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Australian Standard®

Guidance on human aspects of dependability

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- The University of New South Wales
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PREFACE

This Standard was prepared by the Standards Australia Committee QR-005, Dependability.

The objective of this Standard is to provide guidance on human aspects of dependability and the application of human centred design methods throughout the system lifecycle to improve dependability performance. The standard applies to any industry where human machines relationships exist and is intended for technical personnel and their managers.

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60300-2	Part 2: Guidance for dependability programme management	60300.2	Part 2: Guidance for dependability programme management
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INTRODUCTION

This International Standard provides guidelines on human aspects of dependability of systems. It fills the need for a standard to address the dependability of human/machine systems.

It gives guidance on how the human aspects of dependability can be considered at all the system life cycle stages, including ergonomic principles during design and human reliability understanding for system applications.

This standard provides an overview of the principles with some examples of the types of methods that can be used.

It is intended that a supporting standard, which describes more detailed methods that include quantification of human reliability will follow the issue of this standard in due course.

This standard contains recommendations, and does not include any requirements. Attention is drawn to the possibility of the existence of regulatory requirements for systems covered by the scope of this standard.

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AUSTRALIAN STANDARD

Guidance on human aspects of dependability

1 Scope

This International Standard provides guidance on the human aspects of dependability, and the human-centred design methods and practices that can be used throughout the whole system life cycle to improve dependability performance. This standard describes qualitative approaches. Examples of quantitative methods are given in Annex A.

This International Standard is applicable to any area of industry where human/machine relationships exist, and is intended for use by technical personnel and their managers.

This International standard is not intended to be used for certification, regulatory or contractual use.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60300-1:2003, *Dependability management – Part 1: Dependability management systems*

IEC 60300-2, *Dependability management – Part 2: Guidelines for dependability management*

IEC 60300-3-15, *Dependability management – Part 3-15: Application guide – Engineering of system dependability*

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

NOTE Certain terms have been taken from the draft text of the second edition of IEC 60050-191, *International Electrotechnical Vocabulary – Part 191: Dependability*, currently under consideration.

3.1 Terms and definitions

3.1.1
dependability
ability to perform as and when required [1]

NOTE 1 Dependability characteristics include availability and its inherent or external influencing factors, such as reliability, fault tolerance, recoverability, integrity, security, maintainability, durability and maintenance support.

NOTE 2 Dependability is also used descriptively as an umbrella term for time-related quality characteristics of a product or service, and it can also be expressed as a grade, degree, confidence or probability of fulfilling a defined set of characteristics.

NOTE 3 Specifications for dependability characteristics typically include: the function the product is to perform; the time for which that performance is to be sustained; and the conditions of storage, use and maintenance. Requirements for safety, efficiency and economy throughout the life cycle can also be included.

[1] Future IEC 60050-191, definition 191-41-26, second edition, under consideration.

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3.1.2
ergonomics
human factors
HF
scientific discipline concerned with the understanding of interactions among human and other elements of a system that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance

[ISO 6385:2004, definition 2.3, modified]

3.1.3
error resistance
ability of a system to minimize the probability of human error occurring

3.1.4
error tolerance
ability of a system or component to continue normal operation despite the presence of erroneous inputs

[ISO/IEC 24765:2009, definition 3.1034]

3.1.5
human aspects
abilities, limitations, and other human characteristics that are relevant to the design, operation and maintenance of systems and/or their components affecting overall system performance

3.1.6
human-centred design
approach to system design and development that aims to make interactive systems more usable by focussing on the use of the system, applying human factors, ergonomics and usability knowledge and techniques

NOTE 1 Usable systems provide a number of benefits including improved productivity, enhanced user well-being, avoidance of stress, increased accessibility, and reduced risk of harm.

NOTE 2 This standard uses the term "human-oriented design" to refer to the need to take account of humans in system design, but retains the term "human-centred design" used in ISO standards to refer to the specific principles and activities.

NOTE 3 The term “human-centred design” is used rather than “user-centred design” in order to emphasize that this standard addresses a number of stakeholders, not just those typically considered as users. However, in practice, these terms are often used synonymously.

[ISO 9241-210:–, definition 2.7, modified] [2]

3.1.7
human error
discrepancy between the human action taken or omitted, and the action intended[3]

3.1.8
human error probability
HEP
probability that an operator will fail in an assigned task

NOTE 1 This can be based on the ratio of the average number of errors within a certain task in relation to the overall number of error possibilities for this type of task.

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[2] To be published.

[3] Future IEC 60050-191, definition 191-43-13, second edition, under consideration.

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NOTE 2 Human error probability is expressed in a distribution where the distribution needs to be determined in accordance with the human variations and situational variations under which the task needs to be conducted.

3.1.9
human failure
deviation from the human action required to achieve the objective, regardless of the cause of that deviation

NOTE For any particular system or situation the range of human failures is the combination of human errors and violations that lead to system failures and/or hazardous outcomes.

3.1.10
human-oriented design
takes a user-centric approach to design by adapting technologies to meet human performance requirements, account for human limitations, achieve mental comfort and enhance overall system performance

3.1.11
human reliability
capability of human beings to complete a task under a given condition within a defined period of time and within the acceptance limits

3.1.12
human reliability analysis
HRA
systematic process to evaluate human reliability

NOTE Evaluation methods can be just qualitative but can be expanded to provide quantitative results.

3.1.13
mistake
deficiency or failure in the judgemental or inferential process involved in selection of an objective or in specification of the means to achieve it irrespective of whether or not the actions run according to plan

3.1.14
performance shaping factors
characteristics of the external environment, of the task and of humans that shape individual performance

3.1.15
requirement
need or expectation that is stated, generally implied or obligatory

[ISO 9000:2005, definition 3.1.2]

NOTE In the context of this standard, this is a need or expectation which should be met or possessed by a system, system component, product, or service.

3.1.16
situational awareness
human perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future

3.1.17
system
set of interrelated or interacting elements

[ISO 9000:2005, definition 3.2.1]

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NOTE 1 In the context of dependability, a system will have:

— a defined purpose expressed in terms of intended functions;

— stated conditions of operation/use; and

— defined boundaries.

NOTE 2 The structure of a system may be hierarchical.

[IEC 60300-1:2003, definition 3.6]

NOTE 3 For some systems, such as information technology products, data is an important part of the system elements.

NOTE 4 Humans can form part of a system.

3.1.18
violation
deliberate but not necessarily reprehensible deviation from practices deemed necessary

3.2 Abbreviations

ASEP	Accident Sequence Evaluation Program
ATHEANA	A Technique for Human Error ANAlysis
CAD	Computer Aided Design
CAHR	Connectionism Assessment of Human Reliability
CARA	Controller Action Reliability Assessment
COTS	Commercial Off The Shelf
CPC	Common Performance Condition
CREAM	Cognitive Reliability and Error Analysis Method
EFC	Error Forcing Context
ESAT	ExpertenSystem zur Aufgaben-Taxonomie (expert system for task taxonomy)
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes Effects and Criticality Analysis
HCD	Human-Centred Design
HCR	Human Cognitive Reliability
HEART	Human Error Assessment and Reduction Technique
HEP	Human Error Probability
HF	Human Factors
HRA	Human Reliability Analysis
HR	Human Resources
HS	Human System
HSI	Human System Interaction
ILS	Integrated Logistics Support
MERMOS	Méthode d'Evaluation de la Réalisation des Missions Opérateur pour la Sûreté (method for the evaluation of the relisation of an operator's mission regarding safety)
ORE	Operator Reliability Experiments
PSF	Performance Shaping Factor
RR	Reliability Rating
SHERPA	Systematic Human Error Reduction and Prediction Approach
SLI	Success Likelihood Index
SLIM	Success Likelihood Index Methodology
SPAR-H	Standardized Plant Analysis Risk
THERP	Technique for Human Error Rate
UI	User Interface

4 Human aspects

4.1 Overview

Human actions can have a strong influence on the dependability of the whole system and the quality of the output. Therefore important benefits accrue from consideration of human aspects, among which are preventing failures, improving system performance, ensuring safety, increasing reliability and enhancing cost effectiveness. A system that requires human

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interaction involves human(s), machine(s) and the social and physical environment in which they operate. The dependability of the system and the efficiency and effectiveness with which the goals of the system are achieved depend on each component of the system individually and the interactions between them (Figure 1).

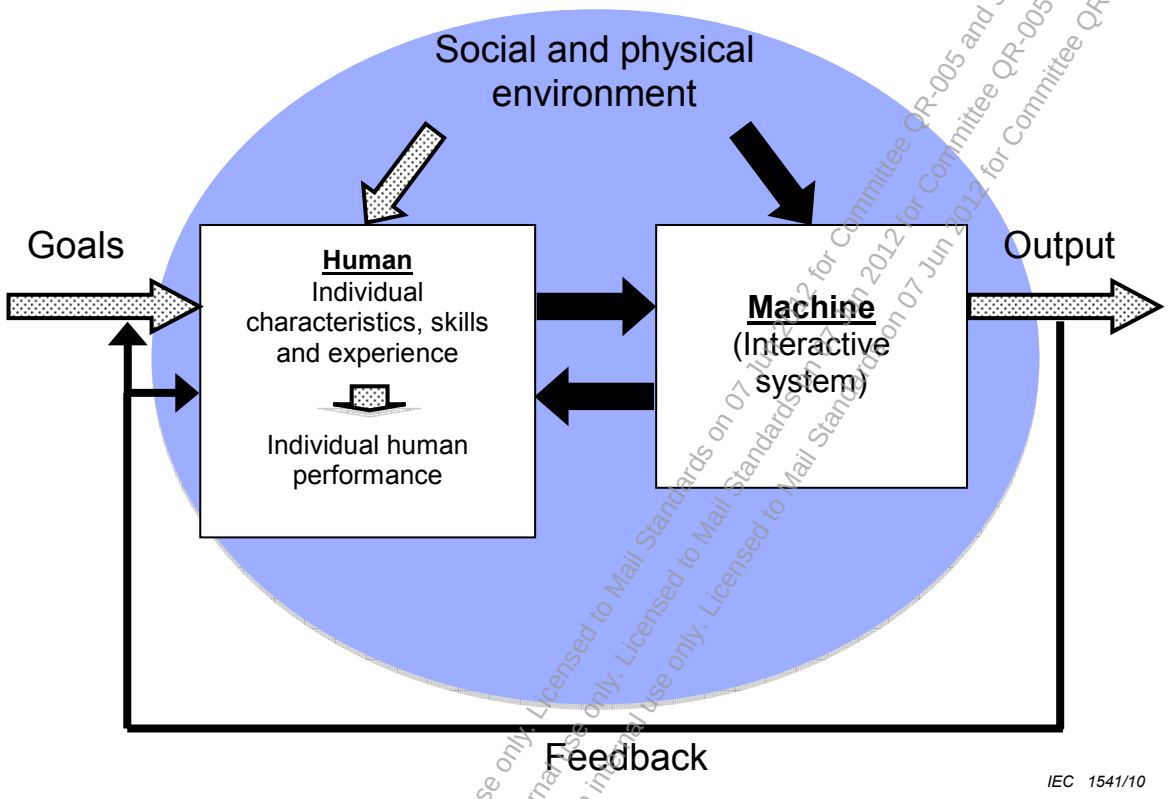

Figure 1 – Components of the system and their interactions

The grey arrows represent the performance shaping factors (PSFs) (described in 4.4).

The components shown in Figure 1 are as follows.

- Goals: what the work system has to achieve (4.2.2).
- Human: person who performs the task (4.2.3).
- Machine: interactive system designed to support achievement of the work system goals (4.2.4).
- Environment: social and physical factors that can influence the human(s) and machine (4.2.5).
- Output: that which should be achieved with the required level of effectiveness and efficiency (4.2.6).
- Feedback: feedback coming from the machine (4.2.7).

4.2 Components of the system and their interactions

4.2.1 Introductory remark

This subclause describes each component of Figure 1.

4.2.2 Goals

The objective of the work system is to achieve goals with a desired effectiveness and efficiency.

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4.2.3 Humans

The role of humans in the system is to perform a task or interact with a machine in order to achieve a defined goal. The human operator can either have a monitoring role (such as in a process control or road traffic control room), or an active role (for example when resolving a road traffic incident).

Human influence can both be negative (e.g. human errors and violations) or positive (e.g. preventing system breakdowns or system problems). Humans can influence the system through action or inaction. Even in an automated system a human is part of the system, through design, maintenance and monitoring functions.

A range of people (shown in Table 1) may be involved in the different phases in the life cycle of a system each influences the dependability of the system through their actions and decisions.

Table 1 – People who influence dependability

Job function	Examples of influence
Project manager	Awareness of dependability needs in system concepts
Designer	• Takes account of human factors in normal use and reasonably foreseeable misuse • Designs for recognition and recovery from fault conditions including where there are multiple failure modes
Operational procedure writer	Establishes procedures that minimize human failures
Operational manager and supervisor	• Ensures appropriate working conditions resources, communication, feedback and training • Motivates operators • Ensures compliance with procedures
Operator	Observes and reports consequences of human error
Trainer	Highlights error-prone situations in training
Maintenance personnel	Understand, interpret and ensure compliance with procedures

Human performance including strengths and limitations and the potential for humans to improve or degrade system operation should be taken into account when considering total system dependability. Although this appears to be additional work with financial implications, the cost of failure, if total system dependability is not considered, could be significant. The possible adverse consequences of human failures (including mistakes, slips, lapses, violations or malicious human actions) are particularly important when the human is part of a complex system with safety, security or mission critical applications. Human error can also have severe consequences in business and e-commerce environments.

For details of human characteristics, see 4.3.

4.2.4 Machine (interactive system)

The machine is designed to achieve functional and performance objectives within the environments in which it is to function.

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During operation the machine receives input from the human through its controls and will provide output that progresses the system's task. The output will often be displayed to provide feedback to the human on the operation of the machine.

For the system as a whole to work effectively the interface and interaction between the machine and the people who work with it at all stages of the life cycle from design to disposal needs to take account of the human aspects. These include the fundamental human characteristics together with specific skills and experience, and the tasks that are to be performed. In particular, the interaction between the human operator and the machine (i.e. tasks, displays and controls) should be designed to be easy for the operator to use and to ensure acceptable levels of mental comfort.

4.2.5 Social and physical environment

4.2.5.1 Social environment

Organizational structure, work flows and the resulting social factors influence the human and system performance and need to be designed to support efficient and reliable human performance. An organizational structure is characterized by the transfer of tasks (delegation), decision competence, information, communication and decision paths as well as the number of hierarchy levels. The work process is characterized for example by the work flow method, the shift system, the work time and the work planning and execution.

Other features like leadership behaviour, participation, safety culture and climate can also influence human motivation and behaviour when using a system.

4.2.5.2 Physical environment

Physical environmental factors that affect people, and hence system reliability, include light, noise, mechanical vibrations, climate, dirt, humidity, air pressure, toxic gas and radiation. Environmental factors can directly influence the capabilities of human beings (e.g. noise, toxic gas, etc.), or they can influence interactions between people and machines (e.g. mechanical vibration) or they can influence the machine itself (e.g. side winds when driving a car). However, apart from their negative effects, they can also provide a feedback function that enhances the ability of the human to interact effectively with the machine (e.g. the engine noise/vibration when driving a car).

Some factors of the physical environment can require people to use protective equipment (e.g. breathing apparatus). Some individual human limitations can require the use of assistive technologies (e.g. reading spectacles or specialized input devices). These technologies can have an effect on their ability and will need to be taken into account in design.

4.2.6 Output

The task goals should be achieved with the required level of effectiveness and efficiency.

4.2.7 Feedback from the machine to the person

Appropriate feedback from the machine is an important characteristic of dependable design. Feedback concerning input occurs from the machine to the person through sonic, visual and tactile signals. Feedback concerning the output of the system as a whole provides information on the achievement of the goals.

Feedback is important for a number of reasons. It allows a person to correct undesired behaviour of the machine or the system as a whole in order to improve performance or to correct undesired actions. In addition, lack of appropriate feedback can produce errors, e.g. when a computer is slow to provide visual feedback in response to the delete button, the operator will often repeat the action. Feedback can also contribute to performing a task more accurately, e.g. feedback from the car brake pedal helps the driver brake smoothly. Feedback

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from the machine and the system also help provide situational awareness. In some circumstances, feedback can result in a change to the goals.

4.3 Human characteristics

4.3.1 Introductory remark

Human beings have a set of physical, cognitive and psychological characteristics that vary from person to person (4.5.2). These characteristics provide fundamental limitations to the human capabilities that need to be taken into account in systems design. Appropriate training and experience will enable people to work more effectively, but only within their limitations.

Human reliability and performance will be influenced by the design of the machine and by the physical and social environment (4.5.1). To ensure a working situation with high dependability, the system should be designed so that the stress on the human being due to the work task, work environment and technical design remains within acceptable limits.

4.3.2 Human limitations

The design should take account of human limitations.

a) Physical limitations

- Anthropometric and biomechanical constraints.
- Sensory constraints (e.g. the range of signals that can be perceived and differentiated).

b) Cognitive limitations

- The time needed between perception of a signal and an action in response. This can range from a few hundred milliseconds for skill-based actions where response is quasi automatic (and is not reasoned), to several seconds or minutes where reasoning and analysis is necessary.
- Limitations of short-term memory. Only 5 to 7 items of information can be held in short-term memory. For larger amounts of information, mental models or patterns are constructed.
- Limitations on the amount of information that can be processed at one time (working memory).
- The inability to focus effectively on more than one task at a time or process information in parallel.
- Potential for loss of situational awareness resulting in actions based on incorrect perception of reality.

c) Psychological limitations

- Performance degradation due to physical and mental fatigue or boredom.
- Tendency for decisions and actions to be based on emotional rather than reasoned responses particularly under situations of stress.

Since these characteristics of humans cannot be designed out of the system, the division of tasks between people and the rest of a system and the design of technical systems and interfaces have to be taken into account. The relative strengths of humans and machines should be considered (4.4.3).

4.3.3 Comparison of humans and machines

The allocation of activities and operational steps between human beings and machines should take into account the relative strengths of humans and machines.

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a) Human strengths

- Ability to perceive patterns of light or sound.
- Ability to improvise and use flexible procedures.
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time.
- Ability to reason inductively.
- Ability to exercise judgement.

b) Machine strengths

- Ability to detect small amounts and a wider range of visual and acoustic signals.
- Ability to respond quickly to control signals, and to apply great force smoothly and precisely.
- Ability to perform repetitive and routine tasks consistently and accurately.
- Ability to store information briefly and then to erase it completely.
- Ability to reason deductively, including computational ability.
- Ability to handle highly complex operations and to do many different things at once.

There are major differences between humans and machines.

- Machines can be modified, redesigned, and retrofitted whereas humans cannot. Humans are born with innate, genetically determined differences that are shaped by the environment. Innate aptitudes or abilities are developed through education and training.
- Machines can be manufactured to provide exact output and duplicate precise operation. Humans are not identical and vary across all sensory, cognitive, physical and performance characteristics. Specific aspects of human performance can be made more equal through selection and training.

4.4 Human performance shaping factors

4.4.1 General

The performance and reliability of people within a system will vary depending on a range of internal and external conditions that differ from person to person and from one instant to another. The factors that influence the capability of human beings to reliably accomplish a task are called performance shaping factors (also known as the context of use).

Figure 1 indicates the types of performance shaping factors with grey arrows.

Figure 2 provides examples distinguishing between external and internal performance shaping factors.

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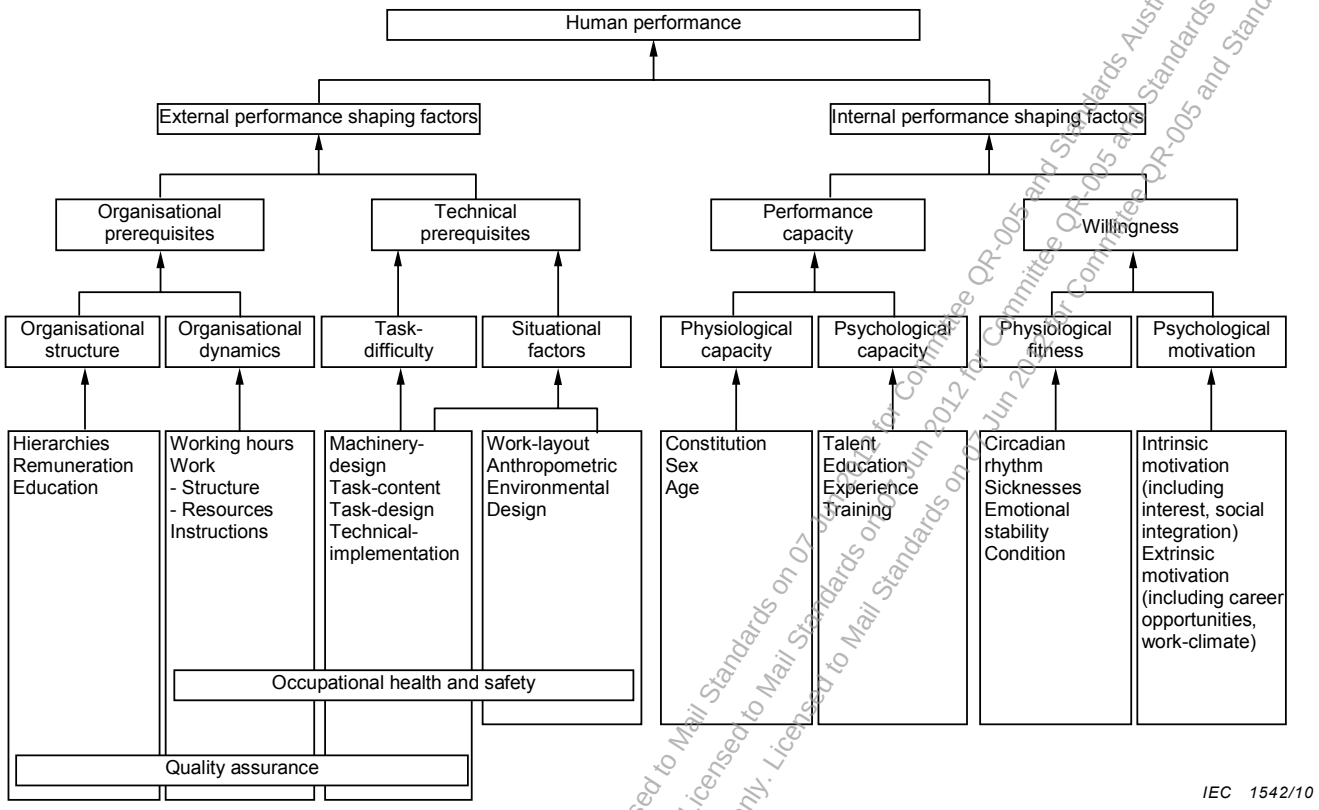

Figure 2 – Human performance shaping factors

4.4.2 External performance shaping factors

External performance shaping factors are the result of organizational and technical prerequisites. Organizational prerequisites (4.2.5.1) can often only be described qualitatively. Technical prerequisites including machine design (4.2.4) and environmental factors (4.2.5.2), on the other hand, can most often be described quantitatively.

Taking account of the external performance shaping factors in design will have a positive impact on the performance.

4.4.3 Internal performance shaping factors

Internal performance shaping factors can be separated into performance capacity and willingness. They represent factors caused by physiological and psychological variations in people and are shown as “individual characteristics, skills and experience” in Figure 1.

These include human limitations (4.3.2), and differences in size and strength, differences in talent, skill, experience and knowledge, psychological variations and motivational factors.

4.5 Human reliability analysis (HRA)

4.5.1 Overview

The analysis of human reliability is part of the overall analysis of the reliability of a technical system. Human reliability analysis involves the following activities.

- Identification of potential for human failure.
- Analysis of sources of error and causes of violations so as to be able to define appropriate counter-measures.

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- Where appropriate, quantification of human reliability so as to be able to quantify the reliability of the system as a whole.
- Decision as to whether improvements are necessary.

4.5.2 Identifying the potential for human error

In general the role of humans in the system is to receive an input such as instructions or information via a sensory process. This input is then subjected to a cognitive process involving knowledge, memory or training to make a decision on how to respond. The resulting decision is implemented by a motor process of action involving the use of appropriate muscles. Often the action generates feedback that provides additional inputs which either confirms the correctness of the action or indicates a problem that needs correcting (Figure 3). This applies whether the task involves operating a machine, following procedures, designing equipment or procedures or undertaking a management or supervisory task.

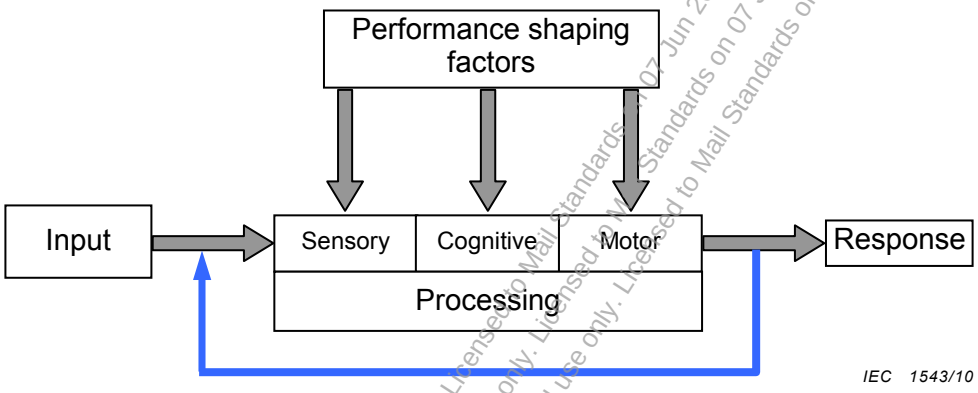

Figure 3 – Simple model of human information processing

The input in Figure 3 includes task goals, environment and feedback.

Information processing and decision making often requires use of memory and can require further external information. Errors can occur at any of the steps of this cognitive process, and the potential for error can be identified by considering each cognitive step, in turn, in order to look for where problems might occur. The potential for human error can also be identified using Failure Mode and Effect Analysis (FMEA) which starts with a task analysis and identifies likely errors at each step of the tasks and how these errors might occur (see Annex A).

4.5.3 Analysing human failures to define countermeasures

An understanding of how and why humans fail helps to define appropriate counter-measures and improve system dependability.

Human failures can be separated into violations and errors. Violations are deviations from a known correct path. They typically occur because there are unintended rewards for incorrect behaviour (for example saving time and effort or peer approval). Rules might be violated because it is perceived that there is a better way to achieve the end, to cover up mistakes or to assist colleagues. Violations may occur maliciously but this is rare.

Errors are when a planned sequence of mental or physical activities fail to achieve their intended outcome. This may be because the plan was inadequate or because the activities did not go as planned. This distinction leads to a classification of errors into mistakes, slips and lapses.

Another type of error is where the action an individual intends to carry out is correct but the performance of the action is incorrect. These errors can also be divided into two groups.

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- Slips, which are failures in execution, often when performing well known and routine tasks automatically with little mental processing, for example typing or driving.
- Lapses are failures of memory or cognition (such as losing ones place in a list) or accidentally following a well known procedure instead of a required new one.

The classification is a useful starting point for analysing causes of human failure. The following approaches may be taken in design when problems are found or suspected.

To minimize violations, reasons why people might act incorrectly need to be considered and "rewards" attached to correct rather than incorrect behaviour. For example violations are less likely where the easy way of doing something is the correct way.

Mistakes are minimized by taking into account the inherent human limitations in design, then by ensuring that people have the correct knowledge and skill for the task and sufficient time to reason correctly. Clear instructions, intuitive displays and controls and aids to memory help minimize mistakes.

Slips and lapses are more difficult to minimize since the person's intention is correct and the errors often arise when performing automatic activities where the individual is not in conscious control. Designs that maintain and check situational awareness, match unconscious mental expectations and provide early feedback that an error has occurred can help ensure that slips and lapses are corrected before overall dependability is compromised.

Clause A.1 lists a number of HRA methods which include techniques for analysing mechanisms and causes of human failures which are then reviewed to define counter-measures. Human failures of all types can also be reduced by considering performance shaping factors in the design of the system and its components and designing to enhance human performance.

4.5.4 Quantification of human reliability

When the reliability of a system is to be quantified it may be appropriate to also put a value on the probability of human error. There are a number of different methods that can be applied to do this. These are listed with brief descriptions in Annex A. Usually, probabilities are applied to slips, lapses and mistakes, taking into account the performance shaping factors. Normally malicious violations are excluded from the analysis (i.e. it is assumed that people are well intentioned but can still make slips, lapses and mistakes).

4.6 Critical systems

A critical system is a computer, electronic, mechanical or electromechanical system whose failure to operate as required can have a significant impact, such as injury or human deaths, major equipment damage or large financial loss. In the design of critical systems, it is particularly important that consideration is given both to normal operation and operation under possible fault conditions where the operator may be making decisions under stress. It is important to envisage how the operator would respond to the widest possible range of abnormal situations, and to design the interface to minimize the possibility of misinterpretation.

Critical systems are normally designed to limit or exclude human intervention. However, when human intervention is needed, the human action is usually required to be correct, swift and decisive to stop or prevent further progress of adverse conditions.

There are broadly three abnormal situations where human input is critical. These situations are not exclusive and some cases may evolve from one situation to another:

a) in an emergency situation, when human decision capability is often degraded, and information can be misinterpreted;

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b) in normal or abnormal situations where the operator does not realise the impact of his/her actions. In this case the operator is not stressed, in fact they may not be paying adequate attention and thus contribute to harm in some way;

c) where the operator cannot know outcomes and needs support in making and following-through decisions (maybe over very extended periods of time).

Appropriate human decisions in these situations can be achieved by the following measures:

- identify the increased potential for and consequence of single person error in highly automated systems;
- simulating emergency situations with prototype interfaces to assess human understanding, and using the feedback obtained to improve the interfaces;
- where there is any remaining potential confusion, training the operators in how to respond to the situation;
- selecting staff who are able to perform effectively in stressful multi-tasking environments;
- training the operators in regular intervals to being able to handle the system under possible fault conditions by hand;
- put in place means to address complacency/lack of awareness, such as staff selection, checking procedures, behavioural safety system, etc.;
- where it is not possible to know the risks in advance, and operators have to act with high uncertainty (e.g. finance, defence, exploration, waste disposal, etc) include procedures and tools for modelling and decision making.

4.7 Human-centred design guidelines

The following human-centred design guidelines will contribute to improved human reliability and system dependability, when applied appropriately.

a) Fitness for use

- Make the design durable, reliable and applicable for its intended use.
- Allocate functions between people and technology appropriately.
- Accommodate physical, cognitive and psychological characteristics of the users.
- Test with users.

b) Simplicity

- Design to be as simple as possible.
- Minimize the need for training.
- Make functions obvious.

c) Error tolerant and resistant

- Make the system error tolerant.
- Design such that it is not possible to make a mistake.
- Design to be fail-safe.

d) Consistency

- Make design consistent with user experience, with real life objects and with similar systems.

e) Standardization

- Use standardized hardware and software where practicable.

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- Maintain identical interfaces for identical functions.
- Make controls, displays, markings, coding, labelling, and arrangement uniform.
- Make appearance distinctive.
- Standardize terminology, look, and feel.
- Make equipment with similar functionality interchangeable.

f) User-centred perspective

- Understand user roles, responsibilities, decisions and goals.
- Provide timely and informative feedback.
- Use familiar terms and images.
- Design within user abilities.
- Maximize human performance and satisfaction.
- Minimize training requirements.
- Facilitate transfer of skills.
- Accommodate physical diversity.

g) Maintainability and maintenance support

- Design for ease of disassembly and reassembly.
- Provide for specialized tools if necessary.
- Provide logistic support where needed.
- Design for common tools.
- Make design easy to maintain.

Annex B summarizes the human factors design influence and impact on system dependability in specific situations.

4.8 Human-centred design process

4.8.1 Human-centred design principles within the design process

Human-oriented design involves the process of engineering the total system design to meet the needs of the human operator and other stakeholders. The aim is to maximize the overall system capabilities and performance in operation.

Whatever the design process and allocation of responsibilities and roles adopted, the incorporation of a human-oriented approach to design should follow the human-centred design principles listed below (and described more fully in ISO 9241-210).

a) The design is based on an explicit understanding of users, tasks and environments.

b) Users are involved throughout design and development.

c) The design is driven and refined by user-centred evaluation.

d) The process is iterative.

e) The design addresses the entire user experience (including how the user will respond to the task, working environment, support, training and long-term use).

f) The design team includes multi-disciplinary skills and perspectives.

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4.8.2 Human-centred design activities

Five linked human-centred design activities shall take place during a system development project (described in ISO 9241-210). They take place throughout the project and vary in detail and degree, depending on the project stage.

a) Plan the human-oriented design activities.

b) Analyse, understand and specify the context of use.

c) Analyse user needs and specify user requirements.

d) Use current human factors knowledge to design solutions to meet these requirements.

e) Evaluate the design solutions against requirements and user feedback, and modify the design and/or requirements accordingly.

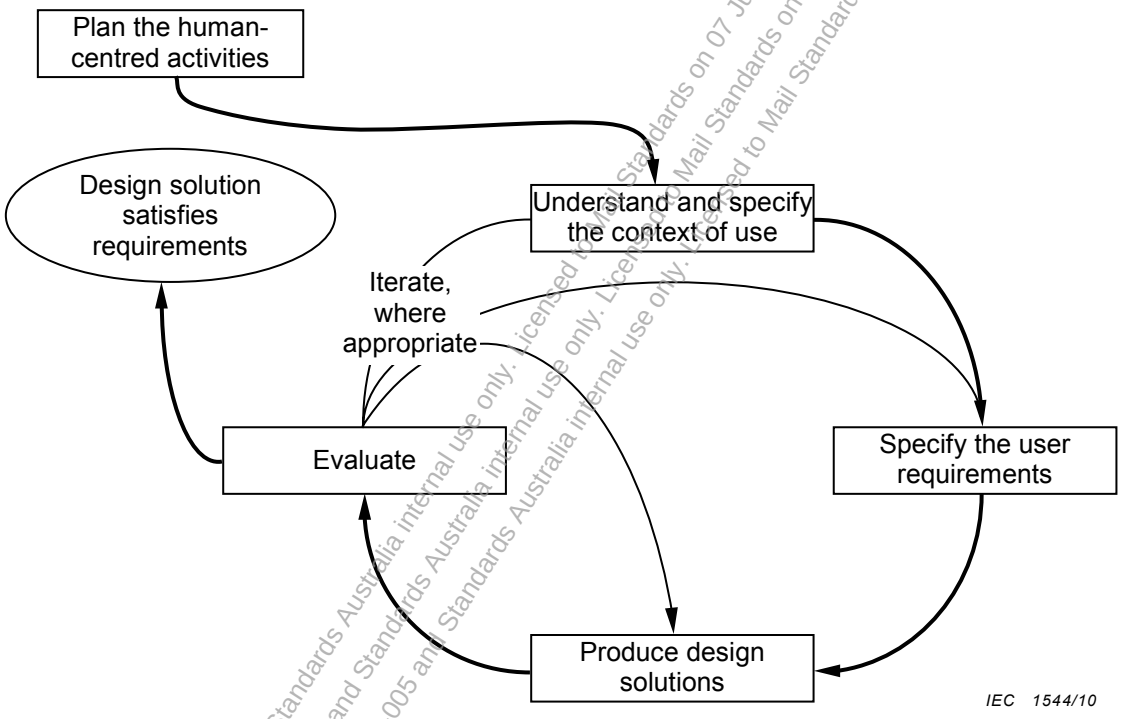

Figure 4 – Human-centred design activities

In practice, these activities can overlap or can represent distinct stages. Later activities can also modify the assumptions made in the earlier stages. Figure 4 (taken from ISO 9241-210) illustrates their interdependence.

5 Human-oriented design in the system lifecycle

5.1 Overview

The purpose of considering human aspects in systems engineering is to incorporate the interests and needs of the individuals and/or groups that will work with the system. This has the following benefits.

- Projects anticipate and address the issues and risks arising from human-system interaction.
- The system has a life cycle phase planning and resourcing designed to combat human factors risks in a cost-effective manner.

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- The needs of the stakeholders in the system are communicated to the development organization.
- Overall system dependability is improved.

The human-oriented approach to design involves the application of human-centred design methods in the system lifecycle whilst being cognizant of the variability of performance and reliability of humans..

Systems should be designed to minimize the potential for human error and to reduce the impact of errors should they occur. To achieve acceptable human reliability, the design process needs to take account of all relevant human issues, such as the following.

- Eliciting and defining the full range of users, maintainer and other stakeholder requirements.
- Defining the contexts in which the system will be used and maintained, including the characteristics of the users, the tasks and the working environments.
- Defining the human performance and mental comfort requirements necessary to achieve system objectives during all phases of the life cycle.
- Identifying potential for human error by operators, maintainers and others who form part of the system during different life cycle phases.

Human-oriented design utilizes the human factor knowledge base for application in user-centric, error-resistant and error-tolerant designs by adapting appropriate technologies to mitigate challenges in meeting human performance requirements and to enhance human-system interaction.

Taking a human-oriented approach to design not only improves human reliability but also has other important benefits, such as listed below.

- Increased productivity, improved performance and greater user satisfaction.
- Reduced errors in design and operation.
- Simplified system operation and maintenance procedures.
- Reduced time in user support.
- Reduced need for special skills training.
- Reduced risks of serious accidents.
- Cost avoidance and reduce life cycle costs.

5.2 System life cycle

Human aspects should be integrated with systems engineering and the system life cycle process. The system life cycle concept adapted from IEC 60300-3-15 is shown in Figure 5 to identify the key human-oriented design influence in the system life cycle. The system life cycle stages are briefly described as follows.

– The *Concept/Definition* stage is to identify the market needs, define/identify the operational use environment/timeline, define preliminary system requirements and confirm feasible design solutions by producing technical specifications for the system design. The process activities involve the definition and analysis of requirements, architectural design, and functional design/evaluation to provide high-level system specifications. The human aspects to be considered at this stage are the variability of performance and reliability of persons who will be operating the system. HCD activities should commence with a plan which includes all the requirements.

– The *Design/Development* stage is to plan and execute selected engineering design solutions for the realization of system functions. This is transcribed into an appropriate system development effort, including engineering modelling, prototype construction, risk assessment, and interface identification of system and subsystem elements. Continued

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attention to the variability of operators is necessary at this stage. Maintenance needs should also be identified at this stage in order to ensure the appropriate access is catered for in the initial design. The variability of performance and reliability of those humans who will carry out the maintenance should be considered.

– The *Realization/Implementation* stage is to execute make-buy decisions for acquisition and deployment of subsystem elements. The realization efforts deal with activities such as technology applications, manufacturing, packaging and supplies sourcing to ensure the complete transformation from system design to the specified product or subsystem elements. The realized products or elements can comprise a combination of hardware and software functions. Implementation includes such activities as integration of system functions, verification of subsystems and installation of the system. Training of operators and those who will maintain the system should be conducted at this stage.

– The *Operation/Maintenance* stage is used to deploy the system for delivery of service and to support system operational capability by means of maintenance. The process activities include operating and maintaining the system for service in accordance with system performance requirements, operators and maintainers training to maintain skills competency, customer interface to establish service relationship, and record keeping on system performance status and reporting failure incidents to initiate timely corrective and preventive actions.

– The *Enhancement* stage is to improve the system performance with added features to meet growing user demands on the system. The process activities include software upgrade, hardware addition, repair and overhaul, skills training, simplifying procedures to improve operational efficiency, obsolescence management, organizational restructuring to increase expediency and customer value. All the human aspects considered in previous phases should be revisited to realise any improvements that may be achieved out of the knowledge of operating the system.

– The *Retirement/Decommissioning* stage is to end the existence of the system entity. Upon termination of system service to the customer, the system might be disassembled, redeployed for other use, or disposed of where possible without affecting the environments. The physical and mental characteristics of those who will be operating the disposal and recycling process should be considered.

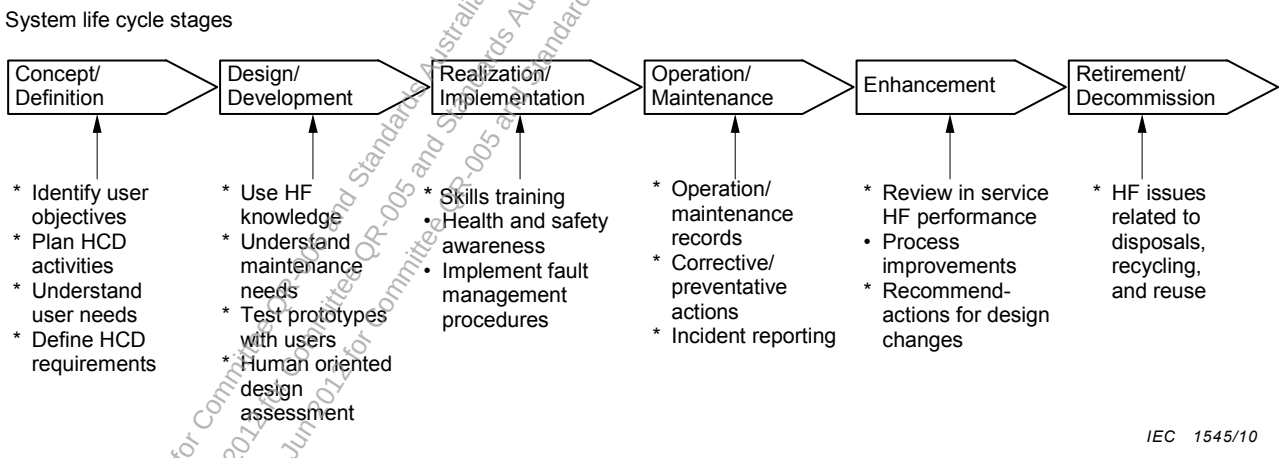

Figure 5 – Human aspects of the system life cycle

5.3 Integrating human-oriented design in systems engineering

Integrating human-oriented design in systems engineering is done throughout the system life cycle, especially during the design/development, realization/implementation and operation/ maintenance stages. It is during these stages that human-oriented design has the most influence on systems engineering tasks related to design enhancements, safety features, automation impacts, human-system performance trade-offs, ease of use and workload.

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The key activities are listed below:

a) Obtain a complete and in depth understanding of the needs of the users and user organizations.

b) Identify risks to dependability arising from human involvement in the system (related to both unintended errors and potential malicious human behaviour).

c) Identify factors that will shape human performance (see 4.5).

d) Apply human factors knowledge to the design in order to achieve optimum human performance and minimize risks.

e) Iterate proposed design solutions and incorporating feedback from users into the design.

These activities are described in more detail in the following clauses. The resources allocated to the use of human-centred design activities should depend on the projected benefits of carrying out the activities at particular lifecycle stages and the associated risks if they are not carried out. Risks to be considered should include the possibility of not achieving requirements for reliability, dependability or other stakeholder needs, the operational or business implications and the associated costs of any necessary rework. The best practices are described below and listed in Annex C.

6 Human-oriented design at each life cycle stage

6.1 Overview

Annex C provides a list of the activities that are necessary to implement human-oriented design at each system life cycle stage. These are summarized in this clause.

6.2 Concept/definition stage

6.2.1 Concept

At the concept stage, it is important to obtain a clear understanding of the objectives which the user or user organization wants to achieve through use of the system, to assess the viability of these objectives and to identify any risks that might need to be incorporated into specifications and considered during design. Dependability requirements for the system should be specified, as this can affect human roles within the system.

6.2.2 Human-centred design planning

A human-centred design plan is essential to establish a strategy for managing the human-centred design effort to support system development and operation. The objective is to address human-centred design issues to improve total system performance and reduce developmental and life cycle costs. This is achieved by optimizing human performance when the system is operated and maintained in the application environment. The planning approach should include the following activities.

- Derive the goals for the human-centred activities from the overall organizational goals for the system.
- Determine the resources devoted to use of human-centred design methods. This should depend on the level of risk that would be incurred by the project at each stage if human-centred methods were not used.
- Specify how and when human-centred activities integrate into the overall system life cycle and how input from the activities is used in the system life cycle.
- Decide which methods will be included, and how they will link together in the life cycle.
- Make allowance for iteration where necessary.
- Identify the need for and cost of user involvement.
- Define outputs and criteria for success for each activity.

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- Identify the necessary specialist skills and plan how to provide them.

A human-centred design plan should be developed in the early concept/definition stage of the system life cycle to maximize its effectiveness to influence system definition and framework development. The human-centred design plan should be part of the system overall plan.

6.2.3 Understanding the needs

The roles of each group of stakeholders likely to be affected by the system (including user groups and maintainers) should be identified, and the tasks that they are to perform should be analysed. The extent to which ease of use and error-free human performance are important should be established. The overall context of use in which the system is expected to be used should be identified, including the environmental factors (see 4.2.5.2) and the organizational structures, tasks and work flows (see 4.2.5.1). Field visits might be necessary to obtain this type of information.

6.2.4 System requirements

The purpose of incorporating human issues in system requirements includes the following:

- provide human-centred design inputs to develop system specifications;
- include human-centred design requirements in the quality assurance process;
- include human-centred design requirements for outsourcing and subcontracting;
- establish human-oriented procedures for system operation and maintenance.

The objective is to achieve a human-centred, error resistant and tolerant system framework that is suitable and usable for effective system operation.

- User requirements should be established in conjunction with potential users.
- The intended behaviour and performance of the system with respect to the users should be established.

6.2.5 Human-centred design requirements

The human-centred requirements analysis provides the necessary information and relevant data for the following activities:

- determination of human-centred design issues in system application and operating scenario;
- integration of human-centred design principles into the system context;
- tailoring the human-centred design project to meet system requirements.

Human-centred design requirements should include the following:

- operator and maintainer roles and responsibilities;
- human-system interfaces influencing user performance efficiency and effectiveness;
- specification of the context in which the system will be used, including the environmental factors (see 4.2.5.2) and the organisational structures, tasks and work flows (see 4.2.5.1);
- system performance metrics including operator/maintainer performance;
- mental comfort and user satisfaction requirements;
- system architecture design affecting human-system interactions;
- system application environment impacting human resources and requirements.

The human-centred design requirements should be presented to relevant stakeholders to obtain feedback. Scenarios of use can be used to present the requirements. They have the

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benefits of being relatively easy to test and being easy for other project stakeholders to understand.

The human-centred design requirements analysis should be conducted in conjunction with the human-centred design plan during concept/definition stage of the system life cycle. This facilitates the tailoring process working to meet specific project needs in the system definition. The project tailoring process is described in IEC 60300-2.

6.3 Design/development

Human-centred design analysis in system design is conducted during the design/development stage of the system life cycle. The objective is to ensure that

- human-system capabilities and limitations are properly reflected in the system requirements,
- human-system performance characteristics provide relevant information to identify design options and alternatives,
- human reliability and other human related system dependability risks are identified, assessed and appropriately addressed in design.

System specifications and the operation and maintenance procedures should take into account of the following elements:

- human performance such as human capabilities and limitations (see 4.3.3), workload, function allocation, hardware and software design, decision aids, environmental constraints, and team versus individual performance;
- training needs such as duration of training, training effectiveness, skills retraining, training devices and facilities, and embedded training;
- staffing requirements such as staffing levels, team composition, and organizational structure;
- personnel selection such as minimum skill levels, special skills, competency and experience;
- health and safety risks that can arise at all subsequent stages of the life cycle. Issues include hazardous materials and conditions, system and equipment design for safe operation, biomedical influences, protective equipment, and warning and alarm requirements.

The design of the system should take into account that humans need to detect, diagnose and correct faults during operation including complexities where there may be multiple failures.

The system should be reviewed in accordance with applicable knowledge of human sciences, style guides, standards, guidelines, regulations and legislation, and prototypes should be evaluated by users to refine the usability of the developing system. The system should be tested as part of verification and validation to ensure that it meets the requirements of the users, the tasks and the environment, as defined in its specification. This can be achieved using a prototype in a simulated working environment to test how humans interact with the proposed design. For more complex systems and/or components, where human interactions are particularly important, the system should be tested during initial operations.

6.4 Realization/implementation

In this stage the product is manufactured, the system components are assembled, and the product is put in place for application and operation.

The human-centred design includes the following activities.

- Review of human-machine interactions in the light of experience.

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- More detailed assessment of risks including human reliability risks of operation and maintenance stage.
- Training in the skills needed to use the system.
- Creation of health and safety awareness.
- Implementation of fault management procedures.
- Review of regulatory compliance.
- Testing of the final system to ensure that it meets human-oriented requirements.

6.5 Operation/maintenance

Errors during operation and maintenance are reduced by good design but not eliminated. It is important that errors are reported so they can be reviewed and improvements made. This requires a culture where error is able to be reported freely without fear of punishment, and understanding of underlying causes of error and the conditions which tend to provoke error. Regular simulation and/or training should be provided in responding to emergency situations and the lessons learnt should be used to enhance the system performance and the human awareness and skills.

Human-centred design assessment in the operation/maintenance stage is intended to check that human-centred design considerations have been adequately integrated into the system for effective performance operation. The assessment is achieved by system testing and performance verification with the aim of producing evidence of conformance to human-centred design requirements in an application environment. The human-centred design assessment process should include the following activities.

- Measurement of human performance and mental comfort in critical tasks.
- Determination of efficiency and effectiveness of human intervention.
- Maintenance of human-centred design test records and assessment data as basis for evaluation and improvement.
- Assessment of ease of maintenance.
- Performance of emergency situation simulations/training in defined intervals and provision of the lessons learnt for enhancement of the system performance and the human awareness/skills.

The human-centred design assessment results should be analysed to support recommendations for design changes, where appropriate, provide rationale for human performance improvements or implement training solutions.

The human-centred design information flow should include sharing with integrated logistics support (ILS) programs where applicable. ILS is a disciplined approach to integrate support considerations into design, to acquire the necessary initial support for the system and to identify life cycle support requirements. The human-centred design program provides the human resource and performance dimension for logistics support requirements and functions. Close coordination between the human-centred design and ILS programs will reduce data redundancies and result in more effective use and sharing of information.

6.6 Enhancement

This stage is to improve system performance with added features to meet growing user demands on the system.

The human-centred design process should include the following activities.

- Collection and analysis of in-service reports to generate updates or lessons learnt for the next version of the system.
- Improvement of the human-centred design process in the context of the wider systems engineering process.

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- Communication with stakeholders on proposed improvements.

The result might be to apply a miniature version of the life cycle in order to implement the enhancement.

6.7 Retirement/decommission

This stage is designed to end the existence of the system entity.

The human-centred design process should include the following activities:

- Examine human factors issues related to disposals, recycling, and reuse.
- Identify risks and health and safety issues associated with removal from service and destruction of the system.
- Define how users will be re-allocated, dismissed or transferred to other duties.
- Plan the break-up of social structures.
- Debrief and retrospective analysis for the replacement system.

6.8 Outsourcing projects and related human-centred design issues

The human-centred design requirements should be incorporated in system specifications and procurement documents. This is crucial for the system to achieve its objectives for coherent design and consistent performance involving proper function allocation and interactions of hardware, software and human elements in system design and operation.

The outsourcing of subsystems development requiring human operation is common in today's complex system development and enhancement projects. Incorporation of commercial-off-the-shelf (COTS) products as system functions often has cost benefits. System support services are frequently used for contract maintenance.

The success factors are dependent on the collaborative efforts of the acquirers and suppliers, the system integrators and service providers through application of supply-chain management and quality assurance processes. Since human-oriented design involves multi-disciplinary actions, it is sometimes necessary for technical experts to deal with resolution of critical human issues related to outsourcing and procurement needs.

Outsourcing human-centred design projects should consider the following issues.

- Conformance to the human-centred design process in ISO 9241-210 and making available work products such as those described in ISO/IEC TR 25060 (context of use description, user needs report, user requirements specification, user interaction specification, user interface specification, evaluation reports).
- Human-system interface requirements to achieve the level of human performance during system operation and maintenance.
- Maximizing the economical demands on utilization of available human resources, skills and training.
- Staffing implications of the human resources, job classification, skill levels and experience needed for the projects.
- Evaluation for design automation trade-off with human operation in terms of applicability, efficiency and cost implications.
- Potential system safety and health hazard areas involving human-system interactions.
- Quality assurance provisions for procurement contracts.
- Reintegration of all outsourced tasks and projects into the total system model for system optimization.

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Human performance testing of COTS products should take advantage of available information from the product manufacturers, records of warranty returns, previous commercial testing and product use experience.

Outsourcing projects should be identified during concept/definition stage of the system life cycle. The procurement contracts should be well established at the completion of the design/development stage. This permits time for subcontractor evaluation, multiple sourcing of preferred suppliers and COTS product assessment for incorporation as system functions to facilitate the system integration process.

7 Human-centred design methods

7.1 Classification of human-centred design activities

Human-centred design activities are classified in ISO/PAS 18152 as follows:

- HS.1 Life cycle involvement activities: in each stage of the system life cycle.
- HS.2 Integrate human factors activities: in business strategy, quality management, authorisation and control, management of HS issues, HF data in trade-off and risk mitigation, user involvement, human-system integration and development and re-use of HF data.
- HS.3 Human-centred design activities*:* context of use, user requirements, produce design solutions, evaluation of use.
- HS.4 Human resources activities*:* human resources strategy, definition of standard competencies and identification of gaps, design of staffing solution and delivery plan, evaluation of human resources system solutions and obtaining feedback.

The methods that can be used to support these activities include the following.

a) Human-centred design analysis methods

Human-centred design analysis methods are used to define system concepts, describe application/mission scenarios, determine functional requirements and assign tasks for appropriate skills allocation. The various analyses provide a means for identifying human-centred design related goals, objectives, critical design issues, and further evaluation needs to meet system performance requirements involving human interactions.

b) Human-centred design methods for design and development

Human-centred design methods for design and development are used to incorporate all necessary human-centred design criteria into the human-system interface design. The human-system interface includes system hardware, software, procedures, work environments and facilities associated with the system functions requiring human interactions. The process is designed to convert the results of the human-centred design analysis activities into design criteria for human factors project development and implementation.

c) Human-centred design methods for test and evaluation

Human-centred design methods for test and evaluation are used to verify human-system interface and procedures to ensure that the system can be operated, maintained, supported and controlled in its intended operating environment by the users. These methods facilitate identification of critical human-centred design issues in operation and maintenance for problem resolution and process improvement.

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Annex C provides a summary of practical methods for human-centred design analysis, design and development, as well as test and evaluation.

7.2 Applications of human-centred design methods

The human-centred design methods for general analysis, evaluation and assessment applications are based on systems engineering techniques. They should be used in conjunction with other engineering methods and technical disciplines in system design and implementation. The human factors engineering methods listed in Annex C contribute to the best practices for human-centred design, as shown in Table C.1.

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Annex A
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Examples of HRA methods

There is a distinction between the HRA methods of the first generation and the HRA methods of the second generation.

First generation methods treat human failure in the same way as hardware failure with the output from human tasks substituted for equipment outputs. Human actions are considered in a binary fashion, i.e. as success or failure to achieve the required result from a task. Tasks and subtasks are considered to have an inherent failure probability which is then modified by performance shaping factors which are based on the evaluation of the ergonomic environment. Methods differ in the way in which they estimate the basic human error probabilities (HEP) and incorporate performance shaping factors (PSFs).

HRA procedures of the second generation model and evaluate the role of the context and human decision-making behaviour which can have adverse effects on the system.

Table A.1 provides a description of the various methods and details on how they are applied.

Table A.1 – HRA methods and their application

Method and short description	Level of use
ASEP – Accident Sequence Evaluation Program: simplified version of THERP for pre-assessments (with conservative estimates during pre-assessments). Critical tasks are broken down into subtasks which are arranged on a human performance event tree. HEPs for subtasks are obtained from tables published in NUREG/CR-4772 (US regulatory Commission 1987). Guidance is also given for allowing for PSFs in the HEP. Standardized action decomposition: critical actions and diagnosis of disturbances if applicable. Overall recommendations for commitment on one HEP per critical action; detailed judgment on human-machine interfaces not required. Time-related HEP-diagnosis, given curves are based on an expert consensus. Allows for fast pre-selection of important tasks.	ASEP is used if a quick but not very precise quantitative estimation is needed for screening. This is the case in low power and shutdown states of nuclear power plants for instance where the number of action to assess is large and a time-efficient method is needed. ASEP is a first generation HRA method, allowing for assessment of ergonomic problems in the working environment.

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Method and short description	Level of use
ATHEANA – A Technique For Human Error Analysis: thorough analysis of the context and of decision-making provides the system analyst with detailed knowledge about the potential for erroneous human decisions. The method identifies human failure events (HFEs) by considering accident scenarios. HFEs are characterized by unsafe acts i.e. actions (or omissions) which result in degraded plant performance and by the error forcing context (EFC). The EFC includes both PSFs and plant conditions that make human error likely. HFE is quantified by combining probabilities of EFCs, the probability of an unsafe act in the EFC and the probability of an EFC given the unsafe act and additional evidence following the unsafe act. The quantitative estimates are based on expert judgment similar to the SLIM approach.	ATHEANA is used in a number of studies in particular in the nuclear environment. ATHEANA is a second generation HRA method, allowing for thorough qualitative analysis of the influence of the context on human behaviour and decision making. Can be used for analysis of post incident error where error forcing context of the incident occurs.
CAHR – Connectionism Assessment Of Human Reliability: the method requires operational events or other behavioural data to perform its assessment. It consists of: (1) a structured framework for data collection, (2) a method for qualitative analysis of the collected data, and (3) a method for human reliability assessment. For the assessment the method distinguishes the task and the context under which the task needs to be performed, the cognitive demand that the task and the context place on the human, the human compensation mechanisms and the resulting behaviour.	CAHR can be used for either assessing classical ergonomic problems or interrelations of multiple conditions and factors. Applications range from nuclear, automobile, aviation, and air traffic to maritime management. CAHR is a second generation HRA method, allowing thorough qualitative analysis of the influence of the context on human behaviour and decision making in a time efficient manner.

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Method and short description	Level of use
CREAM – Cognitive Reliability And Error Analysis Method: The human control mode applicable to the scenario is selected from 4 “contextual control modes” (human reliability is assumed to increase as level of control increases). The context of the task or scenario is described using CREAM’s 9 common performance conditions (CPCs). (CPCs are similar to PSFs.) Potential errors are identified and classified into a number of groups that describe error modes and error causes. For the assessment CREAM uses similar tables to THERP but only after having performed the analysis of the essential contextual control modes.	CREAM is widely used for quick assessments of the context on human performance and provides insights on the level of a screening technique. CREAM is a second generation HRA method, allowing a qualitative analysis of the influence of the context on human behaviour and decision-making and a coarse quantification.
ESAT – Expertensystem zur Aufgaben-Taxonomie (expert system for task taxonomy): PSF-related quantification of discretionary tasks. Determination of a reliability rating (RR, on a scale of 1 to 10) by assessments (“ratings”) of given PSFs. The functional connection between HEP and RR is partly determined by expert assessments (based on generic knowledge on human work performance) and partly by measuring work performances. This method has been applied for the design of cockpits in aviation.	ESAT stems from aviation but is still occasionally used also in other industrial settings like assessing human errors in production. ESAT is a first generation HRA method, allowing for assessment of ergonomic problems in the working environment.
FMEA/FMECA – Failure Modes And Effects Analysis identifies failure modes (i.e. what is done incorrectly) and failure mechanisms (how it is done wrongly or psychological error mechanisms) and its effects. As with equipment, FMEA probabilities error modes occurring can be estimated and the criticality of errors can be estimated by considering their probability of occurrence and the magnitude of the effects.	FMEA and FMECA are commonly used for equipment reliability and extended into human reliability as either a qualitative or quantitative tool. For more detailed guidance see IEC 60812.

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Method and short description	Level of use
HCR/ORE (Human Cognitive Reliability / Operator Reliability Experiments): HCR methods recognise that the success or failure of an operator depends on the time available for action. HEP is the fraction of time required for diagnosis and response time available. HCR/ORE was developed on the basis of operator reliability experiments (ORE). For tasks described in procedures, time-related and time-unrelated failures of diagnosis are distinguished. There are 6 HEP-time-curves available (according to the type of reactor and dynamic of failure) normalized on the average time requirement (Median). PSF-related HEP quantification for the time-unrelated failure is performed by considering 8 given error mechanisms. Guidelines for a decision-tree-type PSF-modelling are also given. For tasks that are not represented in procedures, a quick method for assessment of the HEP is offered	The approach was developed because the original HCR (human cognitive reliability model) approach, distinguishing between skill- rule- and knowledge-based behaviour, was proven to not be a valid approach towards human reliability. HCR/ORE requires simulation experiments to be conducted before it can provide valid assessments. Due to the efforts combined with this requirement current use is limited to some nuclear control room actions. HCR/ORE is a first generation HRA method, allowing for assessment of task performance dependent from the time available; ergonomic problems are addressed in a limited way.
HEART/CARA – Human Error Assessment And Reduction Technique: Intended for generic, system-based tasks (e.g. put system X into operation) rather than for elementary tasks (e.g. manipulate switch X). A nominal value for HEP is selected by comparing the task with a list of 8 generically defined tasks for which HEPs are defined. HEP is then modified by a rating for PSFs selected from a list of 38 PSFs. The method received further development into generic task types in air traffic management under the name CARA.	Easily and quickly manageable. Many of the PSF-figures are based on empirical studies; disadvantage: model calibration is insufficient. The technique is hence not suitable for estimating the reliability of Human actions if a high precision in the assessment or a high reliability is required (e.g. actions leading immediately to adverse effects in the system). HEART and its successors are first generation HRA methods, allowing for assessment of task performance in the sense of a more detailed screening rather than a thorough assessment.

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Method and short description	Level of use
MERMOS – Méthode d'Evaluation de la Réalisation des Missions Opérateur pour la Sûreté (Method for the evaluation of the realization of an operator's mission regarding safety). MERMOS avoids the term "human error" and distinguishes missions (set of tasks to be performed); mechanisms are established by humans on how to coordinate the mission and probable outcomes of such coordination. Multiple failure paths that lead to mission failure are identified using a process structured by considering strategy, action and diagnosis. Probabilities are assigned to path elements by expert judgment. Data stem from operational experience as well as simulator observations.	MERMOS is used extensively in the French nuclear industry. It was validated several times and received regulatory acceptance. MERMOS is a second generation HRA method, allowing thorough qualitative analysis of the influence of the context on human behaviour and decision making.
SHERPA – Systematic Human Error Reduction And Prediction Approach. Starts with task analysis and classifies bottom level sub-tasks by type (action, retrieval, checking, selecting and communicating). Determine credible error modes for subtask using SHERPA check list for error modes. Consequences are described and the possibility of recovery at a later task noted. Probability and criticality of each error for each subtask are given an ordinal rating (high, medium, low).	First generation method that provides a structured comprehensive means of identifying errors in performing specific tasks and qualitatively rating their importance. Used to seek error reduction strategies. Does not incorporate system or organizational errors.

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Method and short description	Level of use
SLIM – Success Likelihood Index Methodology: Experts identify relevant PSFs (e.g. complexity of task) and nominate endpoints on a scale from 1 to 9 (e.g. 1 = simple and 9 = complex). The point on each scale at which ideal performance is expected is noted and used to rescale ratings according to the distance from an ideal value. Each task is rated for each PSF on these scales. A success likelihood index (SLI) is calculated on the basis of an overall sum of weighted PSF ratings and is transformed to a probability scale by applying at least 2 reference-HEPs. Prerequisite: proven reference-HEPs and relevant PSFs are available; PSFs are clearly assessable. The determination of reference-HEPs is problematic and predetermines the results that can be achieved.	SLIM is used if a flexible method is required and no specific data is available. Also PSF-interdependencies are not taken into account. Therefore the results of the method can only provide a screening. SLIM is a first generation HRA method, allowing for assessment of task performance in the sense of a more detailed screening rather than a thorough assessment.
SPAR-H – Standardized Plant Analysis Risk (SPAR) HRA: consists of a two-step process to identify nominal human error probabilities (HEPs), and then modify those HEPs on the basis of summary-level performance-shaping factors (PSFs) and dependence. Significantly, this method required analysts to complete a relatively straightforward worksheet, which was then used to estimate the PSFs and the HEP of interest. SPAR-H has inherent limitations of modelling and analysis that should be clearly understood.	The SPAR-H is a screening method and should not necessarily be preferred over more sophisticated and detailed approaches, such as a technique for human event analysis (ATHEANA) in situations that require detailed analysis of the human performance aspects of an event. SPAR-H allows addressing in a limited way first and second generation HRA issues on the level of screening.
THERP – Technique for Human Error Rate Prediction: this is the standard method for human reliability in respect to ergonomic issues. Produces in-depth task decomposition into elements using THERP taxonomy, errors for elements represented in event tree format. Nominal HEP is assigned to each task element by selecting 'appropriate' HEPs from a data base of around 100 factors. Nominal HEP is modified by multiplier for PSFs if applicable. Dependence between errors for the task elements is modelled. Curves are produced for the probability that a human will respond to a disturbance in a given time are based on an expert consensus.	THERP is used when a thorough assessment of the tasks is required and the overall system dependability relies on critical actions. Decision-making and the influence of a wide spectrum of contextual factors cannot be assessed. THERP is a first generation HRA method, allowing thorough assessment of task performance and providing detailed ergonomic requirements for system design. It is not suitable for assessing decision making or to consider the range of contextual conditions sufficiently.

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Annex B
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Summary of human-oriented design activities and their impact on system dependability

B.1 Overview

This annex gives some examples of human-centred design activities that when used appropriately, will improve system dependability.

B.2 Automation

Table B.1 – Automation

Human-centred design activity	Impact on system dependability
• Provide automation information and operating status and other feedback to system user. • Make features easy to use. • Ensure safe operations within the user's capacity and capability. • Alert user of automation failure or degradation, and potential unsafe modes of operation. • Provide error resistant and error tolerant features that are not unnecessarily difficult to use to prevent unauthorized or accidental access. • Provide means for manual override (with safe-guards)	• Enhancing availability of system functions. • Improved system performance due to automated functions. • Enabling users to carry out the required tasks to avoid increased cognitive demands, extreme workload situations, interruption or distraction imposed on the user. • Simplifying user training needs and requirements for system applications. • Minimizing errors and risk arising from error.

B.3 Design for maintainability

Table B.2 – Design for maintainability

Human-centred design activity	Impact on system dependability
• Build in redundancy where practicable and cost-effective to reduce unscheduled maintenance. • Design for modularity, lowest replaceable unit and throwaway assembly. • Incorporate built-in-test capabilities, remote and self-diagnostic features. • Incorporate quick and easy access to all assembly units requiring maintenance for inspection, removal and replacement. • Minimize the numbers and types of tools and test equipment needed for maintenance. • Incorporate self-healing and self-adjustment features where applicable and practical.	• Improved maintainability. • Improved reliability. • Simplification of maintenance functions. • Enhancing testability, diagnostics, and fault identification. • Reduced maintenance time and logistic support resource requirements.

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B.4 Computer-human interface

These activities are based on ISO 9241-110. For more detailed guidance on user interface design, see ISO 9241, Parts 2, 12, 13, 14, 15, 16, 17, 20, 151 and 171.

Table B.3 – Computer-human interface

Human-centred design activity	Impact on system dependability
• Make the interactive system suitable for the task so that it supports the user in the completion of the task. • Make the interactive dialogues self-descriptive so that it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed. • Make the interactive dialogues conform with user expectations so that it corresponds to predictable contextual needs of the user and to commonly accepted conventions. • Make the interactive dialogues suitable for learning so that they support and guide the user in learning to use the system. • Make the interactive dialogues controllable so that the user is able to initiate and control the direction and pace of the interaction. • Make the interactive dialogues error-tolerant so that despite evident errors in input, the intended result can be achieved with either no, or minimal, corrective action by the user. • Make the interactive dialogues capable of individualization so that users can modify interaction and presentation of information to suit their individual capabilities and needs.	• Improved system usability and serviceability. • Increased system speed. • Reduced number of errors.

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B.5 Incorporation of displays, controls and alarm functions

For more detailed guidance on displays and controls, see ISO 9241, Parts 300, 302, 303, 304, 305, 306, 307, 308, 309, and 920.

Table B.4 – Incorporation of displays, controls and alarm functions

Human-centred design activity	Impact on system dependability
• Make displays and controls legible, identifiable, and distinguishable under all conditions. • Locate controls in a consistent manner in grouping and arrangement for easy access to the user. • Design the control movement and direction in a consistent manner. • Design the controls with sequential operations to follow a fixed pattern. • Design the controls for maintenance and adjustment to be protected to avoid accidental activation. • Design the coding for controls to differentiate among the controls with uniform application of the code throughout the system. • Simplify coding entry and identify error for re-entering codes. • Design alarm functions to be visible and auditable. • Design alarm functions to provide unambiguous and clear indication of the cause for the alert, inform the user of the priority and nature of the problem, and possible responses. • Incorporate alarm input validation to prevent false alarms. • Provide voice communication systems where essential and applicable in alarm and emergency situations.	• Improved maintainability. • Improved testability. • Improved system operation and maintenance tasks. • Reduced number of false alarms. • Improved safety and security in system performance. • Simplifying user training needs and skills requirements.

B.6 Incorporation of input devices

For more detailed guidance on design of input devices, see ISO 9241, Parts 4, 9, 400, 410 and 920.

Table B.5 – Incorporation of input devices

Human factors design activity	Impact on system dependability
• Design of keyboard entry and fixed-function keys. • Design of pointing devices (mouse, joystick and trackball, light pen). • Design of non-pointing devices (touch interactive devices and touch panels, voice activated controls). • Design inter-changeability among input devices	• Improved accessibility. • Improved operability. • Improved usability.

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B.7 Environment

For more detailed guidance on workplace environment, see ISO 9241-6.

Table B.6 – Environment

Human-centred design activity	Impact on system dependability
• Modular designs for lowest replaceable units. • User control of workplace environment (ventilation, illumination, temperature, humidity, noise).	• Improved maintainability. • Improved human performance and satisfaction in workplace.

B.8 Safety

Table B.7 – Safety

Human-centred design activity	Impact on system dependability
• Workplace safety for accessibility and operation. • Equipment-related safety for user operation. • Hazard avoidance designs. • Human reliability analysis.	• Improved human performance in a safe environment. • Risk mitigation for degraded system performance. • Statistics on human performance.

B.9 Security

Table B.8 – Security

Human-centred design activity	Impact on system dependability
• System security and authorized access. • Security safeguards and protective measures and controls. • Physical security. • Information security.	• Improved system performance integrity. • Risk reduction.

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Annex C
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Best practices for human-centred design

This annex lists the most important activities in ISO/PAS 18152 that are relevant at each lifecycle stage (together with their reference numbers), and gives examples of methods and techniques that can be used to implement them.

Table C.1 – Examples of methods and techniques that contribute to best practices

Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
1.1 Concept	Identify expected context of use of systems (forthcoming needs, trends and expectations) (1.1-1) Analyse the system concept to clarify objectives, their viability and risks (1.1-2)	– Future workshop – Preliminary field visit – Focus groups – Photographic surveys – Simulations of future working environments – In-depth analysis of work and lifestyles
	Describe the objectives which the user or user organization wants to achieve through use of the system (1.1-3)	– Participatory workshops – Field observations and ethnography – Consult stakeholders – Human factors analysis
	Define the scope of the context of use for the system (3.1-1)	– Context of use analysis
1.2 Planning a) General	Develop a plan to achieve and maintain usability throughout the life of the system (2.4-1) Identify the specialist skills required and plan how to provide them (2.4-2)	– Plan to achieve and maintain usability – Plan use of HSI data to mitigate risks
b) User involvement	Identify the HS issues and aspects of the system that require user input (2.6-1) Define a strategy and plan for user involvement (2.6-3) Select and use the most effective method to elicit user input (2.6-4) Customize tools and methods as necessary for particular projects/stages (2.7-4)	– Identify HSI issues and aspects of the system requiring user input – Develop a plan for user involvement – Select and use the most effective methods – Customize tools and methods as necessary

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Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
c) Risks	Assess the health and well-being risks to the users of the system (1.2-6) Assess the risks to the community and environment arising from human error in the use of the system (1.2-7) Evaluate the current severity of emerging threats to system usability and other HS risks and the effectiveness of mitigation measures (2.5-3) Assess the risks of not involving end users in each evaluation (2.6-2) Plan and manage use of human factors data to mitigate risks related to HS issues (2.5-1) Evaluate the current severity of emerging threats to system usability and other HS risks and the effectiveness of mitigation measures (2.5-3) Take effective mitigation to address risks to system usability (2.5-4)	– Risk analysis (process and product) – HSI program risk analysis
1.3 Understanding needs a) Context of use	Identify and analyse the roles of each group of stakeholders likely to be affected by the system (1.1-4) Describe the characteristics of the users (3.1-3) Describe the cultural environment/ organizational/ management regime (3.1-4) Describe the characteristics of any equipment external to the system and the working environment (3.1-5) Describe the location, workplace equipment and ambient conditions (3.1-6) Decide which goals, behaviours and tasks of the organization influence human resources (4.1-1) Present context and human resources options and constraints to the project stakeholders (1.1-6)	– Successful identification of critical stakeholders – Field observations and ethnography – Participatory workshop – Work context analysis – Context of use analysis – Event data analysis – Contextual enquiry – Visibility diagram – Reach envelope
b) Tasks	Analyse the tasks and work system (3.1-2)	– Task analysis – Cognitive task analysis – Work context analysis – Application/mission analysis – Functional flow diagram – Operational sequence diagram – Flow process chart – Decision/action diagram – Action/information requirements – Timeline – Integrated computer-aided manufacturing definition – Workload analysis – Situation awareness analysis – Link analysis – Human performance reliability analysis
c) Usability needs	Perform research into required system usability (1.1-5)	– Investigate required system usability – Usability benchmarking – Heuristic/expert evaluation – Predetermined time standards

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Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
d) Design options	Generate design options for each aspect of the system related to its use and its effect on stakeholders (1.2-1) Produce user-centered solutions for each design option (1.2-2)	– Early prototyping and usability evaluation – Develop simulations – Parallel design (tiger testing)
1.4 Requirements a) Context requirements	Analyse the implications of the context of use (3.1-7)	– Define the intended context of use, including boundaries
b) Infrastructure requirements	Identify, specify and produce the infrastructure for the system (1.3-2) Build required competencies into training and awareness programs (1.3-4) Define the global numbers, skills and supporting equipment needed to achieve those tasks (4.1-2)	– Identify staffing requirements and any training or support needed to ensure that users achieve acceptable performance
c) User requirements	Develop an explicit statement of the user requirements for the system (3.2-2) Generate and agree on measurable criteria for the system in its intended context of use (3.2-4)	– Scenarios – Personas – Storyboards – Establish performance and satisfaction goals for specific scenarios of use – Define detailed user interface requirements – Prioritize requirements
1.5 Analysis requirements	Assess the extent to which usability criteria and other HS requirements are likely to be met by the proposed design (2.5-2) Analyse the user requirements (3.2-3) Present these requirements to project stakeholders for use in the development and operation of the system (3.2-5) Identify any staffing gap and communicate requirements to design of staffing solutions (4.2-6)	– Identify and analyse the success of critical stakeholder requirements) – Common industry specification for usability requirements – Environment/organization assessment
2. Design/ development a) General	Generate design options for each aspect of the system related to its use and its effect on stakeholders (1.2-1) Produce user-centred solutions for each design option (1.2-2) Design to enable customization to support specific market and user needs (1.2-3) Distribute functions between the human, machine and organizational elements of the system best able to fulfil each function (3.3-1) Develop a model of the user's work from the requirements, context of use, allocation of function and design constraints for the system (3.3-2) Produce designs for the user-related elements of the system that take into account the user requirements, context of use and human factors data (3.3-3) Produce a description of how the system will be used to support integration of system components (3.3-4)	– Function allocation – Generate design options – Physical ergonomics – Participatory design – User interface guidelines and standards

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Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
b) Prototyping and evaluation	Develop simulation or trial implementation of key aspects of the system for the purposes of testing with users (1.2-4)	– Prototyping and usability evaluation – Develop prototypes –Develop simulations – Drawing – Mock-up – Scale model – Manikin – CAD environment – Technical, manual and functional evaluation – Use human factors engineering data for evaluation
c) Human resources	Decide which goals and tasks of the organization influence human resources (4.1-1) Define the global numbers, skills and supporting equipment needed to achieve those tasks (4.1-2) Identify current tasking/duty (4.2-1) Analyse gap between existing and future provision (4.2-3) Identify skill requirements for each role (4.2-3) Predict staff wastage between present and future (4.2-4) Calculate the available staffing, by taking into account the working hours, attainable effort and non-availability factor (4.2-5) Identify and allocate the functions to be performed (4.3-1) Specify and produce job designs and competence/ skills required to be delivered (4.3-2) Calculate the required number of personnel (4.3-3) Generate costed options for delivery of training and/or redeployment (4.3-4) Evolve options and constraints into an optimal training implementation plan (4.3.5) Develop and submit to trial a training solution to representative users (4.3-6) Define how users will be re-allocated, dismissed or transferred to other duties (1.5-3)	– Work domain analysis – Task analysis – Participatory design – Workload assessment – Human performance model – Design for alertness – Plan staffing

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Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
3. Realization/ Implementation	Maintain contact with users and the client organization throughout the definition, development and introduction of a system (1.3-3) Evolve options and constraints into an implementation strategy covering technical, integration and planning and manning issues (1.3-1) Revise design and safety features using feedback from evaluations (3.3-5) Deliver final training solutions to designated staff according to agreed timetable (4.3-7) Collect user input on the usability of the developing system (1.2-5) Test that the system meets the requirements of the users, the tasks and the environment, as defined in its specification (1.3-5) Review the system for adherence to applicable human science knowledge, style guides, standards, guidelines, regulations and legislation (1.4-3)	– Risk analysis (process and product) – User feedback on usability and user experience – Use models and simulation – Guidelines: common industry format for usability reports – Performance measurement – Design criteria checklist
4. Operations	Produce personnel strategy (1.4-1) Review the system for adherence to applicable human science knowledge, style guides, standards, guidelines, regulations and legislation (1.4-3) Deliver training and other forms of awareness-raising to users and support staff (1.4-2) Review health and well-being risks to the users of the system (1.4-5) Review the risks to the community and environment arising from human error in the use of the system (1.4-6) Perform research to refine and consolidate operation and support strategy for the system (1.4-8)	– Work context analysis – Organizational and environmental context analysis
5. Enhancement	Provide means for user feedback (on human issues) (4.4-2) Analyse feedback on the system during delivery and inform the organization of emerging issues (1.3-6) Assess the effect of change on the usability of the system (1.4-4) Take action on issues arising from in-service assessment (1.4-7) Take effective mitigation to address risks to system usability (2.5-4)	– Organizational and environmental context analysis – Risk analysis – User feedback on usability and user experience – Work context analysis – Continuous direct observation – Sampled direct observation – Interviews and questionnaires
6. Retirement	Collect and analyse in-service reports to generate updates or lessons learnt for the next version of the system (1.5-1) Identify risks and health and safety issues associated with removal from service and destruction of the system (1.5-2) Define how users will be re-allocated, dismissed, or transferred to other duties (1.5-3) Plan break-up of social structures (1.5-4) Debriefing and retrospective analysis for replacement system (1.5-5)	
7. Outsourcing	Take into account the stakeholder and user issues in acquisition activities (2.3-1)	– Common industry format

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Life cycle stage	Best practices from ISO/PAS 18152 (ISO/PAS 18152 reference number given in brackets)	Example methods and techniques
8. Integration a) Business strategy b) Quality management c) Authorization and control	Contribute to the business case for the system (1.1-7) Define usability as a competitive asset (2.1-1) Set usability, health and safety objectives for systems (2.1-2) Develop user-centred infrastructure (2.1-4) Relate HS issues to business benefits (2.1-5) Define and maintain HCD and HR infrastructure and resources (2.2-3) Increase and maintain awareness of usability (2.2-4) Develop or provide staff with suitable HS skills (2.2-5) Implement the HR strategy that gives the organization a mechanism for implementing and recording lessons learnt (4.1-4) Enable and encourage people and teams to work together to deliver the organization's objectives (4.1-6) Create HR capabilities to meet future system requirements (conduct succession planning) (4.2-7)	– Program risk analysis – Develop and maintain HSI infrastructure and resources – Identify required HSI skills – Provide staff with HSI skills – Establish and communicate a policy on HSI – Maintain an awareness of usability
d) Staffing	Decide how many people are needed to fulfil the strategy and what ranges of competence they need (4.1-3)	

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