Control room design - guidance document EEMUA 201 3rd edition updated 2018

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The role of the Control Room Operator in managing risks of modern process plant is indisputable. Detecting deviations early, diagnosing the causes reliably and responding promptly and appropriately all contribute to the avoidance of major accidents and reduces reliance on automated systems. To do this, Control Room Operators need to maintain good situational awareness. This is achieved by accessing data via the Human Machine Interfaces (HMI) provided in the control room and accessing other sources of information, including communication with colleagues. However, their ability to perform this critical role will depend on them being healthy and alert.

Control room design can have a big influence on the ability of the Control Room Operators to perform their role effectively. In particular:

- A good quality HMI can ensure they have the data they need in a useful format;
- The working environment can affect health and alertness;
- Physical design and provision of equipment can support effective communication.

Unfortunately, despite the availability of standards and guidance, the design of many control rooms fails to achieve good practice. EEMUA has recognised an opportunity to update and develop its existing guidance document EEMUA 201 to become a more complete, practical and useable guide to control room design. EEMUA have contracted Wilde Analysis Ltd to rewrite the guide.

Two barriers to adoption of existing standards and guidance have been identified:

1. Engineers assigned the responsibility for designing control rooms do not recognise the importance of adopting human factors principles;
2. Guidance is perceived as impractical or inappropriate for 'real life' application.

In order to overcome these barriers the updated guidance reflects the practicalities of engineering projects. Also, input has been gained from experienced Control Room Operators in addition to Human Factors Consultants, Control Room Designers and Regulators to determine what the guidance needs to say and how it should be presented.

This paper summarises the contents of the updated guidance, highlighting how it can be used to optimise control room design in order to reduce process safety risks. It will discuss the issues where views of experienced Control Room Operators differ significantly from current theory and explain how these can be rationalised in practice. Key messages will include the requirement to consider human factors from the very inception of a control room project and to ensure active participation of Control Room Operators throughout. The updated version of EEMUA 201 includes a number of templates that can be used by project teams to guide them through the various design stages so that they develop an optimum solution whilst utilising best practices.

Keywords: Control room design, human machine interface (HMI), human factors, ergonomics, situational awareness, process safety.

Introduction

The Engineering Equipment and Materials Users Association (EEMUA) publish a range of guidance documents to assist its members and industry as a whole to identify and implement good practice. In 2002 it published EEMUA 201 "Process plant control desks utilising human-computer interfaces - Guide to design, operational and human-computer interface issues." An updated second edition was published in 2010.

In 2018 Wilde Analysis was commissioned to write a third edition of EEMUA 201 in response to changes in technology and practice. As well as updating the existing content it was decided to develop the document into a more complete guide for designing Control Rooms taking in the building, physical aspects of the Control Room, working environment, console design and the Human Machine Interface (HMI) including displays and graphics. Emerging issues such as control devices used outside of the Control Room and current and recurring security issues were covered. A stronger focus on human factors was included throughout.

The aim of the current update EEMUA 201 is to provide improved guidance to people involved in the design and evaluation of Control Rooms including new build and modification projects.

EEMUA Publication 201 is not a standard and is not intended to replace any. Designers will be expected to identify and adhere to any applicable standards and regulations; and any company and project specifications. The role of EEMUA 201 is to provide guidance on how compliance can be achieved as part of a wider context of striving to provide the best Control Room possible to end users.

How does Control Room design affect safety?

People working in a Control Room have to be protected from harm. This means that hazards should be eliminated, reduced and controlled, local building regulations should be adhered to and occupied building risk assessments should be carried out where appropriate.

From a process safety perspective the actions performed by Control Room Operators (CRO) are a concern because the errors they make can contribute to hazardous events, and failure to respond to events can allow events to escalate, leading to potentially damaging consequences.

The primary focus of EEMUA Publication 201 is how the design of a Control Room and associated systems can affect:

- Situational awareness;
- Health and alertness of CROs.

Situational awareness

Situational awareness is the way that people know what is happening around them. In the Control Room setting it is the CRO's mental awareness of the state of the system they are monitoring and controlling and their ability to project the future state based on the information available. A key factor in achieving good situational awareness is making sure the HMI presents information in an appropriate way allowing quick and efficient interaction with the system. This will be supplemented by other information available to the CRO through communication with other personnel and direct perception.

Operator health and alertness

Supplying the best technical facilities does not guarantee success if the people using it are not in the position to perform effectively. If a CRO is fatigued mentally or physically, stressed, demoralised, lacking competence or distracted they will be less likely to act proactively and will have a reduced ability to detect, diagnose and/or respond to events promptly and reliably. The design of the Control Room and how it affects the working environment can have a significant effect on this and should be considered as a critical factor in managing process safety risks.

Development of the third edition of EEMUA 201

Whilst changes in technology prompted the updating of the guidance document, the opportunity was taken to develop it further. The aim was to make it a more useful document. A number of strategies were taken to achieve this including collecting practical experience and focussing on real life design processes.

Learning from practical experience

Although standards and guidance (including previous editions of EEMUA 201) have been available for many years, observations suggest that the design of Control Rooms often fails to fulfil the requirements of CROs and other users. On closer inspection it appears that in many areas it is often not clear what constitutes a good design and in other cases theory and practice do not appear to be aligned.

In order to make EEMUA 201 as useful as possible it was decided to distribute a questionnaire to ask for practical experience on a range of topics where existing guidance did not appear to be clear. The intention was not to provide statistical data but to determine if there was a general consensus on a topic or significant differences of opinion. 37 responses were received from active and past CROs, Control Room designers, ergonomists and regulators.

In order to collect additional practical input the findings from the questionnaire were presented at a seminar (EEMUA 2018) where some of the issues were discussed. Comments made by participants were recorded and incorporated into the updated guidance document.

Real life design

In the ideal world the design of a Control Room would start with a very detailed understanding of the CROs' requirements and work backwards from there. That would determine the equipment required, the size and shape of the console desk, which would then determine the size, shape and layout of the control room. However, the real world does not always work like this and the process followed is often the exact opposite. Unfortunately, instead of providing the CROs with what they need the result often requires them to fit to the system that they are given.

One of the aims of rewriting EEMUA 201 has been to support project teams involved in implementing new or modified Control Rooms. It recognises that the ideal situation is for a team of competent ergonomists to be engaged to drive a human centred approach but that in the real world this is often not possible. It is hoped that presenting clear guidance will result in a better appreciation of the human factors during design and result in more effective Control Rooms.

Findings

The objective of the new edition of EEMUA 201 is to optimise Control Room design in order to reduce process safety risks. The objective of this paper is to highlight some of the more interesting issues encountered during the rewrite. In particular issues where views of experienced CROs differ significantly from theory, or where theory appears to be lacking.

A number of findings and observations related to situational awareness and CRO health and alertness are discussed below. They are not in any particular order of importance.

Types of displays (graphics)

Previous editions of EEMUA 201 introduced the concept of providing different types of display or graphic for CROs to use to monitor and control the system (e.g. overview, control, detail, status etc.). However, only limited information was provided about what each type should display.

Overview displays have been identified as of particular importance because they help the CRO maintain situational awareness and recognise potential problems early. To achieve this they should provide a continually updated 'at a glance' picture of the current state of the system being controlled and convey essential information to determine whether any particular parts of the plant need attention.

In general the information shown on an Overview display should be sufficient to allow the CRO to confirm that the system is running as intended and achieving its main objectives. This is likely to include an indication of system throughputs, mass and/or energy balance (indicating if inputs and outputs are equal), status of critical equipment (e.g. online, standby or tripped), data from parts of the system that are known to be sensitive to process variations or have the greatest impact on overall system performance.

Trend displays are often the most effective way of presenting data on Overview displays. They are consistent with human strengths to detect patterns and subtle changes, which is not the case for numerical values. Also, gauge type displays allow the CRO to quickly establish if a parameter is within a desirable range without having to mentally process data.

The alarm status of sub-systems can be shown on Overview displays using colour. This may not indicate the specific cause of the alarm (i.e. which parameter is outside specification) but direct the CRO to the sub-system that requires attention. However, to be effective this requires good performance of the alarm system, otherwise Overview displays will be showing multiple alarms too often, which is of very little value to the CRO (see EEMUA 191 for further information about alarm management).

Providing more than one Overview display may be useful to the CRO for use during different modes of operation (e.g. start-up, shutdown, steady state, emergency).

The general expectation is that an Overview graphic is kept permanently displayed. It is provided for quick and frequent glances rather than a working graphic. Large screen displays have the added advantage that they can be shared by others but normal sized screens on the Console Desk can be also be used.

Use of colour on displays

There has been a recent trend towards reducing the use of colour on control system displays, and the adoption of a 'grey screen' approach. However, this has often been unpopular with CROs who tended to feel the traditional, colourful displays were more useful. It is not always clear if this is purely because they find it difficult to change or because there is a fundamental problem with the concept of minimal colour. Another explanation may be that many existing systems have been poorly configured so that CROs do not use the graphics to identify active alarms and instead rely on alarm lists.

The idea of the grey screen or minimal use of colour was to ensure that the most important information (typically alarms) would stand-out from other information. Therefore, if the same colour is used in a number of different ways the impact of the colour is likely to be reduced. For example, if red is used exclusively to show high priority alarms it will be very easy to notice active alarms on a graphic. However, if it is also used to indicate shut valves and stopped pumps the visibility of alarms will be reduced and they may be more likely to be missed.

The reaction of the CROs indicates that they see value in some use of colour for status indications other than alarms. This is a good illustration that there is no single correct solution and a compromise is required. On balance reduced use of colour has advantages, but full minimisation is not necessarily the best solution. This means colour can be used to show routine status information as long as it does not detract from critical information. So bright colours can be used for alarms and pastel or less saturated colours could be considered for status information. Whatever colour scheme is selected it needs to be fully documented and applied consistently on every display and graphic.

Showing data on displays

There are many different ways of showing data, but often the default is to provide numerical values, which does little to support the CRO in detecting changes or understanding what is happening.

Where possible, data should be shown in context, which will usually require it to include an indication of whether targets are being achieved and how close the parameter is to specified thresholds such as alarms and trip points. The figure below shows how an analogue display can be used to present this context.

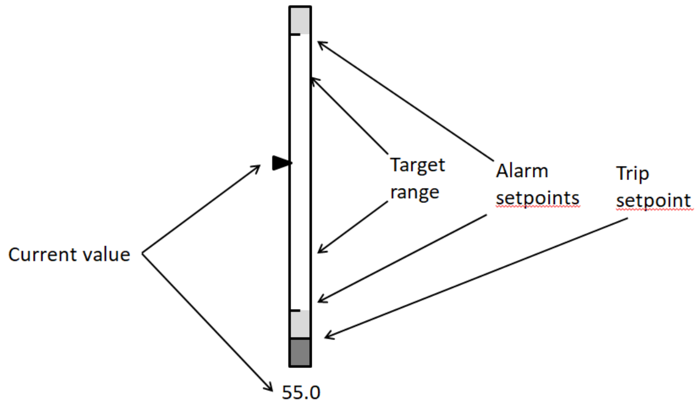

Figure 1: Method of showing data in context

An advantage of this approach is that multiple data points can be shown for easy comparison and the CRO can quickly detect which parameters are off target or in alarm.

Number and arrangement of 'normal sized' screens

CROs will often say they would like more screens to view displays and graphics. When asked, the minimum number of screens preferred ranged from four to 12; and the maximum from four to 22.

After careful consideration it was concluded that four 'normal' sized screens located on the Console Desk should normally be sufficient for the CRO to fulfil their role effectively. This is based on what a human can handle in practice. If more screens are considered necessary this is generally a sign that either the displays are badly designed (i.e. the information required is scattered across displays) or the CRO is overloaded (i.e. they have to monitor more information than can be reasonably be handled). Up to four additional screens may be provided, but these would be considered as secondary screens, that could be used by the CRO to monitor other parts of the system if required, and may be available for others to use (e.g. at very busy times, during training etc.). An area of contention is whether the 'normal sized' screens should always be arranged in a single row on the desk, or whether a double row arrangement (one on top of the other) is acceptable. The concern with the double row is that they require the CRO to look up to view, which can put strain on their neck. However, double rows are relatively common and CROs very rarely (if ever) complain about them.

The conclusion was that screens are used for different purposes as follows:

- Work screens - used by the CRO when interacting with the system using input devices (e.g. mouse, keyboard). Display Screen Equipment (DSE) rules should be observed, which normally requires them to be around eye height of the CRO when sat at the console desk;
- Monitor screens - used by the CRO detect situations requiring their attention and to confirm system status. Location in terms of ergonomic requirements are less important and visibility and legibility are the main requirements.

Overall, it was found that a "quad" arrangement of four screens in two rows (2 x 2) is popular with CROs and is considered acceptable in most instances.

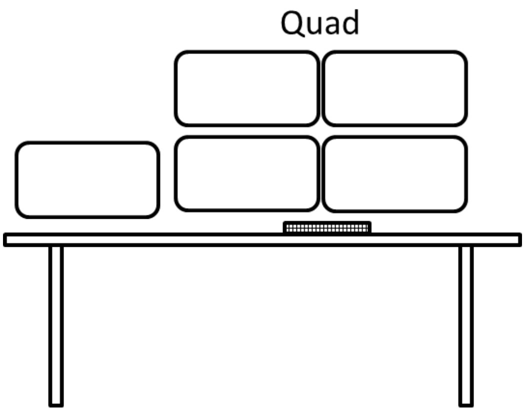

Figure 2: Use of quad groups of screens, shown with an additional screen alongside used for standard office applications etc.

Large screens

Most modern Control Rooms will include one or more large screen displays. In some cases they are an integral part of the CRO's interface and used extensively. However, in many cases their purpose and use has not been properly considered and so the benefits are not clear.

Large screen displays should normally be used by CROs for monitoring only during normal operations and may act as a focus for the team handling abnormal operations including emergencies. Their location in the Control Room, design of displays and means of control should be determined by the needs of these people under these circumstances.

Lighting in control rooms

Creating a pleasant working environment in the Control Room will contribute to the CROs' alertness, wellbeing and ability to perform their job. Lighting is considered to be one of the most important factors. However, obtaining valid and useful guidance about lighting has proven to be surprisingly difficult.

The two main variables when designing a lighting scheme are the types of lamp to be used and illuminance.

It seems likely that most lamps fitted in the future will be Light Emitting Diode (LED) type. These can be obtained with different 'colour temperature.' Cooler lighting (more blue - less yellow and red) is close to natural daylight, considered to help concentration, promote a pleasant working environment, and is generally considered most appropriate for a Control Room. Some lamps are sold as 'daylight' or 'full spectrum' but these terms are not formally defined and so further investigation is required. An additional consideration when selecting the type of lamp is whether reliable colour rendering of items viewed in the Control Room is important, as that will depend on the spectrum range required.

It is clear from the information provided by CROs that there is no ideal level of illuminance. It is a very personal issue, partly affected by age, and depends on the activity being performed, which can change continuously. Increasing illuminance levels can boost alertness, but CROs will often do the opposite and turn the lights down at night. It was concluded that a differentiation should be made between background and task lights. Background lighting levels should be similar to the background colour and intensity of displays in order to reduce eye strain. CROs should be given control over task lighting so that they can select the illuminance they prefer and adjust it to suit the activities they are performing.

An additional consideration is lighting requirements during an emergency shutdown and/or power failure. Standard practice in other areas (e.g. offices) is to provide a percentage of lighting units with some form of battery backup to allow safe egress. This may not be appropriate for a Control Room as the CRO is likely to remain there for some time to monitor systems and coordinate response activities. Where possible, full lighting should remain in the Control Room on power failure. If this is not possible, the location of lighting units with power backup should take into account tasks to be performed during the scenario.

Windows in control rooms

The trend over recent years/decades has been to avoid windows in control rooms, particularly on major hazard sites. This has been driven by safety concerns, particularly resilience to explosions. The attitude seems to be that it is too difficult or expensive to provide windows so they are not considered. But this overlooks the perspective of the people who have to work in the control room, usually for long hours. Lack of windows is something that CROs will often complain about!

As a result of feedback from CROs the updated guidance will be that windows shall be provided in Control Rooms wherever reasonably practicable. This requirement should be considered when locating the Control Building and orientating the Control Room, taking into account any safety and security issues.

If a window is not considered possible, "virtual windows" are now available that provide a video feed from an external camera to an internal screen designed to look like a window. They are being proposed for commercial aircraft and may be an option for Control Rooms where a physical window cannot be provided.

Control room dimensions

It has been suggested in the past that between 9 and 15m^2 of usable area is required per working position. However, experience suggests that whilst this may be appropriate for larger Control Rooms with a large number of CROs it is not sufficient in many cases. As a result the updated EEMUA 201 recommends that the smallest Control Room to accommodate a single CRO will be around 30m^2 with a square or near square shape. For two CROs, 45m^2 may be sufficient, with a further 10m^2 per additional CRO.

The other dimension that causes discussion is ceiling height. Part 3 of ISO 11064 (ISO 1999) has always specified that 3 metres should be considered the minimum, but lots of control rooms have been built with less. As a result it was considered whether this guidance could be relaxed. However, it was concluded that higher ceilings have many advantages including improved options for lighting and ventilation, and the psychological impact of creating a feeling of space. Also, it increases flexibility for locating large screens, which is required if double rows of normal sized screens are to be mounted on the console desk or if the desk height is adjustable.

Adjustable desk height

It was normal in the past to provide desks at a fixed height. Adjustable desks are now readily available and becoming more common in control rooms. Desks with limited height adjustment are intended to accommodate people of different height whilst seated. Other desks have a large height range so that they can be used whilst seated or standing (referred to as sit-stand desks).

Whilst some Control Room designers and ergonomists were adamant that adjustable desks should be provided, feedback from CROs suggested that they were not so convinced about the advantages. This maybe because of a lack of practical experience, given that most have been working at fixed height desks. However, on this basis the guidance is that the selected desk should be suitable to accommodate the CRO population, but if this is fulfilled height adjustment is a 'nice to have' feature.

Humanising features

Although a Control Room is clearly a workplace, humanising features that create some variation in colour and texture, provide visual stimulation or have a relaxing effect can improve the CRO's wellbeing and subsequently their performance. Although fish tanks have been popular in in the past, feedback was that they should only be considered if there is a clear interest shown by the CROs. Pictures may be displayed on Control Room walls to create visual interest, but the subject matter of pictures (e.g. work related or other subjects such as nature or landscapes) should be determined by the CROs.

Ceilings should be light in colour. A pale, pastel or earth tone colour should be considered for walls, and floors should be darker. Different colour schemes may be selected if dirt is expected to be a problem as grubby surfaces can create an unpleasant impression.

Surfaces in the direct view of the CRO when sat at their Console desk should not create any contrast with the displays they use and should not have any features that may cause distraction. A feature wall using a stronger colour, pattern or texture may be considered for walls outside of direct view if the CROs feel that this could help stimulation.

Emerging issues

The section above has summarised some of the updated guidance in the new edition of EEMUA 201. Whilst generating this guidance it has become apparent that certain topics are developing rapidly and so it is useful to be aware of these changes although guidance is not readily available.

Access to control systems outside of the control room

Technology allows people to access control systems from remote locations (i.e. not just the main Control Room). As well as security considerations (see below), there are other issues to be considered when deciding whether to enable such functions and how to implement them

The use of devices providing remote access to the control system should be considered as an integral part of the system and included in the original design. They should not be considered as a separate function. They should either be "read only" or a robust mechanism should be provided to ensure the point of control is clear at any time. An assessment should be made of why people will be accessing the system remotely so that the correct device can be provided. It must be clear who will receive and who will be responsible for responding to any alarms and other events.

Plant Information (PI) systems provide an interface to a control system, making process data available to standard computers. They allow data to be downloaded from the control system for storage and analysis using spreadsheets and other applications. PI systems are generally not designed to achieve a high level of reliability and CROs should not become overly reliant. In many cases CROs use PI because of shortcomings in the control system HMI. It is much better to improve the HMI than to create a situation where CROs rely on a potentially unreliable PI system.

Use of simulators for training

Process simulators can provide great benefit in training operators, enabling them to practice routine and emergency procedures in a safe environment, and enabling competency to be measured. They have been available for a long time but in the past the costs was often seen as prohibitive outside of specific industries (e.g. nuclear). Technology has significantly reduced costs and high fidelity simulators that closely mimic the real system can be cost effective. Also, lower fidelity simulators using standard computers are available covering a wide range of applications.

Whatever form of simulation is used, a structured and recorded training programme should be developed and followed. The training objectives should be clearly defined to ensure maximum benefit is achieved. Virtual reality is likely to become more available for use in training. It may prove cheaper than creating and using physical simulators, and could be very useful for a new Control Room to allow training to start before construction.

Competency requirements should be identified and the best available method of obtaining and demonstrating that competence should be used. Whilst preferred, even a high fidelity simulator is not suitable for developing all types of competency required by a CRO.

Security

There are three main concerns with regard to security:

1. Physical intruders;

2. Industrial espionage;

3. Malicious interference to control and safety systems

Increased use of standard computer technology by control and safety systems and increased connectivity have increased vulnerability to electronic or cybercrime.

There are many steps that can be taken to reduce the vulnerability to security breaches or limit their effects. Many of these measures are taken during the design and commissioning and need to be regularly reviewed and audited to ensure that the measures remain appropriate.

Security should be designed in at the outset and not viewed as an additional issue to be dealt with separately. It should be one of the constituent parts of the business continuity planning and needs to be resourced at a level likely to meet the desired business continuity criteria.

Risk assessments should be carried out to determine the levels of security required based on level of threat and vulnerability of the systems being used. They should include a security task analysis to identify the vulnerabilities that may occur due to the different ways that people may access the control or safety system and associated network.

Risk assessments should also consider the means of recovering after a security breach (physical or cyber). This should include use of back-ups and redundant systems. Effectiveness of arrangements should be reviewed and audited regularly.

The output from the risk assessments should be used to define the security mechanisms to be deployed through design and operational controls including security procedures to be followed by anyone accessing the control or safety system and network. Inspections and audits should be carried out to confirm that the required level of security has been achieved and is being maintained.

Additional features of the guidance

One of the aims with the rewrite of EEMUA 201 was to make it as useful as possible particularly for people involved in designing or evaluating Control Rooms, making sure human factors received enough attention. This has been achieved by providing a number of tools as appendices in the updated guidance document.

Human Factors Integration Plan (HFIP)

HFIP are a way of ensuring human factors issues and opportunities are identified and managed so that appropriate solutions are implemented through design. To be effective an HFIP should be developed as early as possible in a project and reviewed and updated throughout. Unfortunately in real life projects human factors are often considered too late or overlooked entirely.

A template for creating a HFIP has been included in the new edition of EEMU 201. It provides a structure based on standard project phases and should be populated with project information at each stage. A key feature of the HFIP is that it recognises that in real life projects assumptions often have to be made. It requires that the basis for these assumptions is documented and reviewed as more reliable information becomes available.

It is hoped that future projects will use the HFIP template and that this will result in a more structured and effective design process with a better appreciation of human factors; and that this will result in better Control Rooms.

Evaluation Checklist

Design of Control Rooms can occur at many different times ranging from the early stages of a project through to one that has been in use for many years. However, the requirements remain the same and so a single evaluation checklist has been provided.

The checklist prompts an evaluation of the key aspects of control room design. It asks questions in a way that requires the person carrying out the evaluation to consider whether the design is appropriate for the specific application. References are provided to the relevant sections of the guidance document to reduce the time and effort required when comparing the design with the requirements.

Task Requirements Analysis (TRA)

TRA is a high level task analysis method. It provides a focus on the types of tasks likely to be performed on a system and on the design features required to support those tasks. An example TRA has been provided in the updated version of EEMUA 201to assist project personnel to perform this very useful analysis. As well as the CRO, it covers other users of the Control Rooms including Field Operators, Supervisors, Maintenance personnel, Commissioning teams, contractors and guests.

Method for optimising arrangement of screens and panels

Previous guidance has been to identify ‘primary’ and ‘secondary’ screens and panels; and to arrange them accordingly. But in real life Control Rooms, many screens are used differently depending on circumstances and CROs often have to manage data from a number of different systems. Even the ideal scenario where one system provides all the data required by the CRO introduces challenges for Control Room layout because inevitably a Personal Computer (PC) is required, and can disrupt the optimal screen arrangement.

The updated version of the guidance includes a tool that can be used for evaluating and optimising the arrangement of screens and panels in the Control Room. It reflects the fact that some are used for work, others for monitoring and many used for both. The tools advises how all these can be addressed in design. The figure below illustrates how this can be carried out.

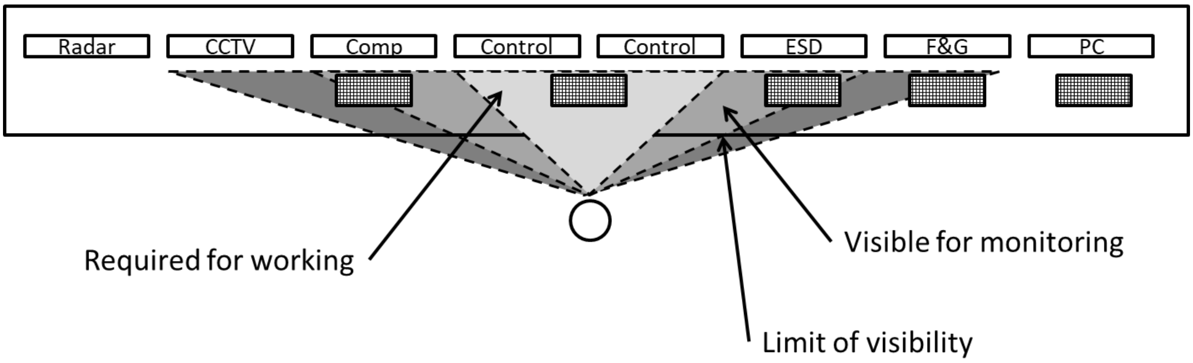

Figure 3: Evaluating the arrangement of screens and panels

Conclusions

The new edition of EEMUA 201 includes updated guidance reflecting current technology and practice. A number of areas have been identified where theory and practice do not agree and others where the theory was simply lacking. It is hoped that the new edition will prove to be a useful document for anyone involved in the design and evaluation of Control Rooms.

One of the key messages to be taken from the updated EEMUA 201 is that Control Room Design is a human factors issue. This means that an understanding of human factors is required to ensure the inevitable compromises of design are optimised. A human centred approach means CROs need to be actively involved throughout any project. Introduction of a new control room should always be managed as a project and any modification to an existing control room requires robust management of change. The opportunities presented by effective Control Room design include process improvements, reduced maintenance costs, standardisation and connectivity, improved working environment, easier training and improved security and resilience.

References

EEMUA 2018, Alarm systems and controls, seminar held at Mottram Hall, Wilmslow on 12 July 2018

ISO 1999, Ergonomic design of control centres - Part 3: Control room layout, first edition.