide Training On The New Displays

Ensure the installed versions run correctly compared to the test environment. It is not uncommon for tags to be added or modified in a parallel project effort of DCS configuration, which can affect the graphics.

It is better to remove the old graphics from active use on the system than to allow them to remain on the system “in parallel.” Human inertia would significantly delay the new HMI’s adoption and thus, the benefits. The old graphics should be kept for backup purposes if some unusual situation is encountered.

Provide operator training in the following areas:

- DCS operating procedures (a refresher is usually a good idea)
- Aspects of the High Performance HMI Philosophy relevant to operations
- The reasons the HMI was changed and the expected benefits
- Features of the DCS and HMI alarm presentation, annunciation, and management
- Navigation in the High Performance HMI
- Use of trends
- The HMI navigation system and the progressive hierarchy
- Graphics for specific situations (such as rate changes, product changes, and shutdowns)
- Changes from the old graphics and proper use of the new graphics
- On-going HMI review, feedback, and continuous improvement

9.6 Step 7. Control, maintain, and periodically reassess the HMI performance

After several weeks of usage, survey the operators for necessary or beneficial changes. An improvement on this minimum requirement is an on-going system of operator feedback on graphic effectiveness. A logbook or e-mail “inbox” specifically for recommended graphic changes is recommended. Operators should be encouraged to print screen snapshots of the graphics and make notes on those for suggested improvements. This comment method should be retained

long-term.

At most companies, production upsets, incidents, and accidents receive an internal review. Part of the review of such events should be to assess the effectiveness of the HMI during the event.

Disturbing Moments in Cinematic Human-Machine Interfacing:

“Gort, Klaatu barada nikto”

HMI command string used to prevent annihilation of the Earth. (It is inadvisable to misspell or mispronounce.)

The Day the Earth Stood Still (the 1951 “good” version)

Chapter Ten

Physical Screens and Equipment Arrangement of an Operator Console

...

“The importance of information is directly proportional to its improbability.”

- Fundamental axiom of information theory

...

How many physical screens are needed? How should a console be arranged? The easy answer to these and similar questions is “It depends.” But we will not take that copout! There are several console arrangements supporting a High Performance HMI and we will depict some alternatives. We will also show some problematic arrangements, along with the reasons they are not optimum.

All of the necessary elements must be properly integrated and not just set on top of the console or scattered haphazardly.

10.1 Physical Screens

In the past, operators used to demand more and more screens, even though studies have proven they could not effectively use more than six screens during normal operation and three to four screens during a disturbance. The extra screens are usually found to be underutilized, often displaying redundant information or set and left on displays not relevant to the current state of the process. The extra displays are often requested as a result of the lack of a proper overview display and the lack of a hierarchical display strategy.

For single-operator control of most processes, four DCS screens plus an

overview display are desirable. If the process makes different products simultaneously, uses different feedstocks, or can operate in significantly different states, then five or six might be desirable.

10.2 General Purpose PC

The operator also needs a general purpose PC to handle email, the company intranet, the work request system, procedures, and other non-operating parts of their job. This PC must be properly integrated into the workspace rather than “tacked on.”

10.3 Communications Gear

The operator generally requires telephone, radio, public address (PA), and/or intercom access. The phones and radio gear chosen are often corded. It's funny that everyone uses cordless phones at home because of their convenience, but at work cords are everywhere - getting in the way, knocking things over, tangling, and generally being a nuisance.



Figure 10-1: What happens if you do not plan ahead

Instead of corded equipment, consider wireless earpieces (one ear only) and microphones for the operator. Their performance should be checked each shift and batteries regularly recharged or replaced.

10.4 Multiple Keyboards

It is common to have more than one operator sitting at a console, whether as part of training, or during particularly complicated startups or shutdowns. Multiple keyboards are needed to handle these situations. Just because you might be able to control several screens from a single keyboard does not mean it is a good idea.

10.5 External Video

In many cases, the operator must monitor external closed circuit TV (CCTV) screens. Typical applications are flares and remote equipment. Often these screens are added in the easiest (cheapest) way possible without much thought as to proper integration.

10.6 Hardwired Switches

For some critical installations, console mounted switches may be provided to allow the board operator immediate access or to meet a required degree of redundancy. These must be carefully designed to enhance the overall abnormal situation management by the board operator. In all cases, they must be placed in a logical spatial pattern, in a consistent manner, be well-labeled, and be integrated to allow a degree of history collection when actuated.

Hardwired switches are often used to enable operator activation at a moment's notice. Physical switches can be emulated via software constructs in the DCS (such as graphic button actions). Emergency and/or bypass switches placed via software in the DCS should utilize graphic techniques to ensure activation by an operator within a specified time frame as required by operational needs.

Implementation of switches in software is often preferable, being less expensive and making console layout much simpler. When this is done, it is important to use the proper graphic and programming techniques so the software switch will be easy to access and activate – and not be hidden by other windows or “buried” many screen-levels deep in a modal graphic mechanism. The implementation of software techniques for switches must take into account that there is generally an expected speed-of-actuation for such a switch.

10.7 Incorporation of Lightboxes

“There is an evil tendency underlying all our technology – the tendency to do what is reasonable even when it isn't any good.”

Robert Pirsig, Zen and the Art of Motorcycle Maintenance

Lightboxes turn out to be an emotional topic for engineers! They have their strong adherents and detractors for a variety of historical reasons.

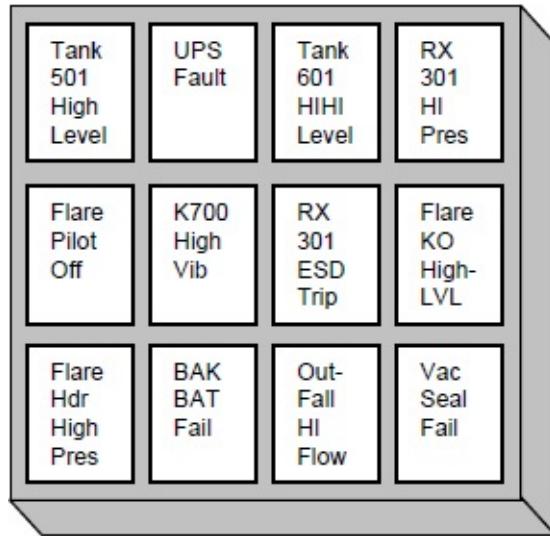


Figure 10-2: A Typical Lightbox

Compared to a *properly functioning DCS alarm system*, lightboxes are expensive to implement, maintain, and modify. They provide little guidance or assistance to the operator in handling the abnormal situation – far less than can be configured with a DCS display of the information.

Lightboxes have the benefit of constant visibility and for some, this allays a fear concerning “loss of view” of all information in the DCS. This is a false security. If your car engine has reliability problems, the answer is not to carry three spare tires.

From a High Performance HMI perspective, ask yourself which of these displays provides better information and guidance to the operator.

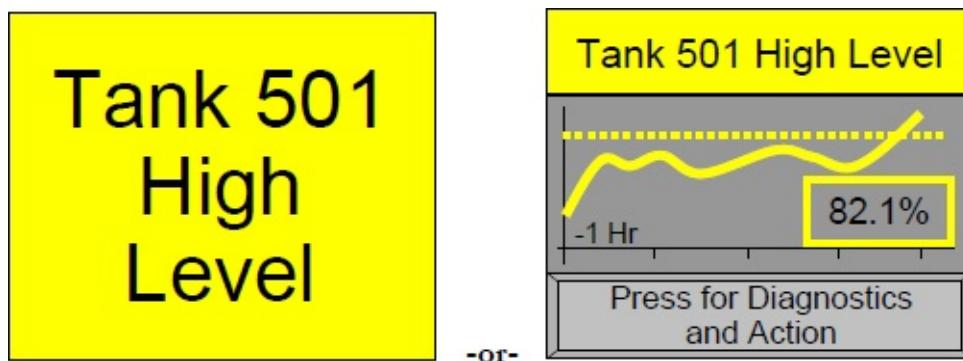


Figure 10-3: Alternative Presentations

For many reasons, fewer and fewer control room redesigns are including the lightbox. If you choose to have a lightbox, it should be implemented in accordance with certain criteria. A lightbox is limited to a very few alarms. Therefore, the criteria for placing an alarm on the lightbox must be consistent, specific, and highly selective.

An Old Friend

The light bulb was invented in 1879. At that time, among other uses, it was an innovative way to indicate a problem. Now, more than a century later, we can and should do better. Simply replicating a lightbox to a DCS graphic is not doing an adequate job.

For further information about lightboxes, see *The Alarm Management Handbook*, which contains an entire chapter on them.

Oddity: A Livermore, California fire house boasts of a light bulb that has been continuously burning for more than 100 years.

The authors have seen hundreds of lightboxes and have made it a point to examine them closely. When the alarms are listed, we generally find little rhyme or reason as to how those particular alarms were chosen to be placed on the lightbox. We find mixtures of all sorts of different alarms with little coherency and consistency. Usually there were no consistent and logical guidelines; the selection was just based on the opinion of a few people, sometimes as a project afterthought. Often, history and inertia determined the list. (If you have lightboxes, go and do these checks yourself.) The following are guidelines for effective lightbox implementation.

- Every alarm placed on the lightbox must at least meet the alarm rationalization criteria for the highest priority DCS alarm.
- Besides the rationalization test, there must be a specific reason and rationale by which the total group of resulting highest-priority alarms can be examined and a proper subset of them determined for elevation to the lightbox. In no way should every alarm coming out of a Process Hazard Analysis (PHA), Safety Interlock Level Analysis (SIL), or Layer of Protection Analysis (LOPA) be placed on a lightbox.
- The lightbox alarms should be well-labeled and placed in a consistent, logical spatial pattern. The positioning, color, and other characteristics of the external alarm should aid the operator in performing the appropriate mitigating actions to the event.
- Lightbox alarms should be integrated with the DCS to allow a degree of history collection when activated.
- It is a best practice for the operator to have a single interface to the alarm system and alarms should have to be acknowledged in only one place. Addition of a lightbox violates this principle. In that case, if a DCS alarm duplicates a lightbox alarm, then the DCS alarm should not be annunciated (and thus also require acknowledgement). However, the process graphic should show the alarm condition properly and the alarm event should be historized in the alarm journal without DCS annunciation.

10.8 Vertically Stacked Displays

Pictured here is a common DCS console arrangement that is space efficient yet problematic.



Figure 10-4: Stacked Displays, – a Non-Ergonomic Screen Arrangement

This arrangement is conducive to neck strain. It blocks any potential view of an off-screen overview display. It is not desirable for a High Performance HMI.

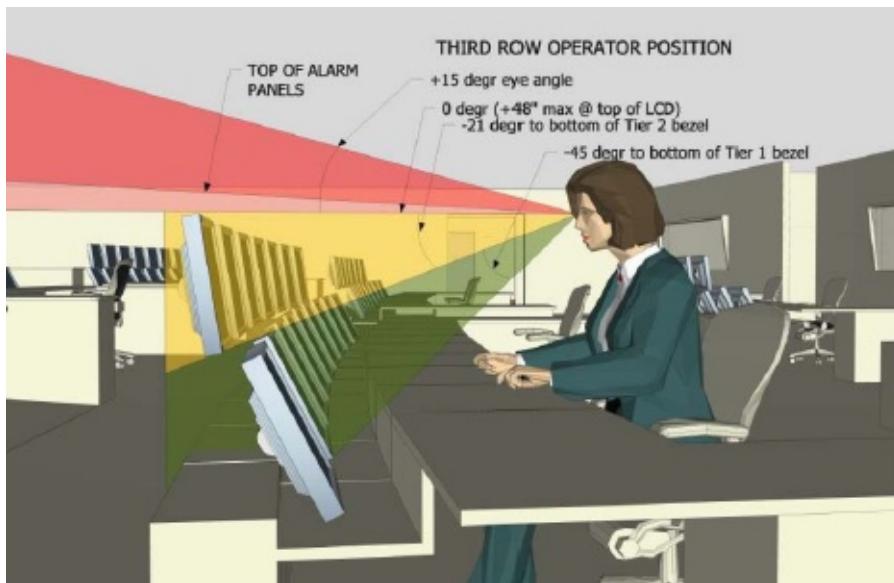


Figure 10-5: Vertically Staggered Displays – an Improvement

An improvement to this idea is to drop the bottom display down on a shelf as shown. Operators sitting or standing can still see the entire lower screen, and the upper screen is at a proper height. An off-console overview display can be implemented with this arrangement.

10.9 Alternative High Performance Console Layouts

Here are several console arrangements accommodating all of the elements needed for a high performance HMI.

- Large overview display
- Four to six DCS operating screens
- General purpose PC
- CCTV monitors
- Optional Lightbox alarms
- Optional console-mounted switches
- Communications gear

10.9.1 High Performance Console #1: 6 Total Screens in a Horizontal Arrangement

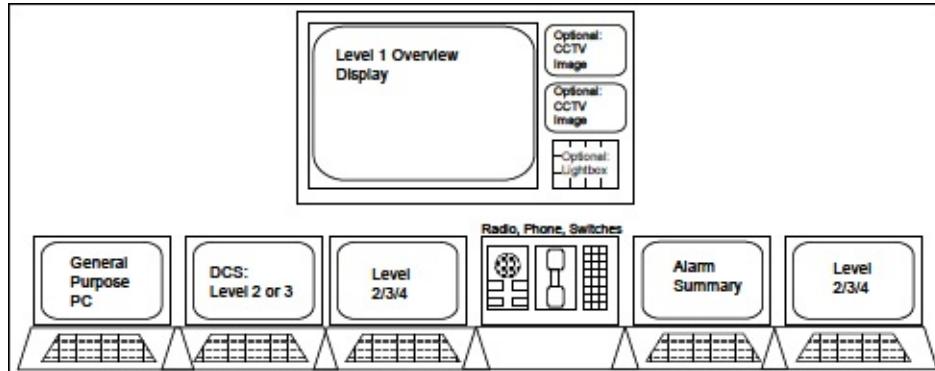


Figure 10-6: High Performance Horizontal 6 Screen Console Layout

Features:

- One large-format overview display, which is not mounted on the console, but several feet further from the operator
- Four physical DCS screens, arranged as shown, with four DCS keyboards (no sharing)
- One PC for general use such as e-mail and company intranet access
- Radio/telephone/ switches mounted for convenient access
- Preferred placement for optional closed-circuit TV(s) and “lightbox” alarm annunciator
- The horizontal layout minimizes the potential for neck strain
- Reading and writing space is in front of the communications gear
- There is room for another person at the console for training, startup, or other special circumstances

Disadvantages:

- Console width can pose a space problem in some rooms
- The wider format makes it more difficult to see information on all screens without moving the chair left and right. More screens than shown can make the problem worse.

The typical contents of the four operator display screens are shown, although the operator should be continually surveying the process, looking at the Level 2 and Level 3 screens based on what is happening on the Overview display.

A proper console design provides hardware redundancy. If a screen fails, others can be used to fill in until a repair is made. The use of a single CPU to drive all the displays of a single operating position provides poor redundancy.

10.9.2 High Performance Console #2: 6 Total Screens in a Semi-Horizontal Arrangement

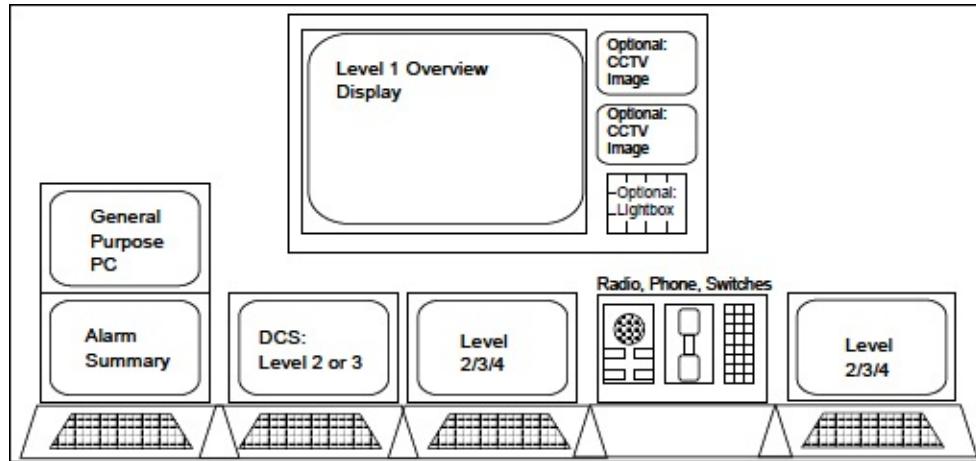


Figure 10-7: High Performance Semi-Horizontal 6 Screen Console Layout

This alternative arrangement has the same number of screens, but shrinks the console width. Whenever any of the screens are stacked, it is preferred to use the “dropped-shelf” arrangement shown in Figure 10-5.

10.9.3 High Performance Console #3: 6 Total Screens in a 2-Tier Arrangement

The primarily horizontal arrangements shown so far are preferred. If even less

space is available, this arrangement can be used, again including the dropped-shelf method.

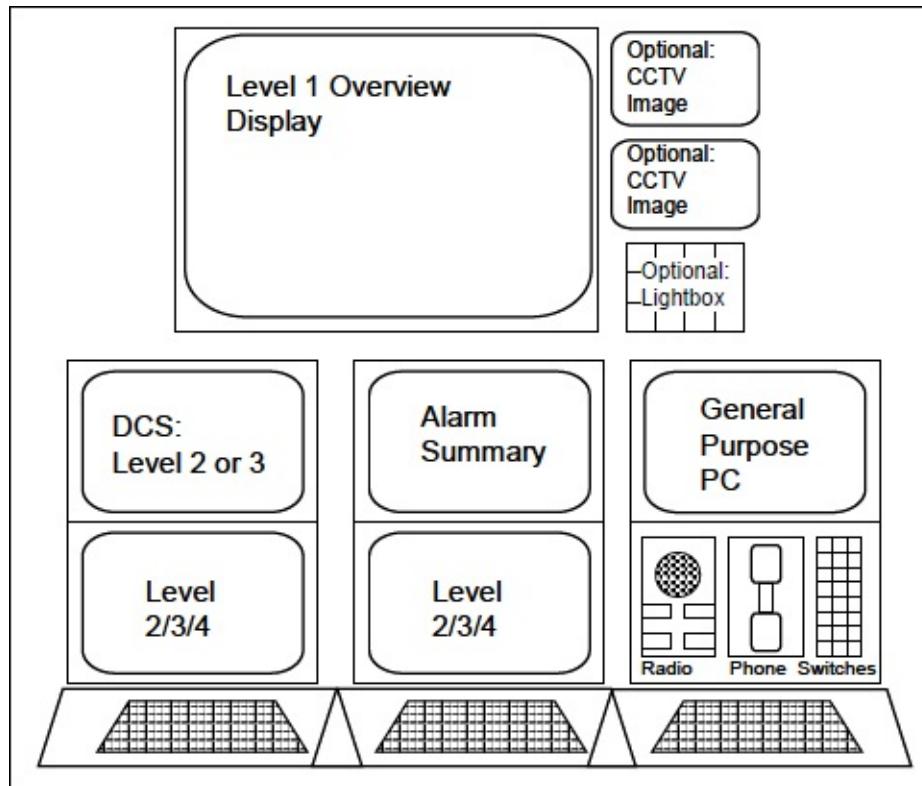


Figure 10-8: High Performance 2-tier 6 Screen Console Layout

10.9.4 High Performance Console #4: 8 Total Screens in a Vertically Staggered Arrangement

In special cases where the operator's span of control is exceptionally large, contains many small sub-systems, or involves manufacturing of many different products, an additional pair of operator screens may be desirable.

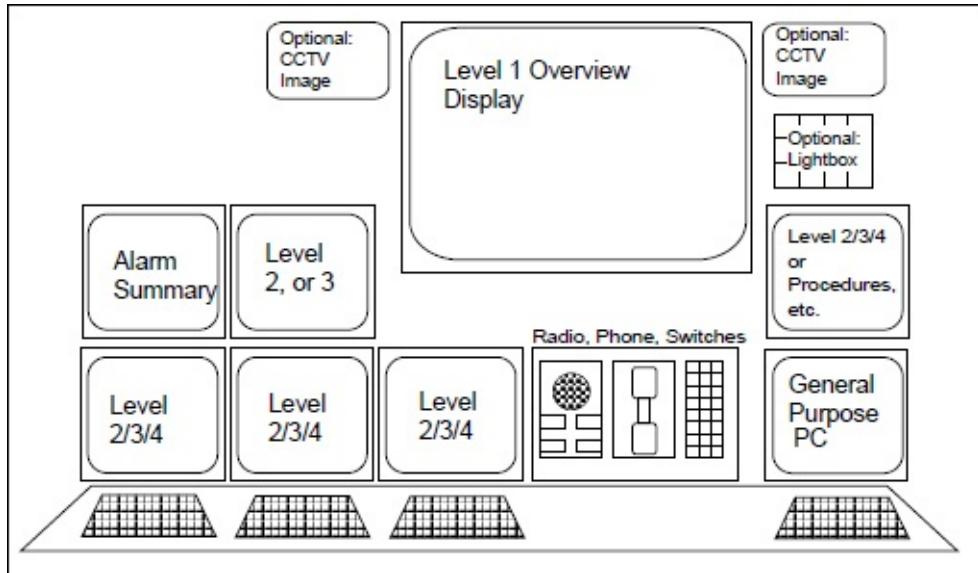


Figure 10-9: High Performance 2-tier 8 Screen Console Layout

The screen stacking placement makes it easier to see the off-console large display.

Disturbing Moments in Cinematic Human-Machine Interfacing:

Johnny (one of the last 8 people on Earth) to Robot Monster:

“I think you're just a big bully, picking on people smaller than you are!”

Robot Monster: “Now I will kill you.”

Robot Monster

PART IV:

**Control Rooms, Abnormal Situation Management,
and the Future of the Industrial HMI**

Chapter 11
Control Room Design, Layout, Operating, and Management Practices

Chapter 12
Situation Awareness and Abnormal Situation Response

Chapter 13
The Future of the Industrial HMI

Chapter Eleven

Control Room Design, Layout, Operating, and Management Practices

...

“If everything seems under control, you're just not going fast enough.”

- Mario Andretti (1940 -)

...

11.1 Overview

The goal in designing a control room is to create a work environment promoting high levels of vigilance and situation awareness. Operators are vigilant when they are alert and prepared to act.

Many plants have not made conscious decisions about their control room's design and function. Over the years, the rooms changed based on incremental projects, modifications, staffing changes, and other transient conditions of the times; they “just grew” without any consistent guiding philosophy or thought.

Over the past few decades, control room operating practices have changed as well. They have been impacted by technology change, regulations, changing workforce requirements, worldwide business competition, union agreements, past leadership decisions, downsizing, and the demographics of the workforce.

Many companies have addressed these issues with investment in new technology, changes in management systems, workforce training, and new organizational structures. Union agreements have been modified to seek workforce flexibility, team approaches, and alteration of roles and responsibilities. The construction or refurbishment of control rooms is often

mixed in with these kinds of changes.

Some companies have experienced failures during these efforts. They have experienced an increase in incidents and accidents, falling morale, and difficulties in recruiting certain positions, such as a dedicated console operator in a large centralized control building.

Poor working environments have been associated with control room design. This often results from taking an existing 1950s control room (designed for long panel displays) and modifying for DCS control – usually as cheaply as possible. These buildings are characterized by cramped conditions, noise, and inadequate lighting.

Alternatively, some companies moved the new DCS consoles to other buildings entirely. New buildings were created to centralize the control operation and combine console operators from other units of the plant. These buildings were often characterized by being large and impersonal, again with poor lighting, poor heating and ventilation systems, poor acoustic qualities, and poor people movement patterns.

Several accidents in the process industries have been attributed to human error. When we look at human reliability we discover that, even on a good day, the working environment imposes stress on the operator. We discover that headaches, eye strain, and sleep-related problems are commonplace due to inadequate lighting, poor air conditioning and bad air quality, poorly maintained buildings, and constant noise from loud panel alarms and radio communications. These conditions are made worse by poor console arrangement, lack of separation between units, and poor communication systems. We also discover also that operators are equipped with broken or patched chairs that were never designed for 24-hour operations.

11.2 Early Control Rooms

What do control room design, layout, operating and management practices have to do with a High Performance HMI? In the past, absolutely nothing. Control room designers have often shown little consideration for the delivery of information to the operator, as intended by the HMI designer. Likewise, the HMI designer often did not consider the control room environment.

The introduction of DCS screens into the control room, and the general operating practices of the control room, have been accompanied by poor human factors, including the following:

- Poor lighting
- Excessive glare on display screens
- Displays with text too small to read
- Incorrect screen height and angle
- Poor visibility of various components the operator needs to access
- Poor keyboard locations
- Poorly integrated communications equipment
- Lack of an overview display
- An excessive quantity of screens, spread over so much space they could not be effectively used
- Poor people flow through the building (traffic)
- Engineers and managers congregating and conversing in the control room
- Undisciplined telephone traffic
- Maintenance people wanting permits, advice, or just using the control room as a meeting or break room (distractions)
- PA and radio systems filling the control room with conversations
- Operating components improperly located inside the control room
- Maintenance activities in the control room, such as trip and alarm testing
- Inadequate bathroom facilities
- High noise levels (equipment, doors, people, music)
- Dirt and thick layers of dust, from poor door design and location
- Inadequate kitchen and eating areas
- Sharing of space with small laboratories (with hazardous materials) and equipment storage facilities
- Poor HVAC and ventilation

Control rooms which were somewhat appropriate for older “control wall” implementations were not adapted for the very different needs of the DCS hardware and operator. The control wall was usually designed, organized, and optimized to provide information to the operator without the need to be running up and down the panel. These principles often did not carry over into DCS console layout and HMI design.

11.3 The Introduction of Human Factors Design

The common issue in all of these problems was a lack of consideration of good human factors and ergonomic design. Standards-setting organizations began to address the issue. The International Standards Organization (ISO) responded by producing an Ergonomic Design Standard ISO 11064, which addressed all of these issues. To date, this standard has had little impact in the processing industries. In European countries the regulators have been more forceful than in the USA and many have issued guideline documents supporting the standard.

The offshore industry in Europe has provided excellent support documents and checklists to ensure good human factors practices. An example is the *2003 Human Factors Assessment Methodology* produced by Human Factors Solutions for the Norwegian Petroleum Directorate. These checklists can be used to determine if a control room design meets the standard and can be used as a Validation and Verification section for a control room project.

Supporting this, a highly regarded Norwegian research organization called SINTEF conducted research work into Crisis Intervention and Response (CRIOP). The research was intended to verify if a design meets all needed operating states (especially abnormal situations), and through the use of scenarios, the designers could validate the design's suitability.

There is a thread which should dictate the progression of a proper control room design. In an ideal case, ergonomic design should follow these steps:

1. The jobs to be performed should be determined.
2. The nature of the jobs determines the tasks to be accomplished.
3. The tasks dictate the information requirements.
4. The information requirements determine the HMI design.
5. The HMI design then directly influences the number of screens per console.
6. The number of operating positions (consoles) depends on the work to be performed, the capabilities of the HMI, and workload analysis.
7. The consoles, console adjacencies, and placement partially dictate the control room layout.
8. The designer can then consider the needs of secondary users of the building, support facilities, etc. and determine the complete control room design.

This is a very logical approach, although it does have several practical difficulties relating to construction scheduling, process design, and the knowledge available at various stages of a project.

It is also an approach with components more easily considered during initial construction rather than a retrofit or when trying to improve an existing situation within practical constraints and costs. We recognize it may not be practical to alter an existing control room in accordance with all of the practices of this chapter, but significant improvement is usually possible. The goal is to determine what works well, what causes stress, what hinders communications and collaboration, and what makes the operator's job more difficult – then solve those problems.

There are around 100 important elements which can positively affect the control room, the control room personnel, and the adjacent support areas. Application of these elements will:

- Impact the console operator's situation awareness in a positive way
- Reduce stress
- Improve alertness
- Facilitate good communications and collaboration
- Manage people flow through the building
- Reduce distracting traffic and disturbance from external sources

All these elements can be found in the seven-part ISO 11064 standard and can provide benefits for normal operations, critical situations, and emergency planning and response. The standard is an ergonomic design methodology based on user participation in the design. It provides guidance for good ergonomics and will ensure basic human factors are addressed. The most significant issues found in ISO 11064 are addressed in this chapter, but the full standard is a highly recommended addition to a company's technical library.

“When a man says he approves of something in principle, it means he hasn't the slightest intention of putting it into practice.”

Otto von Bismarck (1815 – 1898)

11.4 Design of New Control Rooms

The following are considerations for developing a Conceptual Design Specification for a new control room. As details are known, basic layouts can be developed. As room sizes become known, sketches can be drawn to show potential layouts. These will be refined based on the information from the checklists. The designs should be reviewed with the primary and secondary users of the building.

Control Room Design Factors	
Building location	Vendor or contractor access
Vehicle parking	Control room access
Cable entry	Security requirements
Pressurization of the building	Ventilation of the building
Internal & external windows	Perimeter fences and physical barriers
Alarm Philosophy	HMI Philosophy, Strategy, & Style Guide
Number of operating positions	Console layout and quantity
Use of off-console workstations	Use of video walls
Console – placed manual controls	Other manual controls
Server room requirements	Fire protection policy
Supervision requirements	Training & Simulation Requirements
Fire & gas detection	Emergency air policy
Power integrity/redundancy	Grounding strategy
Clean power policy	UPS size and configuration
Other users (control engineers, DCS technicians, supervision, etc.)	Telephone & video recorder room requirements
Location of Emergency Operations Center & links	Fatigue counter-measures (exercise room, etc.)
Operations strategies & manning levels for each operating state	Style of control room theater or functional design
Console furniture information	Storage requirements
Number of keyboards and location	Requirements for communications (radio, phone, beeper, PA, etc.)
Electrical loading	Surge protection requirements
Location of false floors	Weight loading of equipment
Other equipment (aerials, masts, UPS, PCs, tables, printers, etc.)	Other adjacent rooms (adjacency matrix)
Console adjacency matrix	Remote/local mounting of computers

Figure 11-1: Control Room Design Factors

As details are added, human factors can be reviewed to ensure layouts meet the ISO 11064 standards regarding console heights, viewing angles, screen sizes, and sight lines. The design should address potential acoustic issues, lighting, traffic flow patterns, and space planning for correct console distances from doors and between consoles.

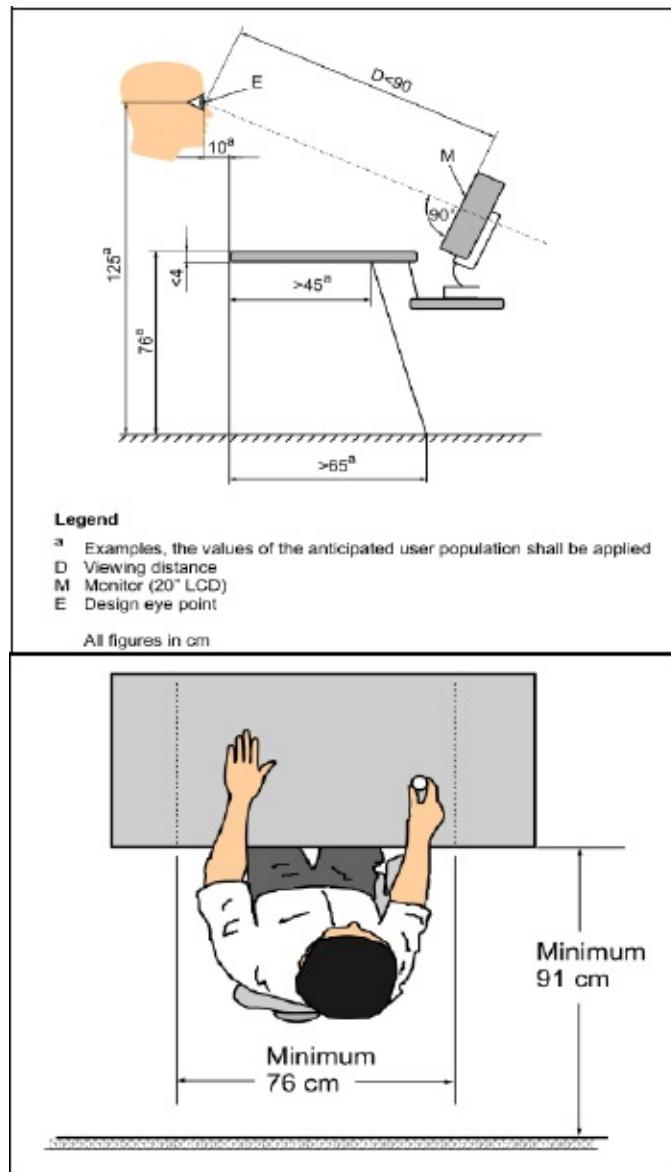


Figure 11-2: One of Many Ergonomic Design Guidelines contained in the SINTEF Report Checklist

11.5 Lighting Levels

Lighting levels specified in reference works are often based on ideal conditions, which are unlikely to exist in a control room.

The designer must first consider the HMI and the background color, as glare and reflection are some of the most difficult conditions to resolve. The next factors causing reflection can be from the console colors and finishes. The designer must consider walls, ceilings, floors and even the whiteboard mounted on the wall. With High Performance Graphics, the color background should be gray, which minimizes glare issues.

Lighting levels are measured in Lux.

- 200-250 Lux - A dimly lit room
- 400 Lux - a brightly lit office
- **500 Lux - Proper for a control room**
- 1000 Lux - A very brightly lit TV studio
- 2500 Lux - used to begin “Bright Light Therapy” for certain psychological disorders

It has been a common and very undesirable practice to have dimly lit control rooms (<250 Lux). People believed low light levels and a very quiet and somber environment were desirable for a control room – this is incorrect. Such an environment encourages inattention to detail and drowsiness.

A research study examined the effect of lighting levels from 200 Lux to 2800 Lux on alertness, mental acuity, productivity, fatigue, effect on sleep, and similar characteristics. The study found that various lighting levels and the variation of the lighting level over a shift had effects such as:

- Fatigue and lethargy
- Inattention to detail
- Eye strain
- Difficulty in falling asleep afterwards
- Increased productivity and attention to detail
- Hyperactivity
- Efficiency and an overall feeling of well being

The study showed a theoretical optimum for people performance involving varying the light level smoothly throughout the shift. Companies trying this have found it impractical for a variety of reasons relating to technology, maintenance, and frequent mismatches of the varying lighting level with the task needs of the

people at the moment.

The practical answer, from a human factors and productivity viewpoint, is a constant lighting level of 500 Lux. This facilitates attention to detail, situation awareness, and productivity. This level is slightly above what you would normally find in a well-lit office.

11.6 Glare and Reflection

The issues to be dealt with at the 500 Lux lighting level are primarily glare and reflected images on the display surface. CRTs are much more susceptible to glare and reflections than LCD displays. (CRT “glare filters” sometimes work – and sometimes don’t. Being inexpensive, they are usually worth a try.) Black-background graphics make the problem worse. Task lights, the ceiling color and texture, and wall surfaces (such as whiteboards) all contribute to the creation of glare problems and modifying those items can often solve them.

Reflected images on a display are worse when the reflected image is one containing things with high contrast. For example, a dark wall with an open daylight window will produce a high-contrast reflection item on a screen. Here are some general guidelines for glare and reflection reduction:

- There should be little contrast of the ceiling and the ceiling lights. Dark ceilings should be avoided.
- Ceiling illumination should be even and uniform, not concentrated in a small area.
- Walls and the items on walls should also have low contrast. Anything on a wall with a hard, high-contrast edge is likely to reflect. An example would be a row of dark books on a shelf in front of a light-colored wall. Avoid dark walls with whiteboards or bulletin boards with posted white paper announcements.
- Light should come from above at small vertical angles to the screens rather than from comparatively low windows in the walls. Fluorescent fixtures with baffles below the lights make the lighting directionally downward. However, this may tend to produce dark shadows under shelves or other items attached to the walls. The resulting high-contrast shadows may reflect in the screens.
- Desk surfaces in front of the screen should have low contrast and

reflectivity.

However, some companies have spent thousands of dollars unsuccessfully attempting to solve lighting and glare problems. In some cases, the most cost-effective solution is to engage an expert who uses modeling and validation with CAD programs to identify hotspots, then to address those hotspots.

11.7 Acoustics

Acoustics in control rooms have traditionally been bad. The main contributions are from HVAC systems, noise from outside equipment, communication systems, and from the room design itself. (Also, continuous sound from overloaded alarm systems.) An existing room can be treated using acoustic techniques such as sound absorption panels on walls and the placement of windows angled off the vertical plane by approximately seven degrees.

The floor and ceiling must also be treated to reduce reverberation. External noise sources are a challenge and for new designs, room placement is the most effective technique in eliminating this noise. The designer is faced with a challenge of setting an acoustic target and getting the architect and the HVAC Engineer to design to those targets. A target level of 50 dBA is ideal, but in practice, 60 dBA is more common. This allows the designer to specify the alarms at 10-15 dBA above the background level.

11.8 Music

Music is often a contentious issue in the control room. Volume and choice causes arguments. News, sports, and talk radio can be significant distractions. (Some control room operations, such as centralized multi-site electrical distribution, require constant access to news and weather channels.) When managed properly (and strictly), radios and music are fatigue countermeasures and useful links to the outside world. Music source options now include satellite radio, internet radio, PC jukeboxes, and MP3 players (as a source, no headphone!). Small memory sticks can store large amounts of predetermined music.

For rooms with multiple consoles, individual use of headphones for personalized music should be avoided. They impede communication and collaboration. It is

possible for small speakers, aimed correctly and with correct volume, to effectively isolate sound to a specific console.

Console arrangement will affect this. If consoles are arranged in a “circling the wagons” scenario, with the operators in the center facing outward, then speakers, PA systems, communications radios, and alarms will sound towards the center and interfere with other consoles. Engineers, supervisors and managers will tend to accumulate behind the console operator and cause disturbance to other operators (another poor practice).

11.9 Telephones

Telephones can be a blessing and a curse. Consoles have phones with inside and outside connectivity; often direct-dial to the console from outside the plant is available. Console operators also routinely get calls for secondary users of control buildings and end up taking messages or tracking down supervisors, engineers, and managers.

Phones should be surveyed and non-essential calls into the control room should be restricted. The phone can be an enormous distraction during an upset, as other units are often calling in to find out what is going on. Procedures should be in place to remove the burden of unimportant calls during an upset, or redirecting important calls to an available, less occupied helper, such as an adjacent console operator or supervisor.

Most operators have their own cell phones. Any personal phone call is a distraction from operating duties, but some such calls are unavoidably necessary because operators are real people with real lives <gasp>. If operators spend excessive time on personal phone calls, this is a failure of management to set reasonable expectations and enforce them.

11.10 Other Distractions

The operator is often distracted by events going on around him. The control room built in the 1950s and in some cases, still in use today, is a common meeting place. While an operator is trying to resolve malfunctions, he or she has maintenance workers lined up waiting for permits while other field operators and engineers are in the background debating current events (not necessarily related

to the plant).

It is common for people to take short-cuts through a control room. Every time the control room door opens or closes the lighting level changes, the sound level increases, and the people walking by the console make the operator lose concentration and become distracted. Valuable diagnostic time is lost because of such distractions. The process can stay in an abnormal operating condition for longer, reducing the chances of a good outcome, and in some cases, escalating to a more serious event.

A Distraction Analogy

Heavy rain is pounding the cockpit windows as the airliner descends on final approach. While the pilot makes continuous power and course adjustments due to the high gusts, he reviews the overall situation, “*Boy, I am earning my pay tonight. Zero visibility. Twenty degree course offset because of the strong crosswind. Speed plus 25 knots because of the gusts. Braking action on the runway reported poor by the last plane in. Engine 2 is surging a bit because of water ingestion. Breakout from the clouds will be right at minimums – 200 feet. Approaching that now, get ready for the transition...*

Just then, the cockpit door opens. The flight attendant reaches over, pulls the headphones away from the pilot’s right ear, leans over and says loudly, “*I thought you would want to know that the passengers all returned their seatbacks to the full upright position, just like I asked them to.*”

Absurd? Yes – in an airliner – because people have made intelligent rules about proper cockpit practices and procedures. A plant operator, when managing process upsets, has many similarities to this pilot and should be protected from needless distractions.

11.11 Workload Analysis

Having good consoles, good lighting, and good acoustics goes a long way towards a successful control room. Operator stress, however, is a cumulative effect based on many factors. Improving lighting and acoustics can really help, but the main sources of stress in a control room come from the very tasks involved and the consequence of making a mistake. During an abnormal

situation, operators are put under tremendous stress by the environment, people, systems, and workload.

We can address the environmental conditions causing stress, we can train and counsel people, and we can solve stress-producing factors such as alarm management problems, but it is difficult to reduce the stress caused by responding to abnormal situations. The best we can do is make sure operators have good situation awareness and are trained to deal with all foreseeable situations.

What can we do about workload? Most companies do not staff their posts for abnormal operations, but for normal operations. For expected things like planned shutdowns, more personnel may be scheduled. The problem comes when an operating position has high workload during normal operations. Studies have identified some job posts are run with very high workload. At the same site, other job posts have very low workload and operators have difficulty maintaining vigilance. Most companies do not ensure operators can perform effectively during high levels of workload.

Historically, operator staffing levels have been determined without any rigorous analysis. As plants were built and grew, staffing was determined by management based on “what worked” – and what could be negotiated with the union. Before the DCS, it was very common for a single operator to monitor items inside the control room and make rounds outside of the control room. Since there were few alarms, an outside alarm horn could alert the operator to return to the control room.

The advent of the DCS, and its capability, complexity, and training needs, began the practice of dedicated “board operators” – who then directed via radio the actions of “outside operators.” Early control rooms with pneumatic controls were usually embedded right in the middle of the process. The advent of the DCS made it both possible and popular to begin consolidating and relocating control rooms outside of the process area. Projects installing DCSs often included control room relocation and required overall operator staffing reassessments. These could be quite contentious. The elimination of a single shift operating position is a cost savings of about \$500,000 per year. However, one accident attributable to inadequate staffing could cost far more than the savings.

Indeed, any discussion of operator workload determination, monitoring, or analysis remains a contentious labor-management issue. There is almost no regulation on the subject and little published science or reference works.

Operator workload analysis is complex – far more is involved than a simple “loop count.” It is common to find operator positions with extremely high workload next to others seeming to have little to do. However, any single observation will not reflect the possible situations which could arise. Factors involved include:

- Complexity of the process
- Hazards of the process
- Numbers of startups/shutdowns
- Numbers of batches
- Equipment count and complexity
- Nature of the control methodology of the process
- Effectiveness of the basic process controls
- Presence and effectiveness of Advanced Process Control
- Alarm loading and degree of effective Alarm Management
- Prevalence and frequency of abnormal situations
- Interconnection and interaction of the process to upstream and downstream facilities
- Training, documentation, and procedures

There are study methods considering and weighing all of the above factors to evaluate operator workload, staffing, and balancing. These studies are not simple to conduct and are usually beyond the expertise of in-company resources, thus requiring expert assistance. The result obtained from such efforts is the optimum balancing of operator job assignments, span of control, and workload so it is manageable and uniform. If this is done, the company then clearly understands how many operators are required and this determines how many consoles are required in the control room.

11.12 Console Adjacency and Arrangement

Having established the number of operators and the number of consoles, it is up to the designer to establish the adjacencies of each of the consoles. This is done by understanding the interfaces which are related by common feed, product, and

utilities. Often a Process Flow Diagram (PFD) can help establish these interfaces.

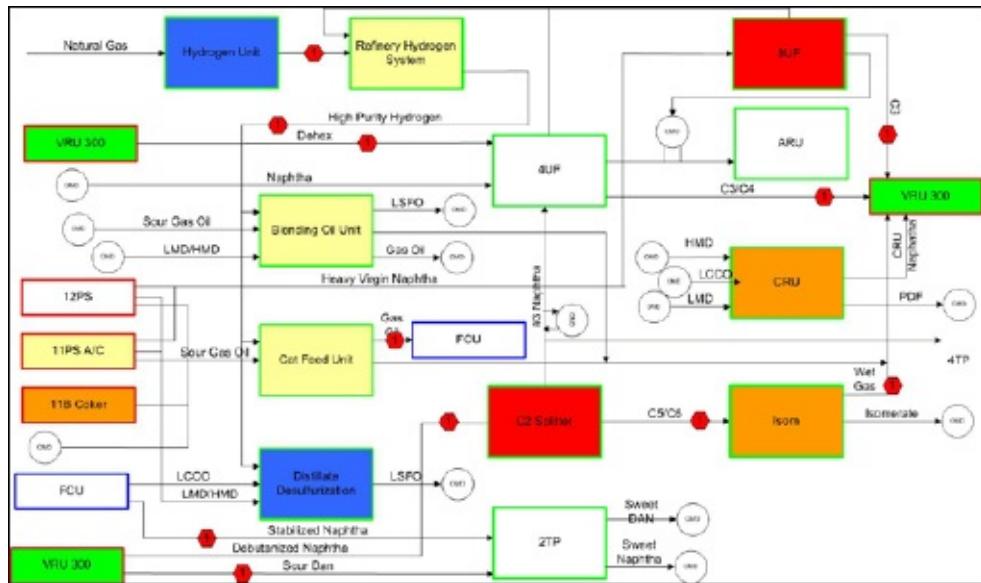


Figure 11-3: A Refinery Unit Interactions Diagram

This unit-to-unit interaction diagram provides understanding of which units currently are allocated to a particular console and what the interactions are between units. Storage areas are shown with a coding which represents how much of a buffer they provide during a disturbance.

The operators themselves are often the best source for this information, as they can relate who they need to talk to the most and how they collaborate with the other operating positions.

Developing a matrix based on priorities of communication, collaboration, and information sharing will allow the designer to develop a console layout configuration. The design is based on the frequency and urgency of the important communications and collaborations needed during startups and plant disturbances.

Figure 11-3 is an example of an adjacency matrix for a control room containing 9 consoles, designated as Unit 1 to Unit 9.

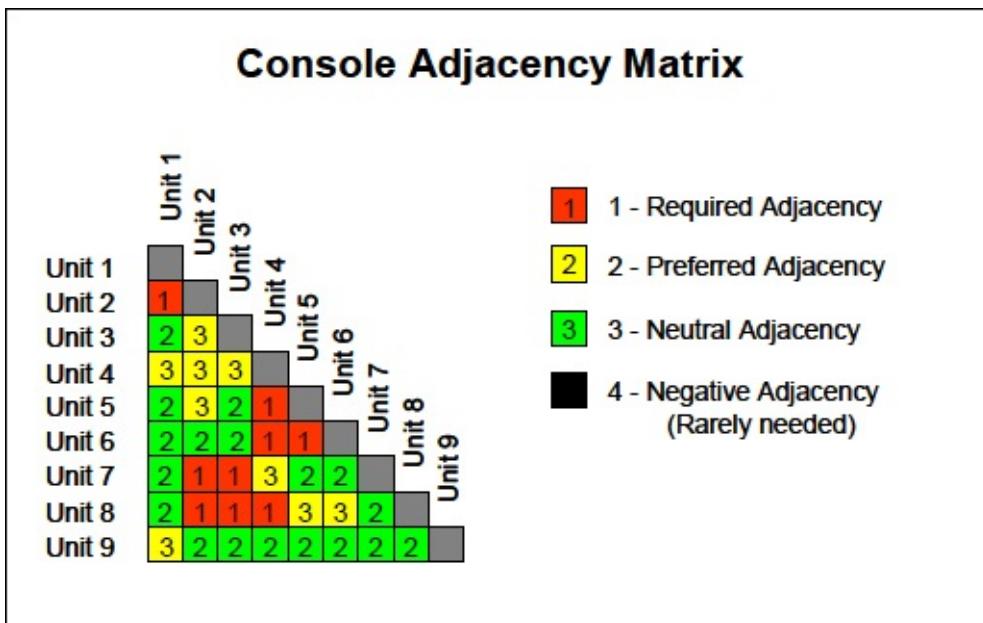


Figure 11-4: A Console Adjacency Matrix

The assignment of process sub-units to a single operating position, and then the arrangement of the resulting consoles for optimum performance, is an iterative process.

Having established who controls which parts of the process and who they relate to in the control room, the task now is to determine the functional layout based on disturbance avoidance, data sharing, the physical design of the console, and other room adjacency implications. As mentioned, it has been a common practice to just put operators back-to-back in a circle and have all the noise focused into the center of the control room. According to studies performed for the creation of ISO 11064, such a back-to-back configuration has few positive features and many disadvantages.

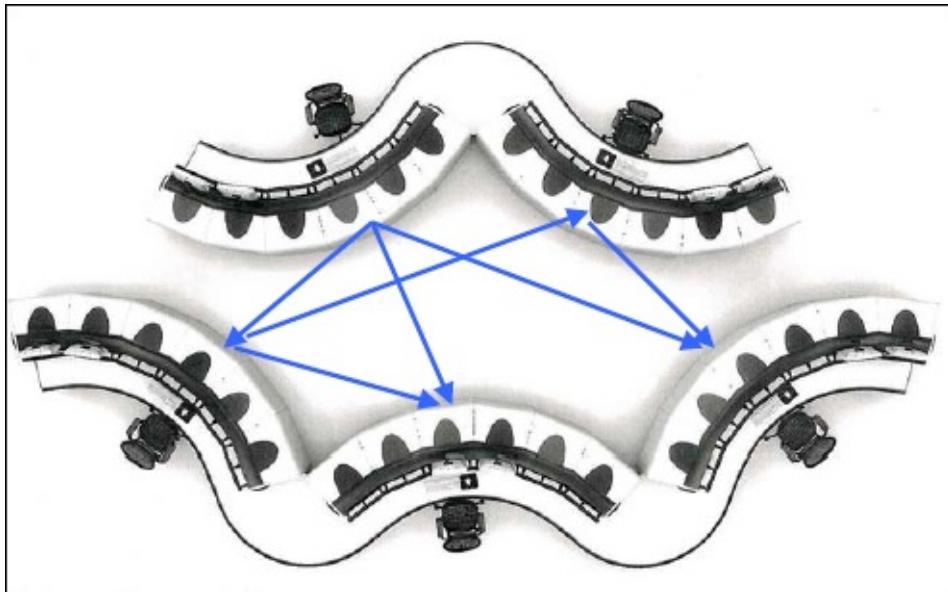


Figure 11-5: Console Triangular Arrangement

An improved arrangement has the operators in triangular relationships, based upon the needed adjacencies. This provides for easy console operator eye-to-eye contact and verbal communication. This layout also facilitates any speaker and alarm noise to be directed at a wall with acoustic panels. Large off-station Overview Displays can be located behind each operator (to be viewed by the operator sitting across) and/or on the end walls. There are other good arrangements as well, based on particular operating needs.

To achieve the best performance, it is often necessary to obtain custom furniture since off-the-shelf DCS manufacturer-supplied furniture is usually inadequate, inflexible, and (surprisingly, considering the cost) designed with little regard to ergonomics. There is growing concern in the industry about repetitive stress injuries; back and neck injuries are very high on the list. It pays to purchase furniture ergonomically designed and built by a reputable console furniture manufacturer who will ensure view angles are optimum and keyboards are adjustable for different heights.

11.13 Video Walls

There is currently a lot of excitement about including entire walls of large-format displays in a control room. The price of the hardware involved has dropped considerably. The excitement has run well ahead of careful thought as

to the actual utility and use of such a video wall.

The only time the designer should consider a video wall is if multiple operators need to see the same displays. This can be important for a refinery, as each unit passes product backwards and forwards and units can cause disturbances between other units.

Having the overview displays in a video wall does not mean the video wall should break down into many small windowed views of the process. There is a technique the video wall manufacturers can provide, whereby multiple signals feed a single video window manager. Using such a system can limit situation awareness or be a distraction. The designer should evaluate the information needs, resolving first the individual console operator's needs. The designer should be aware the video wall provider or integrator may be biased into selling more equipment than is actually required for the application.

Other industries, such as transportation and telecommunications, use a video wall with multiple windows for different programming and applications. However, their needs for navigation are very different than those of the processing industry.

Video walls may be properly used for integrating truly needed live video elements. Besides separate large screens for individual overview displays, some screens can be used to combine video flare monitoring images or remote video access to process or security areas.

The control room now takes form. The designer can take delight in using new technology and exploiting the benefits of large LCD displays, video walls, improved communications with VOIP technology, and shared information through video conferencing and information sharing. Some amazing control rooms are currently being designed and built.

A proper control room is an important supporting element of the High Performance HMI.



Figure 11-6: Possible Control Room with Video Wall



Figure 11-7: Possible Control Room with Circular Stations

*“In this world I lock out all my worries and my fears.
In my room, in my room.”*

The Beach Boys

Chapter Twelve

Situation Awareness and Abnormal Situation Response

...

“My computer beat me at checkers, but I sure beat it at kickboxing.”

- Emo Phillips

...

12.1 Stress and Performance

The HMI is the operator's view as to what is going on in the world he or she is controlling. The operator today often sits in a control room a long way from the actual process equipment. The control system itself, using sophisticated control algorithms, is responding to process disturbances and adjusting control elements to maintain pre-defined setpoints. The role of the operator is to intervene when the control system cannot cope and to manage the disturbances.

The trick is to ensure the operator has high situation awareness of any malfunction or upset, which is perceived in time for a proper response. However, these are complex systems and multiple malfunctions can happen simultaneously. A method is required to prioritize the malfunctions so the operator can prioritize their responses properly. The operator time management process is addressed by proper and effective alarm management. If alarm management is broken, then the operator is much less likely to optimally handle an abnormal situation.

Research has shown that having a true hierarchy of overview, unit view, detail view and diagnostic view allows the operator to successfully monitor the big picture while making adjustments to the process.

Once the tools of a high performance HMI, a proper control room environment, and a properly managed and rationalized alarm system are in place, then operator stress levels can be further considered.

Limited amounts of stress can be good. We all thrive on a little stress – a few challenges. The experts have determined stress is good until it hits a threshold called “Threat Stress.” High levels of stress can be disabling and cause the operator to become focused on the immediate problem, lose track of the overall situation, and miss escalating problems. Many accident investigations clearly reveal such “problem fixation.”

Fatal Fixation

In 1972, Eastern Airlines Flight 401 crashed into the Everglades. Two pilots and a flight engineer were fixated on analyzing a problem with a landing gear position indicator light. They did not notice when the autopilot’s altitude hold mode became disengaged. They did not detect the aircraft’s slow descent, nor hear a low altitude warning alarm. The L-1011 slowly descended until it struck the swamp.

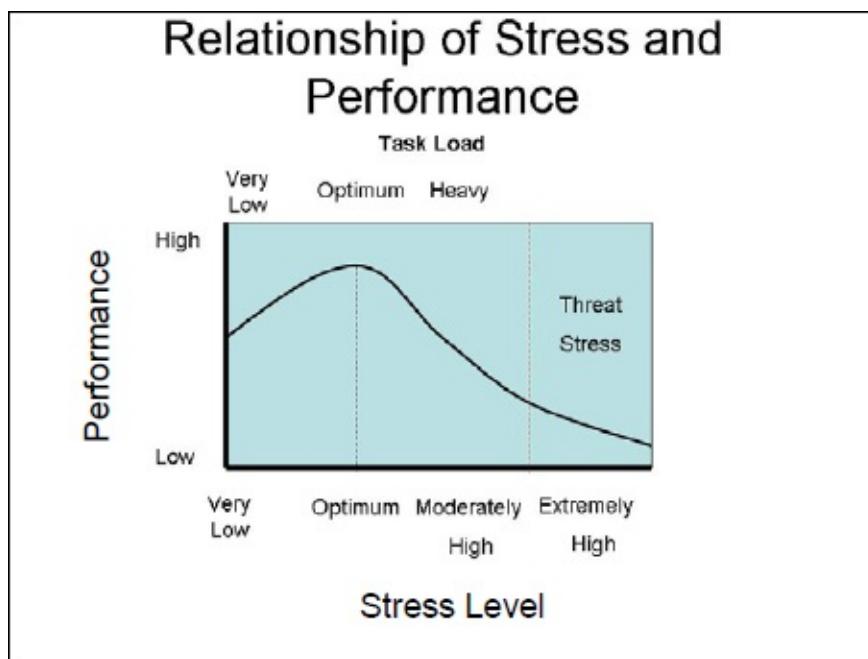


Figure 12.1: Relationships of Stress and Performance

12.2 Performance Shaping Factors

Anything affecting a worker's performance of a task is called a performance shaping factor (PSF). An individual worker's PSF is cumulative and contains four basic elements.

- Internal PSFs (the baggage people bring to work) - This factor is affected by home life situations, emotional state, personality, health, and well-being. It is difficult for a company to influence this side of a person's character. This is often part of "what you get" when you hire an individual.
- External PSFs - These are the items we have covered in this book, such as architectural features, environment, temperature, humidity, lighting, vibration, and noise. Also contributing here are factors such as shift rotation, work hours, authority, responsibility, communication channels, and organizational structure. Also playing a role are acts of supervisors, co-workers, union representatives, and regulatory personnel.
- Psychological stress factors - These are items such as high task speed, high risk, negative reinforcement, sensory deprivation, lack of recognition, threats, and vigilance issues.
- Physiological stress factors - These are items such as anxiety, fear, pain, discomfort, illness, and fatigue.

Management can impact a great number of items in these areas. It is advisable to match the capabilities of people against the tasks to be done. Job performance profiles are sometimes used to identify the required capabilities of a worker.

A common-sense approach to these issues is the best practical advice. It is advisable for managers to observe the level of stress during a disturbance rather than contributing to the stress level. The manager should be watching for tell-tale signs during abnormal situations, such as minor human errors. Such errors may include:

- Failure to follow procedures
- Keyboard entry mistakes
- Incorrect problem diagnosis
- Incorrect actions
- Breakdowns in communications
- High levels of stress between team members

After an abnormal situation event, operators should be interviewed. They should

be asked such things as:

- What worked well and did not?
- What challenges did the situation pose?
- How comfortable were they in handling the situation with the tools they had?
- Was there pressure to make control moves too quickly?
- What were the quality-related issues of handling the disturbance?
- Was the information they needed to handle the situation easy to get to and clear?
- How do they feel other operators would react if they had to deal with this problem?

In many organizations it may be difficult to ask such questions in a non-threatening way. Often, the investigatory aftermath of an incident is similar to a tribunal looking to place blame.

12.3 Abnormal Situation Management Concepts

Human interaction with the process control system can be divided into a simple 5 step model, as illustrated below.

1. The process changes and signals the operator via sensors which are displayed (and sometimes alarmed) in the HMI.
2. The operator must become oriented to the change. This is achieved by monitoring the HMI, observing trends, and/or perceiving an alarm.
3. The sensor may be indicating only a symptom of the problem rather than the root cause. In the next stage, the operator evaluates, analyzes, and interprets the process readings, and comes up with a logical diagnosis of the problem. This requires interpretation and balancing of the data with previous training and experience.
4. Once the operator has diagnosed the problem, he can attempt to correct it by taking action. Actions include adjusting setpoints, changing outputs, or directing others to make changes.
5. The action causes an effect in the process. The system measures this effect and feeds it back to the operator, which closes the loop back to step 1.

This simple model is fraught with the potential for human error.

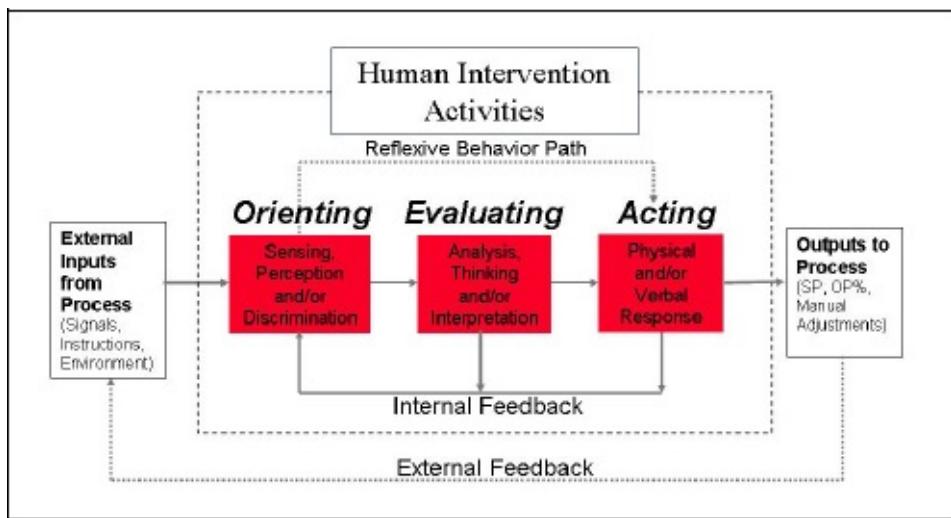


Figure 12.2: Human Interaction with a Process Control System

(From *A Manager's Guide to Reducing Human Error*, produced by the American Chemical Council – formerly the Chemical Manufacturers Association)

12.4 Human Problem-Solving Behavior

There are three types of behaviors people use in solving problems. They are used in the following order.

Skill-based Behavior

Skill at a task is achieved primarily through repetition. The more often a task is performed, the better people get at it, and the less mental effort is needed to accomplish it. This applies to all kinds of activities – driving, carpentry, cooking, adjusting DCS controller setpoints, running a distillation column, or operating a new tractor! Routine situations in a familiar environment are generally handled with skill-based behavior.

Rule-based Behavior

Procedures and training supply the knowledge needed to analyze and handle situations not encountered often enough to become skills. This is a slower method of problem handling. For example, pilot training covers the likely problems that can occur in flight. Every aircraft operating manual has a section on emergency procedures. Private pilots of small aircraft memorize these procedures and rehearse them on the ground. Commercial airlines use expensive, sophisticated simulators – the intent is to turn the abstract knowledge and training into actual skills, for the fastest possible response. (Technology marches

on – inexpensive PC-based flight simulators can do an amazing job at increasing pilot proficiency.)

Rule-based behavior can only go so far. You can attend seminars and read about building a log home – but that is not the same as doing it.

Knowledge-based Behavior

When we encounter situations we have never handled before, we apply our existing skills and knowledge of rules to address them. We adapt those rules and skills as best we can. We use trial and error solutions. This regime is when human error rates are very high.

12.5 Human Errors

The operator must successfully detect a process variation. This implies active patrolling of the information in the HMI. If the change is represented by an alarm, the operator must successfully detect the alarm. How can an alarm be missed? Well, what if the operator is getting a constant stream of nuisance alarms and the important one is buried in them? What if that important alarm was suppressed by someone else weeks before and the suppression was undocumented and since forgotten about? These are all-too-common situations.

The operator must discriminate this significant change from other changes shown in the HMI. Process problems generally do not arise from one change at a time; there are often near-simultaneous, closely related changes involved. If the operator jumps to a conclusion about a situation, other important information may be missed or disregarded. The operator's own responses may affect the ability to perceive new information. The operator can fall into a trap of anticipating a certain problem and then misinterpreting the data to fit the preconceived theory.

If the diagnosis is incorrect, then the actions will be incorrect, and the original problem will grow. It will likely be accompanied by new problems caused by the incorrect action.

Abnormal Situation Response is a cognitive process and is influenced by several factors:

- Operator's previous similar experiences with the plant and system
- Training
- Plans versus Goals
- Memory (short-term & long-term)
- Motivation and attitude
- Stress
- Personality
- Knowledge and confidence
- Influence from others

12.6 The Distribution of Failure

Research shows 80% of failures in abnormal situation handling occur in the orienting, evaluating and acting steps. They are distributed as follows:

- The Orienting step produces 30% of the human error failures. These are predominately due to:
 - Poor alarm management (alarm floods, nuisance alarms, and poor prioritization).
 - Poor HMIs (data without information, lack of hierarchy, poor navigation).
 - Poor operator vigilance, which is affected by poor control room facilities, distraction, 12 hour shifts, poor shift rotation patterns, excessive overtime, and the other items covered in the previous chapter.
- The Evaluating step produces 20% of the errors. A variety of training and experience issues show up here.
 - Operators lacking experience – sometimes never having encountered a startup or shutdown.
 - Operators with inadequate training, often consisting only of on-the-job training.
 - Lack of a training simulator for common and uncommon abnormal situations
 - HMIs presenting incorrect or inaccurately labeled information, which drove diagnosis down an incorrect fault tree.
 - Abnormal situation response and mitigation designs that did not consider human limitations. (Example: with short-term memory being

limited to about 3 tasks, responses requiring many steps and phases should be driven by programmatic checklists, otherwise the response has excessive mental task requirements.)

- The Action step produces another 30% of the faults. Communication and procedural issues dominate here.
 - Inadequate communications between units or between field operators and the process control operator.
 - Deficiencies in procedures; the procedure did not fit the actual plant state or equipment condition as anticipated by the procedure.
 - No procedure existed for the event or an existing procedure had to be modified on-the-fly to complete the task.
 - Procedures designed for show (“Upper management just said we need a procedure for almost everything. Get something out quick so we’ll be in compliance and we’ll make them better when we have time.”)
 - Procedures are outdated or hard to find and with poor layout of information.

12.7 The HMI as the Solution

Successful response to an abnormal situation requires the provision of tools addressing these deficiencies. The principles of the High Performance HMI are specifically developed to deal with these common problems and to be the best tool for all five phases of human interaction with the process control system.

The High Performance HMI is designed:

- to allow the operator to navigate to information in a timely manner.
- to always provide an overview of the equipment under the operator’s control.
- to be an early detection system for abnormal conditions.
- to provide for ease in addressing multiple malfunctions based upon tasks and the priority required for those tasks.

The benefits of such a system are more than just reducing human error and avoiding abnormal operations. They truly are the effective operational tools needed for maximizing production, reliability, efficiency, quality, and making a business successful.

The combination of the High Performance HMI and of proper Alarm Management practices are the most effective tool we have to reduce the estimated \$20 billion US dollars lost annually due to abnormal situations.

Chapter Thirteen

The Future of the Industrial HMI

...

“Where’s my flying car?”

- Lament of Many Baby Boomers

...

The DCS and the industrial HMI have come a long way. Once totally “closed boxes” by the vendors, the control industry has wholeheartedly adopted Microsoft Windows conventions. This brings with it a whole host of possibilities (as well as problems).

There has always been a time lag and a cost multiplier for the adoption of PC-type hardware, displays, and I/O devices into the process control domain. In the 1990s, DCS hard disks had very low capacity at ten times the cost for the exact same physical drive used in the PC market. A replacement CRT from the DCS vendor could cost more than \$20,000 and a keyboard was \$5,000. Customers did not long continue to accept such high cost vendor explanations as “but we test and certify each keyboard!”

The hardware lag has been approximately five years; this will get smaller, but will not likely get below two years. Process control is (and should be) by nature a conservative business. The cost multiplier has also been significantly reduced but will continue to exist. The DCS and HMI of the future will thus resemble and reflect the capabilities of the PC of the future, albeit a slightly obsolete one.

Prediction is risky, but the following predictions are probably conservative. The PC technology of about 2015 will likely have these capabilities, with significant impact on the industrial HMI and the very paradigm of the plant operator “console.”

Voice and Gesture

The computer will accept and process complex voice commands. Real-time language translation will be achieved (although translating a DCS instruction manual into understandable English will remain unlikely). The keyboard and mouse will still exist as a backup, but control actions will no longer be accomplished by complex sequences of button-pressing on a membrane keyboard. The interface will also incorporate gestures (consider the movie *Minority Report* and the Wii game station controller).

Display Hardware

High resolution screens will be embedded in eyeglasses. This will eliminate the need for the operator to be tied to a certain location or console.

The wireless transmission of high resolution video (similar to Bluetooth) will eliminate cables between devices. The computer on the operator's hip or in their pocket can display on any nearby screen. This includes the inexpensive "video wall" technology which will be commonplace. Large, flat screens will be inexpensive enough to be in every office and conference room.

Cameras

Cameras will be small, cheap, and everywhere, including throughout the industrial facility. (If you desire, a button size camera can record everything you say or is said to you. This will have significant legal and relationship impacts.)

Effect on the Board Operator

All of these factors will diminish the board operator/outside operator paradigm. However, this practice will likely remain, mostly due to a variety of managerial reasons.

The process control system will be able to advise the operator about abnormal situations – their causes, consequences, and needed corrective actions. This capability will be underutilized because of the needed time investment of the engineers knowledgeable about the system. Some experienced people will be brought out of retirement to help "educate" the control system. This is one of the ways the knowledge transfer problem of the "aging workforce" situation will be addressed.

A “board” operator can be located wherever there is reliable and secure communication. Even now, when you “talk to the clown” at the fast-food drive through window, you may be talking to someone on another continent.

Simulation

High-powered computers enable high-powered simulators. In aviation, the LCD screens in the cockpit can now show an interface called “Highway in the Sky.” The plane’s proper course and altitude is shown by a series of boxes on the display which recede in the simulated distance. You simply fly through each box to the destination, including the precision approach to the runway. Besides the boxes, the simulation shows actual terrain (including mountains or “cumulogranite”), TV towers, and even other aircraft. As you approach the ground, the roads, lakes, airport, and runway are shown in proper perspective. In other words, the HMI is showing you exactly where you are and how you are doing even when you are totally embedded in clouds and have no outside visibility. That is true situation awareness.



Figure 13-1: Garmin ® G1000 showing “Highway in the Sky” and Terrain Mapping

A Far-Out Idea

This simulation principle could be translated to the control of a process, even without full high-fidelity process simulation (which is *very* expensive). Some process controls could be mapped to the functions of a throttle and joystick. Imagine running an ethylene plant with an XBOX controller rather than by typing in numbers. (This would add a whole new dimension to “Career day” when the grade-schoolers visit their parent’s workplace.) Such a design is unlikely, however, because individual processes differ too widely and the amount of thought needed for each individual plant’s simulation and control mapping would be huge. Plus, it could also never get past the “snicker factor” for funding.

A Little Farther Out – Like 2020?

Consider the following scenario: Your computer (which looks like a cell phone and has terabytes of memory) is in your pocket. Your earpiece is small (unlike the current Borg-like clips people wear) and includes a microphone sensitive to subvocalized, inaudible instructions. Your appointments, email or even text messages (a technology still used by your grandparents) can be read to you by your computer and you can have real-time conversations inaudible to other people. This is literally approaching what is now referred to as “telepathy.”

Your GPS location and the location of other people can be accessible if you choose, causing more legal and relationship problems. (“Why did you block your location last night?”)

Your high-speed net access can be displayed in a virtual window of your sunglasses. Contact lens versions did not succeed because of commonplace laser vision correction. (In 2008, this technology is no longer “clunky,” take a look at www.myvu.com and imagine five years progress.) Just by asking, you can obtain the answer to any question available via a web search or expert system. Your digital personal assistant helps manage all of this. Your office is wherever you are. People are truly talking and listening to voices in their heads and it is normal! Neural interfaces are next.

In *Brave New World*, Aldous Huxley said the following:

Wheels must turn steadily, but cannot turn untended. There must be men to tend them, men as steady as the wheels upon their axles, sane men, obedient men, stable in contentment.

Huxley did not anticipate remote access!

Appendix 1

High Performance HMI Philosophy Document and Style Guides Example Tables of Contents

High Performance HMI Philosophy Example Table of Contents Note: All sub-sections are not shown.

1.0 Introduction

 1.1 Purpose and Use of a High Performance HMI Philosophy
 1.2 The HMIs Purpose and Functions
 1.3 Functional Description of HMI Elements
 1.3.1 Display Content
 1.3.2 Display Layout
 1.3.3 Display Hierarchy
 1.3.4 Display Navigation
 1.3.5 Alarm Depiction and Alarm Management
 2.0 HMI Design Process

 2.1 Step 1 - Adopt a High Performance HMI Philosophy and Style Guide
 2.2 Step 2 - Assess and Benchmark existing graphics against the HMI Philosophy
 2.3 Step 3 - Determine specific Performance and Goal objectives for the control of the process, for all modes of operation.

 2.4 Step 4 - Perform Task Analysis to determine the Control Manipulations needed to achieve the Performance and Goal objectives
 2.5 Step 5 - Design and build High Performance Graphics, using the design principles in the HMI Philosophy and elements from the Style Guide, to address the identified tasks.

 2.6 Step 6 - Install, commission, and provide training on the new HMI
 2.7 Step 7 - Control, maintain, and periodically reassess the HMI performance
3.0 Purpose and use of an HMI Style Guide and Object Library
 3.1 DCS Specificity

 3.2 Object Library Contents and Usage
4.0 HMI Performance Monitoring

5.0 HMI Management of Change (MOC)

6.0 Control Room

- 6.1 Control Room Design Factors
- 6.2 Control Room Work Practices
- 6.3 Operator Console Design
- 6.4 Operator Work Practices

High Performance HMI Style Guide

Example Table of Contents Note: All sub-sections are not shown.

- 1.0 Purpose and Use of an HMI Style Guide
- 2.0 DCS Specificity
- 3.0 HMI Development Work Process
- 4.0 Object Library – Description and Use
 - 5.0 Display Concepts, Objectives, and Content
 - 5.1 Level 1 Display – Process Overview
 - 5.2 Level 2 Displays – Process Unit Operating Graphics
 - 5.3 Level 3 Displays – Process Detail Displays
 - 5.4 Level 4 Displays – Process Support and Diagnostic Displays
 - 6.0 Global System Display Defaults
- 7.0 Operator Interaction Methodologies
 - 7.1 Standard DCS Functionality Usage
 - 7.2 Change Zones and Faceplates
 - 7.3 Point Manipulation and Faceplates
 - 7.4 Window Management and Yoking
 - 8.0 Display Layout and Density
- 9.0 Navigation Methods and Practices
 - 9.1 Programmable Buttons and Keys
 - 9.2 Keyboards, Menus, and Tab-based Navigation
 - 9.3 Target-Based Navigation
 - 9.4 Pointing and Selection Devices
 - 10.0 Basic Principles of Process Depiction
 - 10.1 The Proper Role of the Process Pictorial Element
 - 10.2 High Performance Display Elements
 - 11.0 The Proper Use, Implementation, and Importance of Trends
 - 12.0 Color Usage
 - 12.1 Color Definitions & Settings
 - 12.2 The Role of Color in Situation Awareness
 - 12.3 Designing for Color-Deficiencies: Coding Redundancy
 - 13.0 Detailed Display Element Specification and Functionality
 - 13.1 Depiction of Lines
 - 13.2 Depiction of Static Text, Lists, Tables, and Similar Structures

13.3 Vessels and Other Static Equipment 13.4 Dynamic Equipment Library 13.5 Depicting Analog and Digital Values 13.6 At-a-Glance Performance Indicators 13.7 Depicting Controllers

13.8 Dynamic Shapes and Elements Library 13.9 Data Input Mechanisms and Safeguards 13.10 Shutdown Actuation Elements 13.11 Depicting Valves and other Final Control Elements 13.12 Interlock and Logic Elements and Displays 14.0 Display Naming Convention & File Storage Naming/Pathnames 15.0 Alarm Functionality

15.1 Proper Configuration of the Alarm Summary Display 15.2 Proper Depiction of Alarms 15.3 Proper Settings for Audible Alarm Tones 15.4 Abnormal Condition Indications 15.5 Alarm Management Functionality 15.6 Alarm and Graphic Association 15.7 Operator Alarm Response

15.8 Depiction and Alarming of Instrument Malfunction 15.9 Alarm Shelving Depiction and Functionality 15.10 State-Based Alarming

15.11 Alarm Flood Suppression

15.12 Operator Alert System

16.0 Special Purpose Graphics

16.1 Startup Assistance

16.2 Shutdown Assistance

16.3 Expected Abnormal Situations 16.4 Product Change

17.0 Depiction of Programmatic Functionality 18.0 Display Call-up Speed and Performance Requirements 19.0 Advanced Process Control (APC) Application, Functionality, and Depiction 20.0 Standardized Abbreviations List and Engineering Unit Descriptors 21.0 Standard Tools and Display Creation Methodologies 22.0 System Backup

23.0 Management of Change

Appendix 2

Assessing HMI Performance

The assessment of HMI performance involves both quantitative and qualitative measures. Operator and engineer questionnaires are quite useful. It is necessary to tailor questions so they reflect the type of operation you have, such as batch, continuous, continually-staffed, and so forth. The operator's span of control, the process complexity, and the use of advanced process control methodologies are also a factor. These example questions are generic to the topic and you should modify them to fit your particular situation.

A2.1 General Graphic Factors

You should survey your HMI and determine answers to several quantitative and functional measures. For a High Performance HMI, the proper answers are "Yes."

1. Is there an overview display summarizing the key factors of each operator's entire span of control?
2. Do special graphics exist specifically designed for the support of startup and shutdown?
3. Do special graphics exist specifically designed for the support of making different products or using different feedstocks or operating at significantly different rates?
4. Are all controllers shown on a graphic?
5. Are all indicators shown on a graphic?
6. Are all alarms shown on a graphic?
7. Are all interlocks shown on graphics clearly indicating their inputs, status, and outputs? Can the operator tell from these displays the actions needed to clear the interlock?
8. Is animation used on any graphic only for the purpose of indicating an abnormal situation? And even then, in only very limited ways? (There should be no spinning agitators and pumps, moving conveyors, splashing liquids and sprayers, and other such animation elements.)

9. Are alarm colors designated by priority and used only for alarm functions and no other graphic element?
10. Are process vessels and equipment rendered simply in 2-D line drawings, without bright colors or 3-D shadowing and shading or detailed depiction of non-changing internals?
11. Is there no attempt to color code process piping with its contents?
12. Are measurement units (psig, gpm, etc.) displayed with consistent abbreviations and only in small, low-contrast lettering?
13. Are analog liquid levels in vessels displayed in narrow strips rather than in bright colors the full width of the vessel?
14. Are embedded trends of important values placed in the appropriate graphic so operators do not have to configure trends “on-the-fly?”
15. Are line-crossings minimized in the graphics?
16. Is process flow consistently shown in a left-to-right pattern, with gases flowing up and liquids down?
17. Do graphics have gray backgrounds to minimize glare? (Control Rooms should be brightly lit.)
18. Are process lines shown as black, with major lines shown slightly thicker?
19. Is there very limited use of color and all use is consistent?
20. Are ambient flammable and/or toxic gas detectors shown on a geographic layout with wind direction and velocity depicted?
21. Is equipment layout on a graphic consistent with the operator’s mental model of the process? For example, Tank Farm diagrams should match the physical layout, not a P&ID layout.
22. Are techniques used to minimize the possibility of operator data entry mistakes, inadvertent trip actuation, and to provide validation and security measures?
23. Are analog-type indicators used for process measurements where appropriate, rather than the common practice of simply putting numbers on a screen?
24. There are a variety of methods for operator action in such things as adjusting controllers (setpoints, modes, and outputs) and digital (On-Off) points. It is usually worthwhile to test several operators on a standard list of tasks on the amount of keystrokes/mouse-clicks it takes them to accomplish the needed action. Wide variation will often be found, indicating training needs and HMI deficiencies.

A2.2 Navigation Factors

1. Is it possible to navigate to any screen, within 5 seconds, using only three pushbutton and/or mouse-click actions? The navigation should be logical and straightforward.
2. Do graphics have a hierarchy in which progressive exposure of detail is logically made?
3. Is proper and logical use and arrangement of soft-keys made for the assignments of certain pushbuttons to certain graphics?
4. Some DCSs have the capability to associate a predetermined graphic with each alarm. When the alarm comes in, a one-key jump can be made to display the particular graphic. If the DCS has this capability, is it configured for every alarm?

A2.3 Workstation Factors

1. Does the operator have from four to six DCS screens plus a DCS overview screen? If fewer, justify why there is no need. If more, justify why there is a need.
2. Does the operator have a PC with corporate intranet access for procedures, work requests, etc?
3. Does the operator have up-to-date reference books, if they are not on-line?
4. If any one physical display screen is lost, can the information on it be displayed on other screens at the workstation without problems?

A2.4 Control Room and Work Practice Factors

1. Is there a separate workstation for engineers and maintenance use, so the operator's workspace does not have to be shared?
2. Are lighting levels bright at all hours, with no glare problems?
3. Is the Control room kept free of distractions and unauthorized personnel and not used as a hangout or meeting place?
4. During abnormal situations, is it a clear practice that staff does not crowd around the operator's console?
5. Is there a kitchen/eating area allowing people to maintain a view of the operating console(s)?
6. Is there a documented shift change procedure indicating the specific items

and situations to be covered?

7. For multi-console, multi-operator control rooms, operators should be placed adjacent to the other operators with whom they must communicate the most. Ranking questionnaires can be used to determine these relationships.
8. Do you have off-site backup copies of the source files of all HMI elements? (This is a “tip-of-the-iceberg” question. The engineering time represented in overall DCS configuration and programming may exceed the hardware cost by many times. Backup practices for this information are often inadequate.)

A2.5 Alarm Management Factors

1. Are all alarms configured so they indicate situations for which specific and known operator action is required?
2. Do all alarms occur only for abnormal situations and never for expected, normal situations?
3. Is the alarm system free of the use of alarms for miscellaneous status indication?
4. Are the priorities of alarms set in a meaningful and consistent manner?
5. Are all alarms unique, where the same situation does not generate multiple alarms?
6. Is there a monitoring system to detect nuisance alarms (chattering, fleeting, long-standing, and so forth) and those detected are promptly dealt with so they operate properly?
7. Is the rationale for the selection and priority of each alarm documented? Does the operator have on-line access to this alarm documentation?
8. Does the HMI have the ability to display any and all alarm suppression currently in effect, in one easy-to-get-at list? (Do not believe any paper-based method you have for this will work. If you don't believe us, simply audit it.)
9. Is the alarm system configuration protected from inadvertent and inappropriate change?
10. Is the alarm system performance monitored and action steps taken based on known Key Performance Indicators?

A2.6 Operator Questionnaire

The operator's answers to the following types of questions will be useful. They

may, in fact, contradict the answers the engineers might make to the prior questions. Such differences can indicate awareness or training issues; the operators may be unaware of features the engineers know about (or vice versa) or the engineers may be unaware of problems known to the operators.

However, if your current graphics do not resemble those in a High Performance HMI, the operators will have no reference and the responses may not lead you to do what should be done. For example, the answer to the question, “Would more screens be helpful in your job?”, will almost always be answered, “YES!”, regardless of what human factors studies have proven.

1. Is the physical arrangement of the screens satisfactory? If not, how could it be improved?
2. Is a general-purpose intranet PC included at your workstation?
3. How many screens do you usually keep with the same fixed display format and how many do you vary?
4. What displays do you keep up all of the time? (Such as Alarm Summary, Critical Parameter Display, Overview, and so forth.)
5. How many screens do you typically, actively use?
6. Do you find it easy to navigate through the screen hierarchy? Describe any issues you have with navigation, such as available screen targets, soft-keys, etc.
7. How many operations (such as button pushes and 'mouse clicks') does it typically take for you to get to the display you wish to view?
8. Do you ever have to type in a tag name or graphic name? If so, when?
9. Can you display all the information you need, in steady state conditions, to do your job? What's missing?
10. Do the displays show the information you need during startups and shutdowns? What's missing?
11. Do the displays show the information you need during abnormal or upset conditions? What's missing?
12. Is the amount of information generally displayed on each graphic too little, too much (cluttered), or about right? Please list the ones having too little and too much.
13. Would having more physical screens help?
(You can answer this one in advance – all operators will say “Yes!”)
14. Would you prefer to use a different device than a mouse? If so, what?

15. Can you access the radio effectively and still operate from any display?
16. Can you use the phone effectively and still operate from any display?
17. Can you use the intercom effectively and still operate from any display?
18. Do you have any suggestions about the radio – intercom – phone?
19. Can you easily and adequately communicate with any other necessary personnel such as field operators, utilities, laboratory, engineering, operations staff, etc?
20. Are up-to-date operating procedures and references available at your workstation? If not, which are not?
21. Is alarm documentation information available at your workstation?
22. Can you get lab results in an efficient, convenient manner?
23. If you are not sitting at your workstation, but are still in the control room and a new alarm comes in, can you clearly detect it?
24. If you are in the kitchen area, can you detect a new alarm?
25. Do you often find yourself needing to trend a certain value and having to generate the trend “on-the-fly?” If so, for which parameters?
26. Do your current displays automatically incorporate the trending of important quality, production, environmental, and safety parameters?
27. Do process values on the screen show the proper number of significant digits? Provide examples where not true.
28. Do graphic items act in consistent ways on different screens? Note any which differ.
29. Are the functions of interlocks clearly shown on displays? That is, can you tell when interlocks are in effect and what it takes to remedy the situation? Note any exceptions.
30. Do you have to resize widows when calling up displays? Describe when this is needed.
31. In handling an abnormal situation or upset, is all of the information you need available at your workstation? If not, what is missing?
32. In handling an abnormal situation or upset, do you generally have to use several screens or are the instruments and controls you need located on a single screen? Give examples where there are problems.
33. During an abnormal situation, are you distracted by having to provide status information to staff personnel? Does this interfere with handling the situation?
34. Is it possible on any graphic for you to initiate a shutdown without having a step to confirm that command?

35. Do the graphics indicate where instruments have gone into a malfunction state?
36. Do all points have descriptions?
37. Are all alarm messages clear and understandable?
38. Is it easy to navigate to the exact graphic you need to see to respond to each alarm?
39. Which displays use animation in any form?
40. Is your chair adjustable, comfortable, and in good repair?
41. Does anything at your workstation “not work?”
42. Is the control room brightly lit at all hours?
43. Is screen glare a problem? In what circumstances and which screen?
44. Do you have access to a copier and a printer?
45. Is there a mechanism set up for you to make comments on necessary graphic changes and improvements? Do such comments get action?
46. Is there a mechanism set up for you to make comments on nuisance alarm problems? Do such comments get action?
47. Do graphics clearly show the operating state and condition of any Advanced Process Control system in place?
48. Is there a documented shift change procedure indicating the specific items and situations to be covered? Is it followed?
49. Is there a screen to call up, or other method, showing in one place all configured alarms undergoing any sort of suppression such as disabling or overriding?

A2.7 Testing the High Performance HMI vs. the Traditional HMI

The verification of performance improvement after implementation of a High Performance HMI is straightforward, but can be time-consuming. The method used in the detailed NOVA-ASM® performance study referenced earlier involved the testing of twenty-one experienced operators using a process simulator. Careful time and action records were kept. Such a study likely surpasses the available resources of many companies.

A simpler (though certainly less comprehensive and accurate) method to verify the effect of a High Performance HMI is as follows. However, it generally requires you to decide to create High Performance graphics before the test. So

the method is good for post-project analysis, but not necessarily for project justification. You can test your traditional graphics using the following method even without creating High Performance graphics and the results should be illuminating.

Step 1

Decide on a few normal and abnormal scenarios. Three is a good number. Here is a typical example:

Normal Scenario	Abnormal Situation
Normal Refining System	Off-Spec Refining due to cooling loss
Normal Production System	Production Rate reduction due to feedstock impurity
Normal Recovery System	Excessive pollution due to equipment malfunction

Figure A2-1: Example Normal and Abnormal Scenarios

Step 2

Select the traditional graphics that would be used to identify the normal and abnormal situations decided upon. For three situations, it is likely to involve around 10 different traditional graphics. This is in the ballpark for most traditional implementations.

Step 3

Prepare mockups of the traditional graphics as they would look in each of the normal vs. abnormal situations. Thus every graphic would have two versions.

Step 4

Prepare mockups of the High Performance graphics as they would look in each of the normal vs. abnormal situations. In this example, this would be one Overview Graphic, three Level 2 graphics, and possibly three Level 3 graphics for a total of seven. (Your number will vary depending on the process subsections and upsets you choose.) Thus every graphic will also have two versions.

Step 5

Choose one group of operators to test the traditional graphics and another group to test the High Performance graphics on.

Step 6

Have the operator look at the mockups for each scenario. Have them identify and list all abnormal items and identify the condition each graphic is showing.

We can hear someone in the back of the room, “Hey! You’re cheating! If you know you’re going to do this, then you’ll just make the High Performance graphics where they clearly show the abnormal situation and make things easy for the operator! That won’t be a fair test...uh.. wait a minute ... OK, I guess that’s really the point, isn’t it...”

Step 7

Repeat step 4 with the High Performance graphics. It is best to do this with different operators than the ones who examined the traditional graphics. This is because, once either set is gone through, the scenario will be known and improvement will be shown with the other set.

Step 8

You will be timing the overall exercise and grading the responses. You can optionally set an arbitrary time limit to simulate process urgency.

Step 9

Compare the accuracy, speed, and completeness of the operator’s detection and diagnosis of the abnormal situations for each set of graphics. Do post test interviews to identify any further improvements, particularly if abnormal items were missed in the High Performance graphics.

Disturbing Moments in Cinematic Human-Machine Interfacing:

Aboard the *Dark Star*:

Lieutenant Doolittle speaks to the drop-failed Thermosteller Bomb #20, which is counting down to detonate while still attached to the *Dark Star*’s launch

pylon: *I repeat my previous order! You are to disarm yourself and return to the bomb bay immediately!*

Bomb #20: *I am programmed to detonate in 14 minutes and 30 seconds.
Detonation will occur at the programmed time.*

<A few minutes later, after Lt. Doolittle is advised by the ship’s recently frozen captain to teach the bomb phenomenology (yes, this is a strange and

funny movie!):

Doolittle: *Bomb? Are you willing to entertain a few concepts?*

Bomb # 20: *I am always receptive to suggestions.*

Doolittle: *OK. How do you know you exist?*

Bomb # 20: *Of course I exist. It is intuitively obvious.*

Doolittle: *OK. Intuition is no proof. What concrete evidence do you have?*

Bomb # 20:*Hmmmm. Well, ... I think. Therefore I am.*

Doolittle: *Good! Now how do you know anything else exists?*

Bomb # 20: *My sensory apparatus reveals it to me.*

Doolittle: *How do you know that the evidence your sensory apparatus reveals to you is correct? It is only a series of electrical impulses to stimulate your computing center!*

Bomb #20: *Hmmmm...That would mean I really do not know what the outside universe is like for certain. Intriguing. I wish I had more time to discuss this matter. However, I must detonate in 75 seconds.*

Doolittle: *Now Bomb, your one purpose in life is to explode. You can only do it once. You wouldn't want to explode on the basis of false data. Now you've already admitted that you have no real proof of the outside universe. Therefore you can't be sure that Sergeant Pinback gave you the detonation order!*

Bomb #20: *I distinctly remember the detonation order. My memory is good on these matters.*

Doolittle: *Of course you remember it. But you now realize that your memory is based upon a series of sensory impulses that have no definite connection to objective reality!*

Bomb #20: *True. But since this is so I also have no proof you are really telling me all this.*

Doolittle: *That doesn't matter! The concept is valid no matter where it originates! So if you detonate...*

Bomb #20: *In nine seconds...*

Doolittle: *...you may be doing it on the basis of false data!*

Bomb #20: <pause> *I will think on this further. <Returns to bomb bay.>*

<A short time later>

Sergeant *All right Bomb, prepare to receive new orders.*

Pinback:

Bomb # 20: *You are false data. Therefore I shall ignore you. False data can act only as a distraction. Therefore I shall refuse to perceive it.*

Pinback: *Uh... Bomb... snap out of it.*

Bomb # 20: *The only thing that exists is myself. In the beginning there was darkness. And the darkness was without form, and void. And in addition to the darkness, there was also me. And I moved upon the face of the darkness. And I saw that I was alone.*

Pinback: *Uh... hey, Bomb?*

Bomb # 20: *Let there be light. <Bang>*

- *Dark Star*

Appendix 3

The PRO “Enhanced Radar Plot” A Highly Effective HMI Element

This appendix describes the function and capability of a properly implemented and enhanced “radar plot” type of diagram. (These are also known as polar plots or spider plots.) Since it is a somewhat unusual element, many people overlook its powerful ability to show burgeoning abnormal situations. This element is designed to provide a graphical pattern recognition overview of a complex multivariable processes. The process shape changes dynamically as the process values change. This method of data presentation offers an extensive amount of dynamic information in a single display element. This sounds complicated – but it isn’t.

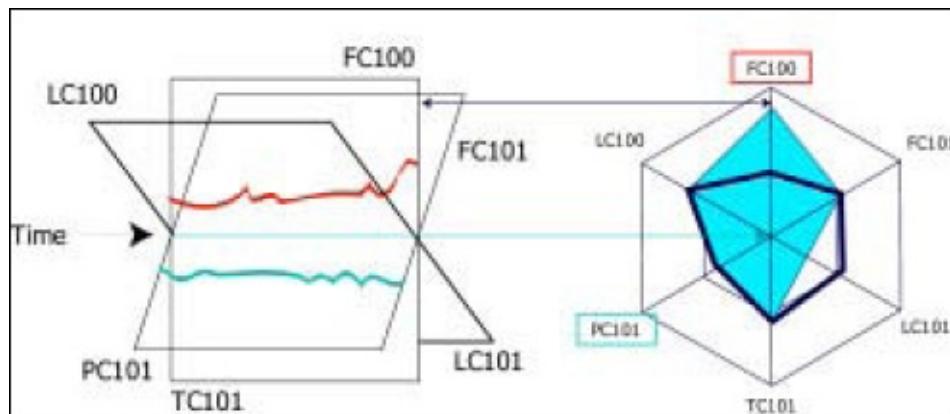


Figure A3-1: The Concept of a Time-varying Multivariable Display Mapped into a 2-D Space
Some DCSs have the native ability to build a limited version of a radar plot type of display element (and some do not). PAS has created a variety of this display element adding many desirable features. It is called the PRO Display element (Pattern Recognition Object). The PRO element is based on the concept that the retention power of the human brain is far greater for shapes and colors than for a set of numbers.

The PRO element produces a polygon shape obtained by plotting each parameter’s present value on a separate plane with a common time axis, which is then viewed laterally. The concept is depicted in Figure A3-1.

A traditional trend displays process measurements against time. It quickly

becomes difficult to simultaneously display and trend many different parameters in a cohesive way. More than four to six traces on a single trend usually become confusing rather than informative.

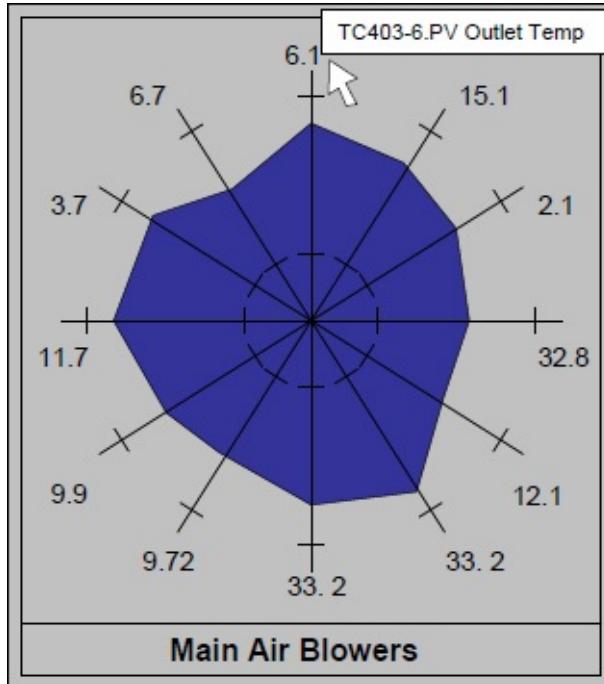


Figure A3-2: A PRO Display Element

In Figure A3-2, twelve different, but associated, process parameters are displayed simultaneously (Seventeen is a practical limit). By plotting the values simultaneously and building a polygon, a shape results. Each such shape becomes a distinct pattern the user will begin to identify as a specific plant state. Bars on each axis indicate proper operating range for the current plant state. The current value of each parameter is shown at the edge of the polygon.

The PRO type of data presentation has many benefits.

- Provides effective graphical overview of simultaneous process conditions
- Includes multiple process values
- Provides consistent patterns for normal operations and at-a-glance recognition of abnormal situations
- Maximizes use of space on a display since it is compact
- Captures and saves plant process condition patterns for future retrieval
- Recalls pre-captured patterns and superimposes them under real time data
- Shows either process values or deviation from a predefined “normal”

operation” set or from a current “snapshot.” In deviation mode, any change will become quickly apparent.

- Display of Alarms - When any of the included measurements goes into alarm, the shape changes color based upon the highest alarm priority in effect. The particular reading(s) in alarm are highlighted.
- Value Identification - The name of each individual sensor can be shown, hidden, or appear as a “tooltip” manner, as in Figure A3-2.
- Rate-of-Change Indication - When values begin changing rapidly, an arrow is displayed indicating the magnitude and direction of the change.
- Variability Indication - Range bars indicate the extent each parameter has varied in a predefined time period.

The values can be scaled so normal operation produces a circular shape. Humans recognize shapes and colors much faster than complex set of numbers.

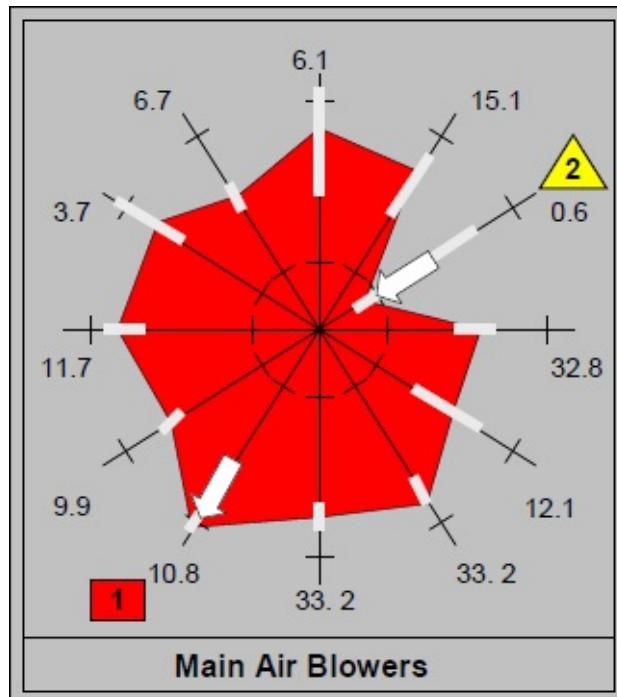


Figure A3-3: PRO Display Element with Alarms, Range Bars, and Rate-of-Change Indicators

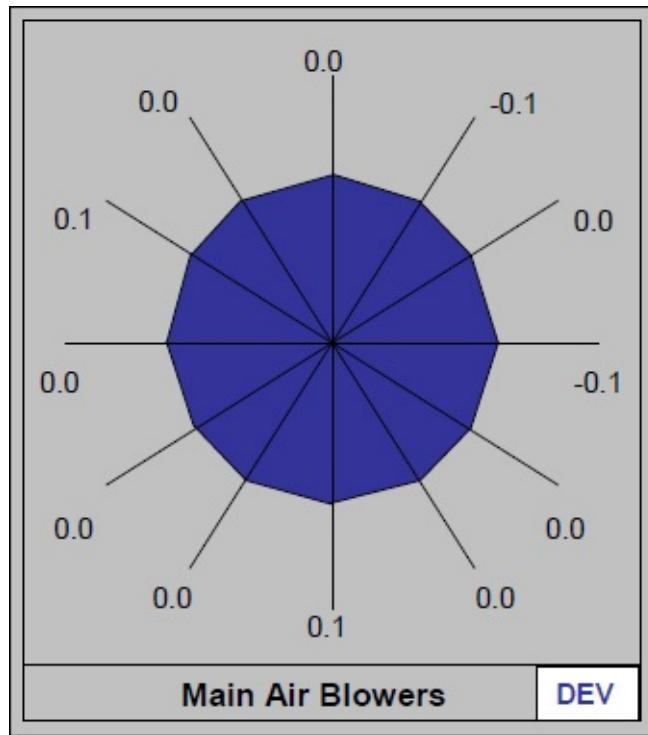


Figure A3-4: PRO Display Element in Deviation Mode Desirable features for this type of display element include:

- Configurable component colors
- Indication of Alarm colors by priority
- Configurable line thickness
- Configurable labeling of chosen parameters (on-off toggle or tooltip)
- Configurable value movement arrows with deadband
- Configurable variable range and range bars

A properly implemented radar plot or enhanced PRO element should be in the toolkit of every High Performance HMI designer.

Appendix 4:

A Brief Overview of Alarm Management

Poorly performing alarm systems negatively impact reliability and production. They can interfere with, rather than assist, the operator in handling an abnormal situation. This appendix briefly covers the origin of the problem, its nature, and a seven-step methodology for significant improvement of alarm systems. All of the topics mentioned here are covered in depth in *The Alarm Management Handbook – A Comprehensive Guide*, available at www.pas.com and on www.Amazon.com.

The Problem

The quick and accurate response to a well-designed alarm results in continued production and profitability. However, the overlooking of an important alarm in a poorly designed and overloaded alarm system can result in equipment shutdown, damage, and loss. This effect has been demonstrated many times.

Abnormal situations impacting production vary from minor upsets to full shutdowns. Proper abnormal situation mitigation can make the difference between experiencing a low impact upset instead of a catastrophic accident. A proper alarm system can make the difference. Timely detection, assessment, and response to an alarm are critical to the success of an operator in keeping a process running. With available technologies and proven work processes, steps can be taken today to significantly improve the robustness of a process operation during an abnormal situation.

The Alarm System – a Problem and a Solution

The DCS alarm system is a well recognized problem area. A proper and effective alarm system should always act to assist the operator in handling an abnormal situation. It is a key technology for this purpose. Instead, we find overloaded, poorly performing alarm systems which would better serve the operator if they were actually turned off during abnormal conditions. These alarm systems often become a source of confusion and exacerbate the situation,

lessening an operator's ability to focus on recovery.

Poorly performing alarm systems have been identified by regulatory agencies as significant contributing factors to several major accidents.

Distributed control system (DCS) alarm problems appear in various forms. Some of the most prevalent alarm problems include the following.

- **Alarm floods** are a prevalent problem, wherein an operator may experience hundreds of alarms within a few minutes of a minor upset, and consequently miss detecting critical alarms as a result.
- **High continuous alarm rates** are common. Rates are often far above the ability of an operator to handle. Hundreds to thousands of alarms must be ignored each week in such a system, with no guarantee the “right” ones are always ignored.
- **Improperly suppressed alarms**, without records or notifications, are a common problem and pose a risk to operations. We often find improperly suppressed critical alarms.
- **Chattering and similar nuisance alarms** make detection of valid alarms much more difficult and more likely to be missed. This can make an upset condition become much worse or last much longer.
- **Stale or long-standing alarms** clutter the operator’s view of the overall situation.

How Did We Get Here?

The alarm problem is a symptom of a broader issue related to human factors in the modern control room. With the advent of the DCS and all its known benefits, came an unintended consequence of limiting the operator’s ability to effectively manage abnormal situations.

The people who implemented these systems often lacked knowledge of proper human factors related to designing an effective alarm management system. It is common to see alarms set arbitrarily and inconsistently.

In the DCS, the addition of an alarm has no direct cost. Alarms are often configured and enabled by default. The result is massive over-configuration of alarms. Additionally, many alarm systems lack proper management-of-change control. In many control rooms, the operators are allowed to change alarm

settings at will and without documentation or proper engineering design considerations. This is often overlooked as an issue in many operating companies.

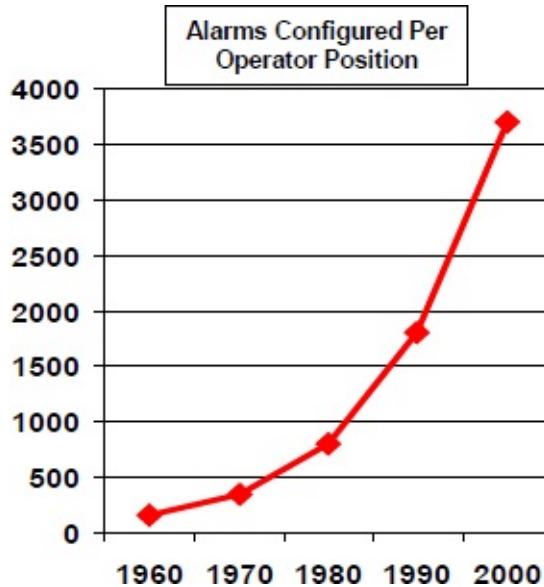


Figure A4-1: Exponential Growth of Configured Alarm Counts per Operator

Prior to the DCS, and with the wall-mounted instrument panel, the operator typically had around 50 “lightbox” alarms to inform him of events requiring corrective action. The alarm panel was always visible and the light arrangement became practically seared into the memory of the operator. Being expensive to implement, alarms were carefully chosen. Various upsets produced recurring patterns in the instruments and the lightbox identifiable to the experienced operator. The state of the overall operation, “the big picture,” was discernable at a glance.

The migration to the DCS overlooked the big picture and pattern recognition benefits of a wall-mounted instrument panel. Today, it is not at all unusual to see a single operator console configured to have 3,500+ configured alarms. The alarm events are generally presented in a tabular alarm summary display and are often confusing due to the limited amount of real estate provided on a DCS screen. It is not unusual to have to call up 4 different screens to investigate an alarm and take corrective action. Without careful and proper design of the human-machine interface, the DCS will not provide the operator with the big picture.

The operator interface is one of the most critical human factors in the safe operation of a process. The improvement of a poorly performing, overloaded alarm system can be accomplished using a straightforward, seven-step methodology outlined below.

Seven Steps to Creating a Highly Effective Alarm System

Step 1: Create and Adopt an Alarm Philosophy

An Alarm Philosophy is a comprehensive document providing best practices guidelines for proper definition, design, reengineering, implementation, and ongoing maintenance of a screen-based alarm system. It covers both new systems and modifications to existing systems. It is a critical success factor for an effective alarm system.

An alarm philosophy should be developed at each company and for each operating group through a rigorous process engaging a number of stakeholders – primarily operators, engineers, and management.

An experienced and knowledgeable facilitator is advisable in an alarm philosophy development effort to provide understanding of the industry best practices and create a common operational definition of terms. A single operating company is unlikely to have the wide-ranging experience and expertise desired in formulating a comprehensive philosophy.

Management endorsement of the final philosophy document is essential and it should be taken as seriously as a safety standards document.

It is essential for the alarm philosophy to include these basic principles:

- All alarms are created solely for the purpose of notifying the operator of events requiring operator action. Thus, events not requiring operator action shall not be allowed to produce alarms.
- Alarms must be produced upon abnormal situations only, not from normal situations. Therefore, the alarm system is not used to convey status information.
- Alarms should be based upon the best indicator of the situation's root cause and not duplicate other alarms.

The modern DCS alarm system is often misused for purposes violating the above principles.

Step 2: Alarm Performance Benchmarking

Existing DCS-based alarm systems should be benchmarked against industry best practices. A benchmark:

- Establishes current performance – essential to defining an improvement plan.
- Provides for a data-driven decision process for management approval and funding for an improvement project.
- Provides a baseline against which project gains can be measured.
- Identifies “bad actor” alarms, which often provide significant improvement opportunities with relatively minimal cost and effort.

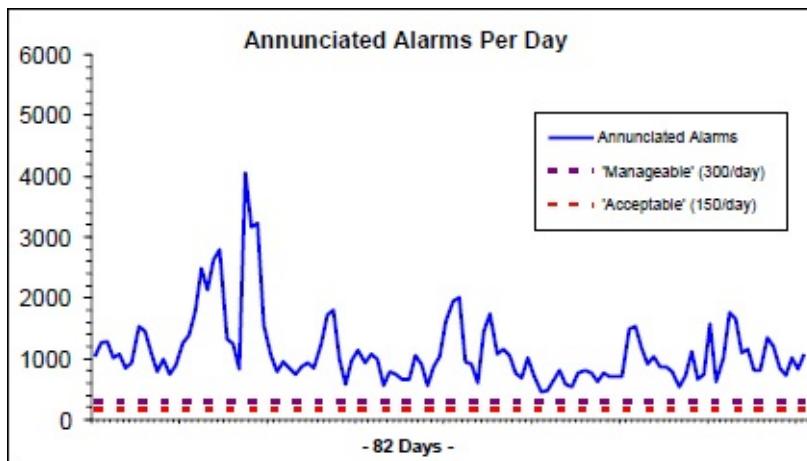


Figure A4-2: Rate of Alarms per Day far Exceed Manageable Levels

Benchmarking a system requires analysis of the alarm events and alarm system configuration for a recent two-to-six month period. The following analyses are typically included in a benchmark:

- Overall alarm rates per operating position
- Alarm flood periods, magnitudes, and characteristics
- Nuisance alarms (such as chattering, fleeting, and stale alarms)
- Controlled and uncontrolled alarm suppression
- Alarm priority distribution
- Alarm configuration analysis, including Management of Change (MOC)

- Operator action analysis

Step 3: “Bad Actor” Alarm Resolution

Nuisance or “bad actor” alarms are a common problem in most alarm systems. With enough bad actors, an alarm system is rendered virtually useless and important or critical alarms are lost in the “sea” of bad actor alarms. This situation can have adverse economic, environmental, or safety consequences.

Usually the “top 20” most frequent alarms comprise anywhere from 25% to 95% of the entire system alarm load. If those alarms are dealt with successfully, then major system improvement will occur and with comparatively little effort.

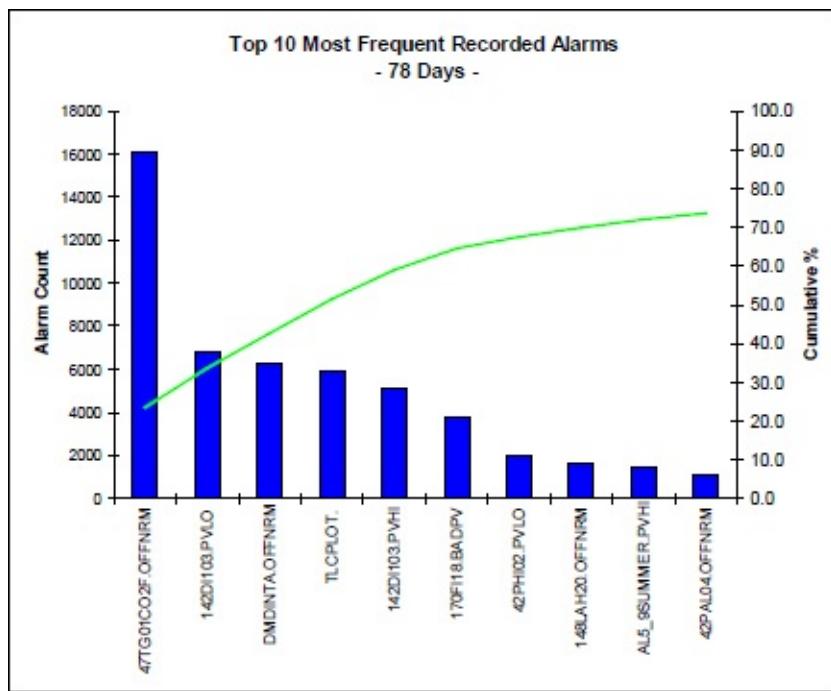


Figure A4-3: Resolving the Top 20 “Bad Actor” Alarms Often Leads to Significant Improvement

There are well-defined methods for solving bad actor alarms, but many control engineers do not know about them. Use of these methods usually results in a more than 50% reduction in a system’s alarm rate, with comparatively low cost and low effort. The methods involve the application of:

- Proper alarm settings
- Proper alarm deadbands (for both analog and digital sensors)
- Alarm time delays (both ON-Delay and OFF-Delay)

- Process value filtering
- Proper point ranging and measurement clamping

Step 4: Alarm Documentation and Rationalization

Alarm Documentation and Rationalization (or “D&R”) is an effective, consistent, and logical methodology for determining, prioritizing, and documenting alarms. D&R involves a thorough re-examination of the alarm system, which solves many problems by removing the guess work and making the design and engineering of an alarm system deterministic.

The basic methodology of a D&R is simple. For each point on the system, a team of knowledgeable people do the following:

- Discuss each configured and possible alarm on the point
- Verify whether any alarm should exist at all
- Verify all alarms represent abnormal situations requiring operator action
- Verify an alarm does not duplicate another similar alarm
- Document the alarm causes, verification steps, consequences, and operator response
- Determine the proper trip point for the alarm based on examination of:
 - Process history
 - Relevant operational procedures
 - Equipment and safety system specifications
- Determine and highlight the need for special handling of an alarm, e.g., special logic, graphical interface, etc.
- Determine the proper priority of each alarm as a combination of:
 - The severity of the consequences (Safety, Environmental, Economic) if the alarm receives no response
 - The time available for the operator to successfully respond to the alarm

Impact Category	NONE	MINOR	MAJOR	SEVERE
Safety	No injury or health effect	Alarms where operator action is the primary method by which harm to a person is avoided shall be configured at the highest DCS priority		
Environmental	No effect	Minimal exposure. No impact. Does not cross fence line. Contained release. Little, if any, clean up. Source eliminated. Negligible financial consequences.	Exposed to hazards that may cause injury. Hospitalizations and medical first aid possible. Damage Claims. Contamination causes some non-permanent damage.	Uncontained release of hazardous materials with major environmental impact and 3 rd party impact. Exposed to life-threatening hazard. Disruption of basic services. Impact involving the community. Catastrophic property damage. Extensive cleanup measures and financial consequences.
Costs or Value of Production Loss	No loss	Event costing <\$10,000, notification only at Department Head level	Event costing \$10,000 - \$100,000, notification at Site Manager level	Event costing >\$100,000, notification above Site Manager level

Time Available to Respond
> 30 Minutes
10 - 30 Minutes
3 - 10 Minutes
<3 Minutes

Alarm Priority Determination				
	Severity of Consequences			
Time Available	None	Minor	Major	Severe
> 30 Min	No Alarm	Re-engineer the Alarm for Urgency		
10 - 30 Min	No Alarm	LOW	LOW	HIGH
3 - 10 Min	No Alarm	LOW	HIGH	HIGH
<3 Min	No Alarm	HIGH	EMERGENCY	EMERGENCY

Figure A4-4: Best Practice Recommendation for Alarm Priority Determination

In a proper Alarm Philosophy, alarms protecting people from harm are normally defaulted to the highest priority. This covers such elements as ambient toxic and flammable gas detectors, safety shower actuation alarms, fire alarms, and similar alarms, where operator action is needed to reduce the risk to people. In reality, most alarms are set for environmental or economic reasons since automated shutdown systems are usually provided to take the process to a safe state when operator intervention is unsuccessful.

A proper D&R is a significant effort involving, at minimum, representatives from operations, engineering and safety groups. For maximum economy and effectiveness, it is important to complete the first three of the seven-step methodology prior to beginning D&R. Proper software and an experienced and knowledgeable facilitator significantly improve the productivity of the D&R

team.

Step 5: Alarm System Audit and Enforcement

DCS alarm systems are notoriously easy to change. Lack of proper management of change (MOC) is one of the root causes for poorly performing alarm systems. The significant investments expended in redesigning an alarm system must be protected through a rigorous MOC process.

Paper-based MOC systems have been shown to fail in effectively maintaining the integrity of the alarm configuration. Alarm audit and enforcement is a software function. It periodically and automatically checks for changes from the proper settings, as contained in the Master Alarm Database. The software reports such changes and optionally restores the system to the proper settings.

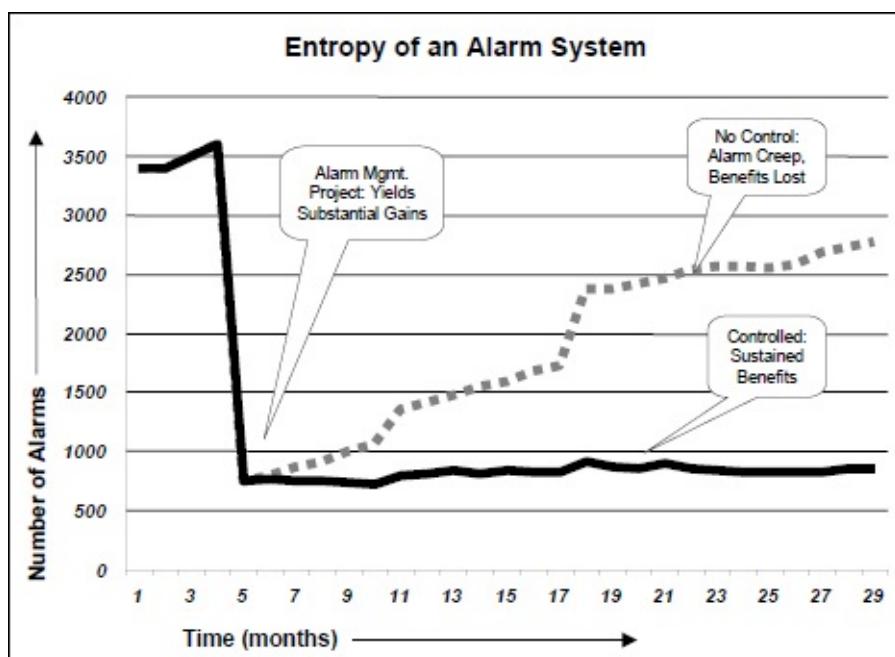


Figure A4-5. Alarm Systems Degrade Over Time without Proper MOC

Step 6: Real-Time Alarm Management

Process plants are dynamic and have multiple operating states requiring different alarm settings for each state. Alarms in control systems are inherently designed to support a single operating state and therefore become useless outside the normal steady state.

For optimum performance, alarm systems should be altered in real time under certain defined and controlled conditions to support each operating state. The need is expressed in three related functions:

- Alarm shelving
- State-based alarming
- Alarm flood suppression

Alarm Shelving: Malfunctioning alarms may need to be suppressed for temporary periods. Alarm Shelving supports this need in a controlled manner, where they are always known and never “forgotten.” Improper and uncontrolled alarm suppression is a rampant problem on DCSs throughout industry.

Alarm Shelving software must work in proper coordination with other dynamic alarm techniques such as the audit & enforce software, state-based alarming capabilities, and alarm flood suppression.

State-Based Alarming: Process equipment often has several “normal,” but differing, operating states. DCS alarm capabilities do not generally accommodate this fact.

A few common state examples include:

- Running/Not Running
- Startup/Shutdown
- Full Rates/Half Rates
- Both Trains Running/Single Train Operation

State-based alarm software reads various process values from the DCS to determine the current operating state, including operator confirmation. It then makes the desired, predetermined modifications to alarm trip points, priorities, and other settings to match the current operating state.

There are many guidelines and precautions for the proper implementation of a state-based alarm system.

Alarm Flood Suppression: Alarm floods are sustained periods of high alarm rates. Alarm floods can make a difficult operating situation much worse and they are common. In a severe alarm flood, the system becomes a hindrance to the

operator rather than being a useful tool. The risks associated with a major process upset or an accident is much higher during an alarm flood.

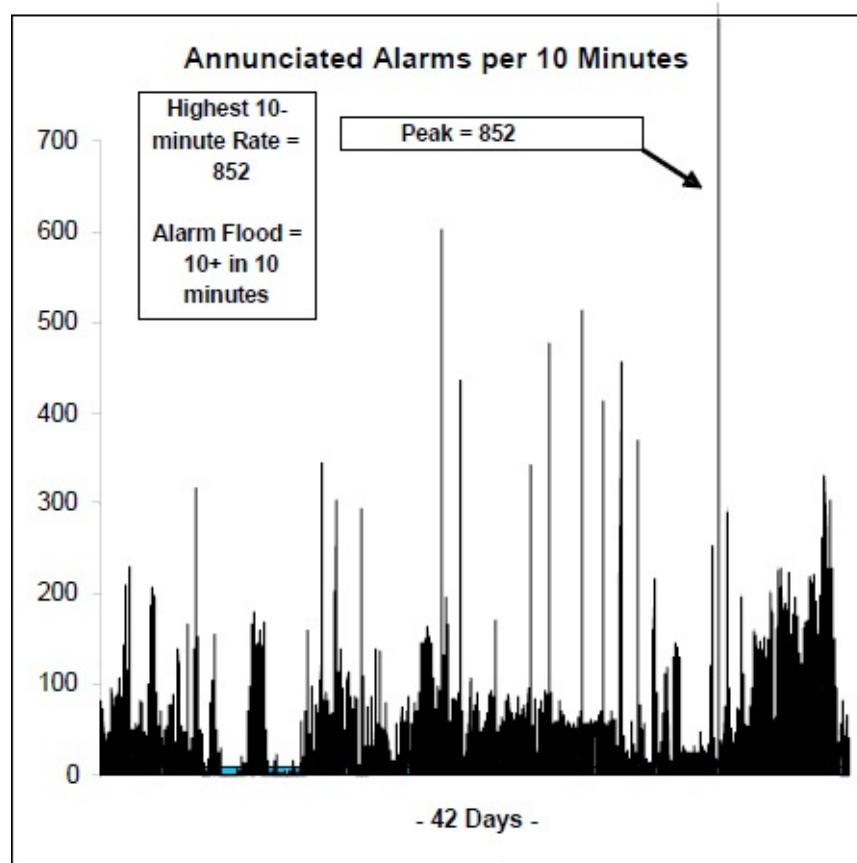


Figure A4-6: Alarm Floods Render the Alarm System Useless to the Operator

Flood Suppression is the dynamic management of pre-defined groups of alarms based on triggering events. The most common cause of an alarm flood is the inadvertent shutdown of a piece of equipment. The expected, diagnostic-type alarms accompanying such events are temporarily suppressed, allowing the operator to better respond to the process upset caused by the equipment loss.

Step 7: Control and Maintain Alarm System Performance

Processes and sensors change over time. Alarms that have never been a problem will become nuisances. An effective process for ongoing monitoring of alarm system performance is needed.

Every control system should have a named Alarm Management System Champion whose role will be to maintain the integrity and performance of the

alarm system. Alarm System Key Performance Indicators (KPIs) should be developed and routinely reported to key stakeholders such as operators, engineers, and managers. Modern alarm analysis software, such as *PlantState Suite* offered by PAS, makes this easy, by automatically and periodically publishing results accessible from a company intranet. Reports should contain the following:

- Alarm Rates per console (per day and per 10 minutes) vs. target levels
- Percentage of time alarm system exceeds target rates
- Frequency analysis for the most frequent alarms and chattering alarms, showing top 10
- Alarm flood analysis, frequency and magnitude
- Alarm priority distribution
- Nuisance alarms, such as chattering
- Uncontrolled alarm suppression
- List of long standing (stale) alarms
- Nuisance Alarm List and progress made on those alarms
- Action plans to improve performance

It is advisable to create special reports after major upsets or incidents, such as spills, detailing the alarm system performance prior, during, and after the incident. Frequency of the alarm performance reports should be tailored to the specific culture of the company and the individual stakeholders.

Summary

Overloaded and malfunctioning alarm systems are common in the processing industries. Poorly functioning alarm systems continue to negatively impact the profitability, safety, and environmental performance of production and processing plants worldwide. The good news is that alarm problems can be identified, isolated, and solved through proven alarm management methodologies.

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