Human Factors For Project Managers

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ABSTRACT
In today’s industrial environments there is an increasing awareness of the need to apply sound human factors principles in the design of both physical environments and automation systems. Although the underlying principles have been well understood for some time, their application is often limited or in many cases only paid lip service to. Often linked to ergonomics and situation awareness the term Human Factors encompasses a wide range of subjects commonly including the design of control rooms, human machine interfaces and alarm systems. However, there are other elements, such as fatigue management, training, workload, communications and procedures that are often overlooked. Organizations address many of these issues through policies and procedures, specifically targeted at day-to-day operations, but provide little guidance in terms of project execution. It is not unusual to find that project managers are surprised by a sudden revelation that work that had not been accounted for needs to be funded and resourced. It is also common for elements to be cherry picked a practice that often leads to additional expense, resource requirements or time.

From the perspective of a former automation project manager and now human factors consultant, this paper will provide insight into how the individual elements should be considered as part of every project. In so doing the paper will identify the best practices out there today along with relevant standards and guidelines.

Introduction
The International Ergonomics Association defines Human Factors Engineering (HFE) as:

‘Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.’

In essence the purpose of HFE is to ensure that the limitations, weaknesses and strengths, of the human element of a system, are considered as an integral part of the design of that system.

Whether as part of a large Greenfield project or a smaller upgrade or retrofit, many projects pay little attention to, or ignore altogether, the basic requirements of the operators that need to run the new equipment. It is generally not an intentional decision to do this, but it is often due to a lack of understanding regarding current requirements and best practices. If evidence is needed of this just walk
into a typical control room and talk to the operators, they are often not shy in relating their frustrations and fears.

This paper is intended to provide some high level guidance on what should, as a minimum, be considered during project execution.

Although it is recognized that all projects are different the paper will use as an example a large Greenfield project that includes the provision of a new control room facility.

So what Human Factors are we talking about?

When we look at a modern facility there are generally three types of operator:

- Dedicated Console Operator
- Dedicated Field Operator
- Inside/Outside Operator

The Console Operator is a control room based position that operates a facility via some form of control system. Their duties do not typically take them into the field and their only view on to the process is via the human machine interface (HMI). The HMI is generally laid out on a console at which the Console Operator sits for the majority of this time on shift.

The Field Operator is, as the title indicates, an outside job that typically performs manual operations in the field. Work direction is often provided to the Field Operator from the Console Operator.

An Inside/Outside Operator is essentially a combination of the Console and Field Operator positions, where he monitors and controls the process from the control room, but also has assigned field duties.

For the purposes of this discussion we will concentrate on the Console role as this illustrates the principles for all types of position. It should also be noted that the physical design of the plant, equipment layout, accessibility and operation should incorporate sound ergonomic design principles, however, these are not discussed further in this document.

In each case we need to ensure that the operators have the tools and systems in place to enable them to operate the plant effectively under all operating conditions. For them to be truly effective they must be aware at all times of past, current and future operating conditions, in other words aware of their situation. The operator uses all of his senses to gain this situation awareness:

- Sight – field observation, human machine interface
- Sound – verbal face to face and via radio, alarms, process sounds
- Touch – vibration (e.g. start of a piece of rotating equipment)
- Smell – chemical presence, smoke
- Taste – chemical presence

Therefore it is important that we recognize each stimulus and help the operator to use them as effectively as possible to:
• Detect changes
• Diagnose changes
• Respond to changes

This operator response model is illustrated below:

![Feedback Model of Operator-Process Interaction](modified from A.D. Swain & H.E. Guttmann, 1983]

Figure 1 – Feedback Model of Operator-Process Interaction [modified from A.D. Swain & H.E. Guttmann, 1983]

So what are the key elements of situation awareness that we can address in the design process:

• Work Team Design
• Human Machine Interface Design
• Communications Design
• Control Room Design

Each of these will be discussed in later sections.

It is also important to understand that these elements are integrally linked; addressing one with no thought to the others can lead to serious issues later in the project. For example designing the HMI, without consideration to the control room lighting could lead to screen glare or high contrast levels between screens and background, resulting in eyestrain.

**Project Definition**

Before we can even start to execute a project we need to secure funding to do so. Capital money is under significant scrutiny today and once a budget has been set, additional unexpected scope changes are certainly not desirable. Therefore it is extremely important that we don’t miss anything up front. A common problem is failing to clearly set out the expectations of the project. Simply putting ‘To increase capacity to 50 tpa’ may be well understood by senior management looking to approve funding, but this does not speak to some of the other goals that are essential in making this a reality. It is no good
increasing capacity if the plant cannot operate safely and within environmental limits. So wouldn’t it be a good idea to add a list of some of the engineering expectations!

Also it should be noted that there is significant cost to implementing good HFE principles in design and these should be in the budget. However, on the reverse of this there are some cost benefits of getting it right, a proactive operator (line 3 figure 2) will potentially save money in process efficiencies, energy usage, equipment wear and tear etc., over an operator forced into a reactive operating stance (line 2 figure 2). The ASM Consortium claimed potential savings of 8-12% of operating costs, a high figure, but perhaps a conservative 2-4% might help justify a project and the additional expense of incorporating HFE.

![Figure 2 – Operator Response to Process Deviations](image)

Another aspect that is also often forgotten is the internal cost of staff to assist in design activities. It is common practice to estimating engineering costs, but what about operators and operations’ support staff that are often the subject matter experts on plant operation.

**Project Execution**

As mentioned above it is an unfortunate fact that due to the interdependencies of each of the key elements there is no straightforward, linear approach to programming each of the requisite activities. This can be illustrated by considering the lifecycle models of the alarm management system and human machine interface as described in ISA-18.2 and ISA-101(draft) respectively.
Due to the presentation of alarms in the HMI the development of the alarm and HMI philosophies are dependent on each other, similarly detailed design of the HMI requires knowledge of rationalized alarms and changes to either in the implementation and commissioning stages often have to be coordinated.
A flowchart of a project that addresses all the HFE elements might look something like the following figure:

![Typical Project Flowchart](image)

**Figure 5 – Typical Project Flowchart**

It is a challenge and one that is complicated by the fact that key project resources may be required to be involved in multiple activities and their time may become a project constraint or critical path.

**Work Team Design**

One of the earliest activities that needs to be completed is the determination of the complement of people that will make up the operations team. Indeed this requirement is stated in section 4.3 of API RP 755 as:

‘... an initial and periodic assessment of the staffing levels and workload balance, such that the implementation of the hours of service guidelines discussed below are feasible and that fatigue risk is adequately managed.’

This not only looks at the number of operators but also at the supervisory and support structures. Firstly there must be a determination of the number of console and field operators that can operate under normal operating conditions as it is still a principle that companies staff for normal operations and manage abnormal situations. There are various ways of going about this:

- Management Judgment
- Time and Motion
- Loop Count (Console Operator)
- Complexity Models
Depending on the experience Management Judgment can be very effective, but is the determination difficult to justify. Time and motion requires the facility to be operational and can be impacted by behavior of the observed. Loop count has been used often as a basis for console positions, but the question has to be asked as to how plant complexity is considered. If the benchmark 250 loops is accurate for a refinery cat cracker, can it also be accurate for a waste water treating plant? A complexity model is often the best solution, combining elements of the other methods to ensure the highest level of confidence for new and existing facilities.

Once the number of operators is decided upon it is time to look at the supervisory structure. Traditionally there has been a shift supervisor assigned to one or more process areas, and his role was well defined as the leader of the on shift team. As experience increased within the teams many companies moved to self directed teams, whereby the shift supervisor played less of a role in tactical decisions and became more and more administrative, and leadership within the work teams was left to the operators, who, being highly experienced, required much less of it. With the current trend of loss of experience we are seeing a return to the traditional work team design with the supervisor taking on a leadership role again. However, with the advent of centralized control rooms, we are seeing two distinct types of supervisors emerging, one in the field, acting as before, and another in the control room, acting as an optimizing and coordination resource for the whole facility. As mentioned before every facility is different and so it is not possible to prejudge the work team design, however, guidance is available from various sources such as the UK’s Health and Safety Executive’s (HSE) document RR292.

Having determined staffing requirements for normal operation, it is now extremely important to ensure that the team can safely manage all abnormal situations, including start up and shut down. Again the UK’s HSE provides some guidance in its document CRR348, in which it discusses an assessment methodology, however, this has to be supplemented with an assessment of operational response to various scenarios. This often requires significant input from the operations team and supporting documents such as PHAs or HAZOPs that can provide valuable insight into credible abnormal situations.

It should also be noted that all changes to staffing, based on a recommendation from the Texas City, Baker Report, should be subject to a process called Management of Organizational Change (MOOC).

An important consideration at this stage is the definition of the previously mentioned Fatigue Risk Management Plant (FRMP). Based on API RP755 this document will not only define hours of service limits, but training and education requirements and any fatigue countermeasures that will need to be provided as part of the control room design.

**Human Machine Interface Design**

ISA-101 defines the Human Machine Interface as:

‘The collection of hardware and software used by the operator to monitor and interact with the control system and with the process via the control system.’

Therefore HMI design considers:
For all systems there should be a set of foundational documents that define the design criteria for the above. The first three design elements are covered by two documents:

- HMI Philosophy – a system independent guide to the site or company specific application of industry standards and best practice principles to the design of the HMI.
- HMI Style Guide – a system dependent guide to the application of the HMI Philosophy on a specific software or hardware platform.

The alarm management system is similarly defined in an Alarm Management Philosophy document.

It is extremely important that these documents are created before design decisions are made or implementation started. They should also ensure that all decisions that are made are well documented and should be suitable for use as part of an engineering package for third party engineering. As much as possible wiggle room in the design should be avoided!

To help in this process there are some industry standards and guidelines that can be leveraged:

- HMI Design
  - ISA-101 (future)
  - EEMUA 201
  - API 1165
  - ISO 11064-5
- Alarm Management:  
  - ISA-18.2 (future IEC 62682)
  - EEMUA 191
  - API 1167

Once an agreed basis for design is determined the next step is to ensure that the alarms are rationalized correctly. Building graphics before this is done can lead to rework, especially if level 1 displays are to be provided. There are three main phases to alarm rationalization:

- Identification
- Documentation and Rationalization
- Configuration

In the Identification phase potential alarms are identified from the design processes such as:

- PHA / HAZOP
- Layer of Protection Analysis (LOPA)
- Safe Operating Limits
• Process Licensor requirements
• Equipment Manufacturer requirements

It is important that alarms identified, as safety critical should be designed according to ISA-84 or IEC 61511.

Once potential alarms have been identified they are documented in a Master Alarm Database, which is initially a repository for alarm configuration data. Once documented alarms are then formally rationalized based on the criteria defined in the Alarm Philosophy. At this stage additional information, that will be used for operator documentation, such as alarm response sheets, is added to the Master Alarm Database entries.

Having completed rationalization alarms are configured into the system, controlled by the facility’s Management of Change (MOC) procedure.

Once this is done the design of the HMI can be completed. It is the norm that most HMI graphics are based on the plant P&IDs, however, it is recommended that this approach is avoided and design is based on a formal task analysis process. This is especially true for any level 1 displays, intended to provide the operator with a constant view of the critical process parameters and alarms.

Other elements of the HMI that also need to be considered include:

• IT computer (email, logs etc.)
• Fire and Gas Systems
• Tank Monitoring Systems
• Data Historian
• Hardwired Alarm and ESD panels

Although typically undertaken as part of the control room design process the HMI design will impose constraints on the console design.

**Communications Design**

The design of the communications systems are somewhat independent of the other elements, however, it is important to consider this early on in the process as it will impose constraints on the control room design, especially that of the console.

There are no real standards used in the design of operator communications systems but it is recommended that, as with the HMI and Alarm System, a Communications Philosophy document is considered. This again will detail the principles involved in the design and includes such things as equipment, redundancy, backup systems, power and even communication protocols. The ability to maintain effective communications under all operating conditions is a vital tool in Situation Awareness.

An additional communications tool, that is often forgotten, is a formal shift handover policy. Shift handover has recently been dubbed a safety critical communication by the UK’s HSE, Human Factors
Briefing Note No.8, and as such it needs to be effective and robust, and not the proverbial high five as the operators pass each other at the gate.

**Control Room Design**

Proper control room design has been shown to be vital in providing the operator an environment that supports Situation Awareness. It is not possible to go into a lot of detail in this paper but guidance is provided in the form of International Standard ISO 11064. This is an excellent document, but far from a ‘Dummy’s Guide to Control Room Design’. The document is currently in 7 parts:

- Part 1: Principles in the design of control centres
- Part 2: Principles in the arrangement of control suites
- Part 3: Control Room layout
- Part 4: Layout and dimensions of workstations
- Part 5: Displays and controls
- Part 6: Environmental requirements for control rooms
- Part 7: Principles for the evaluation of control centres

Part 1 defines a process for control room design that is based on the following model:

![Ergonomic Approach to System Design (ISO 11064 – part 1)](image)

Many of the design criteria discussed in previous sections, such as operator task analysis, are discussed in ‘Phase A: Clarification’ of the process. Part 2 of the document builds upon this to detail the layout of the control suite and control building, identifying functions, rooms and key adjacencies.

Part 3 then looks at the control room layout, considering such things as number of consoles, layout of the consoles, communications etc.
Part 4 concentrates on the ergonomic design of the console, building on decisions made during the HMI design and Part 5 provides guidelines used in the development of the HMI design.

Part 6 provides recommendations for environmental conditions, and finally Part 7 provides guidance for the verification and validation of the design.

Following this process will ensure that the control room is designed to support the activities of the console operator, providing an environment that promotes optimal Situation Awareness.

**What if I only have a small project?**

This paper has discussed some of the issues that a project manager on a large project might face, however, the intent was to provide a framework for all project sizes. Even if the project does not have a control room, or a large amount of new equipment, or changes to the operations team, the principles should be the same. All changes can have an impact on the operator’s performance and none should be so small that they are treated as insignificant.

**Summary**

The intent of this paper was to highlight issues that have an impact on an operator’s performance, which, at the end of the day, has an impact on bottom line profitability. In examining a particular type of project, the key elements that can make or break a project are presented with some guidance as to how to address them. As a minimum using this document as a checklist to prompt consideration of the issues discussed, should be a worthwhile exercise on all projects.

**List of Acronyms:**

- ASM .................. Abnormal Situation Management
- CRIOP® ............. Crisis Intervention and Operability
- EEMUA ............. Engineering Equipment and Material and Users’ Association
- FRMS ............... Fatigue Risk Management Plan
- HFE ................... Human Factors Engineering
- HSE .................. Health and Safety Executive (UK)
- HMI .................. Human Machine Interface
- ISA .................. International Society of Automation
- ISO .................. International Standards Organization
- LOPA ................. Layer of Protection Analysis
- MOOC ............... Management of Organizational Change
- PHA .................. Process Hazard Analysis
- P&ID ................. Process and Instrument Diagram
- SINTEF .............. Stiftelsen For Industriell og Teknisk Forskning

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David is a Chemical Engineer by degree, but has held posts in Control Engineering, Operations and Project Management before becoming a Human Factors Consultant in 2007. He is Chartered Engineer and Fellow of the Institute of Chemical Engineers, and an active senior member of ISA, on the board of ChemPID and several standards committees.