Human factors in engineering and design

Key messages

- Integration of human factors principles in the design and engineering of new or modified offshore petroleum facilities can improve safety, integrity and environment outcomes, and reduce ongoing costs over the life of a facility.
- Human error is more likely to occur where human interfaces have been designed without consideration of human factors.
- Human factors in design and engineering is one of the most effective and efficient means of preventing human error and mitigating its consequences.
- Consideration of human factors during design can eliminate the need for time-consuming administrative controls.

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Key definitions for this information paper

The following are some useful definitions for terms used in this information paper. They are a suggested starting point only and are not prescriptively defined, unless otherwise indicated.

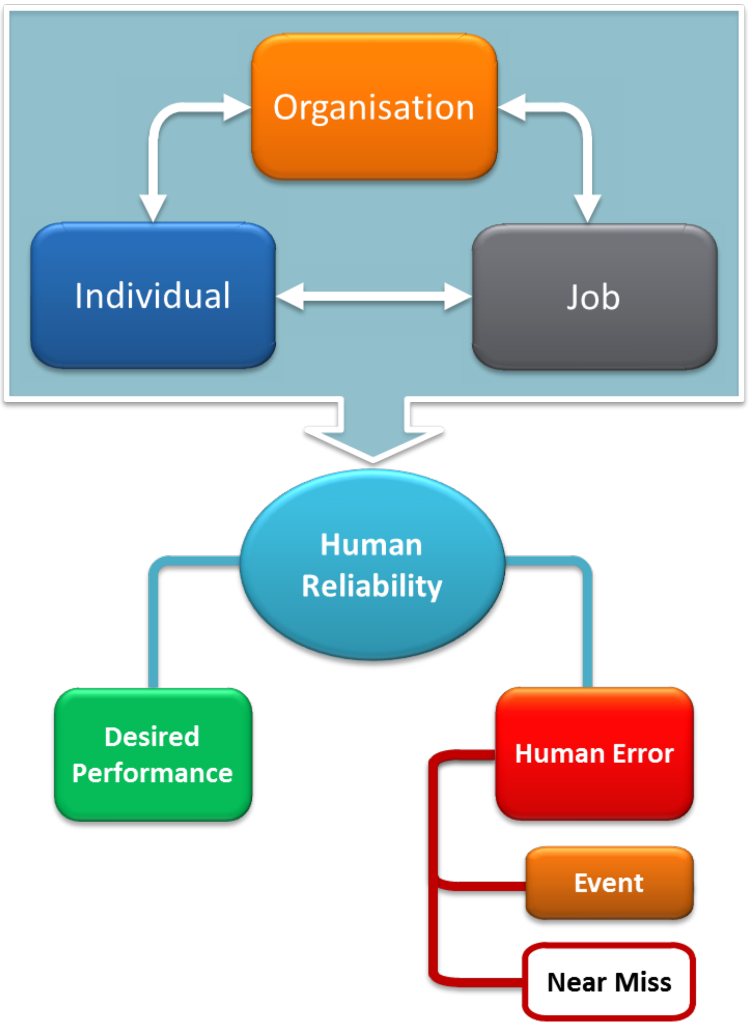
Anthropometry	The measurement of the size and proportions of the human body.
Error tolerance	The ability of a system to function after an error has occurred.
Hazardous event	A collective term encompassing safety, integrity, and environmental incidents, used for readability purposes within this information paper.
Human-centred design	An approach to design and development that aims to make systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques.
Human engineering	Referring to causes related to four categories (TapRoot®, 2007): (1) Human-machine interface problems [problems caused by poor human factors design of equipment interfaces, controls, tools, or jobs]. (2) Poor work environment problems. (3) System complexity problems. (4) Non-fault tolerant system problems [a system in which an error is not detectable or not recoverable].
Human factors	The ways in which the organisation, the job, and the individual interact to influence human reliability in hazardous event causation.
Human reliability	The likelihood that an individual will make an error while performing a task.
Musculoskeletal disorder	An injury to, or a disease of, the musculoskeletal system excluding injuries caused by crushing or entrapment.

1 Introduction to the human factors information paper series

Human error has long been identified as a contributing factor to incident causation. Commonly cited statistics claim that human error is responsible for anywhere between 70-100% of incidents. It may seem logical, therefore, to blame incidents on individuals or small groups of people and to focus remedial actions at the individual level (e.g. training, disciplinary action, etc.). However, by taking this approach in addressing human error, organisations ignore the latent conditions in their work systems that contribute to human error across the workforce. Rather, human error should be recognised as an outcome of combined factors, instead of the root cause of an incident. Organisational, job, and individual factors all interact to influence *human reliability*, that is, the likelihood that an individual will perform their task effectively or make an error.

This publication forms part of a series of information papers focusing on human factors. NOPSEMA defines *human factors* as "the ways in which the organisation, the job, and the individual interact to influence human reliability in hazardous event causation". Reliable behaviour results in desired performance, while unreliable behaviour may result in human error, which can lead to events and near misses. This interaction is represented in Figure 1.

Figure 1 – A model of human factors



The Human Factors Information Paper Series is designed to provide information about the ways in which organisational, individual, and job factors influence human reliability, and how organisations can minimise or optimise the effect of these factors, to assist in the prevention and mitigation of *hazardous events* and drive continuous improvement in safety, integrity and environmental performance.

Further information on human error can be found on the Human Factors page on the NOPSEMA website at www.nopsema.gov.au.

1.1 Intent and purpose of this information paper

Effective integration of human factors (HF) principles throughout the design and engineering of new or modified facilities represents one of the most efficient methods of preventing human error and mitigating its consequences. The integration of HF within design and engineering processes aims to create a workspace that functions in a way that is intuitive for end users. The approach seeks to fit the task and environment to users, rather than requiring users to adapt to the task or environment. *Error tolerant* designs, developed in accordance with HF principles, are less susceptible to human error. That is, they are less likely to facilitate error, and better able to recover when errors do occur.

Human engineering was listed as a root cause in 422 notifiable occurrences reported to NOPSEMA, including 18 instances of serious injury, and 52 instances where death or serious injury could have occurred. The SPAR-H Human Reliability Analysis Method (US NRC, 2005) identifies the multiplying effect that poor human engineering can have on the likelihood of error. Extracts from the SPAR-H are presented in Table 1.

Table 1 – SPAR-H Extract - Error multipliers

"Diagnosis" task: base error rate 1%		
Performance shaping factor (PSF)	**PSF level**	**Error multiplier**
Ergonomics / Human machine interface	Missing/Misleading	50
	Poor	20
	Good	0.5

This table indicates that, in ideal conditions, a worker conducting a diagnostic task has a 1% likelihood of experiencing error. However, where the ergonomic or human-machine aspects of the user interface are misleading, the likelihood of error increases to 50%. Conversely, where these aspects of the user interface are good, the likelihood of error is reduced to 0.5%.

The application of error tolerant design can eliminate or minimise opportunities for error and associated event causation. It can also provide mechanisms which facilitate error identification soon after occurrence. This allows for the commencement of corrective actions earlier in a potential event trajectory than might otherwise be possible. Within an offshore petroleum environment, error tolerant design can contribute to a reduction in the likelihood and consequence of hazardous events across the life of a facility. The integration of HF in design and engineering can also deliver improvements in quality and productivity, reduced costs associated with operations and maintenance activities, and fewer injuries and *musculoskeletal disorders*.

This information paper discusses human factors in design as a job-level performance shaping factor within the human factors framework. It describes some of the contributions that human factors can make to hazardous event prevention during the design of new or modified offshore petroleum facilities.

Please note: Information papers provide information, background and practices to foster continuous improvement within industry. NOPSEMA acknowledges that what is good practice, and what approaches are valid and viable, will vary according to the nature of different organisations, offshore facilities and their hazards.

2 Incorporating human factors into engineering and design

The integration of human factors principles into engineering and design processes is well established as a means of error reduction in high-risk industries such as commercial aviation and nuclear power. Poor human engineering can increase the likelihood of error and contribute to hazardous event causation, and can facilitate injury and musculoskeletal disorders. Within the petroleum industry, consistent integration of HF principles throughout the engineering and design of new or modified facilities can:

- contribute to the reduction of risks associated with human activities to a level that is as low as reasonably practicable
- reduce the likelihood and mitigate the consequences of human error and ensuing hazardous events
- improve human efficiency and productivity
- reduce capital expenses through improved design efficiency, avoiding changes or re-work in late design phases
- reduce ongoing expenses associated with training, competency verification, procedure development and maintenance, and other administrative controls implemented to mitigate poor human engineering
- reduce the need for re-work during construction and commissioning
- reduce facility life-cycle costs associated with operations and maintenance activities
- improve user acceptance, commitment, and buy-in.

A number of standards are available to assist organisations in developing specifications for the inclusion of HF requirements into design. These include publications from the International Organisation for Standardisation (e.g. *ISO/TC 159 Ergonomics)* and ASTM International (e.g. *F1166* & *F1337*). In addition to these technical standards, the *International Association of Oil and Gas Producers* and the *American Bureau of Shipping* have recently published guidance on how to integrate HF into the engineering and design of petroleum projects.

To facilitate successful integration of HF during design and engineering, the following recommendations should be adopted through the lifecycle of the design process (ABS, 2014):

- Human factors activities should be incorporated through all phases of the project, starting at the concept phase.
- Human factors professionals should be engaged, holding appropriate academic qualifications and relevant experience, with representation from the different professional disciplines within the HF field (e.g. engineers, ergonomists, psychologists, etc.).
- The level of HF involvement throughout a project should be determined before the start of the project.
- Management should demonstrate commitment to HF, and a HF champion should be appointed during the transition.
- Close cooperation is necessary between HF personnel, other engineering disciplines, and operations and maintenance representatives.
- Human factors requirements should be mandated in the project design.
- The use of accepted HF design standards should be required within project specifications.
- An early focus on known HF problems and lessons learnt from other facilities or projects should be included within the project plan.

Table 2 provides examples of some of the activities conducted by HF professionals during the design and construction of a new or modified facility.

Table 2 – Human factors activities through the project lifecycle

HF Activity	Project Phase					
	Concept	Select	FEED	Detailed Design	Construction	Operations
Write project HF strategy	x		x			
HF screening	x	x				
Review project standards		x				
Deliver HF awareness training			x	x	x	x
Document, track, and closeout HF issues			x	x	x	x
Generate HF design aides and specifications			x	x		
Task analysis			x	x		
Safety-critical task inventory analysis			x	x		
Valve criticality analysis			x	x		
Control room design assessment			x	x		
Facility layout reviews			x	x	x	
Evaluate human-computer interfaces			x	x		
Review accommodation design			x	x		
Assist material handling study			x	x		
Evaluate noise and vibration			x	x		
Evaluate crane operations			x	x		
Review alarm systems			x	x		
Conduct computer aided design reviews				x		
Vendor package screening				x	x	
Prepare procedures, manuals and labels				x	x	
HF in construction – monitoring and testing					x	
Follow-up evaluation						x

[Adapted from Robb & Miller (2012)]

The following sections provide information about the use of human-centred design to improve human reliability in relation to control rooms and facility layout.

3 Control rooms

Control rooms are essentially a large and complex interface between an operator and a system. The size and complexity of control rooms can vary from large production process control centres and vessel bridges, through to smaller spaces such as crane cabins. Operator error within control rooms can lead to loss of control (e.g. containment of hydrocarbons, vessel position, suspended loads, etc.) which can contribute to hazardous events. The application of human factors principles during the design of control rooms, control panels, and control software can prevent errors from occurring and facilitate post-error identification and recovery.

Example – BP Texas City refinery explosion

On March 23, 2005, the restarting of a hydrocarbon isomerisation unit resulted in a series of explosions. Fifteen people were killed and a further 180 were injured. The Chemical Safety Board (CSB) found that the computerised control board display contributed to the overfilling of the raffinate tower.

The CSB report (2007) described two critical flaws in the design of the display:

- The flow into the unit was displayed on a different screen to the flow out of the unit.
- No material balance calculation was present to highlight the imbalance between the two flow readings.

The CSB found that the location of the two feeds on two different screens diminished the visibility and importance of monitoring liquid in and out, and did not alert the operator to the imbalance between the two flow readings.

3.1 Control room design

A variety of environmental factors within the control room can act as performance-shaping factors, with the potential to increase error likelihood. The following environmental factors should be taken into consideration during the design or modification of control rooms:

- Noise
- Lighting
- Visibility
- Vibration
- Physical layout and accessibility.

3.2 Control panel design

Control panels may contain multiple displays and controls. To reduce opportunities for error control panels should be designed, as far as is practicable, in accordance with the following design principles:

1. *Frequency of use* – frequently used components should be easily accessible.
2. *Importance* – critical components should be conveniently located.
3. *Sequence of use* – the location of components should correspond to the sequence with which they are used.
4. *Consistency* – components with the same or similar functions should be located in the same or similar positions to reduce memory or search demands, and to avoid ambiguity or confusion.
5. *Control-display compatibility* – control devices should be close to their associated displays; the layout of controls should mirror the layout of the associated display.
6. *Clutter-avoidance* – there should be adequate space between controls and display features to avoid misidentification and accidental activation.
7. *Functional grouping* – components with closely related functions should be grouped together.

3.3 Software display

Human factors information can be applied during control system software design to eliminate or reduce the likelihood that an operator will experience error, and to facilitate post-error identification and recovery. The elements of a display should be designed according to the way in which the display is to be used. That is, principles of human perception and information processing should be used to map the physical form of the display to the task requirements associated with that display.

Design standards should ensure that human factors principles are incorporated as far as is practicable into the design of software displays. In particular, consideration should be given to:

- factors known to affect accurate perception of display information (e.g. the degree of discriminability between different elements on the display)
- the operator's likely mental model of the system, which the display should mirror (e.g. an increase in speed, temperature, pressure, or other quantity should be signalled by a movement upward, rightward, or clockwise on the corresponding display)
- processes by which attentional strengths can be capitalised upon and attentional weaknesses can be minimised (e.g. using a combination of visual and auditory signals to facilitate information processing)
- the limitations of working and long-term memory (e.g. the use of predictive displays, eliminating the need for the operator to run mental simulations).

3.4 Alarm rationalisation

Frequent alarms, excessive alarms during a short period (i.e. alarm flooding), shelved/standing alarms, and 'nuisance' alarms can increase the likelihood that an operator will experience error. These types of alarms can divert operator attention from important information, interrupt mental processes, and impinge on working memory capacity, leading to delayed or mistaken actions and potential system upsets or loss of control.

The development and application of an alarm philosophy can be used to guide software design and so avoid many issues resulting from problematic alarms. Given the dynamic nature of systems and working environments, alarm rationalisation should also be conducted regularly throughout the life of the system to ensure that alarms do not become problematic. This process should include:

- development of alarm management procedures
- review of alarm settings and priorities against the alarm philosophy
- review of operations against management procedures
- identification of change requirements
- implementation of periodic review procedures
- compliance with good management of change processes.

To assist organisations in improving the performance of alarm systems, the *Engineering Equipment and Materials Users Association* have published a guide to the design, management, and procurement of such systems.

4 Facility Layout

4.1 Maintainability and operability

Designing for maintainability and operability can eliminate or reduce the likelihood of error, in addition to minimising time and cost associated with maintenance and operations activities. Of particular relevance from a human factors perspective are issues pertaining to ergonomics and accessibility.

Ergonomics, in this case, refers to the physical aspects of work. During design, consideration should be given to ergonomic issues such as materials handling (e.g. provision of lifting points or crane access), clearance between components, and visual access to necessary components to facilitate accurate and efficient task completion. An example of poor materials handling consideration is presented in Figure 2, which shows a dogman climbing on top of a stack of stored pipes in order to guide a load. In this instance, the design of the laydown area and location of the pipe rack does not appear to have taken into account the lifting work that would also need to be conducted in the area.

Figure 2 – Pipe rack location impedes lifting operations

Accessibility refers to the ease with which an item can be accessed for manual operation, replacement, or maintenance. Items known to require manual operation or maintenance should be designed and located in such a way as to be accessible without the need to first remove items or equipment belonging to other systems. The need to isolate, remove and re-install such items or equipment creates additional opportunities for error. Errors experienced during these types of activities can create latent hazards which can lead to delayed but potentially serious consequences.

Consideration should also be given to accessibility of items likely to require manual operation, such as valves and switches. These types of items should ideally be located so as to be accessible from a standing position on the deck, with reference to relevant anthropometric data (size and proportions of the human body). Where this is not possible or practicable, access to such items should be provided for in design through, for example, the inclusion of built-in access ramps or similar infrastructure. The inclusion of such design features reduces the likelihood of errors and rule violations (e.g. climbing over a structure to access a valve), and also minimises costs associated with operation and maintenance (e.g. time and resources required to build a scaffold). An example of poor accessibility is presented in Figure 3, which shows an eyewash station located next to the lay-down area for a lifting basket. The lifting basket creates a potential obstruction should someone require access to the eyewash station.

Figure 3 – Restricted access to eyewash station

4.2 Escape routes and walkways

Escape routes and walkways are a critical component of successful emergency response. During emergency situations, partial obstructions or trip hazards outside of the direct line of vision can result in accident, injury, and interference with emergency response activities. During design activities, escape route and walkway exclusion volumes should be reserved to ensure that they are not impinged upon. Construction activities should also ensure that walkways and escape routes are kept clear, particularly when locating and positioning small bore piping, pipe elbows, pipe sleeves, and edges of railings. Figure 4 shows an obstruction to an escape route, demonstrating the importance of applying appropriate anthropometric information during design.

Figure 4 – Obstruction to escape route

5 References & notes

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