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Ergonomic design of control centres —

Part 1: **Principles for the design of control centres**

Conception ergonomique des centres de commande —

Partie 1: Principes pour la conception des centres de commande

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 11064 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 11064-1 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

ISO 11064 consists of the following parts, under the general title *Ergonomic design of control centres*:

— *Part 1: Principles for the design of control centres*

— *Part 2: Principles for the arrangement of control suites*

— *Part 3: Control room layout*

— *Part 4: Layout and dimensions of workstations*

— *Part 5: Displays and controls*

— *Part 6: Environmental requirements for control rooms*

— *Part 7: Principles for the evaluation of control centres*

— *Part 8: Ergonomic requirements for specific applications*

Annex A and B of this part of ISO 11064 are for information only.

Introduction

Driven by demands for safer, more reliable and efficient operations, innovations in information technology have led to the increased use of automation and centralized supervisory control in the design of user-system interfaces and their associated operational environments. Notwithstanding these developments, the operator has retained a critical role in monitoring and supervising the behaviour of these complex automated systems. As the scale of automated solutions has grown, so have the consequences of equipment and human failures.

The job of the operator can at times be very demanding. The consequences resulting from inappropriate operator action in control rooms, such as acts of omission, commission, timing, sequence and so on, can be potentially disastrous. Accordingly, this part of ISO 11064 has been prepared to set up a generic framework for applying requirements and recommendations relating to ergonomic and human factors in designing and evaluating control centres with the view to eliminating or minimizing the potential for human errors.

A specific control centre project is often part of a design project for a larger system. The design of the control centre should not be developed separately from the objectives and goals associated with the context of this wider system. Consequently, it is necessary to view the ergonomic aspects of a control room design in relation to issues which, at first sight or by tradition, may seem to fall outside the scope of ergonomic design projects. These judgements will need to be taken on a case by case basis and are not necessarily resolved by a prescriptive approach.

This part of ISO 11064 includes requirements and recommendations for a design project of a control centre in terms of philosophy and process, physical design and concluding design evaluation, and it can be applied to both the elements of a control room project, such as workstations and overview displays, as well as to the overall planning and design of entire projects. Other parts of ISO 11064 deal with more detailed requirements associated with specific elements of a control centre.

Ergonomic design of control centres —

Part 1:
Principles for the design of control centres

1 Scope

This part of ISO 11064 specifies ergonomic principles, recommendations and requirements to be applied in the design of control centres, as well as in the expansion, refurbishment and technological upgrades of control centres.

It covers all types of control centres typically employed for process industries, transportation and logistic control systems and people deployment services.

Although this part of ISO 11064 is primarily intended for non-mobile control centres, many of the principles specified in this document could be applicable to mobile control centres, such as those found on ships and aircraft.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 11064. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 11064 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 6385, *Ergonomic principles in the design of work systems.*

ISO 11064-3, *Ergonomic design of control centres — Part 3: Control room layout.*

3 Terms and definitions

For the purposes of this part of ISO 11064, the following terms and definitions apply.

3.1
control centre
combination of control rooms, control suites and local control stations which are functionally related and all on the same site

[ISO 11064-3:1999, definition 3.1]

3.2
control room
core functional entity, and its associated physical structure, where operators are stationed to carry out centralized control, monitoring and administrative responsibilities

[ISO 11064-3:1999, definition 3.4]

3.3
control suite
group of functionally related rooms, co-located with the control room and including it, which houses the supporting functions to the control room, such as related offices, equipment rooms, rest areas and training rooms

[ISO 11064-3:1999, definition 3.6]

3.4
design specification
detailed description of features of the control suite, including room arrangements, equipment, workstation displays and operator controls, which meets the control centre's overall requirements with regard to development, procurement and construction

3.5
function allocation
distribution of functions between human and machine

3.6
functional analysis
analysis identifying those requirements which need to be met by humans or machines in order to achieve the operational goal

3.7
functional specification
record, put together from functional analysis, of what the control centre is to include in terms of objectives, functions, support of users and machines, relationships with external systems, and physical and environmental attributes

3.8
human-centred design approach
approach to interactive system development, focusing specifically on making systems usable, and emphasizing the role of human operators as control agents who maintain authority within a working system

3.9
job design
process of determining what the job content should be for a set of work tasks and how the tasks should be organized and interlinked

NOTE For the purpose of this part of ISO 11064, a definition of job design is introduced which indicates the design of several jobs, instead of one job (such as specified in EN 614-1:1995, annex B).

3.10
local control station
operator interface that is located near the equipment or system being monitored and/or controlled

[ISO 11064-3:1999, definition 3.15]

3.11
primary user
person engaged in those job functions normally associated with control centre activities

EXAMPLES Operator, assistant operator, foreman or supervisor.

3.12
secondary user
person that occasionally uses or maintains the control centre

EXAMPLES Maintenance engineers, cleaners, managers or visitors.

3.13
situational analysis
task analysis in an existing situation to analyse all the behavioural aspects of the work system, such as revealing practical experiences, informal communication, expectations and complaints of current users and any other facts that might be useful for redesign purposes

3.14
task analysis
analytical process employed to determine the specific behaviours required of people when operating equipment or doing work

[ISO 9241-5:1998]

3.15
validation
confirmation by examination and tangible evidence that the particular requirements for a specific intended use are fulfilled

NOTE In design and development, validation concerns the process of examining a product to determine conformity with user needs.

[ISO 8402:1994, definition 2.18]

3.16
verification
confirmation by a systematic examination and tangible evidence that specified requirements have been fulfilled

NOTE 1 In design and development, verification concerns the process of examining the result of a given activity to determine conformity with the stated requirements for that activity.

NOTE 2 Tangible evidence is regarded as being information that can be proved to be true, based on facts obtained through observation, measurement, test or any other means.

[ISO 8402:1994, definition 2,17]

4 General considerations and principles of ergonomic design

4.1 General

Nine principles shall be taken into consideration for the ergonomic design of control centres. They are explained in 4.2 to 4.10.

4.2 Principle 1: Application of a human-centred design approach

ISO 6385 specifies ergonomic principles intended as a guide for the design of work systems. The objective is to design adequate working conditions with regard to human safety, health and wellbeing, whilst taking into account technological and economic efficiency. This part of ISO 11064 addresses the specific case of control centres.

In a human-centred design approach, the combination of humans and machines, in its organizational and environmental context, is considered as an overall system to be optimized. This optimization is achieved by developing solutions that emphasize and maximize the strengths, features and capabilities of both humans and machines in a complementary fashion. The human component, the machine (hardware and software), the work environment, and the control (operation and management) shall be harmoniously integrated during all phases of the design process, as shown in Figure 1. Included in those activities where human-centred design may be relevant are planning, conceptual and detailed design, assembly and construction, commissioning, user training and operations.

A human-centred design approach needs to be integrated into the traditional function-orientated design approach. It is essential that certain human characteristics form part of the basis of the design requirements which underly the final design specifications. The human characteristics to be considered shall not only include basic physical capabilities or limitations, but shall also emphasize the unique cognitive strengths of humans (such as perceptual ability, problem solving and decision making). In addition, knowledge about how operators feel and interact with operations and management, as well as with *designed objects* that include machines (both hardware and software), environments and so on, shall be considered. In addition to the immediate and obvious ergonomic requirements imposed by highly automated and large-scale systems, more subtle psychological demands may require special attention. These include self-fulfilment, motivation and cultural considerations.

If physically challenged people are routinely assigned to work in a control centre, appropriate designs shall be employed to accommodate their specific needs.

4.3 Principle 2: Integrate ergonomics in engineering practice

Ergonomics and its associated tools should be integrated into the project's management guidelines in order for the role of ergonomics to be taken into account by all designers and engineers involved in the planning, design, implementation and operational audit of a control centre. A project should be organized in such a way that an integration of technical and ergonomic expertise is encouraged.

4.4 Principle 3: Improve design through iteration

Design processes are inherently iterative in practice. Evaluation shall be repeated until the interactions between operators and designed objects achieve their functional requirements and objectives. Establishing the validity of an individual element of the design in isolation does not guarantee that the assembled system will be validated. Any modification, however minor, can cause undesirable side effects even if the modification itself is valid (see ISO 6385). There shall be a formal process that defines and controls mechanisms and procedures for scope changes in the design of all aspects of the control centre.

It should be noted that users, either consciously or unconsciously, may adapt their behaviour to modifications, and that such behavioural changes may not be consistent with good ergonomic practice. The incorporation of information obtained from operational experiences, that is operational feedback, is of particular importance in this iterative process (see Figure 1).

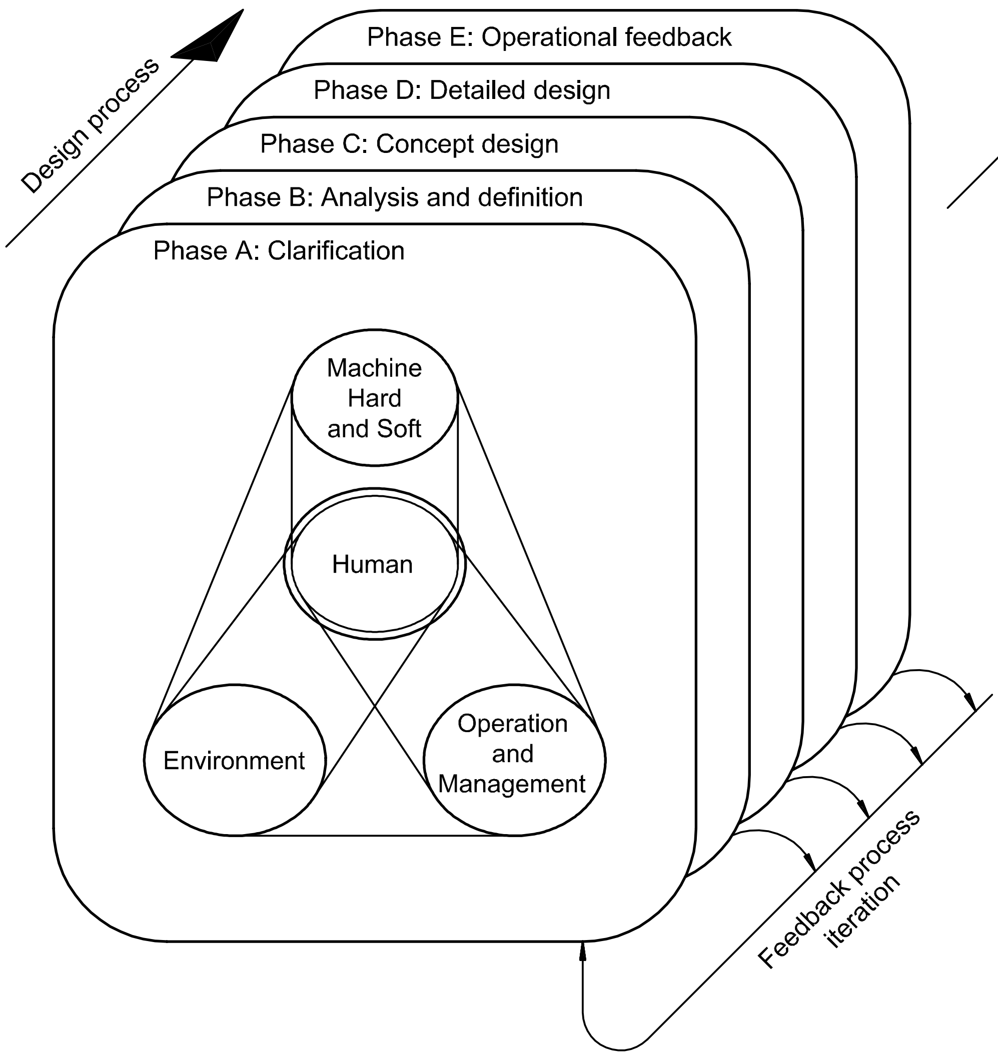

Figure 1 — Ergonomic approach to system designs

4.5 Principle 4: Conduct situational analysis

For any ergonomic design activity, including refurbishment projects, a situational analysis of existing or similar situations is recommended. In this way, the functions of the future system can be thoroughly understood and anticipated beforehand.

The means of performing situational analysis may vary, but include task analysis (see 4.6), operator interviews and incident analysis.

4.6 Principle 5: Conduct task analysis

The tasks delegated to individual control room operators, and to other significant users of the control centre, shall be fully understood (see ISO 6385). The analysis shall consider all modes of system operation including start-up, normal operation, shut-down, anticipated emergency scenarios, periods of partial shut-down for maintenance, the results used in the design process and the development of staffing plans. Some situations may require doubling or tripling staffing requirements and therefore shall be accounted for in the overall design.

An analysis of operator tasks shall be conducted in designing a plant, a control centre or any other system.

The task analysis methods may vary according to the scope and content of each individual project. In the case of an innovative design project, there may be few opportunities for studies of comparable situations. In other cases, for example that of combining several control rooms into one new control room, most of the operator tasks may be carried forward into the new design. Although inherently different, each of these situations should allow some degree of comparable analysis to positively influence the design of a future system.

4.7 Principle 6: Design error-tolerant systems

Human error cannot be totally eliminated. It is therefore necessary to strive for error-tolerant design. An important tool is the use of risk assessment for obtaining information on human error.

4.8 Principle 7: Ensure user participation

User participation is a structured approach where future users are involved in the design of a control centre. User participation throughout the design process is essential to optimize long-term human-machine interaction by instilling a sense of ownership in the design.

Experienced users can offer valuable empirical contributions to the control centre design. Their practical experience is not always documented or well known by designers. Operational feedback derived from user participation should be analysed to identify previous design successes and shortcomings.

4.9 Principle 8: Form an interdisciplinary design team

An interdisciplinary design team should be formed to oversee and influence all phases of the design project. Actual combinations of disciplines included in the design team may vary depending on the overall project scopes or the phase of design. This team may include system and process engineers, ergonomists, architects and industrial designers. For existing systems, users or user representatives shall be included as members of the team. For new systems, both experienced and future users shall form part of the design team.

The design team, including the users, shall be available at the appropriate time throughout the project's life cycle. Plans and accommodations for team participation should be specified in detail at the beginning of the project.

4.10 Principle 9: Document ergonomic design basis

Develop internal documents that reflect the ergonomic design basis for the project, for example fundamental reasoning or significant task analysis findings. The document should be updated whenever there is a change. An appropriate procedure should be developed for this process.

5 Framework for an ergonomic design process

Figure 2 shows a framework, consisting of five design phases, for the control centre design process (Figure 2 is simplified with only some of the iterative loops shown). Typically, all phases should be executed with the overall effort distributed in accordance with the scope of the design project.

The design of a control centre is generally complex, involving, for example, multiple clients, conflicting objectives, diversity of new technologies and possible solutions, ambitious schedules, first time applications and inexperienced personnel. The complexities of a design project can often be accommodated by implementing a methodical sequence of procedures that focus attention on particular topics, on design activities and on iterative reviews.

The framework listed below and given in Figure 2 involves the following phases:

— Phase A: Clarification

  clarify the purpose, context, resources and constraints of the project when starting a design process, taking into account existing situations which could be used as a reference;

— Phase B: Analysis and definition

  analyse the control centre's functional and performance requirements culminating in a preliminary functions allocation and job design;

— Phase C: Conceptual design

  develop initial room layout, furnishing designs, displays and controls, and communications interfaces necessary to satisfy the needs identified in phase B;

— Phase D: Detailed design

  develop the detailed design specifications necessary for the construction and/or procurement of the control centre, its content, operational interfaces and environmental facilities;

— Phase E: Operational feedback

  conduct a post commissioning review to identify successes and shortcomings in the design in order to positively influence subsequent designs.

Each of the above phases is discussed in more detail in clauses 6 to 10 respectively.

The numerous feedback paths shown in Figure 2 relate to the iterative nature of designing solutions for complex problems. New opportunities for enhanced solutions and unsatisfactory designs identified by frequent project reviews shall be recycled back into the process. Careful project budgeting and scheduling should allow for and encourage this iterative process.

NOTE This part of ISO 11064 is primarily concerned with phases A, B, C and E of the project framework shown in Figure 2.

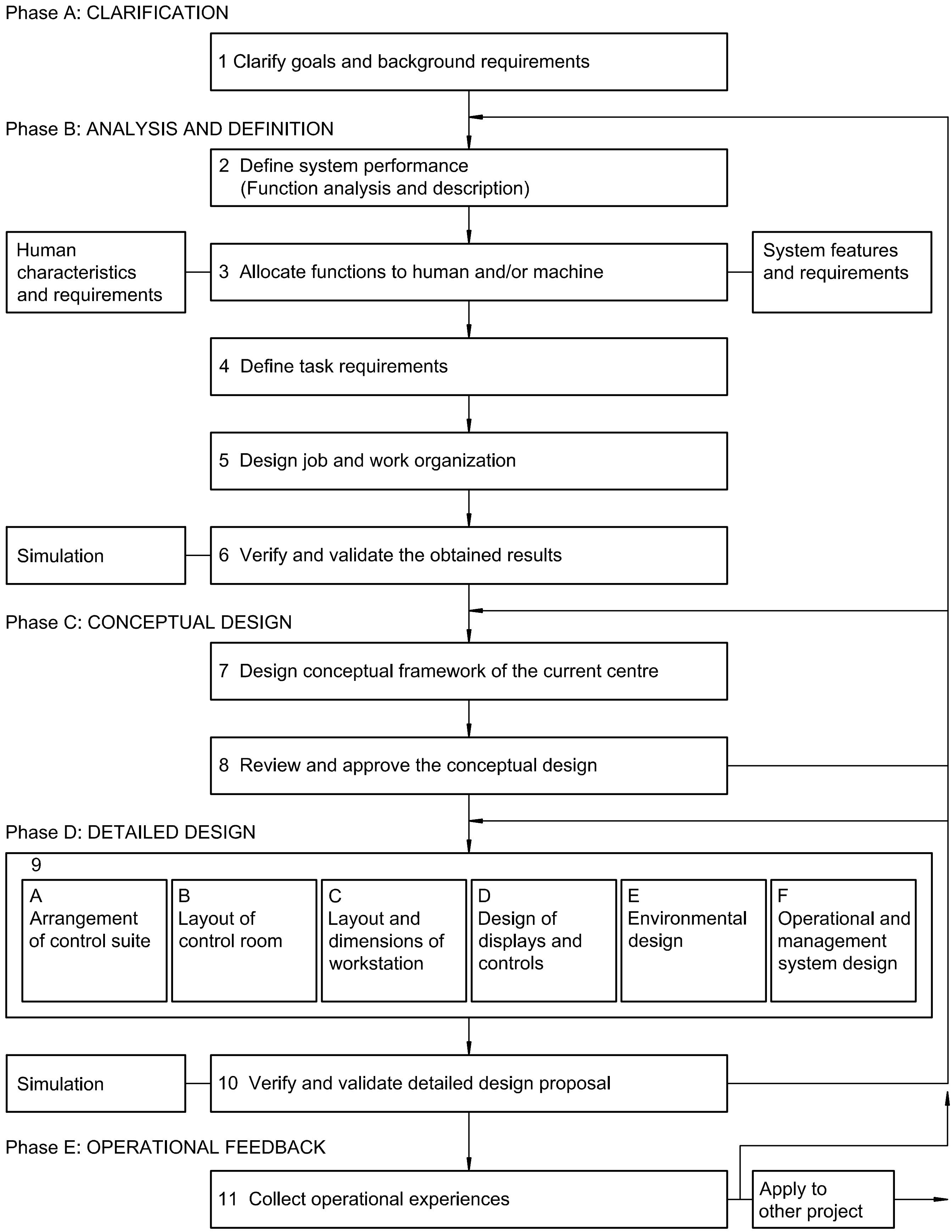

Figure 2 — Ergonomic design process for control centres

6 Phase A: Clarification

6.1 General

The purpose of this phase is to clarify operational goals, relevant requirements and constraints associated with the design of control centre(s) (see annex A).

The role of the control centre and its relationships with other relevant sub-systems shall be identified and documented. A typical example of this is illustrated in Figure 3. The descriptions and functions of the sub-systems, for example process units, power systems, communications systems and so on, shall also be identified and documented.

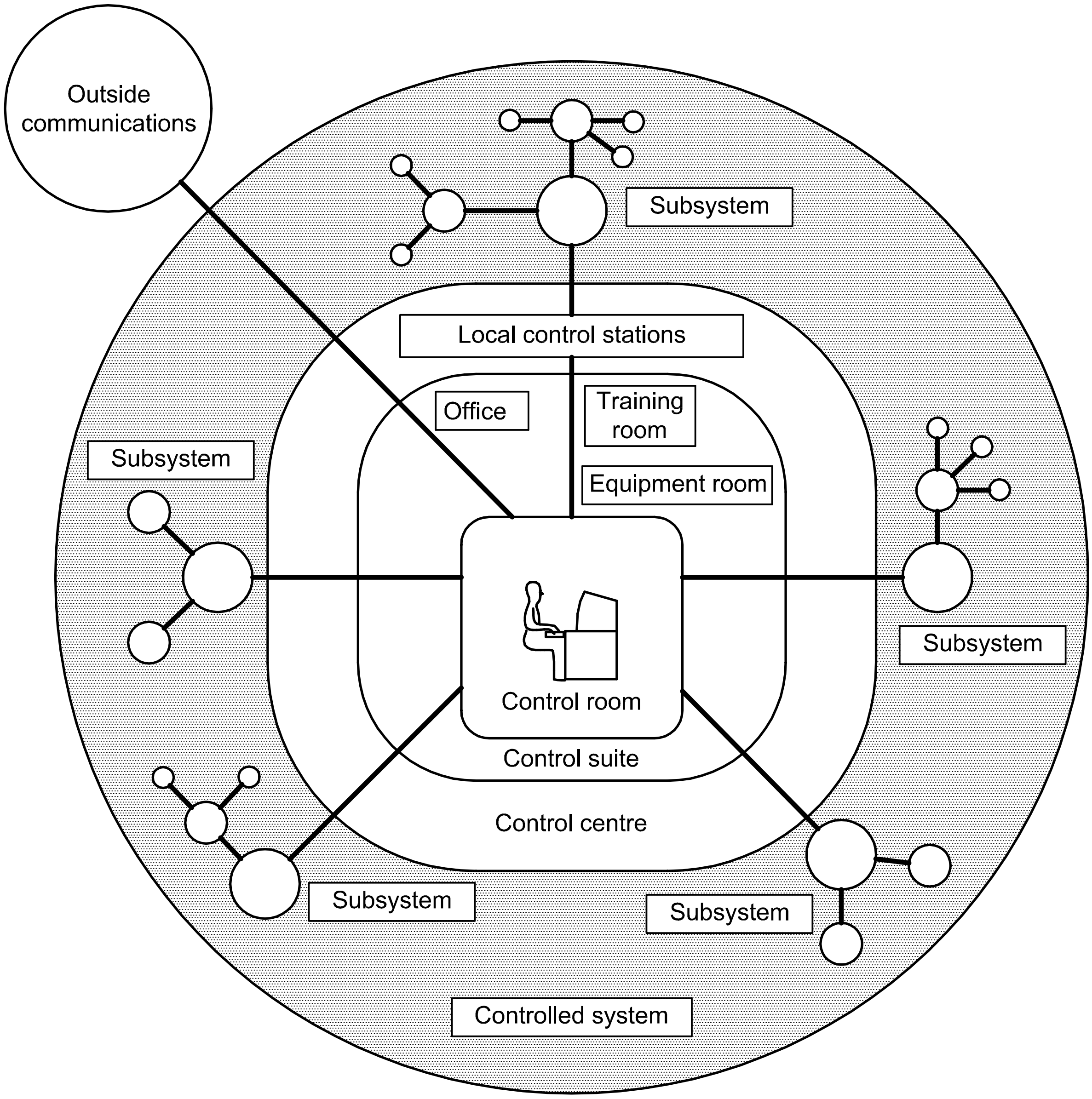

Figure 3 — Control centres and their relationships with other sub-systems

6.2 Step 1: Clarification of goals and background requirements

Phase A involves one step, which is "the clarification of goals and background requirements". Experience from existing or similar control centres can make a valuable contribution to refurbishment or new projects and this experience shall be given appropriate consideration at the start of project.

Inputs for Step 1 may include the following elements:

— user requirements;

— regulatory guides, standards and other formal documents;

— technical information on existing systems and control centres;

— operational feedback information;

— analysis of any existing or similar situations.

Outputs for Step 1 are the following:

— system's functions (that is operational goals);

— various relevant requirements and constraints (refer to annex B);

— conflicting requirements and solutions of compromise.

Some of the methods commonly used include, amongst others, the following elements:

— review of documents, for example project brief, funding appropriation, initial designs;

— conducting interviews with personnel associated with plant management, operations, plant engineering, plant maintenance, as well as collection of other forms of verbal information;

— carrying out audits of control centres, that is the analysis of any similar installations for the same overall project scope;

— conducting technological reviews, that is the analysis of the latest operator-system interface methods and techniques;

— conducting ergonomic and any other trade-off studies.

Any requirements or constraints to be taken into account in the design of control centres shall be identified and documented. These requirements have to include all those listed in annex B.

In particular, the following has to be taken into account:

— functional goals;

— codes and regulations;

— safety and security requirements;

— operational and control requirements;

— ergonomic requirements;

— job and organizational requirements;

- systems maintenance;
- company policy;
- company standards;
- technical constraints;
- resource constraints;
- operational experiences;
- formalizing project uncertainties and change management;
- aesthetics and architecture.

Operational feedback from other projects shall be incorporated (see 10.2) and conflicting requirements empirically detected shall be documented, evaluated and resolved.

7 Phase B: Analysis and definition

7.1 General

The analysis and definition phase has multiple objectives, and includes the following prerequisites as shown in five steps to develop an integrated design proposal of a control centre.

The five steps in this phase are as follows:

- Step 2: define system performance (function analysis and description);
- Step 3: allocate functions to human and/or machine;
- Step 4: define task requirements;
- Step 5: design job and organization;
- Step 6: verify and validate the obtained results.

7.2 Step 2: Define system performance (functional analysis and description)

Based on the findings of step 1 in phase A, a functional analysis shall be carried out and documented in order to identify the ergonomic needs (involvement, analysis and solutions) required to achieve the objectives defined in phase A.

The functional analysis may be undertaken by several methods, that is functional breakdown (IEC 60964), flow charts, simulations and operational walk-throughs.

The scope of the functional analysis shall include all anticipated operational modes of the controlled system:

a) steady state operation, for example: mode or operational state that can be considered normal or routine, that is no system transients or process excursions are affecting the controlled system;

b) normal transient operation (start-up, shut-down), for example: operation or sequence of operations that change the process or controlled systems from one major state or condition to another (for example starting or stopping a process, product grade and/or production rate changes);

c) emergency/abnormal operation, for example: mode or operational state in which short-term recovery or mitigating measures are implemented following an anomaly; post-emergency operation, mode or operational state in which long-term recovery or mitigating measures are implemented, after an emergency/abnormal operation; such operations may impose temporary function/task allocation changes, special safety considerations, job redefinition and environmental changes;

d) maintenance (scheduled or unscheduled), for example: mode or operational state during which some or all of the systems' process equipment, machinery, displays and controls, utilities and so on are unavailable due to maintenance activity; planned maintenance may sometimes call for special procedures, task assignments and equipment sharing especially if the maintenance involves the control centre and its sub-systems.

   NOTE In most cases, these latter operations and conditions require greater operator involvement than for normal steady-state ones.

Outputs of step 2 are: ergonomically related system performance requirements and functions associated with overall operational goals and sub-goals.

Analysis may employ one or more:

1) postulated walk/talk-throughs of operational modes;

2) operational safety and reliability requirements;

3) top-down functional process diagrams;

4) topologies of plant, mill, process and so on.

7.3 Step 3: Allocate functions to humans and/or machines

During this step, the performance requirements and functions identified in step 2 shall be allocated to humans and/or machines.

NOTE 1 An accepted technique is to develop initial hypothetical assignments followed by a series of evaluations. This should culminate in a functional design that has all the required functions satisfied by the appropriate resource, that is machines or humans (see [6] in Bibliography for further information).

NOTE 2 Certain preliminary allocation decisions may be taken on the basis of mandatory requirements arising from legislation (for example safety considerations).

The allocation process should take into consideration the strengths and shortcomings of contemporary machine designs, of humans and of past design experiences and performance and the consequences for safety, productivity and wellbeing.

The variability of the potential user should be considered in this step. The variability includes such factors as age, cognitive abilities, gender, experiences, body size and task-related psychological factors such as vigilance, boredom and teamwork.

The hypothesized allocation shall be assessed against both human and engineering criteria, making further revisions and iterations as necessary.

Outputs of step 3 are:

— sets of functions to be performed by humans;

— sets of functions to be performed by machines, and associated requirements for error-tolerant machine design;

— sets of interaction between humans and machines.

An overview method is described below; references to other allocation methods are listed in annex B.

a) *Performance characteristics*

Machines are more suitable for routine monitoring and for high accuracy or repetitious tasks, whereas humans are better suited to tasks that require adaptation, integration and generalization. Humans are superior strategic and tactical planners (see also [2] in Bibliography).

Functions should be allocated between humans and machines in such a way that challenging, interesting and satisfying jobs are created whilst meeting all the safety and other requirements.

NOTE It should be recognized that allocation of functions between humans and machines may need data acquired in verifications and validation tests. Therefore, final allocation decisions should not be decided too early in the project.

b) *Cognitive and affective support*

Cognitive support refers to the operators' requirements for information to enable him or her to fulfil decision-making tasks and so on. Automation increases the risk that an operator can no longer identify what the system is doing. It may be that the operator's mental model of the process can be best maintained by permitting him or her to perform certain functions that might otherwise have been automated. Likewise, certain functions could be allocated to the operator so that he or she maintains infrequently required skills of either a manual or cognitive nature. Additionally, such factors as vigilance, boredom and fatigue should be considered and the findings documented.

Affective support refers to the motivational needs of man. It is important that the operator feels that he or she has retained control over the system. Similarly, the operator should feel that he or she is being productive and fulfilling a useful role. If these needs are not satisfied, then it is likely that the operator’s overall performance will decline.

The following cognitive and affective support criteria have to be taken into account when allocating functions to humans:

— allow overall authority to be maintained (for example, mode selection);

— facilitate a better understanding of the state of the machine (for example, break point control);

— improve the feeling of usefulness within the overall system;

— maintain a good level of situational awareness;

— support education and training needs.

The following cognitive and affective support criteria have to be taken into account when allocating functions to the machine:

— avoid repetitive and boring tasks;

— improve system efficiency and reliability.

c) *Allocation steps*

An alternative to the fixed allocation of all functions to humans and/or machines is dynamic allocation, whereby the system interface enables certain functions to be allocated according to the prevailing workload. Dynamic allocation enables the operator to maintain his or her operating skills and to take over machine functions in the case of faults. A consequence of dynamic allocation is that it could be necessary to provide additional information or support systems for the operator to enable him or her to perform the role of the machine.

The allocation process is essentially iterative and incorporates a number of steps, the final hypothesis being derived through a process of refinement. The allocation process shall be adequately documented at all stages, to provide data to facilitate and support any subsequent designs. A description of the procedures to be followed within each of the steps is given in Table 1.

Table 1 provides basic procedures for the allocation of functions to humans and/or machines. The primary objective is to achieve a function allocation for which such ergonomic considerations as human abilities, human characteristics and human dignity are fully taken into account. Special consideration should be given to the range of user population including such features as skill levels, differences in cultural background, educational levels and disabilities. The procedures should be repeated until the function allocation reaches a high degree of integrity for all functions.

7.4 Step 4: Define task requirements

A task analysis shall be conducted to determine the fundamental elements of the tasks allocated to humans in step 3. The fundamental task elements to be considered include manual and cognitive activities, task frequency, duration, complexity, communication requirements, environmental conditions and any other unique factors required for one or more humans to perform a given task.

A record shall be drawn up of the task elements based on a systematic breakdown of tasks. These elements include manual and cognitive demands, task duration and frequencies, task allocation, task complexity, environmental conditions and any other unique factors involved, or required, for people to perform a given task.

Studies, walk-throughs, talk-throughs and surveys should be considered as a means to identify and qualify principal tasks and associated constraints, timing and frequency requirements, potential control interactions, prerequisites, safety issues, anticipated environmental conditions, and so on. This also takes into account the characterization of the target application, for example the number of variables, continuous or discrete behaviours, and so on.

The task analysis shall include preliminary engineering solutions based on prior experience or on opportunities for innovation and invention that may be identified.

Table 1 — Basic procedures for the allocation of functions/tasks to humans and/or machines

No.	Step	Procedure
1	Mandatory allocation. Allocation to meet safety and/or regulatory requirements.	1.1 For mandatory automatic functions/tasks, allocate to machine. 1.2 For mandatory manual functions/tasks, allocate to human.
2	Attempt at preliminary allocation in terms of human traits, abilities and characteristics with a view to ensuring the safety and reliability of the system's performance. Allocation according to performance characteristics.	2.1 Re-design system to avoid tasks which cannot be carried out satisfactorily by humans and/or machines [a]. 2.2 Allocate functions/tasks which cannot be satisfactorily carried out manually [b] to machines. Treat as mandatory automatic functions/tasks (see 1.1.above). 2.3 Allocate functions/tasks which cannot be satisfactorily automated [c] to humans. Treat as mandatory manual functions/tasks (see 1.2. above). 2.4 Initially, allocate machine-preference [d] and human-preference [e] functions/tasks to machines and/or humans respectively. 2.5 Initially, leave without-preference functions/tasks [f] unallocated.
3	Allocation according to *cognitive and affective support criteria.* Complementary or flexible allocation from the viewpoint of ergonomics and system efficiency.	3.1 Consider re-allocation of without-preference, machine-preference [d] and human-preference [e] functions/tasks according to cognitive and affective criteria. 3.2 Consider complementary or flexible allocation, which gives users the ability to change the allocation.
4	Ascertain feasibility of automation.	4.1 Determine whether functions/tasks allocated to humans can be implemented effectively using available automation technology.
5	Ascertain feasibility of human performance. Select tasks which are to be supported by operator support systems to assist with signal detection, information acquisition and decision making.	5.1 Assess whether the functions/tasks allocated to humans can be implemented effectively, assuming the availability of operator support systems. Determine whether such systems can be implemented using the available level of technology.
6	Evaluate allocation. Determine need for iteration and revision.	6.1 Repeat allocation procedure if the proposed allocation of functions/tasks is impractical or requires further refinement, or if steps 5 and 6 reveal unacceptable technical limitations.

[a] Functions/tasks linked to neither humans or machines and performed unsatisfactorily by both humans and machines. System should be redesigned to avoid such tasks.

[b] Functions/tasks linked to machines. They are carried out so badly by humans that they should be assigned to machines (automated).

[c] Functions/tasks linked to humans. They are carried out so badly by machines that they should be assigned to humans (manual).

[d] Machine preference functions/tasks. They are carried out better by machines to which they should be assigned, unless dictated otherwise by other criteria.

[e] Human preference functions/tasks. They are carried out better by humans to whom they should be assigned unless dictated otherwise by other criteria.

[f] Without preference functions/tasks. They are carried out satisfactorily by both humans and/or machines. Other criteria may determine assignment.

Output of step 4 is: tasks to be performed to satisfy functional requirements and associated ergonomic performance requirements (for example, speed, accuracy, logic).

For references on methodologies for conducting formal task analysis see [11] in Bibliography.

7.5 Step 5: Design job and work organization

Job design shall be carried out and tasks shall be assigned to particular roles according to the planned work organization.

Inputs of step 5 are:

- outputs of step 4 (that is, tasks to be carried out by humans);
- user requirements (for example, policy for work organization);
- regulatory requirements (for example, requirements for work organization).

Outputs of step 5 are:

- jobs assigned to each operator;
- work organization (structure and number of operators);
- requirements for communications between operators, between control room and local control centres;
- requirements for operating procedures;
- requirements for training;
- requirements for information and control.

Methods of step 5 are:

a) define a tentative work organization that satisfies user and regulatory requirements;

b) conduct job design;

  - define job assignment criteria,
  - define jobs to be carried out by each operator.

Job designs shall match operators' physical characteristics, cognitive and analytical abilities, organizational and leadership skills and social-system factors.

Job design shall consider not only the formal tasks allocated to humans in step 4, but also the social aspects of work organizations and the individual’s needs for job satisfaction, measurable goals and rewarding growth opportunities.

Two major considerations shall govern the job design process:

- what and how many particular tasks and jobs are assigned to an individual (role)?
- how will the organization inter-relate individuals to achieve a balanced operating company?

A job assignment criteria checklist shall be developed to facilitate the assignment of tasks to particular individuals (roles). Some checklist items may include the following:

- workload;
- special license requirements;
- job sharing;
- information and data requirements;
- predictability of the controlled system;
- required tools, physical space and facilities;
- conditions where tasks are to be performed.

Individual skills related to educational background and work experience, such as process knowledge, stress management, analytical capabilities and so on should also be included in the job criteria checklist. The job design shall also identify information that operators need to exchange or share in such cases where teamwork is required to carry out a task.

A preliminary work organization shall be defined that groups the designed jobs to particular roles as prescribed by the overall project's organization plan. Topics for consideration in grouping these jobs may include:

- lines of authority and responsibility;
- team structures;
- traditional psycho-social cultures;
- union/management agreements;
- regulatory requirements;
- physical proximities;
- intercommunication requirements.

The iterative nature of the work assignments may require repeated modification of the work organization design.

The job assignment criteria and work organization shall meet user requirements (for example, policy for work organization) and regulatory requirements (for example, requirements for work organization) clarified in step 1. The results of job and organization design shall be incorporated into requirements for operating procedures, training systems and the functional specifications for the design of control centres.

7.6 Step 6: Verify and validate the obtained results

An intermediate verification and validation of the resulting function/task allocations, task requirements job assignments and work organizations developed in steps 3, 4 and 5 shall be performed before beginning phase C, Conceptual design. During this step, the emphasis shall be on verifying and validating globally all the individual allocations and assignments made in steps 3, 4 and 5. Particular allocations and assignments, tested and confirmed during the iterative processes of steps 3, 4, and 5, may nevertheless be in conflict with other independent classifications and job definitions. All conflicts should be identified and resolved before proceeding to phase C.

A special form of validation shall be performed in this step to review and confirm the progress to date with the project's sponsors, owners, and so on, particularly with respect to the allocation and job definition results. The personnel and automation requirements and associated organizational plans shall be reviewed and endorsed prior to proceeding with phase C.

Job specifications assigned to each operator in step 5 shall be verified and validated.

The job assignment developed in step 5 shall be formally verified to ensure that it conforms to the job assignment criteria.

Inputs of step 6 are:

— outputs of step 4;

— outputs of step 5.

Outputs of step 6 are:

— evaluated function/task allocations;

— evaluated task requirements;

— evaluated job assignments for each operator and work organization;

— endorsement of project sponsors, owners and so on of planned allocations, staffing plans and organization.

Verification and validation of job design should include an evaluation of the proposed jobs in relation to ergonomic principles and error tolerances. The job assignments shall be collectively validated. Prior to validation, a set of validation criteria shall be developed including the job assignment criteria and others, such as those related to the complexity (for example parallel job, need for frequent communication) and overall time constraints associated with typical scenarios. Critical scenarios, for example shut down, emergency, accident scenarios, shall be used to check whether the criteria are met. Computerized simulation (for example time-line analysis) can be a useful means of validation.

8 Phase C: Conceptual design

8.1 General

The purpose of this phase is to develop a comprehensive design project of a control centre that satisfies the allocated functional and task requirements, job descriptions and organizational plans established in phase B. This conceptual design shall include the physical attributes of the control centre, its furnishings and any special amenities, for example rest rooms, libraries, meeting rooms. The conceptual design shall also include the proposed operator interface, that is displays, controls, communications and multimedia applications. This activity should establish the context, target specifications and any constraints necessary to proceed with the detailed design in the subsequent steps.

This phase involves the following two steps:

— step 7: design conceptual framework of the control centre;

— step 8: approve the conceptual design.

8.2 Step 7: Design conceptual framework of the control centre

The results of the previous steps shall be restructured systematically, from the integrated system performance viewpoint, into a series of design concepts and preliminary specifications encompassing all intended aspects of the control centre's physical and functional characteristics. For instance, the results of the job design process that include requirements for work organization (that is structure and number of operators) shall form a basis for determining the work space requirements.

Inputs of step 7 are:

- outputs of step 6 (for example, work organization);
- user requirements, see step 1;
- regulatory guides, standards and other formal documents.

Outputs of step 7 are:

- conceptual design specifications, including preliminary layouts;
- significant known design constraints, that is budget, location, safety, styling, fail-safe redundancy, materials, pre-determined systems, sub-systems and so on;
- applicable regulatory and enterprise related standards, practices, codes and local customs;
- estimate of resource requirements to complete design specifications;
- operational links within functional areas.

Methods/actions associated with step 7 are:

- define design policy (for example device selection policy);
- define design criteria that conform to user requirements and regulatory guides, standards and other formal requirements;
- develop design specifications.

Conceptual design items for the preliminary specification should include:

- space allocations;
- functional links;
- control suite arrangement;
- control room layout;
- workstation layout and dimensions;
- displays and controls;
- information and data flows;
- special security and access controls;
- environmental conditions;
- operation and management systems;
- communications and information links.

This process shall result in several design ideas that can be individually appraised and potentially combined to form an enhanced conceptual design.

Any project governing design policies, for example pre-chosen equipment vendors, system designs and so on, shall be clearly stated and documented during this step. In addition, all applicable user and regulatory guidelines, standards and building codes shall be considered and included in the preliminary specifications, as necessary.

8.3 Step 8: Review and approve the conceptual design

This critical step shall seek the approval of the conceptual design by the owners, users and maintainers of the proposed control centre. The step provides a final opportunity to review and verify that the functional requirements have been accommodated by design ideas and technologies that are feasible, acceptable and in compliance with all applicable guidelines, standards and policies. This step should be viewed as a major milestone that enables the subsequent detailed design to proceed with a minimum risk of major functional revisions and physical changes.

Output of step 8 is: approved conceptual design specifications.

Methods/actions involved in step 8 may include:

— scenario “talk-throughs”;

— scenario “walk-throughs”;

— interface simulations, for example team working, mock-ups;

— computer visualisation and animation studies;

— standards compliance audit.

NOTE 1 "Talk-throughs": check on the conceptual design by means of structured discussions around critical task sequences, using the conceptual design specifications.

NOTE 2 "Walk-throughs": check on the conceptual design by simulating critical task sequences using representations of the design, (for example, traditional mockups, virtual reality based mockups, computer models and so on).

NOTE 3 Usually the end-users participate in both the activities mentioned above ("talk/walk-throughs"), and work procedures for the tasks are used.

The conceptual design specifications developed in step 7 shall be formally reviewed and studied to verify that the proposed designs continue to satisfy the project's functional requirements and remain in compliance with all applicable standards, guidelines and policies. Special emphasis shall be placed on the usability and maintainability of the conceptual designs. All identified concerns shall be reviewed, documented and reconciled as a prerequisite to final design.

9 Phase D: Detailed design

9.1 General

The purpose of this phase is to develop the detailed design specifications for the control centre. The design specifications shall be of sufficient detail to enable the estimating and logistical planning of the control centre's construction. The design specifications shall also be suitable for initiating requests for quotations to vendors for all purchased furnishings, systems, software, special tools and so on.

— step 9: design resource options include:

  — in-house or contracted engineering;

  — employment of system integrators;

  — employment of in-house or contracted ergonomists;

  — in-house or contracted architectural design.

— step 9: design methods and actions may include:

  — suitability reviews and selection of commercially available systems, for example Distributed Control System (DCS), Programmable Logical Control (PLC), VDTs and so on;

  — rapid prototyping;

  — development of style guides.

Appropriate ergonomics data shall be utilized for the design activities conducted in phase D. This phase involves the following steps.

a) Step 9:

— control suite arrangement;

— control room layout;

— workstation layout and dimensions;

— design of displays and controls;

— environmental design;

— operational and managerial requirements.

b) Step 10: verify and validate detailed design proposal.

The listing of steps 9 and 10 implies no particular order for conducting the designs. Each project should be individually evaluated for the purpose of establishing a design plan that is appropriate for the anticipated scope of work, complexity, available resources, schedule, budget and so on.

9.2 Step 9A: Control suite arrangement

In order to develop design specifications for a control suite arrangement, the following activities shall be performed:

— confirm functional areas making up the control suite;

— estimate the space requirements for each functional area, for example control areas, administration areas, rest areas and provision for visitors;

— confirm suitability of planned site, for example space restrictions, local hazards, environment;

— acquire current copies of all pertinent standards, building codes, user building policies and so on;

— verify availability of necessary utilities.

Determination of the operational links between the functional area and the development of a preliminary control suite layout should have been performed during the conceptual design (phase C).

The earlier task requirements and job design process (steps 4 and 5) that influenced the conceptual design shall be the basis for this step.

In summary, this design step should incorporate all of the special facilities that might be included in the control suite. Functional entities to be included are:

— control room;

— meeting room;

— training facility;

— equipment room;

— office;

— maintenance room;

— rest/relaxation room;

— eating area;

— kitchen;

— locker rooms and toilets;

— library for manuals and «as-built» drawings;

— instrument shop;

— visitor's gallery.

The proposed design specifications should facilitate the smooth transition between all the activities to be conducted in the control suite. Area requirements for other supporting functions, such as equipment room, administrative office and meeting room, shall be specified.

NOTE ISO 11064-2 provides specific requirements and guidelines for the design of a control suite arrangement.

9.3 Step 9B: Control room layout

The following tasks have to be undertaken in order to design a layout of a control room properly:

— determine the usable space;

— identify the furniture and equipment to be accommodated within the control room space;

— determine operational links which need to be provided between items to be housed within the control room, including personnel;

— specify circulation requirements for staff and visitors;

— specify maintenance access requirements.

Room layouts have to be based on the task requirements and job design defined in earlier steps, as well as on the user population characteristics. Items that shall be taken into consideration in all layouts include:

— workstations;

— equipment racks;

— storage both on and off the workstation;

— notice board;

— entrances and exits;

— shared off-workstation displays;

— desks, filing cabinets, bookcases and so on;

— printer stands, photocopying machines and so on.

The proposed layout shall support the operating links previously determined, including face-to-face communication, equipment sharing and team work.

NOTE ISO 11064-3 provides specific requirements and guidelines for the design of layouts of control rooms.

9.4 Step 9C: Workstation layout and dimensions

In order to develop design specifications for workstation layout and dimensions, the following engineering tasks shall be conducted:

— analyse and clarify the tasks to be undertaken at the workstation (operation and maintenance);

— identify the necessary functional elements of the workstation;

— develop workstation layout and dimensions.

All ergonomic requirements associated with workstation layout shall be considered, such as:

— displays;

— controls;

— working space;

— communication devices;

— seating, armrests and footrests.

It is recommended that all workstations offer elements of adjustability if it is usually used by operators of different sizes.

9.5 Step 9D: Design of displays and controls

Design specifications for displays and controls that are to be used within the control room shall be developed in this step. It shall be ensured that design specifications satisfy the functional specifications and task requirements allocated in step 3.

Displays and controls may involve a number of hardware and software options, including:

— conventional instruments, for example measuring devices, recording devices, annunciators, push buttons;

  and

— visual display units, for example monitors, software, touch screens and associated software.

In addition to the basic ergonomic requirements (optimal viewing angle and so on), it is essential that special attention is given to cognitive characteristics (optimal work-load and so on) of the users. The density, contents and quality of information and its timely presentation are critical design issues. It is also important to select the device best suited to the control actions.

9.6 Step 9E: Environmental design

The proposed design specifications have to meet ergonomic criteria, particularly with regard to a safe and comfortable working environment. The environmental aspects to be considered in the control centre are as follows:

— thermal environment;

— air distribution;

— air composition;

— lighting environment;

— acoustical environment;

— vibrations.

9.7 Step 9F: Operational and management systems design

Detailed solutions for the operational and management requirements shall be developed in this step. Examples of topics that might be considered are:

— training organization;

— maintenance organization;

— shift patterns;

— training and selection regimes;

— user requirements, including company policies and cultural factors, have to be appropriately reflected in the design;

— contacts with other groups outside the control room have to be taken into account;

— communication requirements, such as between operators in the control suite and operators in local control stations, have to meet operational requirements;

— secondary users' requirements and characteristics have to be taken into account as appropriate.

9.8 Step 10: Verify and validate detailed design proposal

The detailed design developed in step 9 shall be formally verified to ensure that it conforms to the design specifications used in step 9.

Furthermore, the detailed design developed in step 9 shall be formally validated to ensure that it conforms to the user needs.

Inputs for step 10 may include:

— detailed design specifications;

— functional specification.

Outputs of step 10 are: approved detailed design specifications, and design fulfilling the user requirements for the intended use.

Verification and validation shall be:

— integrated with the design process, that is not a separate activity performed once the design process is finished;

— an iterative process;

— a process which can give feedback to the designer to guide the design work towards the best possible solution.

The development of validation criteria is an important aspect of the validation process. A specific document describing the criteria and methods used in the validation and verification process shall be developed.

Compromises taken during the design process shall be well documented due to their importance for validation.

The verification and validation process shall pay special attention to operational safety, human error reduction, ergonomic design and environmental factors and job satisfaction.

10 Phase E: Operational feedback

10.1 General

Upon completion and commissioning of the control centre, operational feedback is used to continue checking on the validity of the design of the control centre during its lifespan. This is achieved by collecting and examining operational feedback information after the start of systems operation.

A post-commissioning audit with the primary goal of recording both the design successes and shortcomings should be performed. The resulting record should be a valuable resource for influencing future projects and evaluation studies.

10.2 Step 11: Collect operational experience

After starting up the operation, any identified ergonomic deficiencies should be collected. Field observations, interviewing or any other systematic methods can be used. To analyse the operational feedback information, task analysis techniques may be used. The results of such an analysis are a useful source of information when designing a new control centre or upgrading existing installations.

Inputs of step 11 include:

— operational practice;

— accident reports;

— deviation reports;

— operational logs.

Methods/Actions in step 11 may include:

— field observations;

— interviewing users;

— task analysis;

— questionnaire surveys.

Outputs from step 11 may include:

- resource information for new project;
- information regarding user's complaints;
- ergonomic deficiencies.

Annex A
(informative)

Examples of systems

Table A.1 — Examples of systems covered by this International Standard

Areas of application		Items tested	Type of operation	Examples of systems
Process control	Industrial processes	Raw materials, energy and waste materials	Batch continuous	Chemical plant
				Food plant
				Power plant
				Petroleum refinery
	Treatment and control	Raw materials and waste materials	continuous	River water processing plant
				Sewage processing plant
	Transmission and flow	Raw materials and energy	continuous	Gas supply
				Electrical grids
	Manufacturing	Products	discrete	Car assembly
Transportation		Vehicles	continuous	Air traffic
				Railway
				Highway
People deployment	Security control	People/Information	intermittent	Bank
				Building
	Civilian emergency response	People/Information	—	Fire station
				Police station
	Military service	Information	—	Military unit
	Information service	Information	—	Paging system
				Broadcast station

Annex B
(informative)

Basic recommendations and constraints to be clarified in clause 6

NOTE This list is given for information only and indicates the subjects which should be taken into account during the course of a design programme of a control centre.

B.1 General system descriptions of the overall project scope

In particular, the following should be taken into account:

- name and overall scope of the project;
- owner or client (governmental, public or private enterprise);
- location and conditions of site (for example, climate, geographical data);
- social impact and background;
- infra-structure and/or available installations;
- type of the overall project scope and its general specifications (for example, size, capacity);
- items tested (for example, raw material, information, people);
- system descriptions (for example, functional, operational);
- project outline (for example, organization, execution, procedures, schedule, budget);
- major time scales;
- upgrading programmes.

B.2 Safety and security recommendations

In particular, the following should be taken into account:

- cause or source of hazard or pollution (for example, flammable gas/liquid, toxic gas/liquid, radioactivity);
- fire protection system;
- intrusion alarm system;
- anti-explosion measures;
- anti-seismic measures;
- diagnostic system for equipment and/or system;
- emergency shutdown system;
- accident management;
- codes/regulations.

B.3 Operational and control recommendations

In particular, the following should be taken into account:

— type of operation (for example, continuous, batch, discrete, intermittent);

— items tested (for example, raw materials, energy, transportation vehicle, information, people);

— tasks (for example, control, monitoring, processing, instruction);

— process characteristics (for example, continuous, batch, discrete, intermittent);

— operational modes (for example, steady state control, programme control, sequential control);

— real-time requirements (for example, dynamic process, fire station);

— on-line requirements (for example, network, human intervention);

— philosophy of control centre (for example, integrated, centralized, distributed);

— back-up philosophy (for example, redundancy, hybrid, hard-wired);

— staffing level (for example, number of operators/staff);

— responsibility;

— shift system;

— arrangements for rest periods.

B.4 Ergonomic recommendations

In particular, the following should be taken into account:

— user population;

— operators attributes;

— work organization;

— job aids and working practices;

— shift rotation system;

— personnel qualification;

— training programme;

— technology transfer;

— cross-cultural aspects (for example, team work);

— visitor viewing;

— security air lock;

— control suite requirements (for example, equipment room, refreshment room, rest room, prayer room).

B.5 Restrictions and constraints

In particular, the following should be taken into account:

— local codes and/or regulations;

— international codes and/or standards.

— owner's standards;

— lack of management information.

Bibliography

[1] ISO 8402, *Quality management and quality assurance — Vocabulary*.

[2] ISO 9241-2, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 2: Guidance on task requirements.*

[3] ISO 9241-5, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 5: Workstation layout and postural requirements.*

[4] ISO 9355-1, *Ergonomic requirements for the design of displays and control actuators — Part 1: Human interactions with displays and control actuators.*

[5] ISO 9355-2, *Ergonomic requirements for the design of displays and control actuators — Part 2: Displays.*

[6] ISO 13407, *Human-centred design processes for interactive systems.*

[7] ISO 10075-2, *Ergonomic principles related to mental workload — Part 2: Design principles.*

[8] IEC 60964, *Design for control rooms of nuclear power plants.*

[9] EN 614-1, *Safety of machinery — Ergonomic design principles — Part 1: Terminology and general principles.*

[10] IAEA International Atomic Energy Agency (ed.), 1989; *Models and Data Requirements for Human Reliability Analysis.* IAEA-TECDOC-499.IAEA, Vienna.

[11] Kirwan, B., Ainsworth, L.K., 1992, *A guide to task analysis*, ISBN 07484 0057 5, Taylor & Francis, London.

[12] Masiano, R.E., Price, H.E., and Van Cott, H.P., 1982, *Allocation of functions in man-machine systems: a perspective and literature review*, NUREG/CR-2623.

[13] Pikaar, R.N. *et al*, 1997, *Ergonomics in Process Control Rooms, Part 1: Engineering Guideline*, International Instrument Users' Associations SIREP-WIB-EXERA, Report M2655X97.

[14] Pikaar, R.N. *et al*, 1997, *Ergonomics in Process Control Rooms, Part 2: Design Guideline*, International Instrument Users' Associations SIREP-WIB-EXERA, Report M2656X97.

[15] Pulliam, R. and Price, H.E., 1983, *Methodology for allocating nuclear power control functions to human or automatic control*, NUREG/CR-3331.

[16] Pulliam, R. and Price, H.E., 1984, Allocation Functions to Man or Machine in Nuclear Power Plant Control, *The Nuclear Engineer*, **25**(3), 79-85.

[17] Price, H.E., 1985, The allocation of functions in systems, *Human Factors*, **27**(1), 33-45.

[18] Rijnsdorp, J.E., 1991, *Integrated process control and automation*, ISBN 0444 88128 X, Elsevier, Amsterdam.

[19] Salvendy, G., (ed.), 1997, *Handbook of Human Factors*, ISBN 0471116904, John Wiley & Sons, New York.

[20] Van Cott, H.P., Kinkade, R.G., 1972, *Human Engineering Guide to Equipment Design*, American Institute for Research, Washington, DC.

[21] Wilson, J.R., Corlett, E.N., 1995, *Evaluation of human work: a practical ergonomics methodology*, ISBN 07484 0084 2, Taylor & Francis, London.

[22] Woodson, W.E., 1981, *Human Factors Handbook*, ISBN 0-07-071765-6, McGraw Hill, New York.

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