

THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

Process plant control desks utilising Human-Computer Interfaces

**A guide to design, operational and
Human-Computer Interface issues**

PUBLICATION 201

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10-12 Lovat Lane London EC3R 8DN
Telephone: +44 (0)20 7621 0011
Fax: +44 (0)20 7621 0022
E-mail: sales@eemua.org
Website: www.eemua.org



ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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Foreword

Health and Safety Executive

Human-Computer Interfaces (HCI) have become an area of increasing focus and importance to the UK chemical and allied industries in the major hazard sector, particularly with the advent of centralised control and the use of computer screens as key interfaces between processes and the operator. The first edition of this EEMUA guide has been widely used and referred to within the Chemical Industries (CI) sector of the Hazardous Installations Directorate (HID) and has proven to be very useful. The guide is equally relevant for: other parts of the major hazard sector e.g. offshore; non-major hazard process and other industries where HCI is used as a medium for process and plant control.

While the term 'HCI' may sound technical it describes something we are all very familiar with – the display screens (VDUs) most of us increasingly use at home and in the workplace. It's that interface, as used in industrial and process applications, which can be so important in maintaining process and major hazard safety. Issues that may be just irritating to users at home or in the office, may have major safety implications as we have learnt from many disasters over the decades from the Texaco Milford Haven incident right up to the more recent Buncefield Oil Storage Depot explosion and fires.

This guide is a very useful resource for industry, designers, manufacturers and suppliers in the major hazard sector. Inspectors and specialists in HID will be looking for evidence that the standards and principles in the guide have been implemented appropriately both for new design, and for ongoing review – and continuous improvement - of existing installations. The degree of rigour expected in applying the guide is of course proportionate to the hazards and risk under control but there are clear business and other benefits to good HCI design and use, as well as safety benefits.

The renewed focus on HCI reflects well the current HID and HSE post-Texas City and Buncefield focus on process safety leadership, workforce involvement and wider human factor issues. Good leadership will help focus on HCI as one of a number of key areas that can influence - and optimise - human performance in the key area of a centralised control room and elsewhere. Good end-user involvement and user-centred design will provide good, workable and valued interfaces, including the HCI.

I commend this guide to you.

Peter Baker

*Head of the Chemicals Industry Division, Hazardous Installations Directorate,
Health and Safety Executive.*

Abnormal Situation Management Consortium

In years past, operators of large industrial processes would perform, monitor and control activities from large panelboards. These contained scores of single loop controllers, indicators with trend charts and alarm annunciators for a limited number of key variables. Because of the cost and limited size of the panelboards, project engineers spent considerable effort designing content and layout before implementation. Once built, operators learned the content, where to find things, and a feel for what was 'normal'. At a glance, an operator could get a sense of the overall process status from just about anywhere in the room. Navigation from one part of the unit to another was easy to learn - one simply walked from one location to another.

Modern Distributed Control Systems (DCS's) have been justified based on improving control and optimisation, increasing throughput, controlling at constraints, and expanding the board operator's scope of control. Consciously or not, the demands on operator capability and performance have significantly changed. Indeed, the job of operators has transitioned from one of considerable reliance on knowledge of the plant layout and memorisation of a number of tasks to one more focused on process knowledge and cognitive skills.

Humans are not particularly well suited for watching computer monitors hour after hour, waiting for something to happen which then rarely does. Plant managers and engineers did not fully understand the human factors implications of the introduction of this new technology into the control room environment. Inadequately designed graphics for the operators in many cases leads to significantly diminished situational awareness and operator fatigue.

The persistent paradox in the process industry is that as automation technology increases in complexity and sophistication, operators face progressively more complex decisions in managing the process. Moreover, the industry's ability to design effective operator interfaces to the process has not kept pace with the task demands imposed by more sophisticated technology. A key factor is the ability to understand the operator's task and interaction requirements and to design the elements of the work environment that effectively support those requirements. Hence, we have entered an era in which there is a consensus throughout the industry that the design of the operator interface, console and control room deserves appropriate skills and resources.

The advent of new user interface technology has further complicated the situation. "Use of sophisticated technology does not inherently increase system effectiveness; increases in effectiveness depend on how technology is used. Technology increases design flexibility, which in turn creates opportunities to dramatically enhance system performance. Flexibility however also creates potential pitfalls and traps for the naive or unwary. A design may enhance system effectiveness by enhancing the effectiveness of operations personnel and mitigating the consequences of human error. Interfaces and human-system interaction design in sophisticated systems, however, have frequently been identified as major contributors to poor operator performance which sometimes results in dangerous or costly incidents and accidents." *

* Mitchell, C. and Sundstrom, G. (1997). IEEE Transactions on Systems, Man and Cybernetics: Special Issue on Human Interaction with Complex Systems, 27(3), p.265.

The process industry is beginning to understand that the development of sub-optimal operator interfaces and work environments can have a significant impact on plant safety and profitability. People experienced in plant operations and control created this guideline document. Grounded in their learning over the past decade, this document provides an excellent overview of the issues that plant management, project personnel and plant technical staff should be aware of as they make decisions regarding the design of the operator interface, console and work environment. The Abnormal Situation Management (ASM[®]) Consortium is pleased to recommend this document to those wishing to improve the effectiveness of console operations.

Peggy A. Hewitt

Director, ASM Consortium

Scope

This Publication relates to Human-Computer Interface (HCI) systems provided for people operating industrial processes and activities on facilities such as chemical plant, power stations, oil refineries, etc. It gives guidance on:

- the factors to take into account when designing an HCI for such processes and activities;
- display hierarchies;
- screen display format design; and
- control room design attributes which affect HCI.

The objective is to help engineers and design teams develop HCI systems which are more usable and therefore result in safer and more cost-effective operation of industrial systems. The Guide is also intended to help reduce the need for re-engineering of systems after installation.

Both batch and continuous processes are covered by this Guide.

Purpose

HCI systems form the essential operator interface to large modern industrial systems. They are utilised in power stations, refineries, chemical plants (both batch and continuous), utility distribution centres and many other places. They provide the vital means by which the operator obtains information on the state of the plant, enters operational parameters, and by which any automatic control action can be overridden and manual control of the plant be taken.

The purpose of this Guide is to help those involved in the design, procurement, operation, maintenance, management, assessment and review of these systems. It is intended to help both improve existing systems and develop new facilities during plant construction. It is for use by engineers and managers in both user and contracting organisations. The objective is not only to make plants more operable, efficient and able to avoid abnormal situations, but to be able to better manage such situations should they occur.

This Guide has been written and widely reviewed by users in industry and is based on what some leading companies are doing. The guidance is designed to be practical and usable. The general guidance is directed towards large sophisticated computer-based process systems, but also contains much general information on HCI.

Relationship between EEMUA 191 and EEMUA 201

Although this Publication (EEMUA 201) and the Alarm Management guide (EEMUA 191) are separate publications, they are very closely related. An alarm system should be viewed as a sub-system of the overall Human-Computer Interface, which the Operator uses to monitor and control the plant. The way in which the alarm data is displayed to the operator should be considered as part of the overall HCI design.

More detail on alarm display is in Appendix 8 as well as EEMUA 191¹.

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Notes on use of this Guide

The main body of the text concentrates on the design philosophy and general principles of HCI systems. Key messages are highlighted in **bold** and/or boxed. Much supporting detail is in the Appendices.

A list of definitions containing terms that readers may find unfamiliar or may cause confusion is given on page xv.

References are listed on page 101.

Definitions

Some of the terms used in this Guide are listed below. The list is not intended to be comprehensive, but to concentrate on those terms that are likely to be unclear or cause confusion.

Within the process industries, a number of different terms are used to describe the 'pictures' seen by the operators on the VDUs. This Guide prefers the term 'graphic'; other terms are included below.

Abnormal Operation	A state of plant where a planned or unplanned significant event or condition adversely affects, potentially affects or indicates degradation in the safety, security or environmental performance or operation of a facility.
ASM	Abnormal Situations Management Consortium.
Back-panel	A hard-wired panel used for displaying indicators and meters, where little or no control action needs to be taken.
Console	All the hardware, including physical screens, that comprise the operator interface.
DCS	Distributed Control System. Sometimes referred to as BPCS (Basic Process Control System).
Display	Usually, a software-generated picture containing a representation of physical plant in the process industry (another term for Graphic).
DLV	Digital Light Valve.
ESD	Emergency Shut-Down System. An automatic protection system which acts to shut down the plant if it enters a potentially dangerous state. In some countries this is called a Safety Instrumented System (SIS).
Format	Usually, a software-generated picture containing a representation of physical plant in the process industry (another term for Graphic). Sometimes just used to refer to the generic layout of a graphic, not containing any particular content.
Graphic	Usually, a software-generated picture containing a representation of physical plant in the process industry.
GUI	Graphical User Interface.
Hard-desk	A hard-wired fixed position physical control desk with meters and indicators for display purposes, and knobs and push buttons for control operation.
HazOp	Hazard and Operability study.
HCI	Human-Computer Interface. A subset of the more generic term HMI.
HMI	Human-Machine Interface.

LCD	Liquid Crystal Display.
Mimic	A specific type of graphic – one that shows the plant item relationships with data values annotated.
Physical Screen	The physical display device. A VDU.
PID	Proportional Integral Derivative. A common control strategy.
PLC	Programmable Logic Controller.
SCADA	Supervisory Control And Data Acquisition.
Schematic	Another term for graphic. Sometimes used to describe a component of a graphic.
Screen	Actual physical device upon which a graphic is displayed.
Soft-desk	A display and control desk, where all display and interaction is performed via computer screens and computer input devices.
Spatial Awareness	Familiarity of the position and function of a display within the 3D space of a control room. Familiarity of the position of indicators on a display workstation.
Trend	A specific type of graphic – one that gives graphs of variables against time.
VDU	A physical display device. Formerly a Cathode Ray Tube (CRT) but now usually a flat screen, LCD device.
Workstation	The keyboard/mouse/computer that drives the physical screen and contains the software for such a task.

1. Introduction

This section provides a basic introduction to HCI control rooms and their evolution over the last 30 years.

1.1 What is a HCI system?

Computer screen-based systems pervade every aspect of modern daily living, from the cash-point machine to the airline booking system. Process control is no exception. The following sub-sections describe how process industry control rooms have evolved to fully utilise modern computer-based interfaces.

1.1.1 “Hard” Control Desks

In the past, most control rooms consisted of hard-wired equipment (such as dials, chart recorders, push buttons and knobs) laid out on large metal panels and desks. In some industries the operator would patrol the panels monitoring key plant variables, adjusting set-points and operating equipment. In other industries the majority of the work was performed at the desk with the panels being used mainly for observation purposes. This type of hard-wired operation meant that in a well designed panel layout, all the indicators that an operator required were generally on constant display around the control room and could be shared with other operators when needed.

Evolution over the years in most industries has seen such control rooms reach a point of relatively high sophistication. Guidelines have been developed for all aspects of the panel and desk layout, from labelling to colour coding.

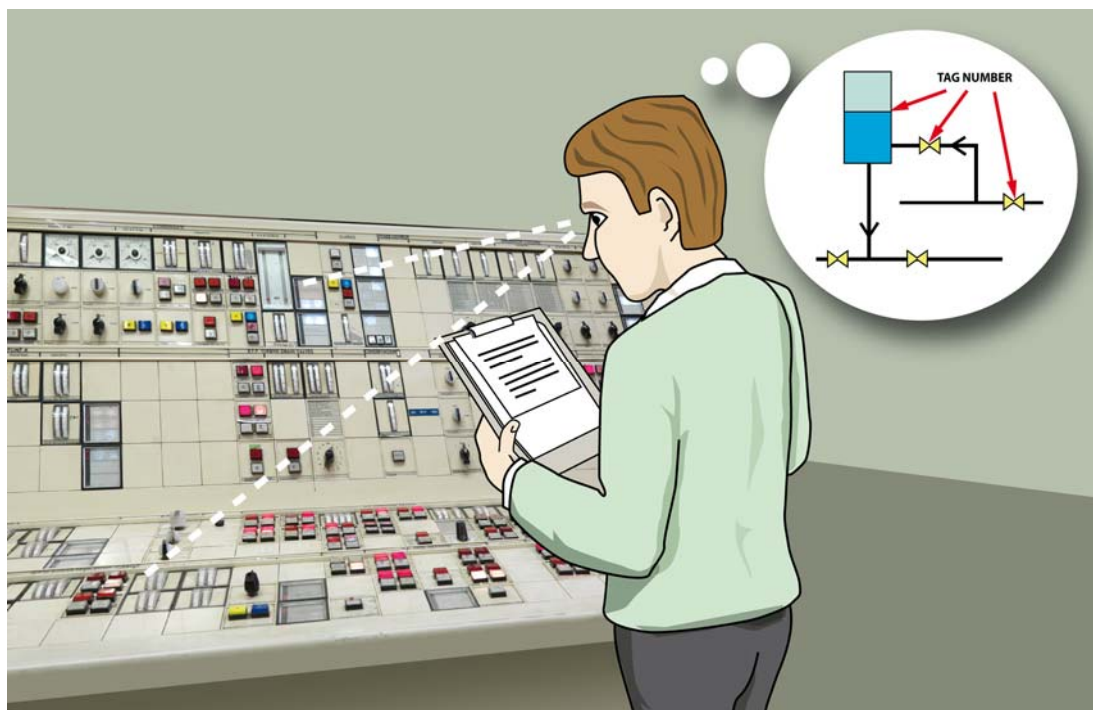


Figure 1 A typical panel-based arrangement

Figure 1 above shows a typical panel-based arrangement with the operator 'patrolling' the rows of controller faceplates.

However, this arrangement suffers from the following disadvantages:

- usually having no obvious relationship to the actual process or equipment (hence the importance of tag numbers);
- the need for large expensive control rooms to house all the panels;
- low control integration;
- the requirement for high levels of surveillance; and
- the deterioration of consistent navigation over time, as new indicators are added wherever space permitted.

That said, a well designed panel layout does have the advantage of providing good spatial awareness. For instance, if an alarm activated it was usually immediately obvious which part of the plant it came from, even from a distance. Desks developed further with the advent of computer operated control systems. The introduction of computer screens allowed the viewing of plant parameters via numeric indication and graphics (trends and display schematics). These screens were usually seen as an 'add-on' facility. They did not allow for operator control action and had to be integrated into the existing desk design.

1.1.2 "Soft" Control Desks – First Generation

The physical nature of the control desk in the process industry has been transformed with the provision of a full 'soft-desk'. This comprises of just computer-based screens through which the operator both views the plant and operates it. In the majority of cases, there is no hard-wired indication facility at all (the exception being sometimes an Emergency Shutdown system). **This then is the HCI.** Where new plant is built such systems are now invariably installed. All the major manufacturers and independent DCS suppliers offer these as standard and many plants are refurbishing their control rooms and replacing the panels and hard-desk with a soft-desk.

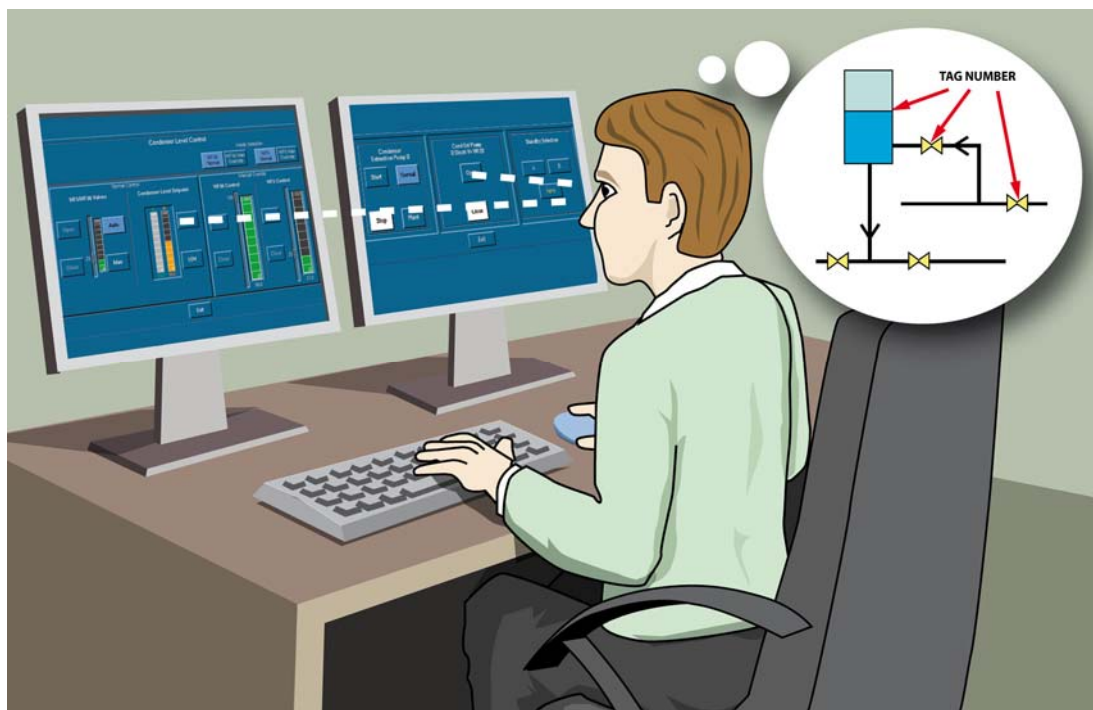


Figure 2 A typical first generation DCS system

Figure 2 shows a typical first generation DCS system with the operator now static whilst different controller faceplates can be called up onto the screens. The operator views the plant through these screens and an alarm list. From the engineering viewpoint this new arrangement provides substantial equipment cost reductions and a much higher level of control integration.

For the operator it provides assistance with plant surveillance, a greater level of automation, the possibility of more consistent navigation, remote operation of the controllers and much improved trending capability.

On the spatial awareness side, the new system was not so advantageous. One control faceplate screen looked very much like any other (only the tag numbers changed) and only a small number of controllers could be viewed at any one time on the VDUs.

1.1.3 “Soft” Control Desks – Second Generation



Figure 3 A DCS system using graphics-based control

Figure 3 shows the new type of DCS which use graphics-based control. The operator can now point directly to an item of equipment, shown on a graphical representation of the actual plant, and open its control faceplate using a mouse or tracker ball.

1.1.4 The Challenge

The issue for design engineers is how to produce a HCI that allows for ease of use comparable to the old 'hard-desk' whilst exploiting the benefits of the extra information capability of software-based systems. The design is also often constrained by the project budget, both in terms of the hardware that can be purchased and the amount of time that can be spent on designing and implementing the graphics.

This guide seeks to give advice to ensure that the correct amount of hardware is procured and the correct level of software sophistication is achieved for any plant, without compromising operability and safety due to cost constraints. Throughout this publication, the term 'Human-Computer Interface' refers to: the hardware and physical screens that make up the operator's desk; the underlying software that constitutes and produces the visual images that appear on the VDUs (allowing information display and control of plant items); and any auditory stimulus (see Figure 4).

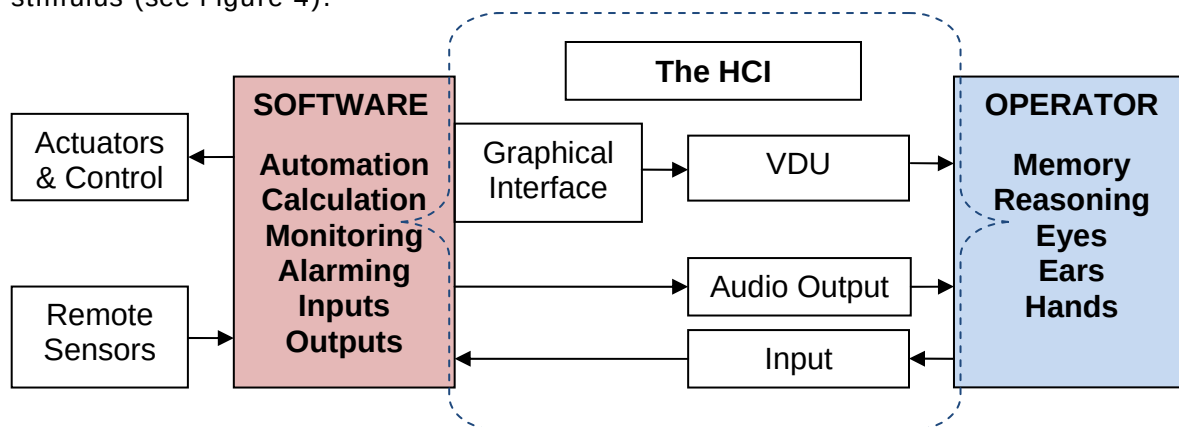


Figure 4 HCI, the sensory interface between operator and plant

As a result, the HCI includes all the features that allow operators to communicate with the software using Windows/Icons/Menus/Pointers (often referred to as WIMPS).

1.2 Key Design Principles

System design is crucial to the operator's role, including the number of screens, the design of displays and the means of navigation around the system. The HCI to a process control system is critical in allowing an operator:

- a) to develop, maintain and use an accurate, up-to-date awareness of the current and likely future state of the process;**
- b) to interact with the system quickly and efficiently under all plant conditions.**

The following categories of operation, which are shown in order of importance in Table 1, need to be considered:

Category 1	Abnormal
Category 2	Normal – the most utilised role
Category 3	Optimisation
Category 4	General information retrieval – this may be delegated to an IT system

Table 1 Categories of operation

In order to achieve the above, many issues must be taken into account. These include: the detailed design of individual graphics; the way that the graphics fit together in the hierarchy; the actual desk layout; the number of screens and the overall operational environment.

Whilst the purpose of the HCI is to provide a means to control a technical process, the design of the interface itself is very much a Human Factors issue. This interface is at the core of the operator's work role. It is often the sole means that the operator has to obtain data and information on the state and performance of the plant, as well as the means by which the operator can influence plant behaviour. In order to design the HCI it is imperative that the operator's activities and tasks are well understood. All the differing operational circumstances must be considered. An operator does not just have to cope with normal or steady state conditions. There are also start-ups and shut-downs, plant condition changes and abnormal situations, as well as looking after the plant when in a shutdown state (e.g. for maintenance to occur). Whenever possible therefore:

A complete appraisal of the tasks performed should be undertaken to capture the full remit of the operator's role.

Whilst the above will capture the operator's activities, a crucial element in the successfulness of the final interface is the acceptability by the operators. This, combined with the intimate operating knowledge possessed by most operators, means that all HCI projects should:

Mandate complete end-user involvement in both detailed graphics design and the overall system design.

As emphasised above, the analysis of activities feeds into the design of the HCI system. In converting this into actual hardware the following principle must be complied with:

The number of physical screens provided in the HCI must allow for complete and prompt access to all necessary information and controls under all operational circumstances.

One of the most important factors in operating a plant both efficiently and safely is being able to have an understanding of the state of the whole plant. *Note: a plant may be subdivided into different operating units, each in a different state.* Well-designed hardwired systems provided this understanding using the physical layout of the desk. All indications were on view - information access was simply a matter of scanning the panels. In a soft-desk implementation this is often forgotten or just not provided, but is essential. Therefore:

The HCI design should allow for a permanently viewable active plant overview display format.

A fully integrated modern HCI will, almost without exception, also provide the alarm system interface. This is an important function in any process and due consideration should be given to the management and presentation of alarms. In this case:

Continuous alarm indication and access to this alarm indication should be provided.

The reliability of the HCI must be considered and be appropriate for the type of plant under control i.e. how much failure is acceptable and what is the bare minimum of equipment that is necessary for running the plant? What actions to take when the HCI fails must be considered.

Control rooms, processes and their requirements invariably change over time. The trend is for more information to be required, rather than less. Whilst it may be possible to build this into an existing hierarchy of display formats, it is inevitable that at some point, in order to maintain the operational functionality of the system, extra screens are needed:

The capability to expand the number of physical screens should be built into the original design.

If a HCI is to perform to its requirements and thus be accepted and exploited by its users (the operators) then ensuring that the Human Factors issues are addressed is as much a key factor as the engineering.

1.3 HCI Roadmap

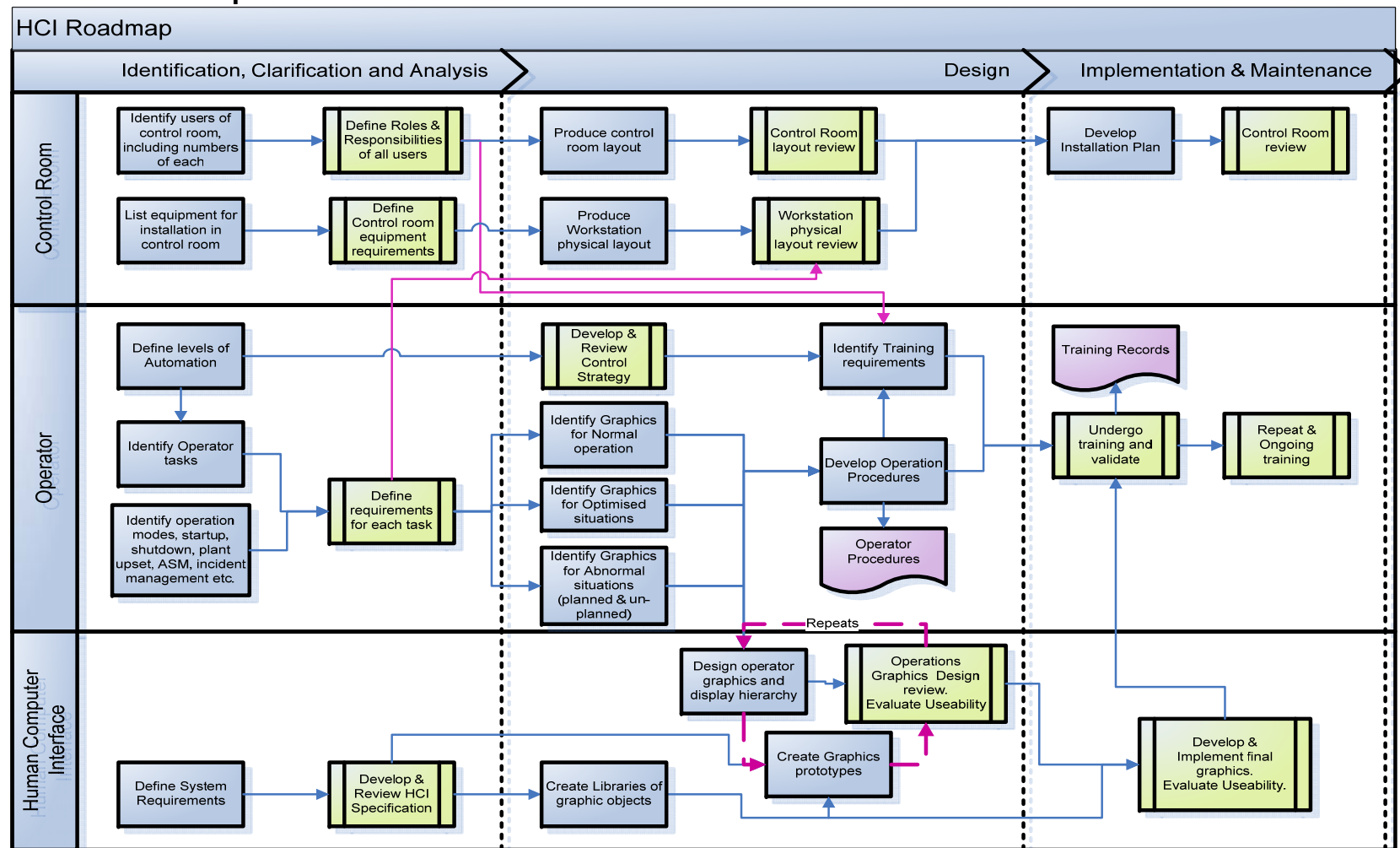


Figure 5 HCI Roadmap

Figure 5 on the preceding page diagrammatically sets out the development process of the HCI Roadmap. It encompasses the various components as described in the remainder of this document, from the overall control room down to the Human Computer Interface. The main blocks correspond to the Chapters of this document. The diagram shows the various activities to be performed along with associated review points. This can be applied to both refurbishments and new plant installations.

The Roadmap (Development Process) in Appendix 1 gives the detail of the review points and serves as a summary of the information found elsewhere in this document.

When considering the Human Factors of a Human-Computer Interface, it is typical (and convenient) to break down the issues into the following areas:

- The organisational context.
- The control room.
- The workstation.
- The HCI.
- The attributes of the operator him/her self.

This tried and trusted approach is illustrated below in Figure 6.

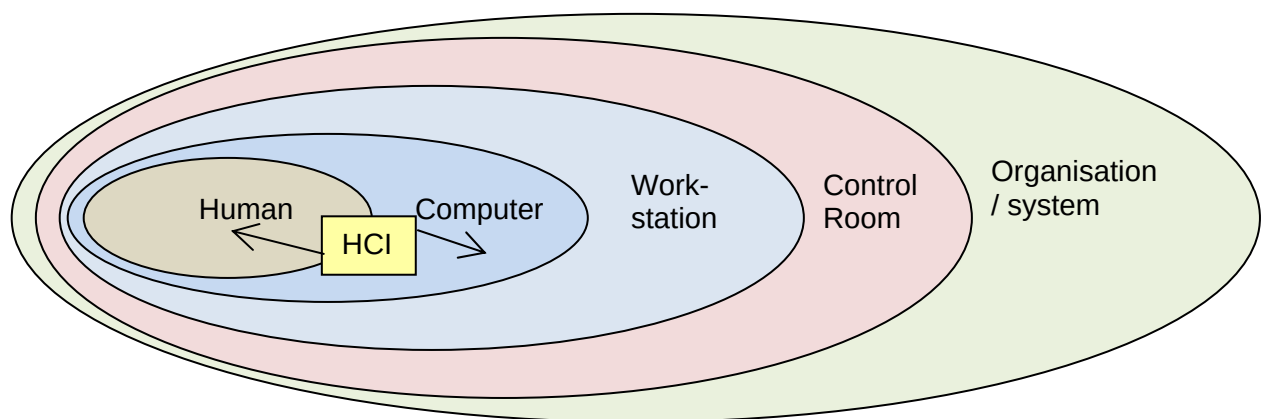


Figure 6 Human Factors of a Human-Computer Interface

The next Chapters of the document will therefore cover:

The Control Room: an introduction to control room design issues that relate to the HCI.

The Operator and Organisation/System. This section is concerned with the attributes and reliability of the human element of the system and the tasks that the operator is required to perform to make the organisation and its industrial systems function.

The Human-Computer Interface looks at making the computer into the right tool for the job, so that it supports the operators in performing their tasks to the required standard under all manner of operational conditions.

2. Control Room

This section provides an introduction to the overall control room design. This guide is not intended to address the detailed issues regarding overall control room design. Many factors have to be taken in to account here and there has been much written in international standards about control room design ^{[2][3]}. Additionally many Human Factors consultancies have a wealth of experience in this area. The use of a specialist control building architect can produce a better designed building which will often be smaller and cheaper, both initially and over the life of the building. This section is therefore intended to provide a high level overview of the issues that need to be addressed when designing a control room.

Dealing with control room issues that affect the HCI requires a multi-disciplinary approach. It needs the involvement of software engineers, hardware purchasers, operations staff and even architects. Support from a high managerial level is also required to ensure issues are addressed.

2.1 Control Room Design Factors

The overall control room environment can contribute greatly to the effectiveness of the control room staff and indeed affect the perception of the HCI.

The following is intended as a short checklist of the factors that need to be considered in the overall design of a control room. Detailed information on the areas listed below is widely available.

- **Different users of the control room.** Operators, maintenance staff, computer staff, managers, cleaners, visitors, etc. These should be divided into primary and secondary users. The differing needs and requirements of each set of users should be considered to ensure that there is no conflict and to enable each user to perform their role to the benefit of all.
- **Control room access levels.** The means of access by the different users and the areas within their scope need to be clearly defined to prevent clashes of interest. This includes access to the physical operating positions.
- **Environment:**
 - Blast resistance;
 - Lighting;
 - Heating and ventilation;
 - Noise levels;
 - Furnishings;
 - Colour schemes.
- **Console design:**
 - Console and related furniture;
 - Size of monitors;
 - Adjustability of keyboards/monitors;
 - Writing space;
 - Power supply, cabling;
 - Phones;
 - CCTV monitors;
 - Radios;

Printers;
Storage requirements;
Hardwired ESD panel.

The physical layout and furniture used for mounting the HCI equipment can have a large bearing on the acceptability of the total product. Built in 'television' studio type panels are impressive, but the current trend is to move from these towards more 'desk top' configurations. These can be very effective, but have to be carefully designed to ensure that the total image is not one of clutter or haphazardly placed monitors. It is likely that operators would be classed as high-end users of such equipment and as such the Display Screen Equipment (DSE) Regulations should be observed. Many older monitors that are fixed into the desk surface are unlikely to satisfy the regulations.

- **Safety requirements:**

Fire prevention;
Fire control;
Emergency exits.

HSE regulations may need to be considered for any high risk hazards.

- **Other requirements:**

Operator's Mess Room;
Meeting room;
Office facilities (photocopier);
PCs (if not incorporated into the console).

Whilst not directly affecting the operator interface, provision of a well placed and functional mess-room is an essential part of the control room. Meal and rest breaks should be properly planned into an operator's working day along with relief manning of the desk as appropriate. It should especially be borne in mind that good operation on an HCI is primarily a sign of good Human Factors design and the mess-room can have a significant effect on operator performance.

It can be useful for the operators' mess facilities to provide viewing access (one way) to the control room, so that they can still be aware of any disturbances. If direct viewing is not possible then some alternative means of audible and/or visual indication should be provided to alert control room personnel of a disturbance if the control room might be unattended (even for short periods).

- **Engineering Facilities.** In large control rooms, it can be beneficial to install additional segregated workstation bays for use by supervisors or engineering personnel. These can be used for tuning, handling upsets or system configuration. In some plants these are installed in separate engineering rooms or offices.
- **Future-proofing.** Invariably control rooms change over the passage of time. The potential need for more workstations/screens and to be able to respond to changes in light of operational experience should be taken in to account.

Many manufacturers offer a range of other information displays via the HCI, for instance data sheets, maintenance sheets, Standard Operating Procedures (SOPs), manuals, etc. Much of this functionality is more appropriate to the maintenance/engineering staff. Only those functions that can directly help the operator should be made available on the operator HCI.

2.2 Abnormal Situation Handling

The handling of abnormal situations is one of the prime tasks to be considered when looking at control room design. (See Section 4.3 for the operator role in this area). These are often high stress situations with the requirement for swift decision-making. Control rooms should be designed to mitigate this stress as much as possible. Consideration should be given to:

- The physical safety of personnel (robust building design).
- The HCI should be well designed to assist the operator.
- In a large control room, each member of the team should know what their responsibilities are.
- All relevant procedures and drawings should be available ^[4].
- Communications protocols and strategy should be in place.
- Crisis management training should be undertaken.

In some types of plant, emergency shutdowns are not without some risk and large financial implications. In a situation where all of the screens are lost but the plant is still being automatically controlled it may be prudent to monitor key process indicators and only shut the plant down when these indicators begin to move into the abnormal operating envelope.

2.3 Communications

It is important to consider communications requirements when designing the control room layout and specifying the equipment to be installed. It is essential that these requirements are considered at an early stage in the design, rather than being considered when layouts and specifications are fixed. In particular, the requirements for 'safety critical communications' should be carefully considered. Examples of safety critical communications could include – shift handovers, communication to field operators and maintenance staff, emergency communications.

Control room communications can be considered in a number of categories:

- **Verbal communication between operations staff within the control room.**

Communication between control room operators can be greatly facilitated by ensuring that the layout of the consoles within the control room aids verbal communication. Consoles should be arranged so that operators have line of sight of each other, and can face and converse with each other over a reasonable distance in a normal speaking voice. In a large control room this may involve grouping consoles into logical operating areas which reflect the interaction and flow of information between operators. The design of the console is also important. For example, the height of the console and hence the line of sight over the top of the console is affected by the arrangement (number, size, slope, banking) of

the screens within the console. Communications at shift hand-over also need to be considered - for instance two operators sharing a screen.

- **Verbal communication between operations staff and non-operations staff.**

Examples could include communication between operators and maintenance staff, between operators and contractors, or between operators and plant technical support staff. The control room and control building should be designed to minimize the impact of this communication on control room operations. Consideration should be given to providing separate facilities – e.g. interface room, conference room, - to allow this communication to take place.

- **Communication external to the control room.**

Communications external to the control room includes with field operators, support staff, emergency response teams and other control rooms. It may be carried out over a variety of electronic systems in either voice or data formats (e.g. VHF/UHF radio, telephone (mobile, fixed), pagers, intercom, public address systems, voice over internet protocol (VOIP), e-mail). Detailed design considerations for these systems is beyond the scope of this guide. However, the key principle is that the systems should be designed and integrated as a significant component of the operating console rather than considered as a separate entity. This may involve collaboration between a number of disciplines (information technology, radio communications, control systems) during the operating console design.

Guidance on Safety Critical Communications can be found in the GB HSE Human Factors Briefing Note No. 8 'Safety Critical Communication' ^[5].

2.4 Control Room Noise

It is important to ensure that background noise within the control room environment is adequately controlled.

Excessive background noise may interfere with verbal communications between operators, prevent the detection of audible alarm signals, and cause reduced mental performance, distraction and fatigue throughout the course of an operating shift. Conversely, an excessively quiet environment may also cause distraction as quiet conversations become intelligible and intrusive across the room to those not directly involved. Indeed it is significant noise above background noise that causes distraction. More detail on noise within the control room environment is given in Appendix 6 Control Room Noise.

2.5 Layout of Physical Screens

Perhaps the most difficult consideration when designing a new HCI is the type and number of physical screens to be deployed. This can affect a number of the other considerations, e.g. navigational requirements which in turn is greatly affected by the factors described in Section 2.1 Control Room Design Factors.

Pressure on project costs has in the past led to the 'number of screens to be used' becoming the focal point for cost reduction without due regard being given to the operational consequences of the decisions taken. However, with the reduction in cost of display hardware (both monitors and workstations) in recent years this is much less of an issue. Control room space considerations also add to project pressures to keep the physical desk compact and again this should not be allowed to dominate over operational needs.

The number of screens to be deployed should always be determined by the operational requirements of the system – including abnormal situations.

The layout of any new HCI should be designed to allow additional screens to be added if, in the light of operational experience, this proves to be necessary.

Wherever possible any third party systems should be integrated into the DCS so that all data is displayed via a single HCI. If this is not possible great care needs to be taken in placing the required physical screens in conjunction with the main HCI screens.

Vertical stacking of screens needs to be carefully designed – it can often prevent communication and not be conducive to good posture.

When designing the overall physical screen layout, consideration must also be given to the accessibility and positioning of other peripheral ancillary equipment such as radios, intercoms, phones, note books, manuals, etc. ISO 11064 Part 3 gives information on physical layout ^[3].

2.6 Large Screens

One consideration, which now commonly occurs when designing a control room with a soft-desk configuration, is that of the use of large screens (previously projector based, but with LCD and DLV systems now more common). These can provide a powerful addition to the operator interface, but have to be considered against the initial and ongoing running costs of such equipment. Additionally the mode of working within the control room will determine their suitability. See Section 4.1.2 Large Screens for a discussion on the HCI design issues of large screens.

3. Operator

This section is concerned with the different types of process plant operation and the place of the operator within these operational scenarios. The operator is key to the HCI design and the sole means by which the plant is controlled. Therefore the design must take into account the capabilities of the operating staff, their fallibilities and the range of different tasks they have to perform. The aim is to ensure that these tasks can be performed reliably and to the level of performance required. All of the above, points to the need for a user-centred design process, involving and taking into account the needs and wishes of the operators, whilst producing ergonomically sound graphics.

3.1 Role of the Operator

The operator in a modern process plant has a number of different activities to perform. At an overview level, these consist of:

- optimisation of production;
- ensuring compliance with environmental constraints;
- managing plant difficulties;
- co-ordination of maintenance, etc.

At the detailed level, the operator is concerned with the actual operation of individual plant items, either at the single component level (e.g. pump, motor) or a composite plant item level. The actual tasks performed will depend on the current state of the plant e.g. start-up, normal operation, change of mode of operation, abnormal situation, normal or emergency shutdown, etc.

Whilst not necessarily having a primary objective of altering the operator's role, most control desk refurbishment is often part of a larger control and instrumentation refurbishment which almost inevitably includes increased automation. The HCI, on a large complex and automated plant, is not designed for normally operating the plant by continuous control of individual basic plant items (e.g. opening/closing valves, starting/stopping pieces of equipment). Hence a redefinition of the operator's role becomes necessary in this case. On smaller plants, 'manual' control via the HCI is still viable. Task and user requirements should always determine the design of this aspect of the HCI.

In the larger, more complex plants, the operator's role typically becomes more one of supervisor and monitor. Rather than performing the majority of daily control actions, the automatic system is allowed to perform that role, whilst the operator concentrates much more on ensuring that higher goals, such as maximising efficiency or limiting environmental emissions, are achieved. More time is devoted to analysing potential problems or dealing with actual shortfalls in performance. The operator tends therefore to have a more reactive than proactive role in the operation of the plant. Only when the plant moves away from its normal operating parameters is major intervention by the operator required.

It should be noted that the actual level of automation should be decided by structured investigations into the allocation of function ^[6].

A modern HCI interface is required to perform satisfactorily for two very different situations. For most of the time the plant will be operating normally and the HCI

must be designed to aid the operator maximise plant efficiency. But when an abnormal period of operation occurs, the HCI must aid the operator in returning the plant to normal operation as effectively as possible. Data that is vital to the operator for the efficient running of a plant may be totally useless in an abnormal situation and may in fact hinder the operator's attempts to rectify the problems by hiding data useful to the rectification of the abnormal situation.

The HCI must support the operator in all the different activities and scenarios with which he/she might be confronted

The design of the graphics, the navigation around the system and the actual physical number of screens becomes critical parameters in the design of a system which is crucial to the operators' role.

3.2 Type of Process

This guide addresses the operation of three types of process plant, which can be defined as:

- the Continuous Process;
- the Batch Process; and
- the Hybrid Process (a mixture of the first two processes).

The process type affects the type of tasks an operator has to perform and hence the HCI design requirements. For instance, in a batch operation many more graphics concerned with the sequencing of events are required than in a continuous process.

3.2.1 The Continuous Process

This process can be defined as:

A process in which material passes in a continuous stream through the processing equipment. Once the process has established a steady operating state, the nature of the process does not depend on the length of time the process is operating.

(International Society of Automation (ISA), 1995)

It should be noted that continuous processes can run for many years, hence making a start-up or shut-down a rare event. Performing these actions is often a time of high safety risk so whilst such events may be planned into a schedule they are seen as abnormal operation by continuous plant operators.

This type of process control usually has a high percentage of PID control loops (analogue).

3.2.2 The Batch Process

This process can be defined as:

A batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input material to an ordered set of process

activities over a finite period of time using one or more pieces of equipment. Batch processes are discontinuous processes. (From the ISA S88 standard).

This type of process control usually has a high percentage of sequence and logic control (digital).

3.2.3 The Hybrid Process

This model may exhibit the characteristics of a batch process on start-ups and shutdowns, but exhibits the same characteristics as a continuous process in normal operation or may run batch processes in parallel with continuous processes.

The characteristics of each of these various processes are described in further detail in Appendix 7 Conceptual Process Models along with logical graphics hierarchies. The basic differences are shown in Table 2 below.

	Batch	Continuous	Hybrid
Abnormal Situation Handling	Not usually significant	Significant	Significance dependant on plant state
Control objectives	Control state transitions	Maintain steady state	Both
Graphics	Task-based	State-based	Both
Output resources used for control	Predominately digital	Predominately analogue	Significant numbers of both analogue and digital
Process hold	Possible	Not available	Partial

Table 2 Different process types

3.3 Automation

The amount of automation present on the plant is a crucial factor affecting the HCI design and the operator's function.

Plants which are not highly automated require the operator to make many actions to operate the individual plant items comprising the plant - right down to opening/closing valves, turning pumps on/off, etc. In dealing with a single process or sequence it may be necessary to have access to a number of these concurrently and hence the number of screens required is likely to be on the high side to ensure operability. The other consequence of a non-automated plant is that the design of the graphics is geared towards the operation of the individual plant items, rather than for more general overall control.

3.4 Manning Levels and Multi-unit Operation

The requirements on manning levels will affect the operator's function and the number of screens to be deployed. Obviously if a single unit is to have more than one operator, sufficient screens and operator input devices must be provided to enable each operator to carry out their required tasks. The system must also protect against confusion over 'who is doing what'.

However, currently the trend is for at most a single operator (especially when plant is in a steady state). The move to reduce the number of operators in a control room needs to set against considering not just when the plant is in steady state but also the operating requirements during the most rigorous of operating situations.

Some plants are now turning to a single operator for more than one unit. Problems presented here are:

- What is the minimum number of screens required for each unit? Does this apply in all circumstances, including abnormal situations?
- What configuration is permissible for sharing screens between units? What minimum number should then be available to each unit?
- How are displays designed to ensure the operator does not confuse which unit is being worked on?
- What is the minimum acceptable configuration in times of system failure?

The provision of 'read-only' screens can be useful for allowing access to other units or for use by different classes of staff.

Useful Human Factors guidance can be found on the British HSE website ^[14].

4. HCI

In previous sections the control room design and the role of the operator within it have been considered. The type of plant being operated has also been discussed. This section concentrates on the control display desk. This is the main tool through which the operator interfaces with the process. It provides most of the data that will be used to make decisions and by which most actions are taken.

The most important aspect of designing a HCI system is to understand, as fully as possible, what tasks the operator will be expected to perform and how the operator needs to perform them. Chapter 3 and the forms in the Operator Task Review Questionnaire, or modified versions, may assist here.

The ISO 9241 standard ^[2] defines three components of quality of use that are applicable to the design of HMIs:

- **Effectiveness.** Does the product do what the users' require? Does it do the right thing?
- **Efficiency.** Can the users learn the HMI quickly? Can they carry out their tasks with minimum expended effort, including the smallest amount of errors? Does it improve the productivity/effort ratio? Does it do things right?
- **Satisfaction.** Do users express satisfaction with the product? Does the new product reduce stress? Do the end users have a more satisfying job?

It should be simple to use and learn (intuitive)
It should be consistent and unambiguous in operation
It should provide a simple and complete picture without unnecessary detail.

Table 3 Operator interface characteristics

Table 3 above lists the key operator interface characteristics. There are many terms used to describe the various components that comprise a HCI. Different industries/suppliers use similar terms for a multitude of components and often with slightly different meanings. The Definitions list at the start of this guide defines the meanings of the terms as used within this guide. The main points to note are that the term **physical screens** refers to the actual VDUs whilst the term **graphics** refers to the software picture that is drawn upon the VDU screen.

As noted in the introductory section the traditional 'hard' desk has evolved over a number of years. As with most products of this level of maturity, a new installation with good design can provide an excellent, ergonomic and easy to use interface. In providing a 'soft' desk HCI for the main operator interface, it is important not to lose the experience that has been built up from the traditional 'hard' desk installations.

However:

The objective of today's HCI designer should not be to mimic the panels of the past but to better them by using the strengths of the new technologies in the way data can be analysed and information presented.

4.1 Define the System Requirements

From the HCI Roadmap in Section 1.3, the first activity is to define the system requirements.

From the issues discussed in Chapter 2 - Control Room and Chapter 3 - Operator, a clear understanding should have been gained of: the equipment required on each operator's console; the minimum amount of free space required for documentation, etc.; and the provision of task and general lighting.

Each system on the console needs to be assessed for the level of redundancy required, impact and mitigation of failure, etc. For example, what actions are taken if one or all of the screens go blank?

4.1.1 Physical Screens

The first issue to consider is how many and what types of screens are required. Often conflicting requirements may arise. For instance, the amount of physical space available for each operator may give constraints whilst the operators may wish to have as many screens as possible.

In all situations, the answer is a compromise between the number of screens that can be physically and usefully deployed, the complexity of the navigation required and the limitations of the system itself. Typical questions to be asked are below.

Questions when determining the number of screens

- How many overview graphics are required?
- What alarm display philosophy is to be adopted?
- How much simultaneous control actions may need to be taken? (be realistic)
- How much general monitoring is required?
- What level of multiple windowing is to be allowed (if any)?
- What level of redundancy is considered adequate?
- Can screens be used for more than one process or 'module'?
- What future expansion may be required?
- How will it affect system performance?

For example, it may be possible to display a pipeline routing system with a relatively low density of data on a single large array of screens which would require very little, if any, navigational complexity. If due to space restrictions, etc., only two or three screens were available then a lot more thought would be required to design the display navigation.

In a complex chemical plant with a high density of instrumentation, lots of inter-connecting pipelines, vessels and equipment, it would be impossible to usefully employ a large number of screens - doing so could increase the operator workload and degrade system performance. Therefore a more compact arrangement would be required with a well designed navigational hierarchy (see Appendix 8).

To determine the number of screens, it is generally necessary to perform an analysis of the operator's duties. This is needed to establish a suitable record of the tasks to be performed using the screens and then map the information

requirements for each specific operational scenario onto screen availability. Such a 'Task Analysis' should be at an appropriate level for the complexity of the job to be analysed ^[7]. It can be relatively informal. The key point is to capture the requirements, in terms of information and action to be undertaken for the specific task, in such a manner as to then be able to justify the number of physical screens to be used and the design of the graphics which will provide the user interface ^[8].

Whilst the analysis and prototyping may take some time, this is a good investment which can help avoid costly software changes later in the process.

In the case of new plant it may not be possible to be able to fully determine all operational requirements until the plant has been commissioned.

The ability to cope with the following types of scenarios is required:

Steady state mode	Monitoring, dealing with minor problems, increasing efficiency, environmental compliance.
Start-up mode	Ability to display all plant items under consideration, plus overall process state.
Shut down	As for start-up.
Abnormal Situations	Sufficient screens to monitor all affected plant areas.

Other factors influencing the number of screens that may be required include:

- **Plant Size.** The size of the plant to be controlled will affect the amount of data input to the HCI and the number of actions initiated from it. In general the larger the plant the more inputs and outputs with the HCI. This affects the amount of data to be displayed, hence the number of screens required, and the number of graphics within the hierarchy. For a small plant, it will be easy to use very few screens or graphics as the amount of data will be limited. This is also, of course, related to the amount of instrumentation installed.
- **Process Complexity.** Complex plants tend to require a greater number of screens and graphics. It is more likely that a number of graphics will need to be on display at the same time to allow the operator a full picture of the state of the process. In addition these complex plants will need to display much detailed information. A balance has to be struck between the number of graphics that are designed and increasing the complexity of a smaller number of graphics.

In summary, there is no magic formula that can give an answer to 'how many screens are required?' for all potential scenarios. Again, the designers must understand, as fully as possible, all of the tasks that the HCI is required to perform. The following methodology, using a step by step approach, and taking into account the items discussed earlier in this section, should assist the designers in making the final choice.

In the case of new plant it may not be possible to be able to fully determine all operational requirements until the plant has been commissioned. Therefore it is

essential to allow for future expansion as invariably operational procedures will change with experience. This should include an allowance for physical space, if possible.

If it is decided to use large screens instead of an array of normal sized screens, then the impact of equipment failure must be assessed.

See Appendix 13 and Appendix 14 for examples of screen configurations and graphic hierarchies.

4.1.2 Large Screens

Large screens displays are no longer prohibitively expensive and provide a different type of display capability. Many sites do now incorporate them as part of their HCI.

Advantages of using large screens are:

- They provide an excellent method for permanently displaying overview information and can replicate the old fixed back-panel of hard-desks. This will give a good spatial awareness capability.
- They provide a good display for occasions where a larger number of staff than usual are in the control room e.g. when commissioning the plant, if a problem is occurring or when staff who are not normally present in the control room need access to information.
- On occasions when the control room is single staffed, large screens allow visibility of the process state from a distance. The operator gains the freedom to work at a different position within the control room.
- In control rooms where a supervisor is present, it is easier for the supervisor to keep track on the process without seeming to be interfering in an individual operator's work.

However, in all circumstances the operator has ultimate 'ownership' of the large screen.

Appendix 13 gives examples of some configurations that have used large screen displays as part of the overall HCI.

The decision on whether or not to use large screens in the control room should be based upon a number of factors. Apart from whether there is enough space to fit them in, the most important questions are:

- How do you operate normally? How do you handle a protracted abnormal situation?
- What is the purpose of the screens? They are primarily to assist the operator and his/her colleagues. However, large screens can be useful to show to control room visitors, without impinging on the operator's space
- Should people be encouraged to gather around the operator to discuss problems and offer advice? Not under normal operation, but see the note on abnormal situations at the end of this section.