ATLAS

ONR Technical Support Framework

Human & Organisational Factors

Guidance on the design, development, implementation & use of Electronic Procedures

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Contents

Introduction: Procedures & Electronic Procedures

1 Introduction

A procedure is an established or official way of undertaking a task, or refers to a series of actions conducted in a certain order or manner. The Office for Nuclear Regulation (ONR) Technical Assessment Guide (TAG) concerning procedure design and administrative controls [TAG-060] identifies the term 'procedures' as referring to *"all written instructions that describe the way in which actions affecting safety should be carried out.".*

In the context of high-hazard industries, it is recognised as being of particular importance therefore, that procedures are developed and followed, as a deviation from an approved method or safe system of work could lead to significant safety related consequences. This is recognised by the ONR which states that:

> *"Procedures providing guidance and instruction to staff are instrumental in ensuring that all activities throughout the life cycle of an installation are carried out reliably and efficiently such that the potential for introduction of human error is minimised [to being] as low as reasonably practicable (ALARP) and safety case claims and assumptions remain valid." [1]*

The regulatory guidance is also clear, in stating that:

> *"All activities which may affect safety should be carried out in accordance with written procedures."*

Notably, the guidance goes on to say:

> *"However, carrying out activities in accordance with procedures* ***does not necessarily mean that there must be a paper procedure in hand****, followed step by step for every task undertaken on the site. Decisions on the way that procedures are used to support consistent and reliable task performance must be based on the nature of the task, its safety significance, the potential for error and the experience of the user."*

The way in which procedures are implemented may therefore vary, and there is a recognition that organisations may choose to implement a variety of methods to communicate or describe *the way in which actions should be carried out.*

Indeed, modern technology and digital systems are now challenging the traditional methods by which procedures are implemented, and also challenge the accepted definition(s). The use of digital media, display technologies, and audio-visual presentation capability can present instructions, or procedures in a **non-written** format, although it is accepted that ultimately, the way in which actions should be carried out will always need to be formally documented (i.e. written).

The use of computers and electronic devices to provide or present 'procedures' is leading to the development and implementation of 'Electronic Procedures' that go beyond the simplistic digital display of written instructions. Such systems are able to take advantage of a variety of presentation methods and features that are not possible or practicable in the form of paper-based procedures.

While there are many potential benefits to the adoption of 'Electronic Procedures', they are not invulnerable to being ill-conceived or poorly designed and implemented. The majority of the guidance relating to the design, development and implementation of paper-based procedures and administrative controls are equally applicable to Electronic Procedures. Further, it is recognised that the use of electronic and digital systems to control and implement procedures present a set of unique factors and potential challenges.

These issues and concerns have been acknowledged by the UK ONR, which has instigated a programme of research to identify industry-based knowledge and good practice associated with the design, development, implementation and use of Electronic Procedures in support of guidance development.

1.1 Purpose

This document has been prepared by the Atlas Consortium under the ONR Technical Support Framework at the request of the ONR [ONR/T973]. The purpose is to set out relevant good practice with respect to the design, development, implementation and use of Electronic Procedures, founded upon two feeder studies that were undertaken to identify lessons learned from both academic research and current industry application.

The purpose of this guidance is to provide the reader with a useful resource that outlines current industry-based knowledge and good practice associated with the design, development, implementation and use of Electronic Procedures.

The primary intent therefore is that the learning is used as a good practice guide for those:

- supporting the development and implementation of Electronic Procedures;
- assessing the adequacy of Electronic Procedures; and
- assessing the adequacy of organisational arrangements with respect to the implementation of Electronic Procedures in support of safety assessment.

This guidance has primarily been developed with Ergonomics and Human Factors (E&HF) practitioners and HF assessment in mind. However, it is not intended to be limited in its application by HF professionals and should be of equal interest to any person with an interest in the design, development, optimisation and implementation of Electronic Procedures.

The guidance may be used to support the development of Electronic Procedure delivery or presentation platforms but is primarily focussed on ensuring that Electronic Procedures enhance and do not degrade the ability of the user and therefore system safety, regardless of technology, capability or platform.

Similarly, this guidance may be used to inform the development of system requirements in support of solution development, but does not explicitly set out to identify system or safety requirements.

This document provides broad expectations on key points that the ONR Inspector may wish to consider when judging whether a dutyholder’s procedures and administrative safety controls are designed and implemented effectively. It is not intended to be a detailed design guide for the design and implementation of Electronic Procedures; nor does it prescribe or endorse specific methods and approaches for assessing them or offer guidance on how to judge the adequacy of their technical content. Inspectors should exercise their own judgement and discretion in the depth and scope to which they apply the guidance but should be cognisant of the safety reliance that is placed on human action and the contribution that failure to implement the required administrative controls and procedures makes to risk [1].

1.2 Scope

The scope of this work was initially set out in the ‘Scope of the services required’ – Technical Work Order Specification ONR/T973 Schedule A [2]. The key required outputs were identified as:

- The identification of key human factors issues associated with the design and introduction of Electronic Procedures.
- A review of human factors literature to identify guidance and good practice.
- The identification of learning from the early application of Electronic Procedures within and outside the nuclear industry.
- The identification of gaps where further guidance is required.
- The production of guidance to inform ONR’s understanding of RGP and in support of inspectors assessing Licensees proposals.

The detailed scope of work was agreed during the project Inception Workshop (21/02/2024) as set out within Section 1.3 (Method).

This document focuses on HF issues and concerns that are specific and / or unique to the electronic presentation of procedures, noting that guidance relating to the development, implementation and presentation of paper-based procedures is similar and will remain largely applicable.

The scope of this document is largely bound by the definitions and terminology set out in Section 2.

Although it is recognised that the success of Electronic Procedures and procedural compliance will be heavily dependent on the way in which the procedures are implemented, detailed discussion of implementation methodologies and the related strategic, managerial, socio-cultural and socio-technical concerns is too broad a topic area to be covered in any detail within the boundaries of this scope of work. Mention of these issues is made where appropriate.

It is recognised that the development and implementation of Electronic Procedures may present opportunities, benefits, challenges and concerns for a variety of other disciplines, including (but not limited to) systems engineers, software engineers, control & instrumentation design, reliability and maintainability etc. Where applicable, the interface with HF concerns has been identified, but detailed discussion of such issues is beyond the scope of this report.

1.3 Method

The information and guidance presented within this document was developed under 3 separate Work Packages (WP) as illustrated in Figure 1.

- WP2: Literature review
- WP3: Learning from Experience review
- WP4: Deliverable Development
    - Relevant Good Practice
    - Guidance Note for Inspectors

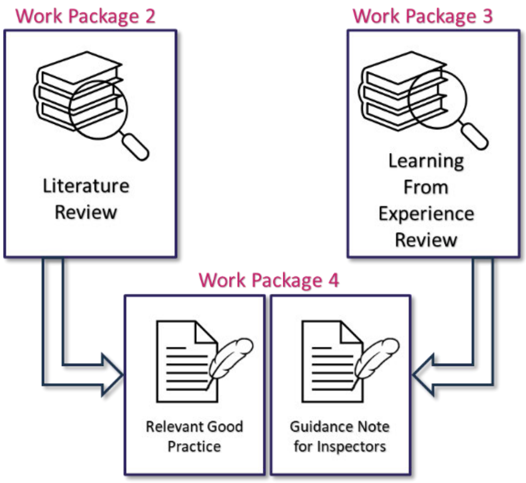

Figure 1: Project Delivery Work Packages

These Work Packages were agreed during the project Inception Workshop (21/02/2024) and are further described below.

1.3.1 WP2: Literature Review

The proposed primary research question was:

> *"What is the evidence base in Human Factors literature surrounding relevant good practice for the design and implementation of Electronic Procedures?"*

This was further broken down into the following research questions:

- What are the main benefits of Electronic Procedures?
- What are the main HF considerations in the design of Electronic Procedures?
- What are the main HF considerations in the implementation of Electronic Procedures?
- What unique considerations are there in the implementation of Electronic Procedures in the context of nuclear?

A detailed study of publicly available literature on the topic of Electronic Procedures was undertaken. The methodology and detailed findings are set out in a 'Rapid Evidence Assessment' report [3]. The report is a supplementary document that was not required as a formal deliverable under this scope of work but is recognised as being key source reference in support of the production of this guidance.

This literature review and any reported Learning from Experience (LFE) was bounded by a focus on the nuclear sector as agreed at the project Inception Workshop.

1.3.2 WP3: Learning From Experience Review

Relevant good practice (RGP) and lessons learned from industry or related research was derived from two primary sources:

1. The output of WP2; and
2. A series of interviews held with industry experts and stakeholders

Discussions and interviews were held with key stakeholders from a number of Licensees including:

- Atomic Weapons Establishment
- EDF – Nuclear New Build
- EDF – Energy (Business Solutions)
- Idaho National Laboratories
- IFE (Halden)
- Sellafield

The discussions focussed around the identification of any key benefits and challenges associated with the introduction of Electronic Procedures, supplemented by the key topic areas identified during WP2.

1.3.3 WP4: RGP & Guidance Note for Inspectors

The output of WP2 and WP3 were collated into a database of information, which was structured according to the key themes that emerged, as identified from the source material. The database, in the form of an Excel Spreadsheet is presented as a deliverable and primary reference alongside this document [4].

The structure of this document is based on the key themes and topic identified as set out in the core supporting references.

To avoid extensive referencing and cross referencing within this document, the source materials are traceable through reference to the key themes and topics within the reference database (spreadsheet).

1.3.4 Caveat

The output presented within this document is provided for information, to support understanding of the topics and themes identified within the scope of work. Any recognised RGP or guidance presented herein is the product of the author's interpretation of the available literature and reference information, and does not represent any formal regulatory position or guidance on these topics.

1.3.5 Meeting the Requirement

Table 1 sets out how the key required outputs identified in Section 1.2 have been met.

Table 1: Requirement Matching

Required output	Delivery
The identification of key human factors issues associated with the design and introduction of Electronic Procedures.	A large set of key HF associated issues are presented throughout this document. The document structure is based on the key topics and themes that emerged as a result of an extensive literature review.
A review of human factors literature to identify guidance and good practice.	A literature review was undertaken and the main findings incorporated into this document. Further output from the review is presented in a 'Rapid Evidence Assessment' report [3] and an Excel Based database [4]. Key industry led guidance is identified in Section 4.2. A list of good practice and guidance documents is presented in Appendix A. Additional guidance and good practice is presented throughout this report.
The identification of learning from the early application of Electronic Procedures within and outside the nuclear industry.	Identification of learning came from both the literature review (WP2) and LFE review (WP3). It was found that the same themes, topics and points of learning emerged from a broad number of sources, therefore the identification of individual sources within this document would lead to significant complexity in terms of cross referencing, which would be to the detriment of readability. Source materials for all points of learning are traceable through the Rapid Evidence Assessment' report [3] and the Excel Based database [4]. It was identified early in the programme of work that much of the existing documented learning and / or guidance associated with the design of paper-based procedures (nuclear and non-nuclear focussed) is equally applicable to the design of Electronic Procedures. To report, repeat and / or summarise such a broad set of literature was deemed impracticable and unnecessary in the context of this scope of work. It was agreed at the project inception workshop that the research would be focussed on the use of Electronic Procedures in the context of the nuclear domain, recognising that many of the key themes and topics (as presented throughout this document) are similar if not identical to those outside of the nuclear industry.
The identification of gaps where further guidance is required.	Many of the underpinning research reports that contributed to the production of this document identified further research required in their own interests. Those deemed to be most prevalent and applicable to the context of this research are presented in Section 14.6.
The production of guidance to inform ONR's understanding of RGP and in support of inspectors assessing Licensees proposals.	This report explicitly sets out good practice and guidance associated with each key theme. This report has been punctuated with key points of guidance (purple boxes) for inspectors in support of assessing Licensees proposals.

1.4 Application

Much of the research encountered within the scope of this package of work was found to relate to the implementation and adaptation of extant procedures to existing facilities. This is reflective of the industry in general that is evolving and recreating extant capability rather than developing entirely new systems without precedent. Whilst it is recognised that the development of new procedures for implementation into new facilities may require some unique considerations, the vast majority of the key themes and topics identified here are applicable to the development of both new and existing capability.

The key guidance documents (as identified in Section 4.2 & Appendix A), are equally applicable to the design and development of both new and existing facilities.

Although the need to undertake systematic and methodical analysis of process in support of procedure development is a recurring theme throughout this document, it is not unique to the development of Electronic Procedures, or the focus of this work.

2 Definitions & Terminology

This document uses the term 'Electronic Procedures' under guidance from the ONR. However, it is important establish the various definitions of procedures and what is meant by 'Electronic Procedures'.

The following sections further define the terms and terminology used throughout this document, identifying similar terms that may be found and used in the supporting references.

2.1 Procedures & Instructions

A procedure is generally considered to be either:

- an established or official way of doing something; or
- a series of actions conducted in a certain order or manner.

In the context of nuclear safety, the ONR identifies the term 'procedures' as referring to *"all written instructions that describe the way in which actions affecting safety should be carried out."* [1]

A Work Instruction is typically a list of tasks to be undertaken in a specific order or sequence (usually chronologically), that provides a sufficient level of detail.

2.2 Synonyms

All manner of terms and combinations of synonyms can be found within the literature associated with the development, implementation and use of Electronic Procedures. A set of synonyms is provided within Table 2.

Table 2: Table of Synonyms

Electronic	**Procedure**
Digital	Operating Procedure
Computer-based	Instruction
Screen-based	Specification
Software-based	Document
Computerized	Process
Computerised	Manual
	Guide
	Directions
	Handbook
	Task
	Recipe
	Rules

Although the source literature commonly refers to Computer-Based Procedures (CBP) or digital procedures, the use of different terms has been rationalised here in support of consistency. Where the term Electronic Procedures is used within this document, it is recognised that other equivalent terms may be used within the supporting literature and references. Where learning from the literature base or the document source references have been paraphrased, the use of any other similar terms has been replaced with the use of the term Electronic Procedures.

2.3 Procedure Types

Within the context of an organisation, procedures may be used to guide and govern all manner of activities, for example:

- Corporate or company procedures that set out internal policies or guidelines and establish the rules and expectations of the organisation and the way the organisation conducts its business. Such procedures may be focussed on behaviours, communicating to employees what should and should not be done as well as how those activities should be undertaken.
- Management processes and procedures that focus on the coordination of work activities, including planning, organising, staffing, directing, and controlling.
- Safety Procedures that provide directions on how work is to be carried out safely in order to control the conduct of hazardous tasks performed within the workplace. Safety procedures will identify hazards and clarify what must be done to manage, eliminate or minimise risks.
- Safe Systems of Work are structured processes and procedures written to reduce the risk of harm when employees face unavoidable hazards at work.
- Work Instructions are task-based procedures that provide operators with step-by-step instructions to be performed in order to successfully achieve a goal. The instructions are intended to optimise safety, reliability and efficiency.
- Maintenance Procedures present instructions specific to the maintenance of facilities, plant and equipment in order to ensure they (continue to) function reliably and safely.

This guidance is pivoted toward the design, development, implementation and use of what are typically understood to be sequential (usually chronological) goal-oriented instructions or procedures required at the point of work to undertake:

- Normal operations (tasks). E.g. performing
  - Plant control tasks, including response to:
    - anticipated deviations
    - abnormal conditions
  - Assembly tasks
  - Equipment configuration tasks
  - Commissioning tasks
  - Maintenance tasks.

Explicitly, this guidance does not *specifically* relate to:

- Corporate or company processes and procedures
- Management systems and procedures
- Emergency response procedures
- Severe accident response.

2.4 Procedures as a form of administrative control

It is important to recognise that a procedure **is a form of administrative control**. An administrative control is a form of control **implemented by operator action**, and therefore is a prescribed set of tasks or activities that also seeks to influence human behaviour and working arrangements. A procedure, and therefore the design, development, implementation and use of [electronic] procedures may represent a significant Performance Shaping Factor (PSF) with respect to human reliability. The ONR recognises this, stating that:

> *Procedures form an essential part of any safety measure where human action is claimed by prompting personnel to complete specific actions and communicate key information to maintain or return activities to compliance with limits and conditions. The mechanisms in place to ensure that procedures are designed in accordance with good practice human factors guidelines, such that they support the end user and reflect safety case requirements will influence the reliability with which safety significant tasks are controlled and should contribute to the substantiation.*
> *[1]*

2.5 Allocation of Function & Electronic Procedure Types

In the context of Electronic Procedure systems and their implementation, there is a broad spectrum of sophistication and fidelity that has significant implications with respect to E&HF.

The level of 'digitisation' of procedures shares many themes with the concept of Allocation of Function [5], whereby at one end of the spectrum, Electronic Procedures may simply be a digital or screen-based representation of a paper-based instruction (e.g. a Word Document or PDF), whereas at the other extreme, an Electronic Procedure may be a fully developed application driven largely by machine-based processes and providing the operator with live process related information with direct control over plant and process.

Figure 2 provides an illustration of the spectrum of Electronic Procedure capability that may be considered and afforded [6] adapted from the IEEE standard (1786) [7].

Functional Ability	COPS		
	Type 1	Type 2	Type 3
Select and display procedure on computer screen	Yes	Yes	Yes
Provide navigation links within or between procedures	Yes	Yes	Yes
Display process data in the body of procedure steps	No	Yes	Yes
Process step logic and display results	No	Yes	Yes
Provide access links to process displays and soft controls that reside on a separate system	No	Yes	Yes
Provide embedded soft controls	No	No	Yes
On operator command, initiate procedure based automation	No	No	Yes

Figure 2: Types of Electronic Procedures & Levels of Functionality

The most commonly cited 'types' of Electronic Procure are taken from the IEEE standard (1786), as defined below:

2.5.1 Type 1 Systems

Type 1 systems are essentially digital representations of their paper-based counterparts, but may offer a small amount of linkage (e.g. hyperlinks) to other parts of the same procedure, or other procedures. Type 1 systems may also include navigation or place keeping aids.

2.5.2 Type 2 Systems

Type 2 systems provide the functionality of Type 1 systems, with the additional capability to use and display dynamic process data. With access to live process data and with incorporated control logic, the system can monitor and evaluate plant conditions to control the display of information and influence the presentation of procedures to operators. Type 2 systems cannot issue control commands, but they may provide access to soft control capabilities that exist outside of the system.

2.5.3 Type 3 Systems

Type 3 system incorporate Procedure Based Automation (PBA), which includes embedded soft controls that may be used to issue control commands to plant equipment, and automated sequences of steps when commanded by the operator. The PBA system can make logic-based plant control decisions based on real time data. At any time the operator is able to interrupt or halt the process. PBA refers to automatic sequences of actions that are started on command by the operator, and for which there are procedures and training that would allow the operator to perform the steps manually if necessary or desired.

This document will largely consider the implementation of Type 1 and Type 2 Electronic Procedure systems. Type 3 systems might also be categorised as computer programmes or applications with a direct interface to plant Electrical Control and Instrumentation (EC&I), rather than the use of Electronic Procedures in the more commonly understood sense. Although many of the issues and concerns identified within this document would be applicable, the implementation of a Type 3 system would be subject to an enhanced degree of design development and assessment, commensurate with the increased level of associated risk.

3 Document Structure

3.1 Key Themes & Topics

The structure of the remainder of this document has been dictated by the findings from the literature review (WP2) and LFE review (WP3).

The key themes and topics are illustrated in Figure 3.

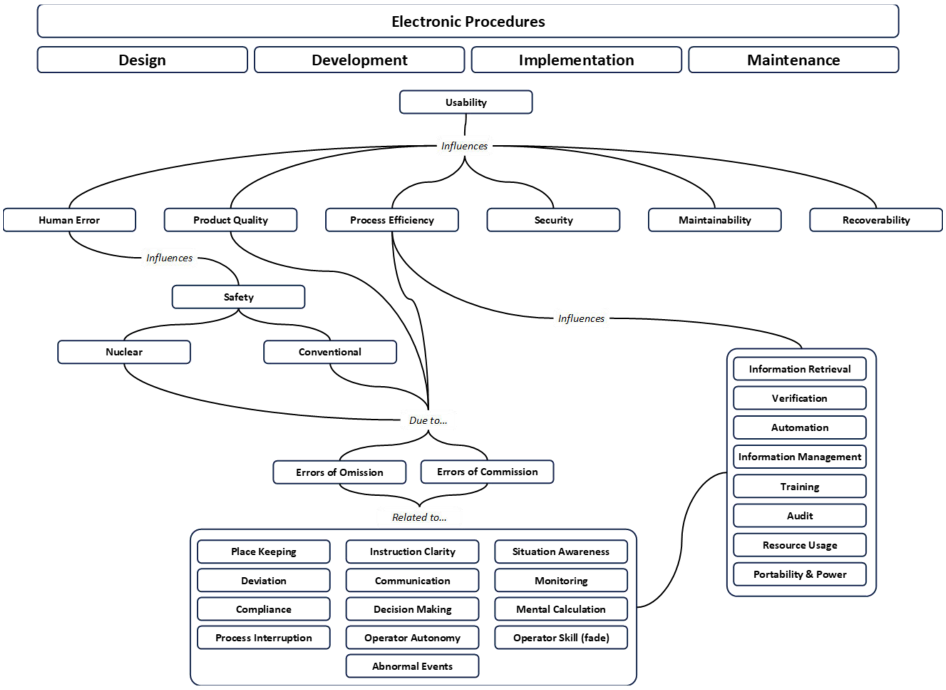

Figure 3: Visualisation of Key Themes & Topics

A larger version of this illustration is presented in Appendix C along with other visualisations that the reader may find useful.

Table 3 below provides an outline of the overarching structure of this document.

Table 3: High Level Document Structure

Electronic Procedures	Section
Usability	4
Human Error	5
Communication & Situation Awareness	6
Operator Skills & Learning	7
Information Management	8
Portability & Power	9
Security	10
Operational Environment	11
Organisational Change: Transition & Implementation	12
Non-safety-related Observations	13

Although one of the stated purposes of this guidance is to support the development and implementation of Electronic Procedures, it is deliberately generic and both technology and solution agnostic. This recognises the significant amount of variability and variety of means, methods and modalities by which Electronic Procedures may be presented to the end-user.

3.2 Paragraph Markings

As an aid to navigation or rapid identification of information, the following paragraph marking scheme has been used.

✓ Identified potential benefits

! Identified challenges & concerns

📖 Learning from experience, identified RGP and /or guidance

Topic specific guidance

The design, development, implementation & use of Electronic Procedures

Key Themes & Topics

4 Usability

4.1 General

There is a wide body of research recognising that the implementation of Electronic Procedures provides organisations with the opportunity to enhance usability, and by association reduce the likelihood of operator error, improve overall process efficiency and reduce costs.

However, although the implementation of Electronic Procedures presents many and significant opportunities to improve the usability of procedures, it should not be assumed. The scientific literature (and press) is also replete with examples of poor system design and learning from experience where 'usability' was not optimised to the detriment of efficiency (and potentially safety). Consequently, the requirement for E&HF to be a key consideration in the development of Electronic Procedures is considered paramount.

Relevant standards and appropriate guidance should be identified and applied to ensure the application of Electronic Procedures is compliant with good E&HF usability principles.

The notion of 'usability' is primarily associated with the ability of the user of a given system or item of equipment to achieve the goal in the most safe, efficient and therefore error-free manner. It is generally acknowledged that the 'usability' of any system has the potential to significantly influence the likelihood of operator error.

4.2 Guidance

In the context of Electronic Procedures, much of the extant guidance is founded upon core E&HF principles associated with the display of information, user interaction with system interfaces and operator physical and cognitive capability.

The list below provides the most prevalent and commonly referenced sources of guidance pertaining specifically to the introduction of Electronic Procedures. However, further guidance on the enhancement of usability is pervasive within and throughout all good E&HF related texts. Full reference details and an extensive list of further reference information is presented in Appendix A.

- NUREG/CR-6634: **Computer-Based Procedure Systems**: Technical Basis and Human Factors Review Guide
- NUREG-0700: Human-System Interface Design Review Guidelines.
- IEEE 1786: IEEE Guide for **Human Factors Applications of Computerized Operating Procedure Systems** (COPS) at Nuclear Power Generating Stations and Other Nuclear Facilities (IEEE 1786-2022). IEEE
- EPRI 1010042: Human Factors Guidance for Control Room and **Digital Human-System Interface Design**
- EPRI 1015313: **Computerized Procedure Systems: Guidance on Design, Implementation and Use of Computerized Procedure Systems, Associated Automation and Soft Controls**
- DI&C-ISG-05: Digital Instrumentation and Controls Task Working Group #5: **Highly-Integrated Control Rooms – Human Factors Issues** (HICR-HF),” *Interim Staff Guidance DI&C-ISG-05 Rev. 1*, U.S. Nuclear Regulatory Commission, Washington, DC (2008).
- INL/EXT-16-39808: **Design Guidance for Computer-Based Procedures** for Field Workers.
- INL/EXT-12-25671: **Computer-Based Procedures for Field Workers** in Nuclear Power Plants: Development of a Model of Procedure Usage and Identification of Requirements
- INL/EXT-15-36658: Computer-Based Procedures for Field Workers - **Result and Insights from Three Usability and Interface Design Evaluations**
- IEC/IEEE FDIS 82079-1: **Preparation of information for use** (instructions for use) of products — Part 1: **Principles and general requirements**
- BS EN ISO 9241 – 210:2019 Ergonomics of Human-System Interaction. **Human-centred design for interactive systems**
- IEC 62023, **Structuring of technical information and documentation**
- ISO/TS 18152:2010 **Ergonomics of human-system interaction** — Specification for the process assessment of human-system issues

- ISO 9241-220:2019 **Ergonomics of human-system interaction** — Part 220: Processes for enabling, executing and assessing human-centred design within organizations.

The Electric Power Research Institute (EPRI) guidance emphasizes usable presentation formats, operator authority, validation of procedures, and redundancy in case of system loss or malfunction. It makes specific mention of the need to:

- Ensure usable presentation formats for procedures
- Stipulate that operators should have final authority regarding control actions
- Provide logging capabilities
- Provide redundancy in the case of loss or malfunction of Electronic Procedures (including alternative procedures)
- Validate each operating procedure using the Nuclear Power Plants (NPP) simulator and performance model.

The design principles set out in the Idaho National Laboratory (INL) guidance focus on topics such as:

- Context-sensitive information
- Supporting task flow characteristics
- Flexibility
- Logical sequence guidance
- Computerised support
- Communication
- Record-keeping.

While the INL developed guidance is considered to be a useful starting point to understand the considerations necessary in developing an Electronic Procedure system within the UK nuclear industry, it is recognised that there are likely to be differences in the design and concept of operations of UK NPPs compared to those in the United States of America (USA). As such, the authors recommended that an iterative process is followed to ensure the system is developed using a prototype, ensuring operator and stakeholder feedback influences design decision making.

The usability heuristics reported within the INL research papers (e.g. INL/EXT-15-36658) were identified as being useful to guide the early development stages of an Electronic Procedure system.

4.3 Summary

There are many facets to usability and the determination of the usability of a system. This research project has reinforced the understanding that there are many complex inter-relationships between the different aspects of usability and human-performance.

It is not the intention or purpose of this document to duplicate or repeat the extensive guidance associated with procedure development, interface development or usability presented within widely available literature. A summary of typical usability considerations, principles and heuristics are presented in Appendix B.

The further content presented here will focus on the key aspects of usability that have been drawn out or highlighted through research as being important in the context of the design, development, implementation and use of Electronic Procedures.

A common theme that runs throughout the literature, and applicable in almost all contexts is the need to undertake a systematic and proportionate analysis of all operator tasks in support of Electronic Procedure development. This aspect of RGP will therefore not be persistently repeated in each section of the document but will be highlighted where it was noted as being of particular importance within the body of research or supporting information.

4.3.1 Interactivity

The implementation of Electronic Procedures (Type 2 and Type 3) is typically based upon the advantage afforded by greater interactivity, system feedback and logic-based decision making. Operators are presented with dynamic and context-sensitive information, often limiting their options, and therefore providing guidance, greater certainty and clarity for the benefit of safety.

The level of interactivity (and sophistication) is almost limitless and infinitely variable using digital systems. The design of such systems requires careful analysis, assessment, and planning, and is more akin to the design and development of Engineered or Electronic Control and Instrumentation systems than the simple transition from extant paper-based procedures in digital form. Relevant good practice associated with the design of Human-Machine Interfaces (HMI) should be applied to the design of Electronic Procedure systems.

4.3.2 Information Presentation - General

In the development of new systems, or the transition from paper-based to screen-based presentation of information, the primary identified benefits associated with Electronic Procedures are related to the flexible and dynamic nature in which information may be presented and interacted with through a digital medium.

4.3.2.1 Identified Potential Benefits

✓ Electronic procedures can enable greater flexibility and tailoring in the way information is presented to the user.

✓ Electronic procedures can offer a high level of customisation in the way information is presented to the user.

✓ Electronic procedures can enable operators to navigate quicky to specific procedural steps, and / or search for procedures.

✓ Electronic Procedures can provide operators with a greater variety of multi-media display options, including interactive images and instructional videos that make task understanding much clearer.

✓ The incorporation of flowcharts in electronic procedure designs have been found to be beneficial for performance and operator outcomes. Research has identified that presenting procedures in the form of flowcharts was an improvement over text-based presentation because of their ability to explicitly relate procedural elements and pathways. Process flow-charts have been found to be superior to success trees, resulted in a lower error rate without extra task time or a higher operator workload.

✓ Paper-based procedures are static, whereas Electronic Procedures can be dynamic and provide operators with instructions that reflect current plant or operating conditions (where the connectivity and logic is built in). The dynamic nature of Electronic Procedures can make workflows more efficient as operators are provided with (or are able to navigate to or obtain) context-specific or related real-time information - therefore mitigating the need for them to search for it elsewhere in another procedure or section of a procedure.

4.3.2.2 Potential Challenges & Concerns

! Greater interaction and interconnectivity between Electronic Procedures can lead to greater complexity and the potential for the operator to lose focus or navigate away from the primary task (see place keeping – Section 5.1.1).

! A fundamental aspect of following a procedure correctly is understanding the task required to be undertaken. Instructions are often found to be poorly written or ambiguous (paper and electronic). The digitisation of a procedure does not automatically lead to a well written procedure.

! Developers may be tempted to provide operators with a greater level of information or capability than is required purely because the system is capable of doing so and not for the benefit of the operators.

There is often a temptation with the introduction of Electronic Procedures, to provide more information and more detail, simply because the system is capable of doing so. This is not always beneficial to the operator and if implemented poorly can be a distraction or detrimental to safety.

! The ability for operators to personalise the way in which information is presented may lead to significant inconsistencies between system users that could in turn increase the risk of error.

Operator customisation options may lead to personal preferences being applied that are not to the benefit of all operators. Individual changes to the presentation of information can lead to inconsistency, that increases the risk of operator error.

! While information overload is a common cause of human error, a lack of information can also significantly influence operator awareness and understanding. A balance is required to ensure the operator has the information necessary to undertake the task, whilst also maintaining a broader awareness of the task requirement and position in the overall procedure, or progression toward a greater goal.

! Paper-based procedures enable operators to annotate, mark-up or create task specific notes alongside the process steps or instructions. Consideration should be given as to how task notes may be entered into / alongside Electronic Procedures and recorded for future reference.

4.3.2.3 Good Practice & Guidance

📖 It is broadly recognised that the transition to Electronic Procedures is an opportunity to undertake a thorough review, rationalisation and programme of improvement of existing practices and procedures.

📖 The operator should be provided with only the information necessary in support of task execution. This should be underpinned through a proportionate level of task analysis.

📖 It is common with Electronic Procedures developed in the context of assembly and manufacturing operations, for operators to be provided with photo and video enhanced task-based instructions to aid comprehension.

📖 Tasks that have been identified as being of particular importance to safety (within the safety case) - commonly referred to as Safety Actions are often given special status within the written procedure. It is common for tasks related to Human-Based Safety Claims (HBSC) (i.e. Safety Actions) to be presented in a different way to add emphasis and focus, and to ensure operators are aware of the safety significance of the task to be undertaken. Safety Actions would typically require additional administrative controls and supervisory checks to be implemented.

📖 RGP within the industry is to write action-oriented instructions. E.g. Verb-noun combinations. Different dutyholders have adopted a standardised method of structuring Safety Related instructions (Safety Actions) in the fashion of: The <OPERATOR> shall <TASK / ACTION> <CONDITION>, or <CONDITION> the <OPERATOR> shall <TASK / ACTION>. The latter is logically preferred as it ensures the operator reads the condition first before starting the action. E.g. the instruction "After draining the fluid, empty the can", is less prone to error than "Empty the can after draining the fluid."

Procedures and instructions should be consistent in their format, structure and syntax. Safety Related instructions should be subject to formal review to verify that they are understandable and actionable by the intended target audience (i.e. operators).

4.3.3 Presentation of Supplementary information

4.3.3.1 Identified Potential Benefits

✓ Electronic Procedures are able to provide operators with further context-sensitive information on request, therefore reducing their reliance on or reference to other procedures (which may not be available), memory or training.

✓ Electronic Procedure systems can provide the operator(s) with access to information at multiple levels of detail to suit their particular needs. Expert users may only need high-level instructions, whereas less experienced operators or novice users can access further detailed information to supplement their knowledge and understanding.

✓ Electronic Procedures can incorporate and provide training functionality, that provides the operator with further detailed information and links to supplementary information on demand.

✓ The nature of digital systems enables content providers and developers to provide operators with flexible paths to more information in the form of links and hyperlinks, improving the efficiency of information access and retrieval.

✓ Studies have found that paper-based procedures often present a large number of warnings and cautions that are not relevant to all operations or tasks being performed by the operators. Electronic Procedures (where implemented properly) provide the opportunity for warnings and cautions to be presented in a context-sensitive way, enabling the operator to heed more attention to the important or prioritised tasks or information.

The number of limits, conditions, warnings and cautions that operators may be expected to hold in memory, or be cognisant of at any given time, can lead to an unreasonable expectation being placed on human capability.

Specific consideration should be given to the quantity and relevance of task specific warnings and cautions being presented to operators at key points in the procedures.

✓ Electronic procedures are able to provide operators with a context-sensitive pre-job brief, giving a greater level of situation awareness concerning the 'live' context of the operations being performed. These briefs or related warnings and cautions can be prompted whenever or wherever necessary, for example after a long break, or a change of personnel / change of login.

✓ Electronic Procedure systems may allow post-job briefings to be completed electronically.

✓ Electronic Procedures can be used to record post-job reviews / reports and briefings or capture any task specific information that may be important to other operators (present or future). The capturing of such information can benefit efficiency and minimise risk typically associated with handover (shift / task) - as further discussed below in the context of errors of omission and commission (Sections 5.1 & 5.2).

4.3.3.2 Potential Challenges & Concerns

! If ill-conceived or implemented poorly, non-linear information presentation enabling operators to follow links to different pages or sections for information can lead to a loss of overall structure or flow. Overly complex procedures with extensive links to information away from the primary task set presents an increased risk of operators deviating from the required task or not returning to the correct point in the sequence. This can lead to inefficiency and potentially increase the risk of error. This is further discussed in the context of errors of omission (linear vs non-linear) below (Section 5.1.2).

Although the introduction of Electronic Procedures may enable a more dynamic approach to the presentation and sequencing of task related information, the number of paths, options and data available to the operator should be limited to only those which are necessary. A sufficient level of analysis and HF consideration is required to ensure complexity (and risk of error) has been minimised as far as practicable.

! It is foreseeable that digital systems implemented to ensure operators are aware of all rules, limits, conditions, hazards and warnings etc. could become very obstructive and intrusive, and difficult to maintain. E.g. the system may require the operator to 'sign-on' to the procedure each time it is accessed which may quickly become frustrating to the user where the procedure is accessed regularly. Significant intelligence and complexity would have to be built into the system to manage this.

! Poor presentation of supplementary information can lead to 'information blindness'. Over complication and use of graphical symbols or coding of information can detract significantly from the clarity of presentation or the salience of the most important information.

4.3.3.3 Good Practice & Guidance

📖 It is common in high hazard industries for written procedures to start with background or contextual information, rules, limits, conditions, hazards and warnings for operators to be aware of before work commences. These sections can be quite extensive, labour intensive & time consuming to administer. Although there is often a series of administrative checks within the procedures to confirm operators are SQEP, have been briefed, a risk assessment has been undertaken and a SSOW is in place, it is often difficult to confirm the strictness by which these checks are complied with. The digitisation and / or automation of this process can increase process robustness and efficiency and relieve personnel of the related administrative burden.

📖 It is common (RGP) in high hazard contexts to require that supervisors confirm that all relevant pre-use checks have been undertaken prior to operations commencing.

Pre-use checks are often relied upon to ensure operations can commence safely. Consideration should be given as to how the implementation of Electronic Procedures could incorporate robust checking mechanisms prior to the presentation of task-based instructions.

📖 Where operators may be stepping out of instructions, or returning to instructions, the system may prompt operators to re-familiarise themselves with safety related information before proceeding or enabling task-based information to be presented, particularly where operators may have deviated from the main process for some time.

📖 To mitigate against operators losing their place in the process flow, it is beneficial for the Electronic Procedure system to maintain a consistent presentation of the primary task information, and present supplementary information in a separate section of the same page or window that does not require the operator to navigate away from the main instruction set.

📖 Where Electronic Procedures include the presentation of plant or process related information and indications, studies have demonstrated that utility of using 'glanceable' feedback, which is aimed to allow easy perception in the constant periphery of one's attention during multitasking. The design qualities that are associated with glanceable feedback include abstraction and comparisons to targets and norms. An example of implementing glanceable feedback principles may be around displaying arrows or other icons next to values to indicate trends or changes.

📖 To improve the visibility of the Electronic Procedure (in dynamic contexts where the process involves multiple operators), the implementation of large supplementary screens / monitors has been found to be a successful way of enhancing overall team situation awareness within the room.

4.4 Operator Workload

There is evidence to suggest that operator workload (physical and mental) can be reduced through the introduction of Electronic Procedures. However, the same is true of well-designed procedures in general. A poorly designed Electronic Procedure implemented in place of a well-designed paper-based procedure will not yield the desired outcomes.

Although operator workload is recognised as a significant PSF that may contribute to human error (see Section 5), the importance of operator workload was deemed worthy of being presented as a separate theme / topic in its own right.

4.4.1 Identified Potential Benefits

✓ There is strong evidence within the literature base to demonstrate that Electronic Procedures, especially those with advanced computational functionalities, can reduce operator mental workload, leading to fewer errors and improved safety.

✓ Additional functionality (examples currently available from Commercial Off The Shelf (COTS) solutions) that has the potential to reduce (mental) workload and reduce operator error include:

- Automated data capture or population – removing the requirement for operators to enter data. This also reduces the risk of data entry or transcription error.
- Data retention within the application removes the need for operators to retain information in memory, mitigating risk associated with recall error.
- Component or item label scanning (bar-code, QR code, Radio Frequency Identification (RFID)) that removes the requirement for operators to remember and / or enter complex unique identifiers typically implemented as alpha-numeric strings. The digital system is able to quickly identify the item and undertake validation and verification checks, and update inventory holdings.
- Automated data manipulation and calculation - removing the burden from operators as well as risk of human error. E.g. translating vessel fluid level heights into liquid volumes, converting units (e.g. inches to cm, different pressure readings), simple counting functions.
- Automated decision making (IF-THEN-ELSE). Structured procedures with logic-based workflows can be implemented in such a way that operators are not required to determine the correct forward path or procedure. The required steps are provided and presented to the operator automatically based on the built-in logic.
- Greater control over the quantity of information presented to the user at any given time, mitigating information overload.

✓ Electronic Procedures can automatically track operation start-times, end-times and calculate durations. Many operations are time-based or require the operator to monitor task-based timings. Electronic Procedure applications are able to automatically initiate clocks, timers or count-down functions (with alerts) that remove the burden from the operator.

4.4.2 Potential Challenges & Concerns

! Although Electronic Procedures are able to significantly reduce operator mental workload and decision making, this may come at a cost. Such features may result in a loss of operator situation awareness, skill-fade and the inability to respond quickly or appropriately to abnormal events or equipment failure. Each of these issues are further explored in the context of human error – see Section 5.

! Significant levels of automation can lead to operator disengagement, unfulfilling and unengaging work where the operator is effectively being controlled by the system (demanding inputs) rather than the operator maintaining control of operations.

! Research suggests that the application of Electronic Procedures in the context of a nuclear plant control rooms will vary dependant on operator role. Errors of omission, situation awareness and workload will differ significantly between Shift Supervisors, Reactor Operators and Assistant Reactor Operators.

Automation (allocation of function to machines) may be detrimental to the operator. Due consideration of the effect of automation on safety, operator performance and wellbeing should be considered.

While the implementation of Electronic Procedures has the potential to lower (subjective) mental workload, poorly implemented or ill-conceived Electronic Procedures could also increase mental workload.

The optimum quantity of information required by the operator to undertake the task should be identified in order to optimise operator workload.

The effect of the implementation of Electronic Procedures may very between roles.

4.4.3 Good Practice & Guidance

Where any significant change to the role of the operator (in maintaining safety) has the potential to increase operator workload, appropriate analysis and assessment should be undertaken using recognised and validated techniques.

The level of operator workload is known to significantly increase the likelihood of human error. Depending on the nature of the task, an assessment of operator workload may be appropriate to ensure the use of Electronic Procedures does not lead to unreasonable or unrealistic expectations being placed on human capability.

It is reasonable to consider that typical and normal operations will be subject to the greatest level of detailed analysis, whereas the assessment of infrequent, rare, uncommon or unlikely scenarios where an Electronic Procedure would potentially be most beneficial, or where operator workload (and situation awareness) may be most severely impacted, may not be considered.

Response to infrequent, rare, uncommon or unlikely events is more prone to human error.

Consideration should be given as to how Electronic Procedures might be applied in support of operator response to such events as these are often not subject to analysis.

Research suggests that there is an optimum amount of data that should be displayed to operators in order to optimise mental workload. This will be context sensitive and should be understood by the system developers in order to optimise the design of the HMI. For example, presenting four to eight indicators of relevant current plant system statuses (the medium level of information quantity) yielded significantly lower subjective mental workload ratings compared to presenting one to two indicators (low information quantity), or displaying all possible status indicators (i.e., 10+ indicators – high information quantity).

5 Human error

Development, implementation, reference to and compliance with written procedures presents many opportunities for human error, which can lead to the initiation of fault sequences and if unchecked, could lead to significant negative consequence.

The implementation of Electronic Procedures (or any change to procedure) therefore carries the risk of the potential for operator error not being adequately considered. Furthermore, ill-considered or poorly implemented procedures (both paper-based and electronic) could lead to new error modes being introduced.

The implementation of Electronic Procedures has the potential to introduce new or unique error modes (that may not be part of the extant safety case). The potential safety implications associated with the use of Electronic Procedures should be systematically and methodically assessed (proportionately) following established safety assessment principles.

The implementation of new, or any significant change to processes or procedures should be systematically and methodically assessed following established safety assessment principles and processes. E.g. HAZID, HAZOP, Task & Error Analysis, Safety Assessment, HAZAN, Task Substantiation. This fundamental principal is instrumental in ensuring compliance with Licence Condition 22.

A useful review and summary of Human Reliability Analysis and its application to Electronic Procedures is provided in Reference [8].

The following sections outline the key themes and issues identified within research and the academic literature base primarily associated with operator error. In keeping with the nature of the research, the potential for error has been subdivided into consideration of errors of omission and errors of commission. Figure 4 provides an illustration of the key themes and topics strongly associated with human error, which provides the basis for the structure of this section.

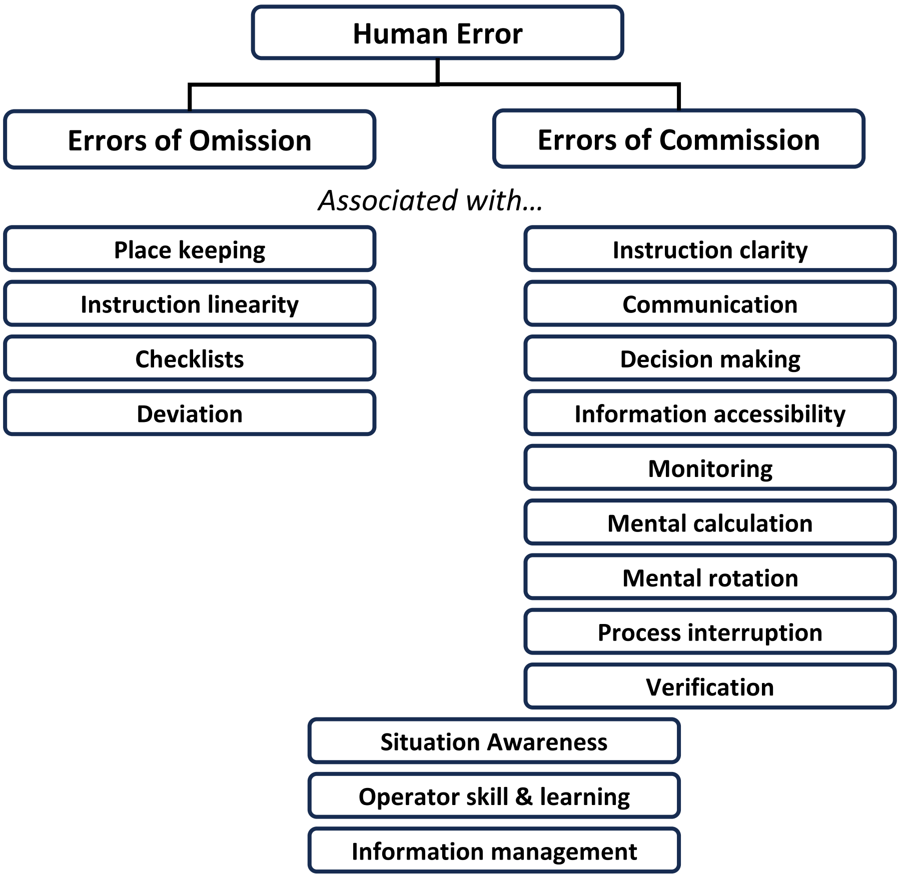

Figure 4: Key Themes & Topics Associated with Human Error

5.1 Errors of omission

5.1.1 Place keeping

5.1.1.1 *Identified Potential Benefits*

✓ Electronic Procedures can help reduce operator error rates and improve the likelihood of successful completion of procedures through the implementation of interactive features such as:

- Digital checklists enabling operators to interact with the system and manually confirm when tasks have been completed.
- A clear indication of tasks that have been completed.
- A clear indication of tasks that are in progress, including which team member is conducting the task.
- Automated task completion status updates where the system is able to establish an action has been performed (through control logic).
- Restricting operator access to task steps (i.e. making them unavailable or not displaying them) before preceding tasks have been confirmed as being complete.

✓ Electronic Procedures may offer greater control over place keeping and potential operator violation by limiting operator access to instructions or information. It is recognised that operators may be tempted or incentivised to proceed with a task even where they are lacking knowledge or information.

✓ The use of Electronic Procedures has been found to have the potential to reduce the number of deviations (i.e. human errors) by up to 50% compared to conducting the same task with paper-based procedures.

5.1.1.2 *Potential Challenges & Concerns*

! The flexible and dynamic nature of user interaction and information presentation presents a number of opportunities for Electronic Procedures to assist operators in place keeping. However, the most appropriate means of reducing the risk of omission errors will be highly context sensitive.

Risks associated with errors of omission should be systematically identified and assessed.

! There is documented evidence that Electronic Procedure checklists lead to improved completion rates and performance in the primary task. However, there is also evidence to suggest that this could lead to lower completion rates of the secondary tasks. It was suggested that this may be due to the secondary tasks being completed simultaneously with the primary task, leading to missteps or operators inadvertently forgetting to check items off, especially where there is a long list of tasks. The researchers proposed mitigating this issue by fading out checked items and highlighting unchecked and upcoming items to draw attention or moving checked items to the bottom of the page and unchecked items towards the top.

Consider how end-users and / or operators have been provided with the capability to maintain awareness or a record of which tasks have been completed in support of place keeping.

! It is noted that paper-based procedures enable operators to read-ahead and potentially skip sections, whereas Electronic Procedures can force a stop or disable the presentation of instructions where prior steps are not complete, or conditions have not been met. This capability relies heavily on correct task understanding and implementation and depending on the level of task complexity or system sophistication, may remain open to abuse and / or violation.

Consider that operators may be motivated or incentivised to deliberately omit or skip steps in the procedure and that they may be able to proceed to undertake tasks for which the pre-conditions for safety have not been satisfied.

Consideration should be given to the potential for operators to deliberately omit tasks steps.

Where there are safety related consequences related to task step omission, safeguarding functions should be implemented.

! Poorly conceived or implemented Electronic Procedure systems, or poor interface design could lead to operators having to navigate unnecessarily between pages or around the system (typically using hyperlinks) that could lead to the operator losing their place, or not maintaining a good level of awareness of where they are in the overall procedure.

! Task handover, between shifts and / or operators and teams is a critical point at which the potential for error (task tracking / error of omission) is increased. This is not unique to Electronic Procedures, but a poorly implemented Electronic Procedure system could further increase the likelihood of error.

Consider the increased risk of loss of control (task tracking or omission error) during periods of handover.

5.1.1.3 Good Practice & Guidance

Errors of omission are common with paper-based procedures as they do not intrinsically provide an easy means of monitoring or maintaining place keeping. Operators are not able to mark a procedure that is printed once and used repeatedly without the procedure degrading with each use, therefore sticky tabs, or book-marks might be used but this introduces significant likelihood of not maintaining an accurate record of place keeping and a high likelihood of missing task steps. The implementation of Electronic Procedures should include digital tracking or place keeping features that enable operators to maintain awareness of their position in the sequence of events. This is particularly important where operators may be using or referring to multiple procedures concurrently.

It is common in high hazard contexts for paper-based procedures to be printed for single use, where the operator physically marks-up the procedure – checking-off the actions that have been undertaken. This creates a physical record and audit of the actions undertaken and place keeping is made easier. The likelihood of omission is reduced as there is a physical record of the action having been completed (checked-off, stamped, signed or dated). This does not however, rule out the potential error of wrongly checking as complete an incomplete action, or for example skipping a whole page in error. This is equally true for Electronic Procedures as with paper-based procedures. There are a broad range of errors that could lead to omission, and the digitisation of procedures does not automatically eliminate them.

The use of Electronic Procedures does not automatically eliminate or significantly reduce the potential for errors of omission. The way in which procedures are presented digitally, and the way the operator navigates the interface has a significant influence on the ability of the operator to maintain place keeping and consequently the likelihood of errors of omission.

Reports associated with the implementation of Electronic Procedures are generally favourable. Users have found Electronic Procedures more usable and helpful compared to paper-based ones. It is specifically noted that operators appreciate features such as automatic place keeping and the provision of supplementary information (see Section 4.3.3).

A study undertaken in the healthcare industry found that embedding alerts into an electronic checklist to remind operators to document important (patient safety) information in a timely manner led to an increase in documentation. However, based on qualitative feedback, the efficacy of this alert function decreased when the worker had set down the checklist to perform another activity, or if they were engaged less with the checklist.

In many contexts (both paper-based and within Electronic Procedures) it is common for both primary and secondary (subsidiary) tasks to be presented together. This provides the operator with the primary goals, and a set of sub-tasks that need to be performed in order to achieve those goals.

📖 Systems (digital interlocks) can be implemented to prevent operators from moving to the next step unless they verify the current step has been completed. More sophisticated systems are able to prevent continuation unless:

- an independent supervisor authorised by the system allows or permits the system to move to the next step; or
- there is a further verification check in place - e.g. photo uploaded, or a bar-code scanned that provides evidence that the step has been undertaken correctly.

📖 In the context of place keeping, or mitigation of risk associated with task or step omission, research suggests that limiting the amount of information on the screen to between 4-8 units of instructions is optimum. This aligns with the general usability heuristic of operators not having to maintain more than 5-7 units of information in short-term memory.

Place keeping, checking and verification that tasks have been completed is of particular importance in the context of HBSCs. Specific and proportionate attention should be given to the presentation and verification of tasks identified as being of particular importance to safety.

The use of a checklist, including cognisance of its length and the number of instructions presented, is a key part of defining HEPs when using common HRA methods such as HEART[1] and THERP[2]. Often, one or more items on a checklist might constitute an operational safety measure e.g. supervisor (i.e. independent) check that a task is accomplished.

📖 Electronic Procedure systems will typically have log-in arrangements to track or record who is undertaking the task(s) and are able to record when tasks were undertaken.

5.1.2 Linear vs Non-linear Instructions

Not all tasks or procedures are linear and sequential. In many cases, operators may be required to perform tasks based on the outcome of previous tasks or observable conditions. Where tasks are non-linear, non-sequential, decision-based, branching, looping or even parallel, this introduces additional complexity for the presentation of instructions and procedures. The likelihood of omission errors increases with the complexity of the instruction set, in particular the linearity of required instructions.

For non-linear procedures, electronic systems can be beneficial but there are pitfalls, and the likelihood of omission is still highly dependent on the method of implementation and the way in which instructions are presented.

Non-linear or complex branching and looping processes can be difficult to administrate and track, and increases the potential for errors of omission and commission.

Specific consideration should be given with regards to operator decision making requirements and the implementation of non-linear processes.

5.1.2.1 Identified Potential Benefits

✓ Digital systems have been shown to offer advantages in terms of the presentation of non-linear processes. Electronic Procedures are able to provide greater flexibility and dynamic, context-sensitive information presentation based on decision making, condition checking or interactive feedback.

✓ A significant advantage to the use of Electronic Procedures is their ability to automatically log task execution data which can be used in support of logic function processing.

✓ Where there are complex, branching, or looping procedures, Electronic Procedures can maintain a log of any operations (or loops) that were repeated in a much more efficient manner. Logging

[1] Human Error Assessment & Reduction Technique
[2] Technique for Human Error Rate Prediction

looping or repeating operations is much harder to achieve using a paper-based system without having to print the same procedure many times (as many times as might be necessary).

- ✓ Reducing the requirement to print the same document or section multiple times where it may be repeated has associated benefits in terms of costs, document management, and security.
- ✓ More sophisticated Electronic Procedure systems are able to summarise the data and present digital dashboards to enable managers and supervisors to quickly identify which tasks have been undertaken. Supplementary information can also be added such as the number of times the process was repeated, task duration and resource consumption statistics.
- ✓ Electronic Procedures are able to introduce logic-based interlocks to prevent operators from accessing task-steps where certain pre-conditions have not been met.
- ✓ As well as providing the operator with additional cues and the ability to track task execution (e.g. checkboxes, greying out), digital systems are also able to easily track or count the number of times a process has been undertaken or run. A record (simple count) of the number of times a specific process has been executed, and the context (components associated), is generally easier to administer in a digital system. This may not have a direct effect on safety but can have an indirect effect on overall safety and compliance through improved record keeping and access to information. It may also be beneficial to organisational or process efficiency, whereby the identification of task steps, processes or procedures that commonly fail (or fail more frequently than expected) can assist in the identification of where further developments or improvements can be made.
- ✓ Where non-linear processes introduce the requirement for operators to make decisions, Electronic Procedure systems can enable supervisors to monitor events remotely and provide remote approval or authorisation. This functionality is also related to decision making (Section 5.2.3), communication and situation awareness (Section 6).

5.1.2.2 Potential Challenges & Concerns

- ! When instructions are non-linear, decision-based, branching or looping, it can be much easier to omit an instruction not just due to skill-based error, but also due to rule and knowledge-based errors.
- ! Complex, non-linear processes can be very hard to understand and assess, especially where there may be a large number of potential branches and outcomes. This can often lead to highly complex systems not being appropriately assessed, or uncommon / unlikely paths not receiving the level of assessment that may be appropriate (being deemed disproportionate).

Where non-linear, branching or decision-based instructions are required, a proportionate (usually significant) amount of systems (task) analysis is required to develop the required level of understanding in order to optimise the design of the process and ensure the logic (and safety) is maintained. In the development of such systems, designers (engineers) will develop Process Flow Sheets (PFS), Process Flow Diagrams (PFD), Mechanical Sequence Diagrams (MSD) etc.

- ! Where ill-conceived or poorly implemented, complex procedures with many potential decision nodes or branches can be difficult to navigate, and operators can lose track of where they are in the process. Specifically, in an automated system this can lead to a significant degradation in situation awareness and an inability to recover (quickly / safely). Situation Awareness and recovery are discussed in Sections 6 and 7 respectively.
- ! Non-linear presentation of instruction presents a challenge for document reviewers / verifiers. Where operations are branching or looping, the reviewer or verifier will need a clear understanding of the logic of the various process flows, and a clear method of ensuring every possible path, sequence or combination of modules has been assessed.

Non-linear instructions can present a unique challenge for document reviewers and verifiers. Specific arrangements and processes should be implemented to ensure the review and verification of non-linear instructions is undertaken comprehensively, and that all possible process paths are considered.

! Iterative testing and process-run-through (PRT) are essential tools in ensuring the procedures are fit-for-purpose. However, iterative testing and continuous development can be costly and is often not undertaken sufficiently. It is considered that lessons could be learned from the computer gaming industry, which faces similar challenges.

! Where task-step tracking and verification is necessary in the context of paper-based procedures, branching and looping operations often require the instructions to be repeatedly presented / printed to enable the operator to continuously check or verify that the tasks steps have been undertaken. This can lead to complex addendums or large blank sections in completed procedures (where repetition was not necessary). Although the use of Electronic Procedures can eliminate the need for printing, their implementation will not directly lead to the elimination of this concern, and operators may still be required to loop through the same operations repeatedly, and track / maintain a record the operations undertaken.

! Non-linear, decision-based processes often rely heavily on operator awareness, understanding and training (i.e. SQEP). Paradoxically, high levels of system automation can lead to a loss of operator situation awareness and skill-fade over time (Sections 6 and 7) which can compound concerns relating to errors of omission and commission.

Operator experience, skills, potential skill-fade, and the loss of situation awareness (Section 6) should all be considered in the context of decision making that may influence the risk of task step omission.

Issues associated with 'skill-of-the-craft' in the context of the implementation of Electronic Procedures are noted in Section 7.2.

5.1.2.3 Good Practice & Guidance

Non-linear procedures are commonly presented as flow-diagrams, that enable operators to visualise the decision making required (decision trees) and gain a greater understanding or appreciation of the overall process logic.

In written form, procedures are commonly presented in an IF-THEN-ELSE syntax, that guides operators in their decision making (see also Section 4.3.2).

It is essential that all task steps are uniquely numbered in order that operators can quickly identify and navigate to the correct / required step.

It is important that operators are able to efficiently identify and navigate to the required task step where decision-based operations are implemented. All task steps should have unique identifiers.

It is common to limit or cap the number of loops or deviations permitted. E.g. the instruction might state that where it is permitted to attempt a process (due to anticipated failure) a number of times. If success is not achieved after a specified number of attempts, then the process should be aborted, and further advice / guidance / support sought from seniors or supervisors.

Instructions commonly state clearly where deviations are permitted and where further advice must be sought if deviation from the prescribed process is deemed to be necessary or required.

Deviation from prescribed process or procedure may be necessary. The potential for (necessary) process deviation should be identified and the associated risks should be identified and managed.

Further consideration of necessary deviation is presented in Section 5.1.4.

5.1.3 Checklist Compliance

Research has led to the identification of three common checklist use non-compliance behaviours:

- failure to mark as complete (checking) completed tasks;
- falsely marking as complete (checking) tasks that have not been performed; and
- inaccurately marking (checking) incomplete tasks as complete.

Within the context of a specific research project, two major factors were identified to explain why non-compliant behaviours were occurring:

- Work practices and task perceptions that have formed over time (i.e. contextual factors leading to deviations from established/prescribed protocol); and
- The variable nature of task length and complexity.

It is evident therefore that compliance with Electronic Procedure checklists can be affected by work practices, culture, task perceptions, and the variable nature of the task (length and complexity). The potential for non-compliance with procedures is not unique to Electronic Procedures. However, poor implementation could increase the risk of deliberate non-compliance.

Consider whether and / or how the introduction of the Electronic Procedure may mitigate the risk of operators verifying as complete, tasks that have not been undertaken - either in error or by violation.

5.1.3.1 Identified Potential Benefits

✓ Electronic Procedures may offer the capability to check whether rules, limits or conditions have been satisfied before allowing the operator to continue (e.g. bar-code scanning of components / tools). Some systems may require a certificate or document to be uploaded before allowing the process to continue.

✓ The implementation of Electronic Procedures often enables greater traceability of procedure compliance through digital recording of who is performing the action (digital sign-on).

✓ Electronic Procedures can facilitate real-time remote supervision and compliance checking, negating the need for additional personnel or scarce human resources to be physically present.

✓ In the context of complex or team-based scenarios, the Electronic Procedure system can automatically identify and log the operators performing or responsible for undertaking safety related tasks.

5.1.3.2 Potential Challenges & Concerns

! It is good practice when using procedures to include a requirement for supervisors to confirm that all relevant pre-use checks have been undertaken, and this aspect of the procedure could be automated if the Electronic Procedure system is able to access the relevant information. However, this could easily lead to a high administrative burden, and it is foreseeable that this system of operation may not be sustained or sustainable.

! Although the introduction of Electronic Procedures can enable greater capability in terms of event tracking and the implementation of hold-points in support of process compliance (and audit), such systems have the potential to significantly increase the burden on personnel (e.g. supervisors and supervision requirements), can be complex to manage in team settings, and are often open to abuse / violation.

! Supervisory controls and the implementation of supervision-based hold-points can be very demanding on SQEP resource, and contentious in a resource constrained environment. Care should be taken to ensure due consideration has been given to the requirement for additional personnel to perform supervisory or approval functions.

The implementation of Electronic Procedures has the potential to introduce additional hold-points and supervision requirements that may place additional demands on human resource.

Consider the potential impact procedure compliance mechanisms may have on process workflow.

! Digital systems can facilitate and enable remote authorisation by improving the ability to share (in real-time) task related information. This has the potential to reduce the burden on supervisors to be physically present while the task (or sequence of tasks) is being performed. However, care should be taken when implementing remote authorisation / approval as this may be open to abuse, or may lead to a degradation in supervision, monitoring, or the overall level of quality control.

! Poorly implemented systems could increase the risk of violation whereby supervisors simply leave their credentials with the operator - essentially over-riding or by-passing the safety function the supervisory function should be providing.

Where remote approval or authorisation is being considered, a holistic assessment should be undertaken to provide confidence that such a system would not lead to a degradation in the overall quality of supervision, monitoring, or quality control.

! Procedure compliance tracking can become problematic in a team setting, or reader-doer context where one-person (the reader) is reading the action to be performed and the activity is being undertaken by a team of people. Responsibility and accountabilities have to be clearly set out / designated.

It is important to clearly identify the roles and responsibilities associated with the conduct of safety significant tasks and to ensure that where safety related instructions / tasks are presented, the person responsible for task verification / compliance is clearly identified and in a position to perform the task safely and reliably.

5.1.3.3 Good Practice & Guidance

Design considerations to mitigate the risk of non-compliance behaviours include:

- Providing further task support for complex tasks;
- Implementing further supervision and retrospective checking; and
- Presenting tasks in a more time sensitive or timely fashion.

It is common within high hazard industries for compliance checks to be undertaken as pre-use checks and before operations start to ensure only approved and certified equipment is present and is being used.

With paper-based procedures, the implementation of HBSCs and Safety Actions will typically require some kind of hold-point for supervisory verification that the task has been completed correctly, with signatures and dates. These additional verification actions can be negated with electronic systems, or further automated (via digital approvals), however concerns relating to the additional administrative burden resulting from excessive implementation of digital approvals and potential violations are noted.

Tasks identified as being of particular importance in the Safety Case (HBSC) should be easily identifiable as such and should be supported by robust compliance (verification) mechanisms.

5.1.4 Necessary Deviations

Regardless of how much assessment, planning and preparation has been undertaken, it is reasonable to consider that there will always be an example or eventuality where there is a need to deviate from the prescribed system or method due to unprecedented or unforeseen (unforeseeable) circumstances.

Deviating from written process greatly increases the risk of omission error, therefore any system (whether paper-based or electronic) must be tolerant of and enable such deviations to take place safely.

Due to the way in which Electronic Procedures are able to exercise far greater control over operator access to task instructions, or restrict progress based on condition / rule-based logic, this can present a greater challenge if such eventualities are not considered and mitigations are not put in place.

Similar issues are raised in the context of Recovery – see Section 7.

In many contexts, it is not credible that every possible eventuality could be considered, therefore it may be beneficial that the system enables the operator to 'break out' of the approved procedure in a safe and controlled way.

Similarly, where the operators may be required to temporarily 'break out' of the approved process, the system should provide the means to safely re-enter the process in a controlled and safe way.

The reason / rationale for deviating from the approved process should be logged / documented as this presents a key point in the process that may increase risk.

Consideration should be given as to how operators might be able to maintain the required level of autonomy and the ability to challenge or deviate from the approved process where potentially unsafe conditions or activities are recognised.

5.2 Errors of Commission

5.2.1 Clarity of Instruction

Although Electronic Procedures have the potential to improve the presentation of instructions (e.g. through more visual and interactive media), there remains a fundamental requirement to ensure instructions are clear, concise, meaningful and actionable.

There is an active community of professionals (not limited to the Nuclear sector), and a significant body of research, information and guidance devoted to the development of instructions that it is impracticable to repeat here.

Needless to say, it is paramount that all procedures and instructions are based on a comprehensive analysis of the tasks required to be performed, and all procedures undergo a thorough review process by a selection of independent stakeholders.

Concerns are commonly raised around the consistency, structure, syntax and phrasing of instructions such that ambiguity is avoided. For example:

- Instructions should be framed as positive actions
  - Avoid negative compliance requirements (e.g. do not…)
- Instructions should be structured as verb-noun combinations
- Instructions should be consistent in their syntax and structure – see 4.3.3.2
- Instructions should not be formed of compound requirements
  - Multiple task requirements should be separated as separate instructions.

These issues and concerns are not unique to the digitisation of instructions; however the introduction and implementation of Electronic Procedures is often cited as an opportunity to significantly review and revise the instructions, therefore they are prevalent in this context.

5.2.2 Communication

The level and quality of communication between operators will affect a number of different factors such as situation awareness, workload, decision making etc. All of which can directly affect human performance and the likelihood of error.

The potential for the implementation of Electronic Procedures to significantly influence the need for and therefore the level of communication has been identified and highlighted by a number of different organisations and researchers. This is therefore given further attention and is discussed in greater detail within Section 6.

5.2.3 Decision making

The implementation of Electronic Procedures introduces the opportunity to digitise and automate many processes that may traditionally have been performed manually. The endeavour is therefore likely to be accompanied by a review of the Concept of Operations (see Section 12.1), and decisions associated with the Allocation of Function between operators and machines (see also Sections 2.5, 4.4.2 & 7.2).

Safety related processes are often heavily proceduralised because significant effort has gone into identifying the safest way of undertaking a task. This again further removes decision making from the operators with respect to which action to take in any given context. Any deviation from the defined process represents an uncontrolled deviation from the safe system of work (and may undermine the safety case). It is often the case however, without significant and extensive analysis or assessment, that complex processes have many different potential paths - that ultimately may require the operator to be given the flexibility (decision-based) and capability to follow an unforeseen path or one that deviates from the defined process.

Recognising that human decision making is prone to human error, the implementation of Electronic Procedures is an opportunity for significant improvement, whilst also an area of significant challenge.

5.2.3.1 Identified Potential Benefits

✓ Electronic Procedures, where implemented correctly, can significantly reduce the potential for decision-based errors through automation, effectively removing the requirement for the operator to make a decision.

5.2.3.2 Potential Challenges & Concerns

! An overly flexible system may allow operators to deviate significantly from the prescribed safe system of work.

! A non-flexible or poorly implemented system may preclude operators from undertaking the safest course of action in an unanticipated scenario.

! Operators may place too much trust in the information presented and may not pay sufficient attention to the specific context. See also section 7.3 – automation over-reliance.

A good level of task understanding is required to establish a good balance between flexibility and autonomy, and safety related controls. Any system that is overly restrictive and does not enable the operators to work in a way they perceive to be efficient or effective may be abused / violated.

Task / process analysis and assessment should be undertaken to ensure that the Electronic Procedures have been implemented in the most efficient and safe way, such that any operator decision-based incentives or opportunities for procedure violation have been minimised.

5.2.3.3 *Good Practice & Guidance*

Different organisations and countries have adopted different approaches, preferences and rationales to the provision of ‘agency’[3] when developing and following procedures. Such is the understanding that the provision of decision making autonomy to operators introduces the potential for human error, the pervasive attitude is to remove agency, autonomy and any opportunity for error as far as practicable.

There is also a strong and pervasive attitude toward caution in the context of providing ‘agency’ to digital platforms delivering Electronic Procedures.

The authors of the IEEE Standard 1786 have adopted a philosophy that essentially precludes Computerised Operating Procedure Systems (COPS) from being implemented as an agent, limiting the use of automation to the evaluation of fully determined step sequences, and guiding against decision making authority within COPS [9]. It has been suggested that advancements in technology will increasingly invite ‘agency’ to be offered in many types of automation, and agency will continue to engage social responses in operators even if we hope to avoid them. Nonetheless, without a fundamental change in the role of procedures themselves as instructions for people, it is cautioned that with the implementation of Electronic Procedures, there should remain the clarity that operators remain in control.

With the application of Electronic Procedures, is it essential that the operator is able to maintain control of the operations being undertaken and that the implementation of the Electronic Procedure does not diminish the essential role or capability of the operator in maintaining safety.

It is normal practice for Electronic Procedures to be 'locked down' to prevent operators from deviating away from defined steps and procedures that have been validated to be safe.
Where the Electronic Procedure system does enable actions to be undertaken that deviate from the 'normal' process, this can be locked-off, such that it requires additional (e.g. supervisor or administrator) permissions for access. The accessing of these functions should be logged (auditable). See also ‘Necessary Deviations – Section 5.1.4.

It is accepted that Electronic Procedure systems (COPS) may evaluate the logical conditions of one or more procedure steps, providing that the results in each case are fully determined (i.e. giving a deterministic result for any given set of inputs) by the step logic and the available process data. Steps with elements not fully determined should require a decision to be made by the operator. Electronic Procedure systems should not be enabled to make such decisions.

5.2.4 Information Retrieval & Accessibility

In the context of complex, safety significant task execution, operators may be required to use or reference a large amount of documented information. Paper-based procedures may be printed in numerous large volumes and can therefore be cumbersome to access and navigate. Paper-based procedures may also require a significant amount of physical storage space, enhanced security protocols and therefore controlled access arrangements.

Such issues can present significant barriers to easy access to information at the point or time of need. Any difficulty in accessing information can influence the operator’s willingness and ability to refer to appropriate instruction and potentially incentivise operators to undertake the task in an unsafe manner.

[3] In the context of this research, ‘Agency’ refers to the level of control and autonomy an operator (or machine) may have when enacting procedures, completing process tasks and working toward the accomplishment of goals.

5.2.4.1 *Identified Potential Benefits*

✓ Electronic Procedures (if well implemented) can provide operators with immediate access to correct task or context-sensitive information at the point of requirement, therefore mitigating the risk of information retrieval error.

✓ Electronic Procedures can be hyperlinked or self-referencing, therefore eliminating the need for operators to remember, know or understand how different procedures may be related, or which procedure is required in any given context. This mitigates the risk of operators referencing or using the wrong procedure, noting that in some contexts, many different procedures may appear to be very similar but are subtly different depending on the specific plant or process conditions.

✓ Large volumes of Electronic Procedures can be held in a database that is easily searchable, enabling operators to access further information quickly as required, therefore reducing any incentive to proceed without reference to what may be important safety related instruction.

✓ Electronic Procedures can enable operators to quickly identify and access product quality records, event logs, task checklists etc. if required in support of abnormal event or incident investigation. Efficient and timely access to such records can benefit safety.

Electronic Procedures can provide operators with efficient access to further (supplementary) instructions and related information appropriate to the task.

Where operators may be required to follow multiple processes that are similar but subtly different, measures should be undertaken to reduce the risk of operators using the wrong procedure.

Consider what additional functionality may be required to enable operators to enter or capture process / task related information or notes during operations for future reference / use.

Consider what arrangements may (need to be) implemented to enable the retrieval and use of Electronic Procedure based data or information captured during use, in support of abnormal event or incident investigation.

5.2.4.2 *Potential Challenges & Concerns*

! The opportunity for the Electronic Procedure delivery system hardware or software to fail introduces new failure modes that may not be part of existing plant risk profiles. See Technology Malfunction – Section 7.4.

An inability to access information efficiently can affect operator performance and efficiency on a number of different levels and in a variety of contexts, for example:

- Poor access to instruction could incentivise operators to work without reference to task specific information, therefore increasing the risk of missing a task step or performing the task incorrectly.
- Inefficient or poorly implemented access to instruction could lead to operators using the wrong instruction. This is particularly important where different similar context sensitive instructions are available.
- The inability to efficiently access or use task completion checklists or event logs could incentivise operators to undertake work in batches and fill-out the forms at the end of a process rather than during the process, increasing the risk of error in recording.
- The inability for supervisors and / or managers to easily access and retrieve task completion or product quality related records could lead to time delays and process inefficiency. This could lead to operations being rushed at a detriment to safety.
- The inability of operators to efficiently access alarm, alert or abnormal event response instructions could lead to operators taking action in an uninformed or unsafe way or may significantly delay appropriate response.

In these contexts, a number of potential benefits to the implementation of Electronic Procedures have been recognised.

5.2.5 Task Duration Monitoring

There are a number of different reasons why temporal factors and task timings may be considered to be important:

- Understanding and tracking how long tasks or processes take can be an important metric in managing the organisation, planning and scheduling etc. This may influence staff availability and in the context of hazardous processes, ensuring an appropriate number of SQEP are available.
- Tracking task or process times and durations can enable managers to establish norms, and identify when, where and how efficiencies may be gained by making changes (to people, processes, parameters).
- The monitoring of process or task timings may be essential for product quality and safety. E.g. run-times, exposure times, chemical reaction times, vacuum times etc.

Where tasks are required to be performed within a given time or are time-sensitive / dependent, it is common to see clocks, stopwatches, digital timers or even egg-timers in plant and control rooms. These enable operators to maintain a closer track of time when undertaking procedures. Operators may often be required to track multiple task timings or durations and may therefore have multiple stopwatches or timers running simultaneously.

Safety related processes that are time sensitive should be given specific attention as the presentation of timing information may be easily overlooked.

5.2.5.1 Identified Potential Benefits

✓

Digital systems have proven to be useful in their ability to automate timings and maintain a log of when tasks were started and completed and can easily compute task completion time. The automation of task execution time logging can:

- Reduce the likelihood of operator error (omission & commission).
- Reduce the administrative burden on the operator and operator workload.
- Improve the audit trail associated with tracking and verifying when tasks were performed.
- Provide enhanced data in support of process analysis and process optimisation, e.g. throughput analysis, scheduling, resource allocation etc.

5.2.5.2 Potential Challenges & Concerns

!

The implementation of a clock is relatively straight-forward on modern digital systems, most computers or devices will have a clock. However, the implementation of task timers, or process timers requires significant consideration and planning and an increased level of embedded complexity within the specific software solution that is not always readily available without dedicated coding that can reduce the flexibility of the system. A thorough understanding (supplemented through tasks analysis) is required when developing procedures, and this is just as important when developing digital procedures as they can be less tolerant to deviations or less flexible when operations do not run to time.

Specific attention should be given to safety related time-sensitive tasks, and how the implementation of Electronic Procedures may influence the ability of the operator(s) to perform those tasks reliably.

!

Poorly implemented digital systems might incentivise the operator to use an independent means of maintaining awareness of time leading to errors associated with timing discrepancies or inaccuracies. Conversely, it may be appropriate and / or more efficient to use or maintain a means of tracking time that is independent of the Electronic Procedure or Control System.

!

The implementation of greater data tracking or control over timing could incentivise operators to rush or violate process in pursuit of achieving performance metrics.

! Poor implementation of Electronic Procedures, with increased emphasis, display or ability to monitor task execution times (even if subtle) could incentivise operators to rush.

It is possible with the introduction of Electronic Procedures, that operators (and managers / supervisors) are provided with a heightened availability of information and data concerning task timings / durations. Mechanisms should be implemented to ensure that this does not incentivise operators to increase the pace of task execution at the expense of safety.

When tasks or task sequences (especially those related to safety) are time sensitive, additional consideration should be given to potential error or failure modes. Operators / human performance will deteriorate (increased likelihood of error) under time pressure. This is a common PSF.

! Task timing tracking and completion time tracking can be highly contentious in an industrial setting. Although task completion time tracking has always been an important metric for operations managers (e.g. time and motion studies), the increased level of detail or information available to managers might easily be abused and have a significant negative influence on staff morale and / or culture.

The implementation of Electronic Procedures is likely to provide supervisors and management with an enhanced ability to track individual task performance, that may be used or considered as individual performance metrics.

Consideration should be given to the potential impact an increased availability and use of performance data /metrics may have on operator psychological or socio-cultural factors and the holistic influence on facility operations.

5.2.5.3 Good Practice & Guidance

📖 When using written documents, it is common for operators (or supervisors) to timestamp the activity, or track task-timings by annotating the printed document. This also improves place keeping and task tracking, whilst also being useful for audit purposes.

📖 Electronic Procedure systems are able to implement supervisory hold-points, acknowledgement, authorisation and /or verification checks that prevent operators from proceeding without authorisation. Care should be taken when implementing these break-points in the context of time-sensitive operations, as if the supervisor is not available, the operator / operations may not be able to proceed.

📖 It is RGP within high hazard industries to consider task pacing as a PSF when undertaking assessment. I.e. the degree to which either the system or human controls the pacing of the task.

5.2.6 Mental Calculation

Mental mathematical calculation tasks are particularly prone to human error.

✓ The use of Electronic Procedures can mitigate the risk of mathematical calculation error by providing operators with access to computational aids. Electronic Procedure technology can enable part or full automation of data collection (entry) and processing, with the potential to reduce or even eliminate the risk of associated human errors.

5.2.7 Mental Rotation: Task Orientation / Alignment

Complex assembly processes or tasks can often be difficult to convey through words. Although paper-based procedures make good use of pictures and imagery, mistakes often occur due to the inability for operators to clearly understand how components should be orientated and fit together. This increases the risk of incorrect assembly due to human error.

✓ Electronic Procedures can offer better imagery, digital models, videos and dynamic instructions that support operator understanding and reduce risk of component misalignment or assembly errors.

5.2.8 Process Interruption &/or Deviation

Operator error commonly arises where processes are interrupted, and operators lose focus or attention. This can lead to place keeping error, modal errors or retention-based errors.

The benefits associated with place keeping, data and information capture, data and information presentation and decision making identified above are key factors in reducing operator error associated with process interruption.

5.2.9 Component / Equipment Verification

✓ In the context of manufacturing, assembly, disassembly or maintenance tasks, Electronic Procedures (applications) can enable greater item tracking (including components and equipment), through the use of unique identifiers and recognition systems (e.g. bar-codes, QR codes, electronic tagging systems (RFID)). These methods can significantly improve efficiency and reduce probability of error in component identification. This can have positive effects on efficiency, audit and overall quality.

✓ Electronic Procedure systems are able to perform automated verification checks and alert operators when equipment or components are for example incorrect, not valid or beyond their certification date. More complex systems may, for example, be able to actively prevent tool use where the tool is not certified or calibrated correctly.

6 Communication and Situation Awareness

It is recognised that the implementation of an Electronic Procedure based system can have a significant effect on the types and levels of communication between operators. In an operational context, operator Situation Awareness may be heavily correlated with communication, therefore both communication and Situation Awareness are key human PSFs.

Research associated with the effect of Electronic Procedures on communication and Situation Awareness is inconclusive, or more accurately, conflicting. Some studies have demonstrated a potential improvement while others showed no significant difference or even a decline. A decline in communication is also not necessarily correlated with a deficit in operator performance. These conflicting conclusions are not unexpected given the result of any intervention that may influence communication and situation awareness will be highly context sensitive.

One of the most common findings is that the introduction of Electronic Procedures can lead to a reduction in communication (most commonly associated with control room operations). The primary causal factors are:

- Operators have greater personal access to information therefore do not need to request it from others (reduced enquiry communication).
- Operators are enabled to undertake more work independently without the need for interaction with others.
- The implementation of Electronic Procedures is often accompanied by an enhanced presentation of data or information that reduces the need to raise queries or clarification questions.
- The implementation of Electronic Procedures may be accompanied by a digital decision making aid.
- The implementation of Electronic Procedure systems is often accompanied by a digital overview of tasks being performed, task tracking and / or greater team transparency, reducing the need for operators and supervisors to request status updates.
- Automated capturing of information reduces the inherent need for operators to communicate and can reduce the burden on the supervisor or team leader to request information.
- Enhancements to information sharing improves overall situation awareness – which is directly correlated with enquiry communication. This is more apparent for distributed teams or groups of operators that are not co-located.

Reduced communication may be an indication of operators having better or enhanced Situation Awareness as a result of Electronic Procedures being implemented well.

Conversely, reduced communication, or perceived need to communicate as a result of a poorly implemented system could have a significant negative impact on both personal and shared Situation Awareness and team cohesion.

! A reduction in communication between operators may be a positive indication of process efficiency and improved personal Situation Awareness. However, the poor implementation of Electronic Procedures and / or reduction in communication could lead to:

- An overall reduction in team communication and shared Situation Awareness.
- An overall reduction in teamwork and team effectiveness.
- An overall deficit in supervisory control.
- The digitisation or over-complication of communication where it may be more appropriate to encourage face-to-face communication.
- A degradation in personal relationships that benefit team cohesion.
- A long-term loss of communication skill. I.e. operators understanding when and how it is appropriate to request information.

Where Electronic Procedures are being or have been implemented, consider how the system may influence the dynamic relationships between operators, particularly in a group / team (control room) setting or environment.

Appropriate metrics should be established, and testing should be undertaken (before and after) to provide robust evidence that the implementation of Electronic Procedures does not have a negative effect on communication, especially where communication is paramount to safe operation.

Claims of improved communication and Situation Awareness should be supported by robust evidence.

6.1 Narrower field of view

Traditionally, NPP control systems have been distributed over many panels with a broad variety of information, indications and displays being available over a large area. The move to computer-based systems has the potential to focus the operator's attention to a smaller number of displays with a tendency to hide information behind menus and windows. Although this concern is not unique to the introduction of Electronic Procedures, it may exacerbate the issue or lead to an increased focus on digital display-based information rather than information available away from the primary interface.

A methodical and systematic study of operator information requirements should be undertaken.

Consider how information should be prioritised to ensure safety critical, high priority or frequently required information remains available to the operator and visible at all times.

! In the context of Situation Awareness specifically, it is noted that:

- Electronic Procedures (digital displays) may focus operator attention on a single display rather than promoting wider awareness of what is going on in the wider context of the working environment.
- Poorly implemented Electronic Procedures (digital systems) that include greater automation can lead to operators not being made aware of activities or plant status conditions that are important to their task / role. E.g. alarms, alerts and indications that are automatically responded to outside of the operator's immediate awareness.
- Focussing operator attention on display screens, leading to loss of immediate Situation Awareness, could significantly compromise personal safety where operators are working in hazardous conditions or using equipment or machinery that requires a heightened awareness of conventional safety hazards in the local environment.
- A significant breakdown in Situation Awareness (and communication) can lead to greater difficulties (compound effect) in the context of an abnormal event, or where there is a need to recover from a failure mode.
- Poorly implemented Electronic Procedures could lead to less information being presented or provided to the operator 'at a glance'. E.g. further information may be available but not on the same screen. This can lead to operators focussing on a specific task or tasks leading to an overall loss of awareness of the task in the context of others, or their positioning in the overall process. Colloquially, it is generally noted as being easier for operators to gain an appreciation of 'where things are' with paper-based procedures that is not easily replicated on electronic systems.

Researchers have proposed that providing functional information such as procedural paths, the purpose and goal of the procedure, the role of a component in a system, and future behaviour of components / plants when operators take action based on the procedural steps can improve operator understanding and awareness.

7 Operator Skills & Learning

7.1 Training

In many contexts, the development and implementation of Electronic Procedures may not influence the fundamental role of the operator or the tasks that need to be undertaken in order to achieve an objective or goal. For example, in component assembly or plant maintenance tasks, the actions that need to be undertaken in order to ensure the product has been assembled, or plant maintained correctly will (should) be the same regardless of the method or means of presenting the instructions.

In the context of control room operations, or advanced control system interaction, the level of integration of the procedure with the control system will alter the concept of operation and the allocation of function between system and human.

In effect, the implementation of Electronic Procedures will always increase the training burden on operators to some degree, with respect to them having to learn a new system or multiple systems. That may typically require training on:

- a new way of operating (concept of operation);
- a new Human Machine Interface (HMI) associated with the delivery and interaction with the Electronic Procedures; and / or
- a new HMI associated with the monitoring and control of plant and process equipment.

In addition, the following potential training requirements may be associated with the development and implementation of Electronic Procedures:

- Training of the personnel responsible for implementing the (new) system.
  It is essential that technical staff responsible for the digitisation of procedures have an excellent understanding of the plant, equipment and processes for which they are creating new content.
- Training of personnel supporting the transition.
  In the short term, additional personnel with an advanced awareness of the system may be required to support the operators as they transition toward the use of the new digitised system.
- Training of personnel in required management and supporting administrative arrangements.
  The implementation of Electronic Procedures will require the implementation of long-term or through-life administrative arrangements that will be new to the organisation or facility.
- Training of personnel in providing long-term technical support.
  The Electronic Procedure will require routine maintenance and technical support, for example recovery of local faults relating to software or hardware issues or updating the procedure content.

The implementation of Electronic Procedures is likely to place an additional training burden on the organisation that if not considered or managed correctly could influence the safety of operations in both the short and long term.

Training needs associated with the development, implementation and through-life management / maintenance of Electronic Procedures should be systematically reviewed, identified and addressed.

7.1.1.1 *Identified Potential Benefits*

✓ There are many studies demonstrating that when implemented well and designed correctly, Electronic Procedures can be intuitive to use and easy to learn. An investment in the 'usability' of the system will therefore pay dividends in the context of training related costs (see Section 4).

✓ If implemented well, Electronic Procedures can enable operators to learn and execute tasks (more) efficiently and effectively due to the greater level and quality of information that can be presented. Electronic Procedures and digital presentation of information can offer significant advantages in the way instructions are presented to operators using a blend of media presentation methods. One specific study noted that "In accordance with the tenets of dual coding theory, people learn at a much deeper level when words and pictures are combined, as opposed to words alone. As such, multimedia is suited to foster the learning that takes place through two channels."

7.1.2 Potential Challenges & Concerns

! Conversely, the poor design, execution and implementation (usability) of Electronic Procedures could lead to:

- Task related training being made more difficult.
- Task execution instruction being poorly presented and made more difficult to learn.
- The introduction of complex administrative arrangements that lead to a decline in quality of Electronic Procedure delivery over time.
- A failure to service and maintain the Electronic Procedure system leading to a decline in quality, stability, reliability and use over time.

! Studies have also highlighted that experienced operators who may have been undertaking the process for many years can find it hard to adapt to new processes as the extant operations are so heavily engrained. These concerns are further discussed in the context of Organisational Change below – Section 12.

7.2 Skill-of-the-craft

It has been illustrated through multiple studies that in many contexts, workers / operators may rely more on their experience (skills-of-the-craft) rather than the prescribed sequence of procedure steps.

The successful completion of well-established operations and tasks that have evolved over a long period may rely on operators performing undocumented or unwritten tasks (work as done vs work as imagined).

Similarly, there may be aspects of the job, or phases of the process that offer operators a relative degree of freedom in the way they perform the task so long as the goal is achieved. E.g. the operator may have the freedom to use one of a number of tools or items of equipment to achieve the same goal. The specific tool or equipment used may not be important and may be open to operator preference.

In these contexts, where worker autonomy is considered to be important, this can add additional complexity to the development of Electronic Procedures that are typically more suited to the delivery of highly prescriptive instructions that are intended to be followed absolutely.

The level of operator autonomy that may be afforded to the execution of any task or sequence of operations will be highly context sensitive and may be heavily influenced by safety assessment (probability and consequences of human error). Operator autonomy may also be influenced by other factors such as the need to:

- Maintain operator engagement (decision making) during task execution.
- Provide a fulfilling role for the operator (job enrichment and satisfaction).
- Maintain operator situation awareness.
- Control operator workload.

Specific consideration should be given to those tasks that are heavily reliant on skill-of-the-craft knowledge, as they may not translate easily, or well into an Electronic Procedure, because it is difficult to anticipate exactly how the procedure will be used and / or how the operator will communicate or record how the procedure was performed.

Consideration should be given to the level of autonomy an operator should be given when performing a process / sequence of task steps. Noting that the level of operator autonomy would also be heavily influenced by the associated risk of error and potential consequences.

Organisations will be required to consider and determine what the optimum level of flexibility or operator autonomy is for tasks that require skill-of-the craft. There may be a trade-off between incorporating computational functionalities that enable more automated decision support and the amount of autonomy afforded to workers.

A comprehensive review of the work instructions prior to converting them to Electronic Procedures is recommended to determine how much skill-of-the-craft information should be embedded into the procedures or provided as supplementary information. The review should consider those tasks that require instructions to be followed explicitly, and those tasks where only guidance is required, and ensure that it is clear to operators where autonomy is afforded.

Heavily prescribed step-by-step instructions may not be applicable in all contexts, and that in many contexts there is an aspect of the 'skill-of-the-craft' to be considered.

Although there may be an optimum way to perform a given task, it may be appropriate to provide operators with the flexibility and ability to exercise judgement or even preference when performing some operations.

The safety significance of affording operators' greater independence would need to be understood, assessed, and any decisions justified. This is strongly associated with the concept of Allocation of Function. See also Sections 5.2.3 and 5.2.8.

! In some contexts, the complexity of the operations performed presents a significant barrier to understanding. One study concluded that:

> *"Despite our best efforts at controlling risk, we are left with a limited understanding of the underlying processes. In the absence of having a comprehensive state of knowledge in terms of how a plant operates, it is difficult to recognize and anticipate what can go wrong. The cause-and-effect relationships between systems, subsystems, and related components are too numerous to contemplate." [10]*

This finding stresses the need for a systematic and methodical assessment of risk and the application of well-established safety assessment, substantiation and justification principles / processes.

7.3 Automation Over-reliance & Skill Fade

The implementation of Electronic Procedures can affect the way in which operators undertake their tasks due to the way in which the system may influence:

- the concept of operations;
- allocation of function (autonomy / agency / automation);
- operator situation awareness; and
- operator workload.

In particular, an increased level of automation and a safety led drive to eliminate human-based decision making that often accompanies the implementation of Electronic Procedures could have a significant long-term effect on operator understanding and skill retention.

! An ill-conceived application or poor implementation of Electronic Procedures could lead to operators 'blindly' following process rather than engaging in the process and understanding the operations being performed. An over-reliance on automated functionalities may lead to an increase in complacency and inattentiveness amongst workers. Such issues are strongly related to the level of trust in automation, and studies have found that a high level of operator trust in automation can lead to reduced levels of attentiveness and situation awareness.

Poorly conceived and / or implemented Electronic Procedures could lead to a reduction of operator awareness and skill-fade over time.

Consideration should be given to the potential for operators to become over-reliant on the system and lose critical understanding or situation awareness in terms of what the system is doing and why.

Where Electronic Procedures are implemented with enhanced features that help prevent operator error, care should be taken to avoid over-reliance on those features. Such features can lead to skill-fade over time and exacerbate problems related to lack of operator understanding, skill and awareness in the context of failure modes and response to abnormal conditions.

Skill-fade due to over-automation is particularly important in the context of safety and where Safety Functions are being executed. Even more so where operators may be required to assume control following an abnormal event or system failure.

Systems capable of, or that implement automated decision making, or automated processes should provide the operator with feedback or a level of situation awareness to mitigate the potential for skill-fade.

Systems that provide operators with a greater level of process-based information or feedback can be useful as a training aid where on-the-job training is taking place as the operator (and trainee) can understand the decision making and the logic of the process paths being taken.

7.4 Technology Malfunction & Recovery

There are a number of common failure modes recognised in the context of procedure use, as exemplified in Table 4:

Table 4: Example Procedure Use Failure Modes

<table>
<tr><th>Failure Mode</th><th>Paper-based</th><th>Electronic</th></tr>
<tr><td>Damage</td><td>Spillage / tear, degradation</td><td>Spillage, drop, impact</td></tr>
<tr><td>Not available</td><td>Operator forgets to take</td><td>Operator forgets to take (portable device)
Loss of power, software failure, hardware failure, network / connectivity failure</td></tr>
<tr><td>Wrong procedure used</td><td>Operator given wrong procedure
Operator picks up wrong procedure</td><td>Operator selects wrong procedure, software / programming error</td></tr>
<tr><td>Wrong data / information presented</td><td>Error during authoring / review</td><td>Error during authoring / review, coding error, software failure, hardware failure</td></tr>
<tr><td>Procedure not used</td><td colspan="2">Operator choice / decision
Operator violation</td></tr>
<tr><td>Procedure violated</td><td colspan="2">Operator choice / decision</td></tr>
</table>

Various mitigation strategies have been identified throughout this document, noting that with the implementation of Electronic Procedures, the mitigation strategies will differ.

7.4.1 Potential Challenges & Concerns

! Most prevalent is the observation that the implementation of Electronic Procedures introduces new failure modes associated with loss of availability as a result of technology malfunction. The consequence of loss of procedure or an inability to refer to a procedure is highly context specific and would need to be assessed on a case-by-case basis.

The whole system of operations (not just the electronic system) should fail-safe under all conditions - at all stages of the process, or operators should be provided with a method of continuing safely under abnormal conditions or working to an approved manual (non-electronic) process.

! Poor development and implementation could also lead to Electronic Procedure systems providing operators with incorrect information (either due to malfunction or incorrect programming). The need for robust development and quality assurance procedures are recognised. Studies have found that operators will (generally) have a high level of trust in the information being presented and may not be inclined to cross-check decisions made by computers. Over-reliance on automated functionality and information presented may lead to complacency, inattentiveness, and a loss of manual control under abnormal conditions. Research is needed to confirm these challenges and identify evidence-based mitigations.

! Conversely, in the context of poorly implemented systems, it has been reported that workers did not trust their procedures because they were out of date or incorrect. Systematic barriers to maintaining procedures—such as the high cost, challenges associated with making procedures accessible given the large number of procedures needed, and infrequent use despite investment—perpetuated workers' distrust of procedural systems.

Consider the level of trust operators have in the information being presented and how this may influence their actions. Both excessive and low levels of trust can cause operational (and safety related) issues.

7.4.2 Good Practice & Guidance

Where the Electronic Procedure system is identified as being safety significant, a proportionate level of testing should be undertaken.

Where the Electronic Procedure system is identified as being safety significant, an assessment of the potential failure modes should be undertaken (e.g. Failure Modes and Effects Analysis), and appropriate mitigation identified and implemented.

It is a common observation (in high hazard industry) where Electronic Procedures have been implemented, for paper-based systems to be available as back-up or reversionary modes and in some contexts, for paper-based systems to be operated in parallel such that the two systems can be compared against each other at key points in the process.

The implementation of alarms and alarm management should be carefully considered.
RGP relating to alarms and alarm management is widely acknowledged to follow the processes and principles as set out in EEMUA 191.

It is common to have parallel systems in place where safety is concerned. E.g. for component tracking, movement control or inventory control purposes, computer-based procedure may be backed up with a parallel paper-based procedure and the two inventory systems compared routinely.

Where safety is concerned, a paper-based version of the procedure should be available or creatable in the event the digital system becomes unavailable. It is advised that backup digital versions of the procedures that can be easily turned into paper-based versions are held on a system independent of the Electronic Procedure system (software and hardware) in the event of significant system failure.

Training should address the limits of automation. Operators should be supported in establishing and maintaining a proper level of trust in the automation to avoid problems associated with overreliance (using automation when it should not be used) and not using (or ignoring) automation when it should be used. The operator's trust in automation should be tested and measured to ensure it is appropriate for each context in which automation is used.

Processes should be implemented to ensure personnel have a well-calibrated level of trust in automation, that involves knowing the situations when the automation can be relied on, those that require increased oversight by personnel, and those that are not appropriate for automation. The system interfaces should support the calibration of trust, such as providing information about the automation's reliability in its various contexts of use and specific functions.

Self-checking and self-validating systems can be implemented to identify where system faults or failures may lead to the presentation of incorrect information or data. The operator can be alerted to the status of the system by conventional means (indications) that will modify their understanding of the level of trust that can / should be place in the information being presented.

8 Information Management

The implementation of Electronic Procedures may significantly influence the way in which information is managed within the organisation. The most commonly cited potential benefits, good practice and challenges are identified below.

8.1 Identified Potential Benefits

✓ The implementation of Electronic Procedures can make it easier for operators to ensure they are working to the latest version, but this is highly dependent on the document / version control and management procedures implemented.

Consider the administrative procedures necessary to ensure operators are working to the latest (approved & safe) Electronic Procedure(s).

✓ The implementation of Electronic Procedures often introduces a greater degree of data collection and control, which can benefit record keeping and auditability in terms of procedure access and completion.

✓ Electronic Procedures can significantly improve the accessibility of data and information.

✓ Electronic procedures can offer significant benefits in terms of ease of change. A single, central change can be immediately rolled out to all (distributed) users.

✓ In the context of manufacture, assembly or maintenance tasks, Electronic Procedures can be integrated with inventory management systems to improve inventory management and / or component tracking capability.

✓ Electronic or digital systems are capable of logging all inputs, which significantly reduces the incentive, or ability to maliciously modify or falsify records.

✓ Reduced clutter / use of desk and / or storage space.

✓ Improved security (see Section 10).

8.2 Potential Challenges & Concerns

! Centralisation of instructions and information management could increase the potential for common cause failure modes to be introduced. An error in document control has the potential to influence many documents and for a fault or failure to immediately affect many documents.

! If Electronic Procedures are too easy to change, it is credible to consider that operators may edit or alter the process without due consideration of the potential safety or process quality implications.

A poorly implemented Electronic Procedure system that makes change implementation too easy could lead to operators modifying the procedure in an unsafe and uncontrolled manner.

! If Electronic Procedures are too heavily locked down or made difficult to change, then the owners of the process may be reluctant to make changes or disincentivised to make change. This can lead to required changes not being made, and potentially unsafe working practices not being addressed.

A poorly implemented Electronic Procedure system that makes change implementation too difficult could lead to operators working to sub-optimal or out-of-date (unsafe) instructions.

! Where Electronic Procedure systems are highly connected to or embedded within plant control and instrumentation systems, any change to the procedure may require a significant change to a safety related or safety implicated system.

Any necessary change to Electronic Procedures that are connected to or embedded within plant control and instrumentation systems may have significant safety implications that will require a proportionate level of assessment (LC22). Careful consideration should be given to integrating Electronic Procedures with control systems and the potential through-life implications.

! Like paper-based records, Electronic Procedures are vulnerable (if ill-conceived or poorly implemented) to record falsification. I.e. a person with requisite access could modify the records after the event, e.g. mark an action or task as being complete or verified without having performed the action. Electronic systems can offer significant safeguards against record modification and falsification as every input can be logged.

Consider what safeguards could be implemented to deter or protect against violation / record falsification.

! Where robust safety measures are implemented to prevent operators proceeding or accessing instructions without certain conditions being met, operators may not be able to proceed if they are not able to verify said conditions, or if they wish to deviate from the process for valid / justifiable reasons that may be unforeseen.

! The introduction of systems that increase the ability of management to monitor individual human performance metrics can be highly contentious.

8.3 Good Practice & Guidance

Organisations are advised to engage with end-users / stakeholders throughout the process, and as early as possible to ensure that potentially contentious features / issues are managed and resolved early and do not become a barrier late in the implementation process.

Extensive end-user testing and process run-though is common-place in the implementation of new procedures. Process run-through (table-top or live) should be implemented as soon as practicable to de-risk the implementation of new procedures.

A sufficient and proportionate test regime is necessary (involving end-users where practicable) to de-risk the implementation of new procedures.

It is generally recognised (within the nuclear industry) that a high level of interconnectedness between the Electronic Procedure system and the plant control and instrumentation system is not advised, as any required change to the Electronic Procedures is likely to require a controlled change to a safety related / rated system.

Well implemented Electronic Procedure systems should provide:

- Easy access to documentation for approved personnel (permission controlled).
- A clear approvals process and audit trail.
- Clear policy / guidance on what type of changes are permissible and what level of review, approval and authorisation is required for any potential modification.
- A central document control function to maintain tight version control over all documents.
    - The ability to modify and publish should be limited to a small number of administrators.
    - A document review and approvals process should be strictly adhered to.
    - Any significant change to an approved document / process should be reviewed by independent representatives from the facility / process, safety, engineering / tooling and Human Factors (as deemed appropriate).
- A controlled method of making changes to procedures.
- A method of tracking changes and the ability to revert back to previous versions.

8.4 Audit

Many of the above issues relating to information management were noted as being pertinent to the subject of audit. Enhanced capture, availability and ability to retrieve data can significantly benefit the ability to compile information in support of auditing (including material and component accountancy).

✓ The following specific benefits were identified:

- The implementation of Electronic Procedures often introduces a greater degree of data collection and control, which can benefit record keeping and auditability in terms of procedure access and completion.
- Electronic procedures can be used to hold records and evidence of task execution (e.g. photos), that can easily be accessed by supervisors or checkers to verify the task has been undertaken correctly. A supervisor may be able to check and verify remotely rather than having to visit plant directly. The capture of photographic records of installation and commissioning activity is common within safety-critical industries.

Although remote verification is a valuable capability that may provide significant benefits in terms of resource usage, the impact on the social and relational aspect of the operation should be considered. There is often value in supervisors being present and familiar on the 'shop floor'.

During a Pilot programme, a site licensee identified significant benefits in the time taken to retrieve information. Specifically, product production notes and quality records were typically to be found in a variety of disjointed documents that took significant effort to collate when required (e.g. during incident investigation). The implementation of Electronic Procedures meant that all product quality and build records were in one place and easily accessible.

9 Portability and Power

The method of implementation of Electronic Procedures with respect to the portability of the system is highly context dependent.

In the context of a control room, concerns over portability and power are less significant (other than loss of power as an abnormal event), as operators are largely constrained in terms of their movement. The Electronic Procedure system is likely to be embedded into the central system or the main control workstations.

In the context of an assembly workstation, these are often fixed or can be partially mobile. These tend to be larger computer terminals with keyboards that are mounted to mobile workstations, or easily transportable.

Where mobile workstations are implemented, cable management and equipment positioning will require specific consideration in support of workplace (conventional) safety and ergonomic design of the working environment. Consideration should be given to the location / positioning of equipment when it is not required - see also Operational Environment – Section 11.

Electronic Procedures can be implemented on small form-factor or personal electronic devices, e.g. laptops, tablets, phones, or bespoke systems where it is important that operators have greater freedom of movement, for example in support of more complex assembly tasks or maintenance tasks.

9.1 Identified Potential Benefits

✓ The portability of modern electronic devices (e.g. tablets) can significantly improve operator access to further instruction and guidance.

✓ Mobile or portable systems can improve the ability for operators to feedback task progress data and for task progress to be monitored and controlled.

✓ Electronic procedures can be implemented on wearable displays, e.g. head mounted. These can offer significant benefits in terms of freeing up the operators' hands, but information presentation and operator interaction (ergonomics) need to be carefully considered.

9.2 Potential Challenges & Concerns

! Poorly implemented Electronic Procedure systems may significantly constrain operator movement. E.g. within a control room, the operator may be required to operate from a fixed console rather than having freedom of movement within the room. Loss of freedom of movement (being tied to a desk) could have a number of implications with respect to:

- Operator physical wellbeing – loss of physical activity or increased sedentary working.
- Operator social interaction – inability to move away from the desk whilst maintaining awareness of operations.
- Reduced communication – see Section 6.

! Portable devices will have smaller screens that may present additional challenges with respect to the display of information and the design of the HMI.

! Power consumption and management can limit the utility of the system and / or significantly increase the administrative burden (battery management / device swapping). Such issues are likely to be less prevalent or down-played during the procurement and / or development phase where through-life costs and long-term administrative arrangements are not the concern of the equipment developer / vendor or the implementation project team.

Issues associated with the long-term administration and sustaining of capability should be identified and given due attention / consideration early in the development phase and throughout the design and implementation phases.

A failure or inability to implement the system correctly, or provide long-term administrative support arrangements, could lead to a degradation of capability with significant through-life safety implications (e.g. poor maintenance of or access to procedures).

! Portable devices may rely on connection to a network which may not be practical in some environments or increases the risk of the inability to access data (maintain network connection) in some complex working environments.

! LFE from the implementation of Electronic Procedures at a specific nuclear plant highlighted potential issues around latency or data transmission to a central computer system. Operators experienced significant delays in system feedback or HMI updates making the overall system very difficult to use. System designers should ensure that strict system performance parameters and requirements are identified and complied with.

Consider the impact (on safety) of loss of operator access to data or information, and / or loss of data / network connection and the requisite system performance requirements.

! Digitised systems may introduce new error modes associated with operator inputs.

Consider the increased risk of operator input error where touchscreens and small displays are used, particularly where Electronic Procedures are directly integrated with plant control systems.

! Safety concerns regarding the use of devices in hazardous environments must also be addressed. E.g. the use of mobile equipment in dynamic environments can be a source of distraction or lead to a loss of immediate situation awareness which can be highly hazardous where the operator is at risk of injury from other equipment / machinery.

9.3 Good Practice & Guidance

Relevant good practice associated with risk assessment, hazard management, ergonomic design and human factors are applicable in this context.

10 Security

Organisational and Operational Procedures (both paper-based and Electronic) are likely to contain sensitive information that must be controlled. Any organisation managing sensitive information will have (require by law) an approved method of controlling access. The implementation of Electronic Procedures can present a number of potential benefits and challenges. The key issues identified through this research are presented below.

10.1 Identified Potential Benefits

✓ Electronic Procedures can provide enhanced control over information security by limiting user access to information and tracking what information has been viewed and by whom.

✓ A reduction in use of paper-based procedures will directly reduce the likelihood of operator error leading to a loss of 'loose', unprotected sensitive information, or classified information being removed from the facility / site.

✓ RFID tags, biometrics, fingerprint recognition and / or facial recognition can be used to improve security, and speed-up system log-in and access to data.

✓ Electronic Procedures have the capability to access a database of information relating to approved users, thereby logging and tracking personnel competencies and training. The system is therefore able to restrict access to information / instructions to only SQEP.

10.2 Potential Challenges & Concerns

! Modern Electronic Procedure development and presentation software is likely to be based on commercial applications that may not be properly accredited or hardened for use in high security areas. Many may require connection to the internet. The cyber-security of the system will need to be assessed.

! Where implemented on portable devices, rather than losing a single procedure, the loss of a portable computer / device could lead to a compromise of a suite of documentation and / or compromise the security of the whole system.

The implementation of Electronic Procedures may change or challenge the conventional way in which information is handled. The potential information security issues should be considered and assessed. Demonstrably robust safeguards must be implemented to prevent the loss of sensitive data.

! Where access to Electronic Procedures is protected using passwords, these are open to abuse and violation as when poorly implemented, the need to repeatedly log-in or change login accounts can be seen as a burden to the operator therefore incentivising violation.

Consider that multiple operators or users may be required to access or use the system simultaneously, and how the system is able to differentiate between inputs by different users.

! Computers and / or electronic devices used in secure areas or settings are often 'locked-down' for security purposes, making access to specific system settings unavailable. This is often true for power management and screen-saver settings. This can be problematic for Electronic Procedures where the system enters power-saving or screen-saving mode after a short period and operators must repeatedly log-in to the system. Sudden loss of display of information or the automatic logging out of the system after a set time can be very frustrating to users and could incentivise violation.

10.3 Good Practice & Guidance

📖 Modern digital systems employ password protection and multi-factor authentication in order to improve information security.

📖 Modern digital systems can enable the implementation of a remote 'kill-switch' capability that can be used to permanently disable any device that is removed from site or lost. However, this system may be reliant on the system being connected to a network.

📖 One site licensee abandoned a specific Electronic Procedure solution following years of development after identifying significant security concerns during penetration testing.

📖 Electronic procedures are often locked-down or hard coded for a reason - to prevent uncontrolled change and tampering - but this can be very restrictive – see Information Management Section 8.

11 Operational Environment

11.1 General

Within the context of the nuclear sector, much of the documented research and associated learning is focussed on the implementation of Electronic Procedures within control room environments.

Similarly, a review of applicable guidance (e.g. NUREG-0700, NUREG/CR-6634, and IEEE-1786, revealed that much of this is tailored toward control room procedures and may not be entirely applicable to field instructions.

It is recognised however, that there are a variety of practices and processes that occur beyond nuclear power generation and control, that may benefit from the application of Electronic Procedures. For example:

- Handling, movement and accounting of nuclear materials
- Manufacture of fissile products and components
- Storage and transfer of active liquors
- Assembly of complex safety related systems
- Maintenance of safety related systems, structures and components.

Due to their safety significance, these processes are often controlled, with operators working to controlled procedures. However, due to their more dynamic and / or variable nature, the working environment(s) may present unique challenges to the implementation of Electronic Procedures.

The following sections highlight the key issues and concerns identified.

Much of the usability guidance relating to the implementation of Electronic Procedures is founded on static use (e.g. control rooms) and may not be directly appropriate in all operational contexts. However, there exists a breadth of good ergonomic advice and guidance on the design and development of portable equipment interfaces. The need to optimise Usability is emphasised in Section 4.

11.1.1 Field Working

The use of Electronic Procedures outside of an office or control room environment presents further challenges in terms of:

- Security – see Section 10
- Portability & Power – see Section 11
- Connectivity / access to data
    - Remote environments with low / no connectivity
    - Complex environments (dense infrastructure / underground) with low / no connectivity
    - Secure environments where portable electronic equipment is not permitted
- Handling and weight
- "Hands-on" working or tasks that require operators to be using both hands
    - Complex manual assembly or maintenance tasks
    - Glovebox operations
- Operator distraction in dynamic, hazardous environments
- Use whilst wearing Personal Protective Equipment (PPE).

The appropriate solution or action to take in these environments will be highly context sensitive. However, few of these challenges are unique, and are not specific to the application of Electronic Procedures, therefore additional guidance and relevant good practice can be found in the public domain, specifically within general Ergonomic and Human Factors guidance.

11.1.2 Contamination and cleanliness

Although not unique to the use of Electronic Procedures, their implementation within contaminated or contamination-controlled environments may present unique challenges with respect to cleanliness and the potential transfer of contamination.

Due consideration will need to be given to how the systems may be cleaned or decontaminated, for example:

- Safety systems that are 'always on' or touchscreens that are permanently active are difficult to clean without risking inadvertent data input.
- Keyboards and mice are prone to ingress of detritus and / or contamination.
- Air cooled computers may incorporate fans that will pass air-born particulates across internal components.

Bespoke input devices are available for use in areas where cleanliness is a key requirement (e.g. component manufacture and hospitals), however, these devices are often compromised in terms of their usability.

Consider how cleanliness of the Electronic Procedure delivery system will be maintained. System cleaning could introduce faults or error modes. Poor maintenance is likely to lead to poor reliability, which in turn will affect access to safety related information.

11.1.3 Explosive environments

! The use of Electronic Procedures is made more challenging in the context of Explosive Environments where the use of electronic devices is strictly controlled.

ATEX[4] rated devices are available, but often are compromised in terms of their usability (and maintainability).

11.1.4 Fixed Infrastructure

! The implementation of electronic systems may require the installation and routing of additional cables and IT systems (e.g. servers, routers, computers) in a location that was not initially designed to accommodate such systems. This may require new penetrations to be made (i.e. holes through walls), or cables and equipment to be located in already congested spaces. The creation of penetrations and routing of cables can be particularly difficult in nuclear safety related / rated premises.

! Many existing facilities have been designed for a specific purpose and in many cases may be space constrained, or not suited to the implementation of additional equipment. If ill-considered or poorly executed, additional equipment required in support of the implementation of Electronic Procedures can significantly compromise the working environment.

! For new facilities, the accommodation of additional equipment required to support the implementation and use of Electronic Procedures may easily be overlooked during the planning and early design phases.

The implementation of Electronic Procedures, especially in existing facilities, could have a negative impact on workplace safety, or the ergonomics of the workplace. E.g. increased clutter, cables, equipment placed along access routes.

Compliance with building regulations and fire safety regulations should ensure that safety is not compromised as a result of the implementation of new digital systems.

[4] Referring to European Union directives relating to Explosive Atmospheres – from the French - ATmosphères EXplosibles.

12 Organisational Change: Transition & Implementation

The implementation of Electronic Procedures should (in most cases) be considered in terms of Organisational Change, which is a significant branch of either Management Science, Occupational Psychology, Ergonomics and Human Factors in its own right.

The design, development and implementation of Electronic Procedures would (normally) be undertaken as part of a *significant* programme of work associated with the development of new capability or a *significant* programme of change to existing capability. Significant, in that the decision to implement Electronic Procedures (as opposed to paper-based) is likely to be a key strategic decision or turning point that could have significant consequences, both positive and negative as identified throughout this document. In particular, the implementation of Electronic Procedures could profoundly influence:

- Operator communication protocols (Section 6)
- Operator skills and training needs (Section 7)
- Information management (Section 8)
- Facility administrative arrangements (portability & power) (Section 9)
- Security (Section 10)
- The design of the operational environment (Section 11).

Given the implementation of Electronic Procedures can represent a significant organisational and / or operational change it is important (in most cases) that it is managed as such. The following key themes have been raised and identified within the published literature and during LFE review associated with the transition toward the use of Electronic Procedures.

12.1 Concept of Operations

A number of studies have recognised that the introduction of Type 2 and Type 3 systems could fundamentally change and shape the concept of operation, and the teamworking arrangement in the [NPP] control room. Further, this may be necessary in order to maximise the potential benefits associated with the implementation of Electronic Procedures. Specifically (as noted above), Electronic Procedures, can enable (or cause) operators to undertake more tasks, work more autonomously, and in parallel (with other operators) as a result of the advanced automation available to them.

The introduction of Electronic Procedures could significantly change the overall Concept of Operations, particularly in the context of control room operations. Further, a change to the Concept of Operations may be necessary in order to realise the potential benefits attributable to the implementation of Electronic Procedures.

In the development of new systems and / or capability, many of the traditional or existing approaches to control room operations (OPEX & LFE) may not be directly applicable or relevant.

The impact of the implementation of Electronic Procedures on the Concept of Operations should be given due consideration.

Although there may be an overall aspiration for the organisation (or facility) to fully digitise their procedures, it is unlikely (except in completely new plants), that all procedures will be digitised, or the digitisation of all procedures is a viable option. Consideration and planning will be required to understand which operational practices and procedures are candidates for digitisation and which are not.

Where the facility is (potentially) operating both paper-based and Electronic Procedures, consideration should be given to how the differing modes of operation will work pragmatically together.

It is unlikely that all facility procedures will be digitised. Consider the need and arrangements necessary to operate a hybrid system of working with both electronic and paper-based procedures.

Consider the extent to which all facility procedures are being digitised holistically, and how the transition will be managed where operators may be required to refer to a blend of both electronic and paper-based procedures.

12.2 Integration Strategy, Planning & Preparation

LFE from plants that have successfully integrated Electronic Procedures has identified that early consideration of the sequence and method of roll-out could help the organisation to realise the benefits earlier. Specifically, strategic planning could identify a way in which groups of procedures could be updated and / or converted rather than attempting to do all simultaneously. Generically speaking, where practicable, an evolutionary approach is likely to be less risky and yield early advantages than a revolutionary ("big-bang") implementation.

The digitisation of procedures is likely to require the engineers responsible to develop a detailed working knowledge of the plant processes. It is unlikely that trained and skilled plant operators will be redeployed full-time to support the digitisation process. The need for detailed task analysis has been identified and is recognised in numerous contexts above (within this document). However, LFE has identified that there is no substitute for 'real world' experience and that unwritten processes and procedures (that may have developed over a long period of time) are often missing or go unnoticed until late in the implementation process. Within the field of HF this is often referred to in the context of 'work as imagined vs work as done'. The challenge for the digitisation programme is to ensure that the accumulated operating experience and implicit tasks or functional aspects of the process are not lost during the transition to Electronic Procedures. To combat this, it is recommended that end-user / stakeholder engagement should be agreed, formalised and the resource requirement secured as part of the Electronic Procedure development programme.

Practical, working knowledge of plant and operations is important to ensuring Electronic Procedures can be implemented safely. Experienced end-users or operator representatives should have an active role in the development of the Electronic Procedures.

The successful implementation of Electronic Procedures will be heavily dependent on the procedure conversion and technical authoring process as well as the hardware and software limitations of the specific solution chosen.

LFE suggests that organisations looking to implement an Electronic Procedure system should consider how and why each procedure is written the way it is currently is on paper, and should, in the early phase of the project, review, standardise and update their procedures. It is noted that the implementation of Electronic Procedures can present an organisation with an opportunity to 'break out of the paper margins' of traditional procedure writing processes and create processes and procedures that take advantage of all the specific capabilities an Electronic Procedure system will provide.

A pilot study concluded that it is beneficial to have a small, stable team of people who are principally responsible for driving through the change (often referred to as 'champions'). Such change programmes can often take many years and be subject to personnel change which can destabilise the programme.

12.3 Being Realistic

Generically, the feedback from those having undertaken the process of implementing Electronic Procedures is that the cost (resource, time and money) of procedure development and the transition to Electronic Procedures can easily be underestimated. This can have a significant effect on the success of the project and ultimately may lead to failure or significant delay. Although this may be a source of frustration to the organisation (and the operators), a prolonged period of disruption and transition may have a negative impact on the safety of operations.

Insufficient scoping, planning and resourcing could lead to a prolonged period of disruption and transition which may have a negative impact on operational safety and could introduce additional risk. Projects should acknowledge that the implementation of Electronic Procedures may require more time and resource than originally anticipated and be realistic during planning.

! LFE suggests that the additional resource and number of personnel required to support Electronic Procedure development, implementation and transition can easily be underestimated. Sufficient planning and scheduling are required to ensure a sufficient number of SQEP personnel are available to support the process.

! Experienced operators are usually in high demand and required on site / plant to manage / run operations. It can be challenging for the project seeking to implement Electronic Procedures to secure their time in support of process development.

! The potential exists when transitioning to Electronic Procedures (as is true for any significant change programme) for systems developers and integrators to over promise and under deliver. COTS or proprietary systems are likely to be constrained in their ability to provide end-users with exactly what they need, or their ability to be adapted to the specific needs of a given organisation.

The management of Electronic Procedures and associated through-life costs may not be immediately apparent during the early system selection and / or development phase. Organisations considering the implementation of Electronic Procedures are advised to consider the through-life costs associated with system maintenance, administration and document control, including additional training and development costs / personnel related requirements. Many factors that may influence through-life costs are captured throughout this document.

12.4 Measures of Performance & Effectiveness

As has already been established, the successful implementation of Electronic Procedures will require the development of a sound baseline understanding of the processes and required operator actions. This will be developed through a systematic and methodical assessment of process and tasks (in the form of Task Analysis).

Without a good understanding of the baseline process, and potential performance metrics or key performance indicators, it will not be possible to gather objective data or evidence to demonstrate any change in performance (whether improvement or detriment). This fact is often missed during the scoping and planning phase. The baselining of system or operator performance can be difficult (time-consuming and therefore expensive) to establish, and there may be ethical considerations or sensitivities to be considered, especially in the context of assessing individual task performance.

12.5 Trials & Iterative Implementation

Studies and LFE have concluded that it is unrealistic to expect that the implementation of Electronic Procedures will be 'right first time'. It is prudent for the organisation / project to plan for iterative change and implement an evolutionary approach toward the transition to Electronic Procedures, ensuring the system is flexible and adaptable to change.

It is recommended that the implementation of Electronic Procedures is tested / piloted on a small sample of operations to identify any potential issues / concerns early in the transition and implementation process. The following three stage process was put forward as an output following study:

1. Analyse the current use of paper-based procedures to identify all physical and cognitive actions a field worker conducts to complete a single procedure step, determine issues with the current workflow that should be improved, and any areas that currently work well in the current workflow that should be kept when transitioning to a digital system.
2. Develop an Electronic Procedure based prototype for a small set of procedures, addressing the needs and considerations identified in step 1.

3. Conduct evaluation studies with the Electronic Procedures prototype with actual operators – some in laboratory/simulator settings and more crucially, some in real-world settings. Feedback from participants should be iteratively fed back into the development of the prototype for refinement and better understanding of the best practice principles.

Where trials or pilot schemes are being undertaken in a 'live' environment, additional safety procedures and administrative safeguards may need to be implemented (e.g. quality control and supervision). This may place an additional staffing and training burden on the organisation and may slow down the process. These aspects will need to be anticipated in order to ensure successful outcomes.

Without adequate or appropriate training, the results from any early testing or pilot scheme may be significantly skewed by poor operator performance influenced by lack of familiarity with the new system. Before any assessment of the Electronic Procedure system is undertaken, it is important that the operators have had sufficient time to be familiarised with the system and any potential learning effect is accounted for. Operators should also be afforded sufficient time to provide feedback on the implementation and use of the Electronic Procedure system.

Evidence suggests that there is significant benefit in capturing ongoing LFE during the implementation of Electronic Procedures and throughout their use in support of continuous improvement. Systems should be implemented to promote continuous learning and improvement in response to any feedback on system use.

Consider how the system has been optimised for update or modification post implementation, as many systems may be fixed or severely limited in their ability to be modified or adapted once commissioned, especially where aspects of the system are hard-coded and locked-down, or even hard-wired in support of safety.

A pilot study concluded that is it beneficial to have a small number of 'super-users' on hand during the transition period to help resolve any issues or concerns.

During a pilot project, a UK site licensee deemed it appropriate to always have a paper-based copy of the procedure available as a reversionary mode in the event of technological failure.

Poor trials and testing could lead to an unreliable system that undermines operator trust in the information being provided. System error, system performance issues or ‘bugs’ need to be avoided during end-user testing (especially during final implementation) as anecdotal evidence suggests that any lack of trust in the system may take a long time to overcome – see also Section 7.

12.6 Anticipating & Managing User Resistance

End-user engagement is essential when implementing Electronic Procedures. Poor stakeholder engagement could lead to resentment, lack of co-operation, resistance and / or lack of compliance. Specific issues noted are:

- Operators may feel discomfort relinquishing control to technology / automation.
- Operators could be left feeling that the change is being 'done to them' rather than in support of them or in collaboration with them.
- Operators could be left questioning "what's in it for me".

It was suggested that a stepwise approach to the transition of Electronic Procedures will likely help place the technology in a more favourable light and encourage willingness to accept and use the Electronic Procedure system.

The organisation wishing to implement the change and transition to Electronic Procedures should set out a clear communication and messaging strategy / campaign to optimise the potential for end-user acceptance, co-operation and compliance. A lack of willingness to comply with procedures could be detrimental to safety.

A lack of end-user / operator willingness to comply with procedures could be detrimental to safety. End-users and operators should be consulted as key stakeholders in the design, development and implementation of Electronic Procedures. Measures should be taken to ensure operators are willing and able to comply with the procedures prior to implementation.

12.7 Potential for Over-Digitisation

! LFE from the application of Electronic Procedures in the nuclear sector has warned against the potential for over-digitisation of procedures, where the implementation or transition to an electronic platform may not be appropriate or in the best interests of end-users (and safety). It has already been noted above that a thorough review of end-user requirements should be undertaken early in the transition process. The following bullet points highlight specific concerns noted from the research undertaken.

- Excessive documentation or over-proceduralisation of what may be considered simple processes (for example, those process that could easily rely on the basic skills of the operators) could lead to misuse, or lack of willingness to comply.
- Excessive or over-use of the capabilities afforded by the Electronic Procedure platform can lead to new (unnecessary) demands being placed on the operators. E.g. to capture data that offers no real / tangible benefit.
- Excessive use of documentation or (electronic) procedures can lead to over-complication rather than streamlining operations.
- Excessive documentation can lead to difficulties in managing and maintaining the full suite of documents due to the administrative burden.
- Excessive documentation or segmentation of procedures can make it more difficult to maintain consistency between documents.

A study associated with petrochemical workers at sites that use Electronic Procedures reported a misuse of the technology that resulted in a greater burden of tasks. The researchers concluded this misuse was indicative of the malfunctions in the organisational system which reflected issues with written documentation around generating excessive information that complicates plant operations rather than streamlining.

Mitigation strategies identified include:

- End-user engagement during procedure development and review.
- Regular (scheduled) review of operator tasks / task steps to ensure only those necessary in support of achieving stated goals are undertaken.
- Regular (scheduled) reviews of procedures and procedure development with a view to consolidating similar tasks and rationalising documents where duplication is apparent, or procedures are surplus to requirement.

Consider the potential for 'over digitisation' during development and, especially for facilities transitioning to using Electronic Procedures, for further or additional process steps and tasks to be implemented that offer no real / tangible benefit and may detract from safe operation.

13 Non-safety related observations

Further non-safety specific observations drawn from the research are identified below.

✓ The implementation of certain types of Electronic Procedures has been shown to enhance revenue generation through a mix of a reduction in incidents or events that lead to lost time (e.g. a reduction in reactor tripping incidents) or direct performance improvement and organisation efficiency such as greater task completion rates.

✓ The use of Electronic Procedures can significantly reduce record storage space requirements. In many safety-related contexts it is necessary to retain records for a long time. Large volumes of paper can be produced. It is common to have these records digitised and digitally archived in order to save on physical media storage requirements. The introduction of Electronic Procedures can significantly reduce paper, digitisation and archiving costs.

✓ The use of Electronic Procedures can significantly reduce paper usage and print costs, especially where the procedure is reproduced each time the operation is performed such that the steps can be signed and approved or verified by supervisors and managers.

! It was noted that the reduction in paper and print costs could be offset by the cost of the technology, including through-life maintenance of the digital systems. This may include the cost of power, batteries for portable devices, ongoing maintenance and replacement of devices due to damage or general wear, software updates / upgrades or obsolescence.

! LFE from the medical sector (although is likely to be generally applicable) is that the capital cost of embarking on a digitisation programme is prohibitively expensive.

14 Summary

14.1 Identified Benefits

The research found evidence in the publicly available literature to support the conclusion that the use of Electronic Procedures ***could*** afford the following benefits:

- Reduced probability of human error:
  - Reduced errors of omission due to the implementation of usability attributes that:
    - Improve place-keeping
    - Improve the presentation of non-linear or non-sequential instructions
    - Improve checklist data entry compliance
    - Improve the management and co-ordination of required deviations
  - Reduced errors of commission due to:
    - Improved clarity
    - Improved operator communication
    - Improved decision making support
    - Improved monitoring / situation awareness
    - Reduced mental calculation
    - Automation / validation
    - Improved teamwork
- Improved process efficiency
  - Streamlined work processes
  - Automated content creation (datasheets)
  - Increased task completion rate (more tasks completed within a given timeframe)
- Cost savings - consequent of reduced error and increased efficiency – see above
  - Reduced use of paper / printing.

The principal goal or aim of any procedure is to reduce the probability of error or deviation from the prescribed procedure, which is assumed to be the safest and most efficient. The various benefits identified contribute or are deemed to be Performance Shaping Factors that influence the probability of human error and process efficiency.

Although there is evidence to suggest that Electronic Procedures have the potential to improve efficiency, it is important to note that in the context of (nuclear) safety, efficiency (time and cost metrics) are secondary to safety, therefore organisations (licensees) that are implementing changes to working practices purely motivated by a drive toward improved efficiency should be approached with due caution.

Efficiency and completion time can be important when associated with recovery from abnormal or hazardous conditions, or when mitigating the consequences of prior fault or error. I.e. Efficiency is important when the operator is required to return the system to a safe operating state (envelope) as quickly as possible.

14.2 Human Error

It is recognised that:

> *"The nuclear industry faces the opportunity to gain great improvements to both safety and human performance by leveraging technology and its inherent capabilities. However, these benefits are not automatically gained by installing a new system. Utilising new technology may introduce new opportunities for errors. It is therefore important to understand the current work processes and the user needs, and to design a solution which provides improvements to the work process and addresses the user needs." [11]*

Fundamentally, a written procedure can only go so far in terms of communicating the required goals and providing instruction on how to perform or accomplish the tasks required to achieve the stated objectives.

Except for the most basic of operations, the skill and experience of the operator (and therefore training) will still be relied upon when performing cognitive and physical tasks. The potential for errors of omission and commission is highly dependent on the complexity of the task required to be undertaken and the way in which the instruction is presented.

Equally, other PSFs associated with the working environment, the nature of the task and the equipment used can have a significant influence on the likelihood of operator error. In many contexts there is likely to be a direct relationship between those factors and the nature and way in which the instructions are presented.

The following factors have been identified (from the literature directly associated with Electronic Procedures) as having a significant influence over the ability of the operator to undertake their tasks most efficiently (without error) and / or provide the organisation with the ability to identify where errors have occurred and assist with recovery.

Common causes of error	Potential benefits of Electronic Procedures
Errors of omission	
Place keeping error	Enhanced navigation, task execution checking and cues to completion
Instruction complexity / linearity	Enhanced navigation, linking, graphical presentation, interactive / dynamic display of information
Poor use of checklists	Improved usability, automation
Operator workload	Reduced workload due to improved usability, automation, reduced communication
Errors of commission	
Poor instruction clarity	Improved clarity through enhanced presentation options
Poor communication	Reduced need for communication (greater availability of information
Decision making error	Automation
Information retrieval error	Enhanced access to information, links and hyperlinks
Input or data capture error	Automation, data validation and checking, improved usability
Duration monitoring error	Task timers, automation
Mental calculation	Automation, calculation and / or conversion tools
Mental rotation	Enhanced graphical presentation, video, interactive models

The introduction of Electronic Procedures has the potential significantly improve many of these factors, and equally, could introduce or exacerbate concerns if ill-conceived or poorly implemented.

14.3 Recognised challenges and concerns

Of course, the use of Electronic Procedures does not guarantee that the above benefits will be realised. Poor implementation could equally lead to increased human error, reduced process efficiency and greater operational costs.

The research found evidence in the publicly available literature to support the conclusion that the use of Electronic Procedures ***could*** lead to:

- Increased risk of operator error (including the introduction of new fault modes)
- Reduced process efficiency
- Reduced operator communication
- Negative influence on operator teamwork
- Reduced operator Situation Awareness
- Automation over-reliance (bias and complacency)
- Reduced procedure compliance.

Further issues and concerns are noted related to:

- Operator 'field of view'
- Skill of the craft
- Technology malfunction
- Trust (in data / information)
- User resistance
- Transition (implementation)
- Organisational culture and legacy issues.

14.4 Practical Implementation

Although focus is likely to be on the digital platform on which the Electronic Procedures will be hosted and presented, there are further practical challenges to consider in particular:

- The potential additional training burden
- Portability and power
- Contamination & cleanliness
- Through-life costs
  - Batteries
  - Updates / upgrades
  - Maintenance
- Installation
- Changes to the working environment
  - Space constraints
- Information and cyber-security.

14.5 Risk Mitigation

It is broadly recognised that to maximise benefit, the consideration of human factors should be integrated at an early stage in any programme of work, and should be applied consistently and proportionately (to risk) throughout the project lifecycle. Further guidance on the implementation and application of Human Factors can be found in a broad variety or documents, particularly ONR TAG-058. Human Factors Integration is not therefore bound within the specific scope of this work.

The potential identified benefits and recognised challenges and concerns have been set out in further detail within the main body of this document.

LFE, primarily taken from the application of Electronic Procedures in the nuclear sector has identified a broad variety of mitigation strategies that have been presented here within the context of any identified issues and concerns.

Many of these issues, and the issues experienced by those implementing Electronic Procedures are entirely predictable and foreseeable, especially where the vast majority of the material used to compile this document is publicly available.

It is important to learn from the experiences of others and industry relevant good practice, to be aware of the potential challenges and implement suitable mitigation to manage the known risks.

Key issues have been highlighted in the context of guidance to inspectors.

Many of the issues / concerns identified here could easily be turned into derived requirements. It is not within the scope of this project to undertake that exercise, but this may be a future consideration.

There is an acknowledgement from licensees (representative of those interviewed) that there will be an expectation from the regulator to provide evidence in support of resolving or addressing the concerns raised herein. As the UK regulatory system is not prescriptive and essentially goal-based, there is some ambiguity amongst the dutyholders as to how to best they capture and present the evidence in support of safety substantiation related to the implementation of Electronic Procedures.

14.6 Gaps & Required Further Guidance

In the process of undertaking this project, a number of information or knowledge gaps, and opportunities for further research and / or development of further guidance have been identified. These are set out in Table 5.

Table 5: Gaps & Research Opportunities

Topic	Description
Use of Electronic Procedures outside the control room	Much of the (nuclear applied) research is focussed on control room operations. There is a general recognition within the literature that further research is required with respect to the use of Electronic Procedures in other contexts outside of the control room (e.g. assembly tasks, component production processes, administrative tasks and controls, supervision, plant configuration, examination, maintenance, inspection and testing).
Fundamental principles or requirements	Although within the context of this research, usability based principles have been identified (see section 4 & Appendix B), it was not within the scope of this project to develop a set of design principles or fundamental requirements associated with the development and implementation of Electronic Procedures. The authors believe however, that it is feasible to develop such principles and end-user requirements based on the output of this project.
Methods of demonstration of compliance	The guidance for inspectors set out within this document could be interpreted as a set of requirements or challenges to be placed on the dutyholder to demonstrate that the risks associated with the implementation of Electronic Procedures have been assessed and managed such they are ALARP. Dutyholders will therefore likely be challenged to provide evidence against the implied or derived requirements. Further research could be undertaken to provide dutyholders with advice and support to promote good practice and consistency in the demonstration of compliance with said derived requirements.
How to baseline system performance – measures of performance and effectiveness	Related to the above point, one specific issue raised relates to the identification of measures of performance and effectiveness. The collection of human, system, or human-system performance data raises many challenges associated with ethics, practical data collection methodologies, data analysis and assessment. Although such issues may be considered core skills in the context of E&HF, this may not be broadly recognised by industry.

Topic	Description
	Further context specific guidance or a mechanism to raise awareness may benefit dutyholders.
Further refinement of the levels or types of EP system (beyond 1-3).	Discussions with dutyholders and stakeholders as part of this project highlighted that many considered Electronic Procedure projects do not fall neatly into the Type 1-3 classification system. The authors were left with the broad perception that although helpful to communicate the general concept of level of sophistication or allocation of function between operators and the Electronic Procedure system, most applied systems do not fall neatly into any particular category or type.
Detailed assessment of Allocation of Function – pros and cons.	This project has identified that there are many potential functions that could be introduced or automated through the implementation of Electronic Procedures. Further guidance and advice could be developed regarding the potential benefits and challenges associated with the allocation of these functions, or guidance (to dutyholders) on appropriate allocation of function assessment techniques to ensure this is given appropriate consideration in the early stages of any project where influence and value added would be greatest.
Development of quantitative HRA methods	It is recognised that the likelihood of operator error when using Electronic Procedures is likely to be subject to detailed HRA including quantitative HRA. The preferred quantitative HRA methods in the context of UK nuclear safety case development (e.g. HEART, THERP, NARA) are limited in terms of their direct relevance and application to the use of Electronic Procedures. The industry would benefit significantly from further research and the development of a set of human reliability data that are trusted and can be applied in this context.
System failure and over-reliance	Poor development and implementation could lead to Electronic Procedure systems providing operators with incorrect information (either due to malfunction or incorrect programming). Studies have found that operators will (generally) have a high level of trust in the information being presented. Over-reliance on automated functionalities and information presented may lead to complacency, inattentiveness, and a loss of manual control under abnormal conditions. Research is needed to confirm these challenges and identify evidence-based mitigations.

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[14] British Standards, "BS EN ISO 9241-210:2019 - Ergonomics of Human-System Interaction".

[15] ISO, "ISO/TS 18152:2010 Ergonomics of human-system interaction — Specification for the process assessment of human-system issues".

[16] ISO, "ISO 9241-220:2019 Ergonomics of human-system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organizations".

A. Appendix A - Further Guidance

In principle, the same Ergonomic and Human Factors principles that apply to the presentation of data and information should apply. Guidance can be sought from:

- British and International Standards
  - BS EN ISO 6385:2016 Ergonomic Principles in the Design of Work Systems [12].
  - BS EN ISO 11064 Ergonomic Design of Control Centres Parts 1-7 [13].
  - BS EN ISO 9241 – 210:2019 Ergonomics of Human-System Interaction. Human-centred design for interactive systems [14].
  - ISO/TS 18152:2010 Ergonomics of human-system interaction — Specification for the process assessment of human-system issues [15]
  - ISO 9241-220:2019 Ergonomics of human-system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organizations [16]
- NUREG/CR-6634: **Computer-Based Procedure Systems**: Technical Basis and Human Factors Review Guide
- IEC/IEEE FDIS 82079-1: **Preparation of information for use** (instructions for use) of products — Part 1: **Principles and general requirements**
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- IEC 60204-1, Safety of machinery – Electrical equipment of machines – Part 1: General requirements
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- IEC 61506, Industrial-process measurement and control – Documentation of application software
- IEC 62023, Structuring of technical information and documentation
- IEC 62507-1, Identification systems enabling unambiguous information interchange – Requirements – Part 1: Principles and methods
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B. Appendix B: Usability Principles & Heuristics

Table 6: Summary Design Principles

Source: Oxstrand, J., Le Blanc, K., & Bly, A. (2016). Design Guidance for Computer-Based Procedures for Field Workers (Report No. INL/EXT-16-39808). U.S. Department of Energy Office of Nuclear Energy. https://doi.org/10.2172/1344173

High-level design principle	What does it mean?	Cited impact on worker/NPP	Examples of how to incorporating the design principle
Provide context sensitive information everywhere possible	Updating the procedure content based on the current situation (i.e., current operation mode, plant conditions, decisions made previously by operators, and values recorded previously in the task execution).	Allows CBP worker to focus on completing the task rather than spending energy on understanding which steps and conditions apply for the current task and state of the NPP. Reduces the risk of unintentionally skipping steps or completing steps out of order.	Alerting workers if the 'as found' state is not within the accepted criteria Providing information about the 'as left' condition when the step is completed
Support all expected task flow characteristics	Task flow characteristics are the components of procedures that a worker needs to action/address, regardless of how the procedures are displayed. Examples of task flow characteristics include conditional steps, time dependent steps, peer-checking, and place keeping. The guidance document has identified 20 different types of task flow characteristics – please see Oxstrand, Le Bland, & Bly (2016) for further details.	Ensures that all types of actions, steps, and other interactions with procedures can be done efficiently on CBPs.	Please see Oxstrand, Le Bland, & Bly (2016) for tailored examples of implementation for the different types of task flow characteristics
Support expected level of flexibility in performing task	CBPs should allow flexibility for workers when performing tasks/completing a procedure in the	Allowing navigation within the steps/procedure will support the	Present procedure steps as a scrollable list of steps (including

High-level design principle	What does it mean?	Cited impact on worker/NPP	Examples of how to incorporating the design principle
	event that a mistake is made, or a circumstance prevents the normal functioning of a CBP component. Examples of flexibilities include navigation and oversight over the steps within the procedure, ability to undo an unintended or incorrect action, deviation from step sequence, and backup methods for CBP functionalities.	overall understanding of the task execution The 'undo' or edit input function will allow workers to fix any errors they made when inputting data Allows workers to utilise their experience and 'skill-of-the-craft' to execute tasks under specific circumstances, where the prescribed sequence of steps may not be the most optimal solution. Having redundancies in place allows for smoother operations if the main functionality fails for whatever reason/situation	previously conducted steps and future steps) Providing an option to navigate directly back to the direct step Implement an 'undo' or edit input function Providing the option for workers to work outside the prescribed procedure flow, if they receive approval to do so, and/or have backup methods in place. Additionally, providing a space to collect justification for the deviation in procedures would be beneficial for record keeping for any approved deviations in practice.
Guide workers through logical sequence of the procedure	CBPs should guide workers through the logical path of the procedure, based on user input, previous decisions, or plant status information. The system should automatically evaluate the procedure path and determine appropriate action going forwards when new information is available to the CBP.	Shifts the burden of the logical sequence (i.e., procedure path) evaluation and determination to the system (and away from the worker) Helps focus the worker on the task at hand and removes the burden of needing to decide which steps are not applicable to the current situation.	Prompt the worker of the relevant conditions needed to make a decision, or acquire the conditions from previous actions/decisions made in the procedure or a plant information database. Ensuring simplified step logic through removing complexity from the instructions/steps in a procedure by presenting conditional steps in a discrete manner. For example, in PBPs, conditional instructions are written as "IF opening valve A-1 THEN perform the following". CBPs can simplify this statement by splitting the steps into two – e.g.,

High-level design principle	What does it mean?	Cited impact on worker/NPP	Examples of how to incorporating the design principle
			"Open valve A-1 or vale A-2?", and then depending on the answer, the procedure will display the actions associated with the opening of either valve.
Provide information needed to control the path through the procedure	Assigning control over the pace and path of working through the procedure to the worker to help balance the benefits of automation and the need to maintain a worker's situational awareness of the plant and their surroundings.	Provides workers with the final say/control over how the procedure is carried out. Supports situational awareness.	The CBP system can provide the workers with information on decisions made and the data points used by the system to make the decision (on the chosen procedure path). Workers should also be provided with the option to revise previous inputs and/or decisions – and if the revision is within allowable/acceptable bounds, then the procedure path should be updated. Supervisor approval may be needed for revisions made to the CBP inputs that can impact equipment/plant status.
Provide computerised support where appropriate and possible	Harnessing the advantages of technology to enhance human performance, e.g., computing calculations	Computerising calculations increases success rate for the task Reduces cognitive workload for the worker Minimising risks of invalid inputs Reduces time needed to execute task by automatically populating data sheets with recorded values, or by automatically displaying data from previously completed tasks into the active procedure	Computerising calculations and generating trends and plots as needed to support task execution Digital correct component verification (CCV) – using computerised support to verify the correct component to take action on (e.g., using barcode scanning to crosscheck against a database of component details) Verifying input values from the worker (i.e., input format or whether

High-level design principle	What does it mean?	Cited impact on worker/NPP	Examples of how to incorporating the design principle
			the inputted value is within logical boundaries)
Include functionality that improves communication	The CBP system and its functionalities can facilitate communications between the field worker and other individuals (e.g., supervisors).	Reduces the time needed for hand offs between the control room and the field, or between shifts Improve communication through the shared understanding established by accessing the same data stored on the CBP system	Automating some of the common communication between the field worker and other relevant roles or organisations (e.g., task status updates to supervisors, peer-checking on specific procedures) Shift turnovers – existing data is stored and passed onto the next field worker on shift electronically, including any outstanding tasks Automatic notification triggers in the CBP system that notifies the control room when conditions are met for a hand-off (i.e., the control room needs to take action following the work of a field worker)
Provide a method to review and save records	NPPs are required to store records of all tasks conducted at the plant. All data, decisions and notes inputted into the CBP will already be saved as data. It is important to ensure this data can be formatted in a way that can be used to create readable documents when required.	Greater ease of access of retrieving records Provides flexibility of using retained data to create documents or reports for varied purposes	None provided in guidance document

Table 7: Usability Heuristics

Source: Oxstrand, J., Le Blanc, K., & Bly, A. (2015). The next step in deployment of computer based procedures for field workers: Insights and results from field evaluations at nuclear power plants. In 9th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies, NPIC and HMIT 2015 (pp. 588-599).

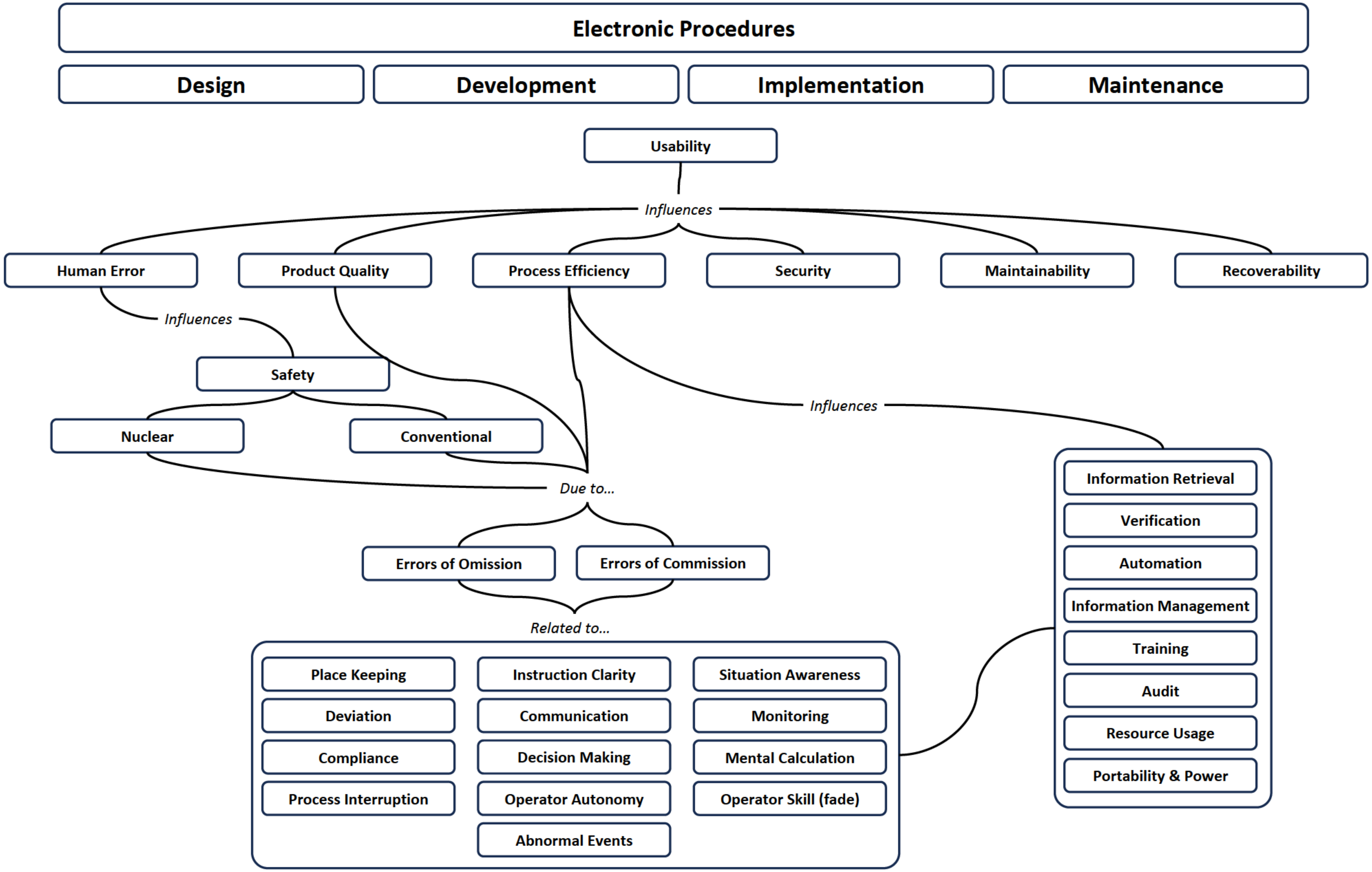
Heuristic	**Implication for Electronic Procedure design**
Visibility of system status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
Match between system and the real world	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
Consistency and standard	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
Error prevention	Even better than a good error message is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
Recognition rather than recall	Minimise the user's memory load by making objects, actions, and options visible. The user should not have to remember instruction from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
Flexibility and efficiency of use	Accelerator unseen by the novice user may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
Aesthetic and minimalist design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
Help users recognise, diagnose, and recover from errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide to provide help and documentation. Any such information should be easy to search, focussed on the user's task, list concrete steps to be carried out, and not be too large.

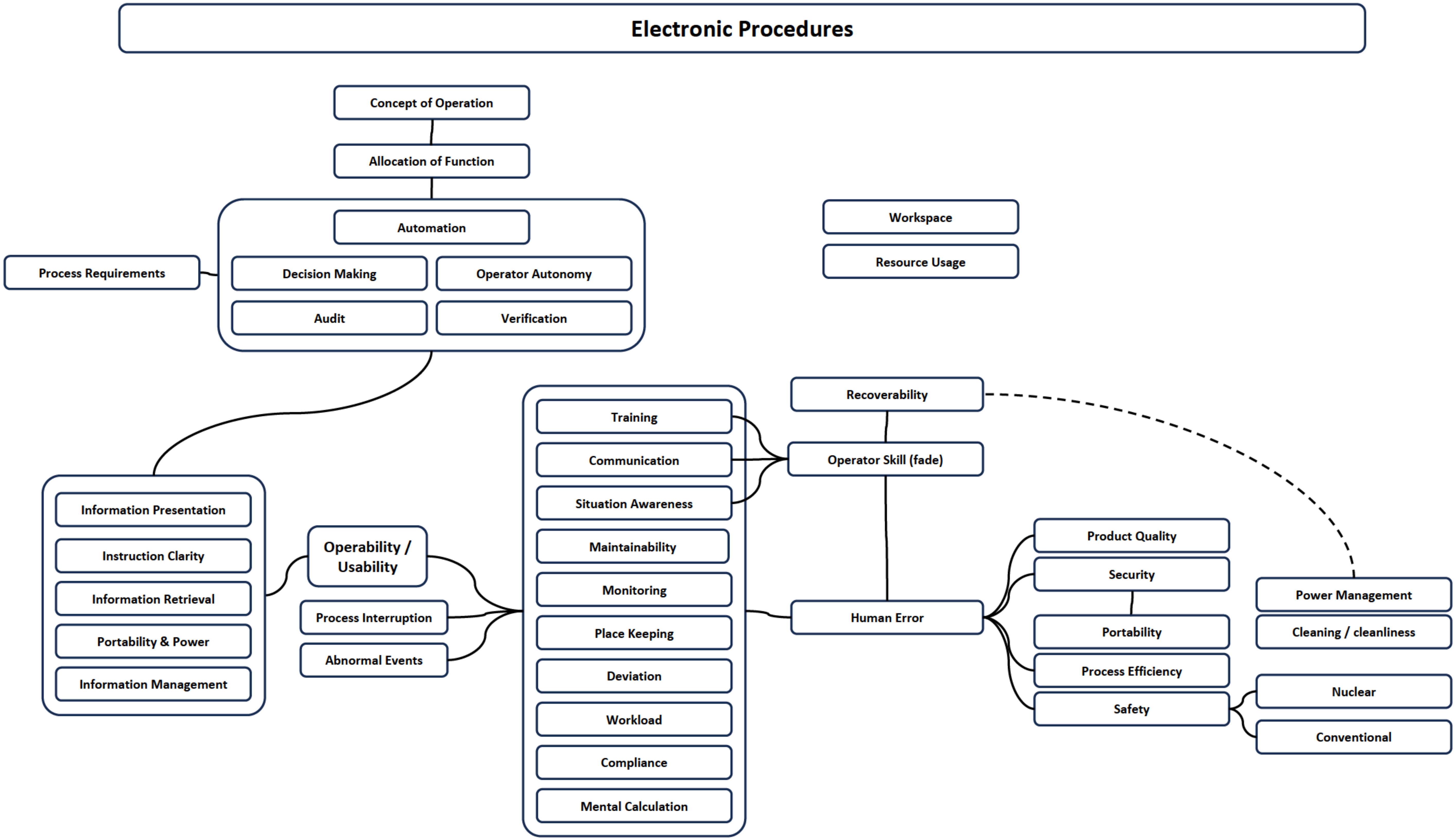
Interface Design & Usability Considerations

Source: NUREG 0700 & EPRI 1008122

- Information Presentation
  - Formatting & Screen Layout
  - Presentation of list-based information
  - Presentation of operator goals
  - Presentation of procedure steps
  - Presentation of:
    - Task importance
    - Warnings
    - Cautions
    - Notes
    - Supplementary information
    - Reference material
- User-system Interaction
  - Path monitoring
  - Navigation
  - Explanations & Help
  - Procedure execution status
  - User control of procedure execution
  - Controlled deviation
  - Recovery
- Functional Capabilities
  - Procedure supervision & control
    - Monitoring & assessment
  - Monitoring of user actions
  - Planning & implementation
  - Plant condition monitoring
  - Plant condition information presentation / feedback
  - Logic based presentation of process
    - Condition monitoring & validation
  - Alerts and indications.

C. Appendix C: Electronic Procedures – Landscape Visualisation




Electronic Procedures
Concept of Operation
Allocation of Function
Automation
Process Requirements
Decision Making
Operator Autonomy
Audit
Verification
Workspace
Resource Usage
Recoverability
Training
Communication
Situation Awareness
Maintainability
Monitoring
Place Keeping
Deviation
Workload
Compliance
Mental Calculation
Operator Skill (fade)
Human Error
Information Presentation
Instruction Clarity
Information Retrieval
Portability & Power
Information Management
Operability / Usability
Process Interruption
Abnormal Events
Product Quality
Security
Portability
Process Efficiency
Safety
Power Management
Cleaning / cleanliness
Nuclear
Conventional

End