

# 1 Human Machine Interface

"A picture is worth a thousand words. In interface is worth a thousand pictures."

Ben Shneiderman

Operator is responsible for operating a process manufacturing facility safely, and efficiently. Process observation can be done through operator's Human Machine Interface (HMI) providing the second-to-second and minute-to-minute pulse of equipment performance, process integrity, product quality and operational effectiveness.

The combination of changing work process, technology and people is driving the HMI to a new level of performance. The operator's GUI (Graphical User Interface) is becoming a core element of an overall plant operations and situation awareness strategy [1].

## 1.1 Human role

We use a man who is skilled to assess the situation, make changes, choose the solutions.

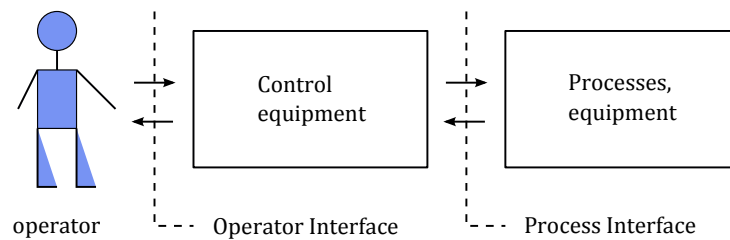


Figure 1: Human role

Most operator control of a process is done through the HMI. Every system's HMI becomes a customized implementation: so processes can be run as safely and profitably as possible.

The arrival of the DCS (Distributed Control Systems), where process signals are monitored by a computerized structure and physical instruments were replaced with software displays.

Some industrial accidents where a poor HMI was cited as a contributing factor. That happened due to improper alarm management and the lack of the DCS HMI to provide the operators with an overview of the process conditions.

**If you think safety is expensive, try having an accident!**

Operator is an important person, the quality of the production or does factory work with profit or loss depend on his/her work.

Table 1: Operator roles

Operator	Question	Interface help
Observes	What is the situation?	Show
Reacts	Is there a problem?	Help
Controls	What is the plan?	

### How to use a human?

Use humans the right way, make work easy and convenient:

- Use the redundancy of information, repeat messages;
- Trust operator with reasonable limits;
  - permit some errors and to take responsibility (let him/her study!)
- Load the operator with wise measures;
- Advice him/her (help and comment)
- Give the right of final decision (except SAFETY!)
- Leave a simple operator-functions, automate the complex ones.
- Train and choose the people.

Something is wrong if operator 99% of the time naps and 1% of the time is in panic.

Duties distribution between operator and the automation can be such a system:

- Informs, indicates a problem, *does nothing*

Shows the operations:

1. all the options
2. some important
3. one

- Informs, *performs if allowed*
- Informs, waits until disabled, *performs*
- *Performs automatically*

1. notifies

2. notifies if asked

- Ignores the operator

Human integration to the control system:

1. What kind of information to provide?
  - What is important?
  - Does he/she able to apprehend? Does understand?
2. What is allowed to do?
  - What are decisions? final decision
3. How to realize all of this?
  - notifications, alarms, trends, charts, windows, figures, etc.

Operator's request: "Give me information, which is necessary such way that I can understand it. Help to decide!"

Operator interface always has a process window (see Fig. 2)

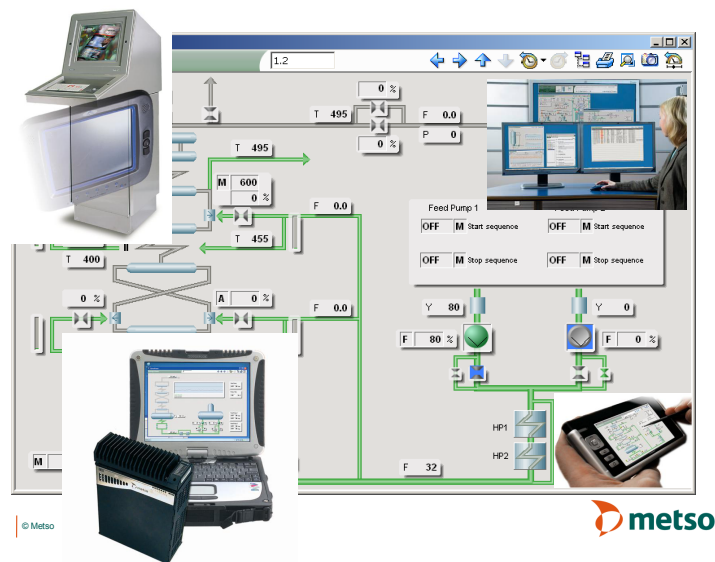


Figure 2: HMI

Person always reacts after the notification through a window.

Table 2: HMI vs Operator tasks

HMI tasks	→	Operator tasks
collect		assess the situation
process		avoid deviations
analyze		detect obstacles
provide data		make decisions

## 1.2 SCADA

Supervisory Control And Data Acquisition (SCADA) by containing the word “control,” implies two-way communication (measurement and control) between the master location and the remote location [?].

HMI principles:

1. Do not hide problems
  - Detect and Report problems;
  - Report if automation deals with problems.
2. Extract and provide an important: do not confuse the operator with colors and animation.
3. Load the operator: when the system is working properly over a long period the operator must not to get accustomed do not observe the process.

HMI access, in general there are four levels:

**No access** Provides very restricted access to the operator stations (OCP). For example, it may enable personnel to call up and observe overview displays only, but not permit any interaction with the database. This level of access is that in which the system should be left when unattended.

**Operator** Provides full access to the functionality of the OCP (Operators Control Program). For example, it enables most displays to be called up, and permits routine interaction with control functions. For example, changing set points, switching loops between auto and manual modes, acknowledging alarms, starting sequences, etc, would all be permitted.

**Supervisor** This is the same as for the operator but, in addition, provides access to facilities for editing schedules, batch logs, etc. It enables access to restricted management information displays.

**Engineer** Provides full access to all OCP and ECP (Engineers Control Program) functions. It also provides full access to all displays, including system diagnostic displays [2].

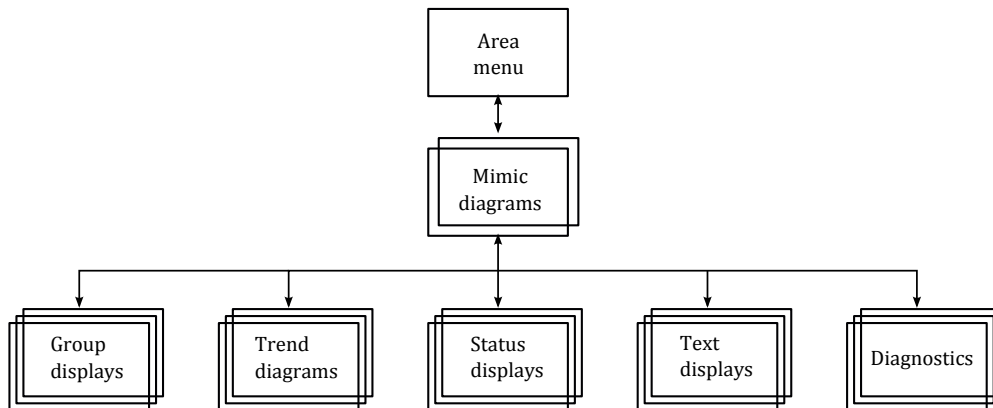


Figure 3: Main types of screen displays [2]

It is usual to have menu displays at the top of the display hierarchy. Menu displays are normally organized on an area basis with, typically, one menu for a number of functionally related major equipment items (units). The function of menu displays is simply to provide access to other display types. These may be organized hierarchically, in which case mimic diagrams would be the next most significant. Otherwise, they would be organized laterally as indicated for the remaining display types. Every display within the system must have a unique reference name/number.

Detailed data should be used based on principle of progressive exposure:

1. Process Area Overview  $\Rightarrow$  situation awareness
2. Process Unit Control  $\Rightarrow$  ongoing process manipulation
3. Process Unit Detail  $\Rightarrow$  detailed examination
4. Process Unit Support and Diagnostic Displays  $\Rightarrow$  troubleshooting

The use of colors and special effects can considerably enhance the effectiveness of mimics.

For example:

- Colored lines to distinguish between process streams and utilities.
- Different width lines to emphasize the importance of different streams.
- Vertical bars to fill vessel shapes to convey a sense of level.
- Color changed to indicate valve status, such as black for closed.
- Flashing of symbols or vessel outlines to indicate a particular status.

- Pop-up message boxes to provide context sensitive information.

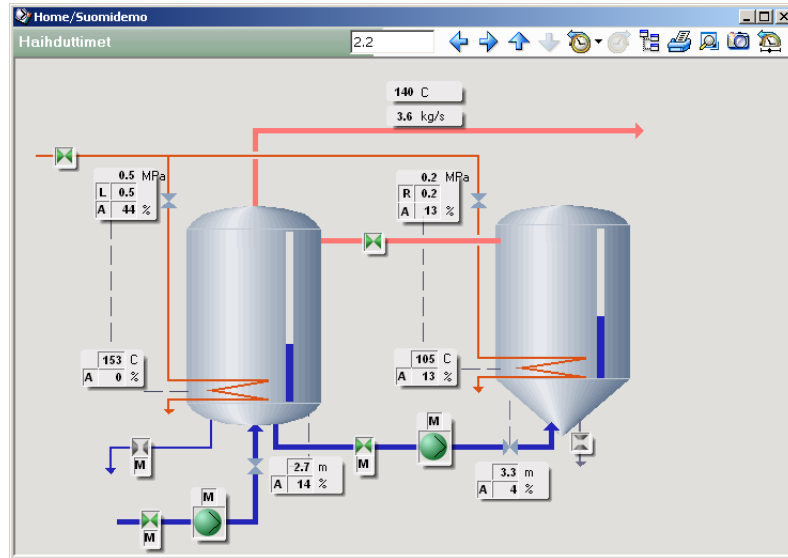


Figure 4: Process Area

### Operating the Motor/Pump/Valve

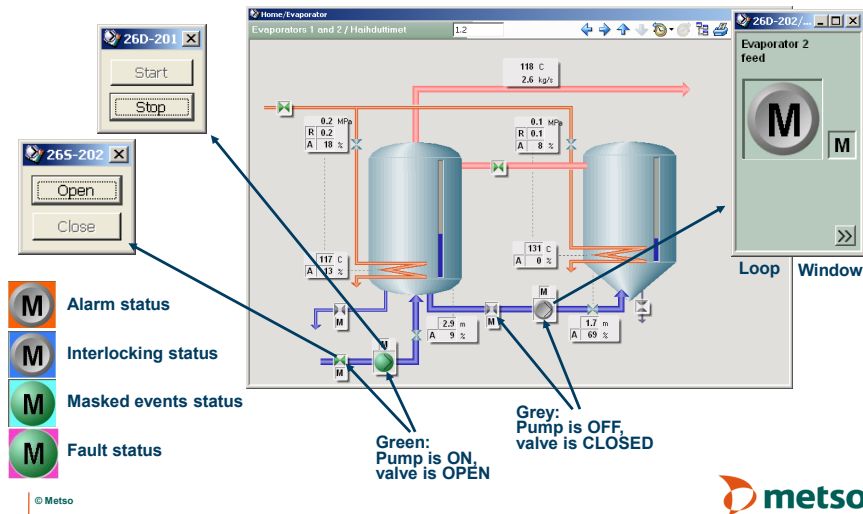


Figure 5: Status indicators

## Alarm List

Acknowledge Page (max 89 pages)

Compress List (active and unacknowledged alarms will remain on the page)

Time display check box (local time / Coordinated Universal Time)

Time	Priority	nbr.	Area	Tag	Tag Description	Event	Acknowledged	Inactivated
08-04-15 12:38:09.687	▲▲▲▲	700	P REFINE	26PIC-101	Evaporator 1 press	MEAS. < LLL	08-04-15 12:40:03.031	
08-04-15 12:38:09.796	▲▲▲▲	700	P REFINE	26PIC-305	Cooling water press	MEAS. < LLL	08-04-15 12:42:25.062	
08-04-15 12:38:10.453	▲▲▲▲	700	P REFINE	26TIC-111	Evaporator 1 temp	MEAS. < LL	08-04-15 12:40:02.046	
08-04-15 12:38:10.453	▲▲▲▲	700	P REFINE	26TIC-111	Evaporator 1 temp	MEAS. < LLL	08-04-15 12:40:01.531	
08-04-15 12:38:34.171	▲▲▲▲	700	P REFINE	25P-100N	Feed pump	Release on 2	08-04-15 12:40:00.521	
08-04-15 12:38:34.234	▲▲▲▲	700	P REFINE	25P-100	Feed pump	Release on 1	08-04-15 12:40:00.000	
08-04-15 12:38:37.781	▲▲▲▲	700	P REFINE	PT2-2104	Hydr supply pressure	MEAS. < LL	08-04-15 12:42:25.062	
08-04-15 12:38:37.781	▲▲▲▲	700	P REFINE	PT2-2104	Hydr supply pressure	MEAS. < LLL	08-04-15 12:42:25.078	
08-04-15 12:41:27.281	▲▲▲▲	700	P PAPER	SNL12P002	Carrier Air Pres Dif	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:30.687	▲▲▲▲	700	P PAPER	SNL13P002	Carrier Air Pres Dif	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:30.953	▲▲▲▲	700	P PAPER	SNL20F001	Coal Mass Flow	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:34.250	▲▲▲▲	700	P PAPER	SNL20P007	Mill Oil Pressure	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:34.312	▲▲▲▲	700	P PAPER	SNL30P007	Mill Oil Pressure	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:34.406	▲▲▲▲	700	P PAPER	SNL40P007	Mill Oil Pressure	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:42.312	▲▲▲▲	700	P MPULP	SNA02L001	Drum Level	MEAS. > HL	08-04-15 12:41:55.375	
08-04-15 12:41:53.984	▲▲▲▲	700	P PAPER	SNL14P002	Carrier Air Pres Dif	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:54.250	▲▲▲▲	700	P PAPER	SNL30F001	Coal Mass Flow	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:41:54.296	▲▲▲▲	700	P PAPER	SNL40F001	Coal Mass Flow	MEAS. < LL	08-04-15 12:41:57.375	
08-04-15 12:42:02.406	▲▲▲▲	700	P CHEMI	SNR01Q001	Flue Gas Oxygen	MEAS. > HL	08-04-16 09:12:55.843	
08-04-15 12:42:02.453	▲▲▲▲	700	P CHEMI	SNR02Q001	Flue Gas Oxygen	MEAS. > HL	08-04-16 09:12:55.843	
08-04-15 12:42:06.406	▲▲▲▲	900	P AREA64	SNZ00U201XU	Flame	OFF	08-04-16 09:12:55.843	
08-04-16								
08-04-16 10:02:41:609	▲▲▲▲	700	P REFINE	25FC-100	Pressure control	MEAS. < LLL	08-04-16 10:16:11.765	08-04-16 10:15:12.609
08-04-16 10:02:41:609	▲▲▲▲	700	P REFINE	25FC-101	Ref. 2 outlet valve	MEAS. < LLL		
08-04-16 10:02:41:609	▲▲▲▲	700	P REFINE	25FC-100	Ref. 1 outlet valve	MEAS. < LL		
08-04-16 10:04:03:609	▲▲▲▲	700	P REFINE	25FC-101	Ref. 2 outlet valve	MEAS. < LL	08-04-16 10:16:09.781	08-04-16 10:15:18.609

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-Select the related picture with double click  
-You can browse alarms with scroll bars

Figure 6: Alarms

- Animation is limited and used for abnormal situations. No gratuitous animation:
  - spinning pumps,
  - moving conveyors,
  - splashing liquids.
- Depiction of process values is made in the context of information (not just numbers on the screen).
- Important information and key performance indicators have embedded trends.
- Limited use of colors. Alarm colors are used only display alarms.
- Display access requires a minimum number of keystroke actions.
- Display elements have consistent visual and color coding.

## 2 High Performance HMI

### HMI Evaluation Methodology

1. Operators can easily track the process in normal conditions
  - sufficient process information.
2. Operators are confident they can effectively monitor abnormal or upset conditions. Operators information system performance in an abnormal situations.
3. During an abnormal, upset or emergency conditions operator can track process using only the HMI.
4. During an abnormal situations the engineers and supervisors must not interrupt the operator by manipulating the operator's displays or making their own adjustments to the process.
5. Non-operating tasks re not required of the operator during abnormal conditions. Whenever there are critical process activities demanding the operator's attention, there must be no unnecessary tasks, duties or disturbances.
6. The HMI must meet all of the major criteria
  - General graphic factors,
  - Navigation factors,
  - Workstation factors,
  - Alarm management factors.

### 2.1 Data

#### Data is not information!

There is a big difference between data and information. Most poorly constructed displays show a lot of data, but little information.

Illustration of the difference between data and information is given below [1].

Poor design: just data.

What can you say about cat's health? Is it sick? If you are not veterinarian no knowledge can be obtained from this Table 3.

Imagine that you observe complex process with dozens of such kind of tables. Can you be sure that in abnormal situation it will be possible to track process and make right actions in order to return process to the normal state.

Slight improvement: general range.



Table 3: Cat's blood test: view 1

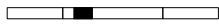

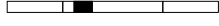



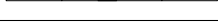
Test	Result
HCT	31.7%
HGB	10.2 g/dl
MCHC	32.2 g/dl
WBC	$9.2 \times 10^9 /l$
GRANS	$6.4 \times 10^9 /l$
L/M	$2.7 \times 10^9 /l$
PLT	$310 \times 10^9 /l$

Table 4: Cat's blood test view 2

Test	Result	Range
HCT	31.7%	24.0 – 45.0
HGB	10.2 g/dl	8.0 – 15.0
MCHC	32.2 g/dl	30.0 – 36.0
WBC	$9.2 \times 10^9 /l$	5.0 – 18.9
GRANS	$6.4 \times 10^9 /l$	2.5 – 12.5
L/M	$2.7 \times 10^9 /l$	1.5 – 7.8
PLT	$310 \times 10^9 /l$	175 – 500

Examination of the Table 4 will give you a slight idea about the current situation. That knowledge is based on the position within the range.

Table 5: Cat's blood test view 3

Test	Result	Range	Indicator Low-Normal-High
HCT	31.7%	24.0 – 45.0	
HGB	10.2 g/dl	8.0 – 15.0	
MCHC	32.2 g/dl	30.0 – 36.0	
WBC	$9.2 \times 10^9 /l$	5.0 – 18.9	
GRANS	$6.4 \times 10^9 /l$	2.5 – 12.5	
L/M	$2.7 \times 10^9 /l$	1.5 – 7.8	
PLT	$310 \times 10^9 /l$	175 – 500	

Graphical indicators give information at glance, see Table 5. The individual numbers are not

even needed as long as the indicators are in the proper range.

Information is *data in context made useful*.

### Analog representation

Humans are analog beings. Interpreting digital display takes longer and requires more mental effort. Graphic panels could be displayed for several seconds on screen and viewer understands immediately the current situation.

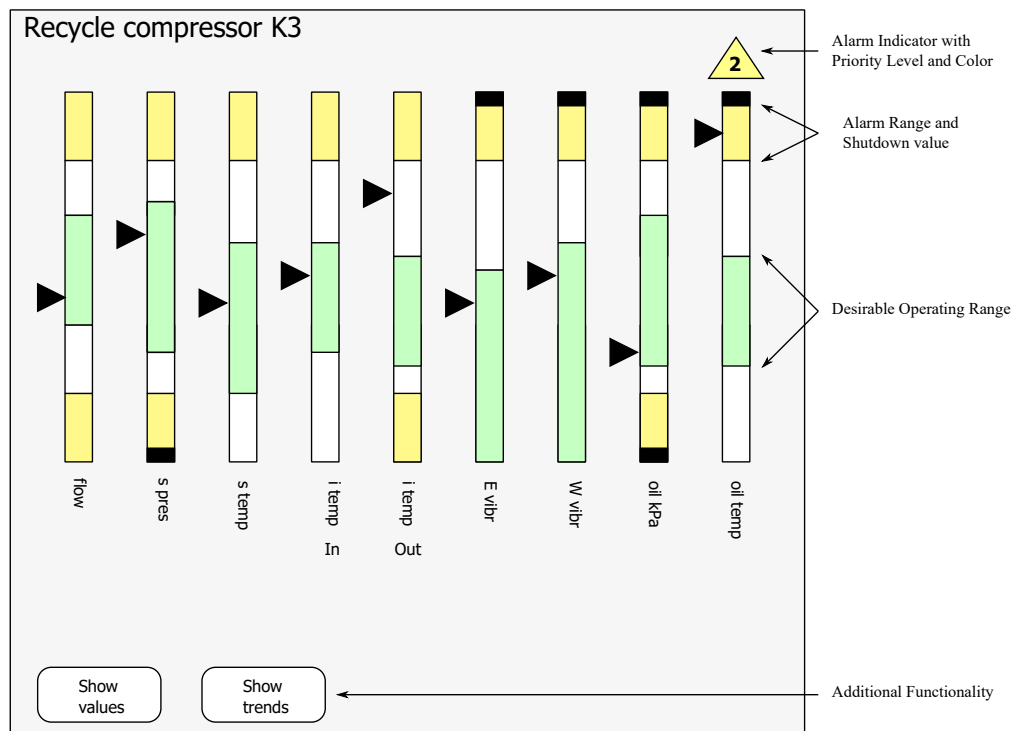


Figure 7: View of a Compressor

Fig. 7 depicts moving analog indicators. Operating status is visible at glance. If all indicators are inside the green region process is at the normal state.

### Trends

Trends are essential for properly presenting important data. *Important values should be trended!*

A much better solution than trending on-the-fly is to ensure every **Level 1**–Process Area Overview and **Level 2**–Process Unit Control have at least one trend of important values of the operation.

The information content of trends is far more valuable than depiction of many typical “P&ID” elements on graphics.

Let’s take a look at the following example:

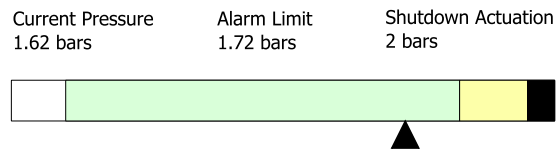


Figure 8: Current Situation

Operator only sees what is the current situation, but he cannot observe the general picture at all. In reality pressure was stable for a while, but began to rise an hour ago. And if this continues, it will reach the alarm point in a few minutes (Fig. 9a).

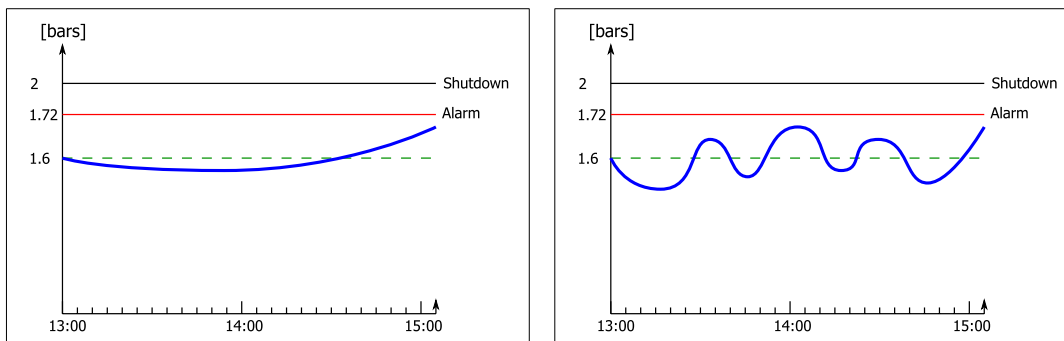


Figure 9: Trend showing: Slow Increase or Oscillation

On the opposite the pressure has been oscillating around the desired point with period of 30 minutes, but not getting up to the alarm point (Fig. 9b).

- The scale of Y-Axis should be a tight scale where meaningful change of value is immediately detectable (current value  $\pm 2 - 5\%$ ). Scale span values should be shown and adjustable.
- Normal process bounds, quality limits should be indicated.
- Manual adjustment by operator should be possible. “Re-trend” button should allow to return to the automatically-calculated values.
- Display of multiple traces should be consistently implemented [1].

**Controller:** A proper trend of controller will show process value, setpoint and controller output. Diagnosing controller problems and valve problems.

## 2.2 Colors

For HMI color usage is restricted for very specific reasons: drawing attention to important situations. Color choices and usage must be applied consistently throughout the entire project. Proper use of colors is a factor in making graphics easy to use and comprehend.

### Background Colors

Background color of display should be a light gray. This manages problems of:

- glare,
- contrast,
- color interference,
- fatigue.

Gray backgrounds have minimum interference with other color choices.

### Foreground Colors

- A minimum number of color should be used and quite sparingly.
- Bright intense color is used only in order to pay operator's attention to abnormal conditions.
- Color is used in conjunction with text, shape, filled/unfilled status, texture or similar aspect.

Color should not be used in an attempt to indicate the type of the material: cannot be achieved consistently though the whole project and memorized by the operators. Proves to be a *distraction*.

If the process running correctly, the screen should display little or no color.

### Process Vessels

- Interior: should be uniformly shaded without gradients.
- Shape: representative but without much details.
- Size: should be relative to the process importance and relate to physical size.

### Process Flow

- Process lines should be dark gray or black.
- Significance should be differentiated by thickness, not color.
- Use arrows to indicate flow direction on primary lines.

- There should be no more than 2 or 3 line types.
- Depicted consistently.
- Flow from left to right ( $\rightarrow$ ).
- Vapors flow up ( $\uparrow$ ) and liquids down ( $\downarrow$ )
- Process lines should enter and leave the screen in consistent ways (labels).

**Text**

- Amount of text minimized, but not eliminated.
- Font - **non serif**.
- Ensure consistency with abbreviations.
- Live values (changing) differ from static text. Live value (bold or dark blue)–static text (black).
- Values are presented with precision needed by the operator.

## 2.3 Alarms

Any value in alarm must be shown clearly and consistently.

- Color is related to alarm priority.
- Unacknowledged alarms should be distinguished from acknowledged alarms.
- If more than one alarm is in effect on value, the highest priority alarm should be indicated.

If possible separate diagnostic-type alarms from primary alarms.

**Diagnostic alarms:** indicate instrument malfunctions not solvable by operators and requiring maintenance attention.

Priority system:

1. Priority 1–Highest (Red);
2. Priority 2–2<sup>nd</sup>Highest (Yellow);
3. Priority 3–3<sup>rd</sup>Highest (Orange);
4. Priority 4–Reserved for Diagnostic Alarms (Magenta)

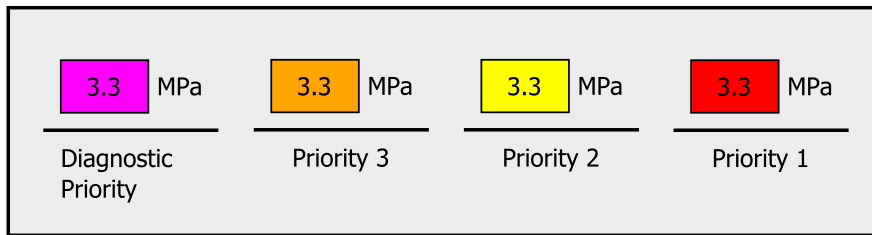


Figure 10: Method 1 (Not Recommended)

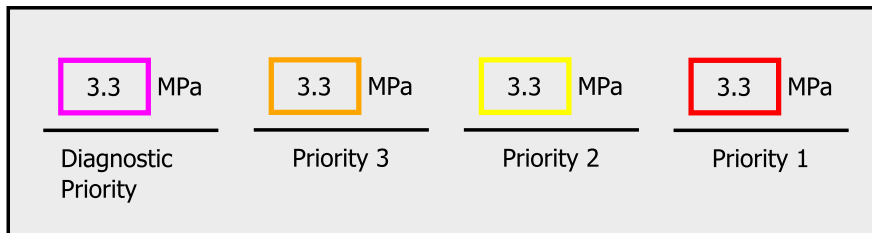


Figure 11: Method 2 (Not Recommended)

### Indication

For the acknowledge condition flashing of the solid block nor ensures that value is always visible.

Alarm priority is shown only by color and not redundantly coded, color-blindness can be a problem.

Problem: the specific type of alarm is not shown.

In the following method alarm types are coded into the separate alarm indication element.

In actual practice method 4 has significant problems:

- Coding can occupy a lot of space,
- Plus dozen more alarm types may be available.

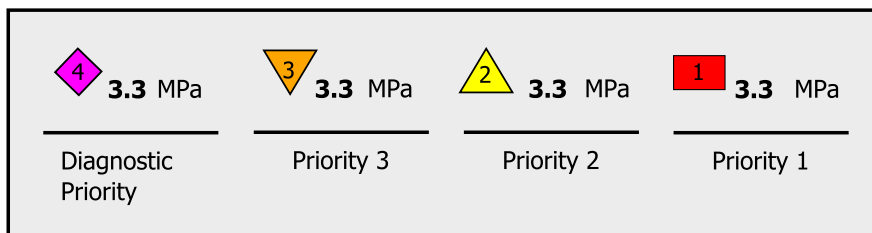


Figure 12: Method 3 (Recommended)

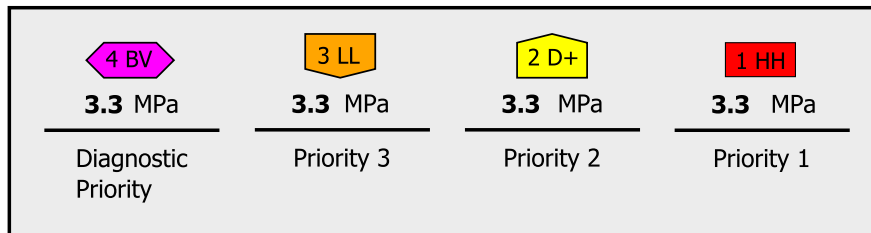


Figure 13: Method 4 (Not Recommended)

- Too much information [1].

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

Every alarm priority chosen should have its own unique alarm sound.

- Sound level should be enough for easy detection. A sound starting at lower level then rising can be very effective.
- It should be possible to turn off alarm sound for the lowest alarm priority during periods of high alarm loads. While visual notification should remain in place [1].

## 2.4 Elements

Develop standard shapes and sizes for equipment, instrumentation , interlock systems, etc.

### Controllers

Controller should be depicted as physical entity not as additional information to the controlled valve.

Effective depiction will show only four items (with more detail available):

1. Controller Process Value – current readings in Engineering Units.
2. Controller Setpoint – in Units of PV.
3. Controller output – expressed as Percentage (-5%–105%).
4. Controller Mode – Automatic (AUTO), Manual (MAN), Cascade (CAS), etc.

### Valves

Avoid tiny scales to show output percentage or variable shading. One-click access to the faceplate will reveal this information when needed to operator.

## Shutdown

Operators must be able to manually and quickly shut down operating equipment. Make sure that important action with significant consequences has a confirmation mechanism that avoids inadvertent action. The “cancellation” option should be consistently implemented. The “defaults” of such mechanism should be on the safe option.

Multiple displays may be needed to cover the same equipment. Purpose-build: startup, normal operation, state or product transitions, shutdown.

Situation awareness: show past and what is coming up next.

These types of displays are applicable to startups, shutdowns, transitions and similar mode changes.

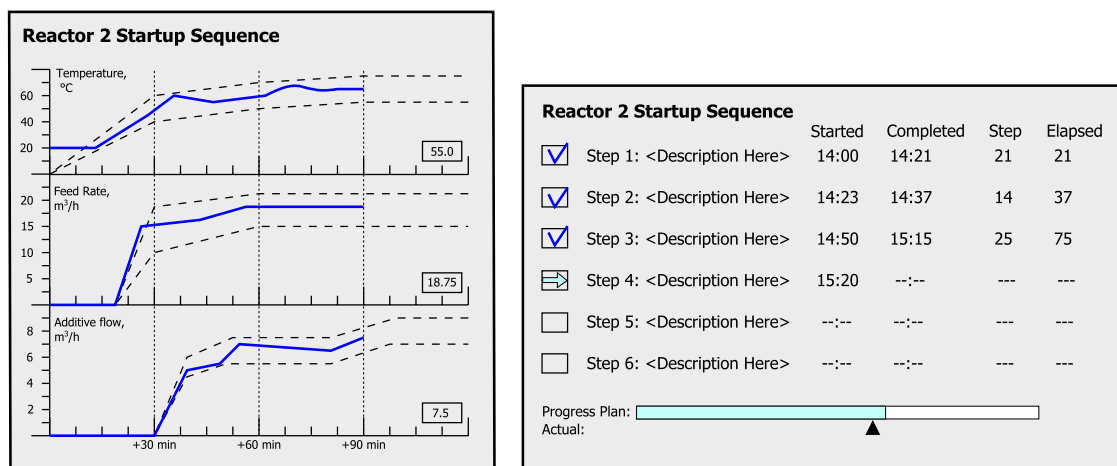


Figure 14: Display elements used for Startup

Poor startups and shutdowns cost money and large avoidable quantities of off-specs material [1].



# Bibliography

- [1] B. Hollifield, D. Oliver, I. Nimmo, and E. Habibi, *The High Performance HMI Handbook*. Plant Automation Services, 2008.
- [2] J. Love, *Process Automation Handbook: A Guide to Theory and Practice*. Springer-Verlag London Limited, 2007.