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Human Factors Module

Human Factors in the Development of Air Traffic Management Systems

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Abstract

This document is, within the Human Resources Domain, one of the human factors modules. These modules deal with human performance. This module provides an introduction to the integration of human factors in the development of air traffic management systems.

The module will provide the reader with an awareness of the importance and benefits of integrating human factors in the process of developing air traffic management systems. The module will accommodate an understanding of the factors involved in the system life-cycle, a guidance for steering the integration of human factors in the system development process and methods to support this process.

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EXECUTIVE SUMMARY

The module is intended to provide the reader with an awareness of the importance and benefits of integrating human factors in the process of developing Air Traffic Management (ATM) systems. The module will accommodate an understanding of the factors involved in the system life-cycle, a guidance for steering the integration of human factors in the system development process and methods to support this process.

Chapter 1, 'Introduction', outlines the scope, objectives and target audience for the module.

Chapter 2, 'Human Factors', provides a brief overview of human factors - what it is and some concepts.

Chapter 3, 'Costs and Benefits of Human Factors Integration', highlights the benefits of integrating human factors in the system development process, such as reduced development and operational costs and improvements to the efficiency of the system.

Chapter 4, 'Integrating Human Factors in the System Life-Cycle', outlines the change process to accommodate and the organisation needed to handle the system life-cycle. A walk through a typical system life-cycle outlines the integration of human factors in the process.

Chapter 5, 'Human Factor Methods', provides an overview of methods, some identified in Chapter 4, used during system development.

Annex A provides a checklist for human factors integration in the system life-cycle.

Annex B outlines some guiding principles for task automation.

Annex C lists and explains some typical negative effects of task automation.

Annex D gives some guidelines for designing human-machine interfaces.

Further annexes contain references, a glossary, and abbreviations and acronyms.

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1. INTRODUCTION

'One of the lessons we learned early on in our modernization program, was that ignoring human factors in our major acquisitions can cost us dearly, both in the expense of re-engineering and in schedule delays. We've (the FAA) made it a requirement that human factors must be systematically integrated at each critical step in the design, testing, and acquisition of any new technology introduced into the air traffic control system.'

(Del Balzo, 1993, p. 3)

The integration of human factors in the development of ATM systems is often neglected despite the fact that it is a very important issue. The quotation given above summarises the lesson that has been learned by many people the hard way. The trouble is that unless the approach to ATM systems development changes, many more people will make the same mistakes.

In a world of increasing air traffic, the response has been to restructure the airspace and introduce big information technology systems. Information technology which has given us the capacity to handle large amounts of information has also left it to the human operator to handle the unstructured problems and the situations where judgement has to be exercised.

The flexibility and adaptability which are characteristics of human activity have meant that ATM systems have been developed with a primary concern for technology, or in other words the approach has been technology-driven.

There is, however, increasing concern that this approach, no matter how many benefits it has brought us in the past, will no longer suffice. There is a concern that we will soon reach the limits of the human operator's ability to handle traffic. As the bandwidth of the information technologies will increase significantly in the future, the bandwidth of the human operator will remain relatively constant.

While the human operator in some respects will become the limiting factor in tomorrow's ATM systems, it will also be the adaptability and judgement of the operator which will make those systems safe and effective.

1.1 Scope and Purpose of this Document

This module is made in recognition of the increasing importance of humans interacting and working with technology in air traffic management. The document does not set out a detailed account of this vast and complex area. It merely scratches the surface and is intended to provide the reader with an overview of some of the aspects to consider during the design or acquisition of ATM systems.

The aim of the module is to provide readers with:

- ♦ an overview of the human factors to be taken into account during system development;
- ♦ an understanding of the importance, costs and benefits of integrating human factors in the development process;
- ♦ an overview of the phases in a system life-cycle, where concern for human factors is needed and what to do about it;
- ♦ a short introduction to some of the techniques and methods to use for integrating human factors.

The target audience for this module may have one of the following profiles:

- ♦ manager of air traffic services, responsible for system development or procurement;
- ♦ procurement official with no prior human factors knowledge;
- ♦ system designer, who has no prior human factors knowledge;
- ♦ human factors specialist involved in the system development who needs guidance or refreshment on how to integrate human factors in the development process.

1.2 Outline of the Document

The document should answer the following questions:

Question	Chapter
♦ What are human factors?	2
♦ Why are human factors important in the development of ATM systems?	3
♦ What could happen if I do not take action to integrate human factors in the system development process?	
♦ How do I manage and plan for human factors?	4
♦ How do I integrate human factors in the system development process?	
♦ What methods can I use during the system development?	5
♦ What should I do to integrate human factors?	Annex A
♦ What are the principles for automation design?	Annex B
♦ What are the negative effects of task automation?	Annex C
♦ I need some guidance for the design of human-machine interfaces. What do I do?	Annex D

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2. HUMAN FACTORS

Human factors are for this report defined as a multi-disciplinary effort to compile and generate knowledge about people at work and apply that knowledge to the functional relationships between people, tasks, technologies and environment in order to produce safe and efficient human performance.

Human factors include concern for cognition, behaviour, aptitudes and performance.

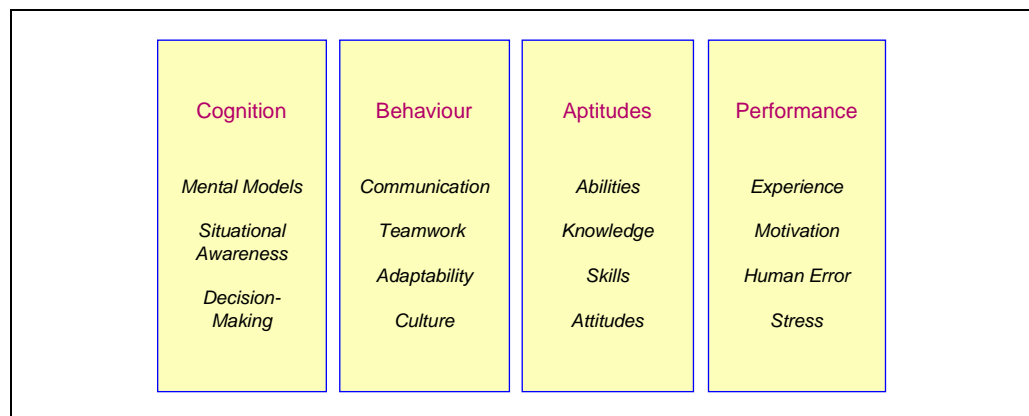


Figure 1: Human factors areas

We may break down the human factors into several issues: those that are dealing with the factors related to individuals, such as ergonomic factors and cognitive factors, or those that are dealing with interactive aspects of human activity, such as teamwork, communication and task sharing.

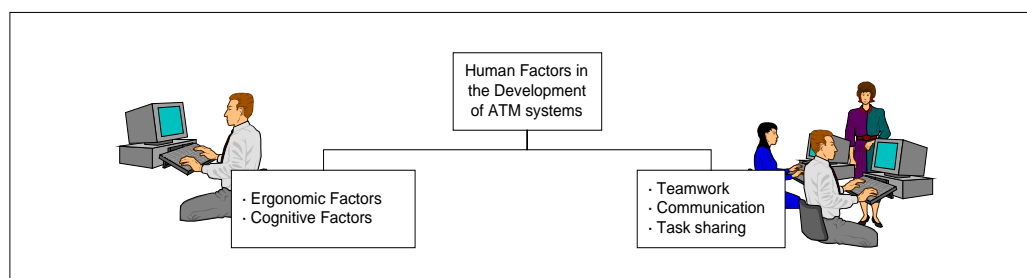


Figure 2: Human factors in the development of ATM systems

This chapter provides a brief overview of some of the basic concepts in each of these areas.

2.1 Human Cognition

Human cognition, or cognition in short, refers to our mental processes and their components, such as attention, perception, memory and decision-making. Sub-chapters 2.1.1 to 2.1.3 give a brief introduction to some fundamental concepts and models to assist the understanding of human cognition.

2.1.1 Some Basic Concepts

Some concepts are basic and fundamental to the understanding of human thought processes, such as:

- ♦ mental model and mental picture,
- ♦ situational awareness,
- ♦ decision-making.

Mental Model and Mental Picture

Mental models are the cognitive representations whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions about future system states.

A mental picture is a representation of a situation in a moment-to-moment snapshot of the actual situation based on the mental model and the actually perceived external cues.

Situational Awareness

Closely linked with the mental picture is situational awareness. Situational awareness describes the extent to which the operator has an integrated and detailed understanding of the operational environment (see [Figure 3](#)), and can be defined as the:

‘... continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events.’

(Domingues et al., 1994)

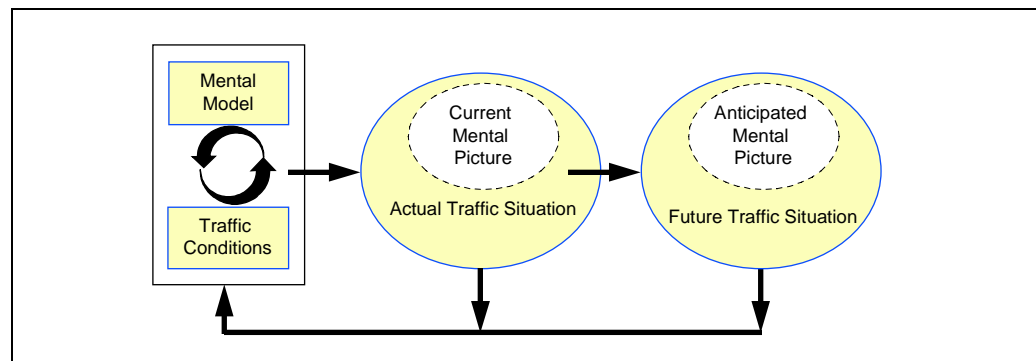


Figure 3: Situational awareness stems from information about the traffic conditions and a mental model of how to interpret the information based on previous experience

Decision-making

Decision-making is an active cognitive process which selects one out of a set of possible courses of action. Decision-making requires careful consideration of the pros and cons of different alternatives.

In most cases, the Air Traffic Controller's (ATCO) decision-making process can be described as a three-step process. The three decision steps answer the following questions:

1. Is a control action necessary or is monitoring sufficient?
2. What kind of control actions will have to be conducted to reach a specific goal?
3. When is the control action to be delivered?

2.1.2 Human Information Processing

Our ability as humans to think and solve problems is a complex phenomenon. It is hard to understand just how our brain connects with our eyes, ears, mouth and hands to make them work together or how we can co-ordinate complex tasks with other people, manipulate advanced equipment and solve difficult problems.

In order to understand all of this we may use a simplified view on human thinking. The way we solve problems may in simplified terms be described as the processing of information (such as that done by a computer), and it is therefore sometimes referred to as the 'Model of Human Information Processing'. The following outlines the basic cognitive structures, such as memory, and describe the mental processes that take place. For a more thorough description see 'Model of the Cognitive Aspects of Air Traffic Control' (EATCHIP, 1997).

Cognitive Structures

The model we shall use of the cognitive structures for human information processing is made up of four elements:

- ♦ **Working (or short-term) memory:** The working memory is a short-term buffer with a limited capacity for new incoming data and information. It can only handle a set of about five to nine elements or combined elements (called chunks) at the same time. Without active rehearsal procedures, memory traces fade within a few seconds.
- ♦ **Long-term memory:** A long-term memory structure allows information, information processing routines and programmes to be stored for later retrieval.
- ♦ **Input/output system:** The input/output system takes care of the interaction with the working environment and the cues received by the operator. It is organised in functional loops, such as radar screen information loop, flight-strip information loop, co-ordinating/tactical operator loop, RadioTelephony (R/T) communication loop, etc.
- ♦ **Process control system:** The process control system is a kind of internal evaluation system which makes sure that action, in our case Air Traffic Control (ATC), takes place as planned by the operator. Therefore, the most important function of the process control system is to maintain situational awareness.

Information arrives at the process control system through the input/output system (modelling the sensory input from the eyes and ears, for example). The information is processed by the process control system in the short-term memory. The processing is done through the application of knowledge 'chunks' from the long-term memory. The processing result is executed (as an action taken by the human) through the input/output system.

Mental Processes

ATC has much in common with the control of goal-directed behaviour in general. The main difference between ATC and the cognitive control of one's own actions is that the operator has to direct external activity which needs to be co-ordinated with others.

Five different processes (see [Figure 4](#)) should be considered in the description of ATC:

- ♦ **Monitoring** refers to the continuous or intermittent comparison between the anticipated traffic situation and the actual status of the system.
- ♦ **Controlling** in the strict sense of the word denotes an intervention which actively tries to change the traffic situation.
- ♦ **Checking** is a process of situational scanning which takes place intermittently or as a consequence of unexpected events.
- ♦ **Diagnosing** is an active process of information search which tries to explain unexpected or new traffic situations.
- ♦ **Problem-solving** is an active reasoning process for devising a solution to a problem and adjusting the mental model accordingly.

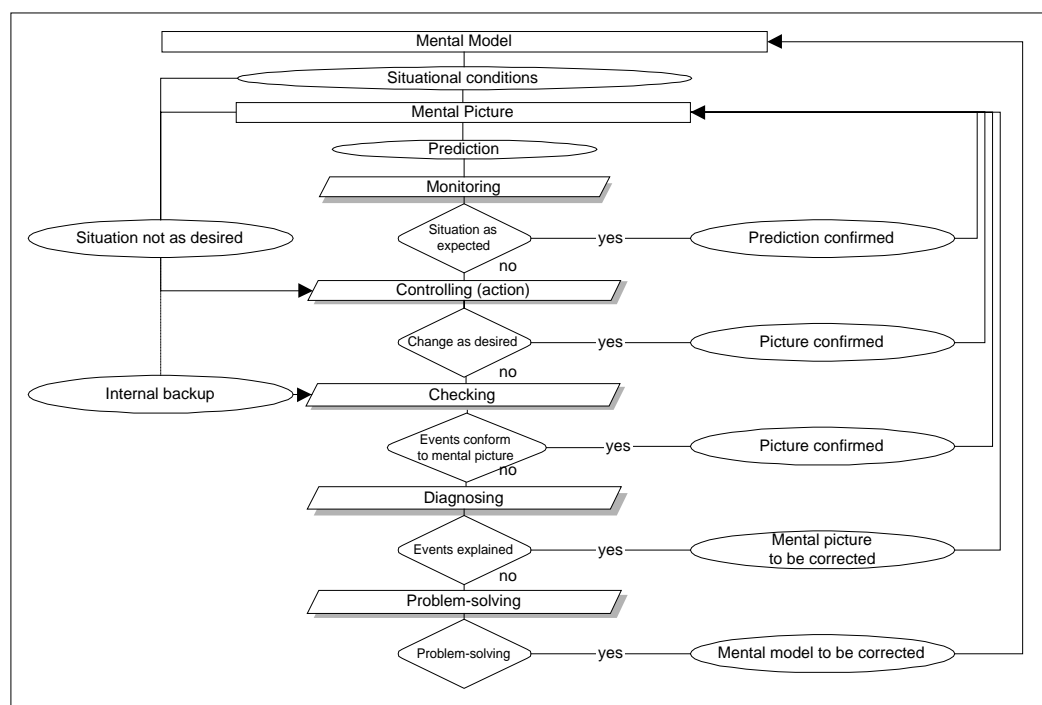


Figure 4: Basic functions of ATC

2.1.3

Performance Factors

Human performance is not a constant. It varies according to significant situational factors and with the mental resources available to the individual.

Figure 5 shows some of the factors that influence an ATCO's situational awareness.

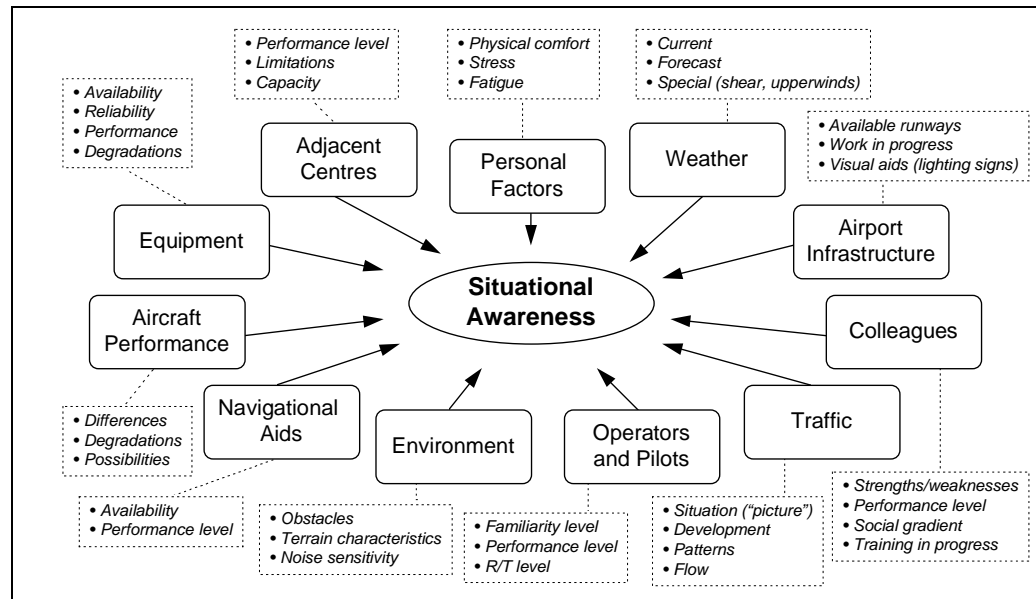


Figure 5: Factors influencing situational awareness (Ruitenbergh, 1997)

From the many influential factors shown in [Figure 5](#) it is generally agreed that the stress and urgency surrounding a task are most predominant within ATC. The level of workload, for example, has a strong impact on the ATCO's situational awareness. If the workload is too low the awareness drops because of low vigilance, and if the workload becomes too high the ATCO risks losing the traffic picture.

2.2 Ergonomic Factors

The working environment of the ATCO can generally be separated into the Controller Working Position (CWP) itself and the surrounding environment. The working position of an ATCO has to support his or her effective performance. The factors influencing performance aspects of an ATCO's work relate to visibility, auditory input, control inputs, physiological factors, anthropomorphic factors (factors related to the size and proportions of the human body) and communication. [Figure 6](#) shows, for example, some of the constraints on the visibility of controls and displays affecting the operator's performance.

Design of the outer working environment has to take aspects such as lighting levels, reflection from windows, noise levels, heating and humidity in the room into account.

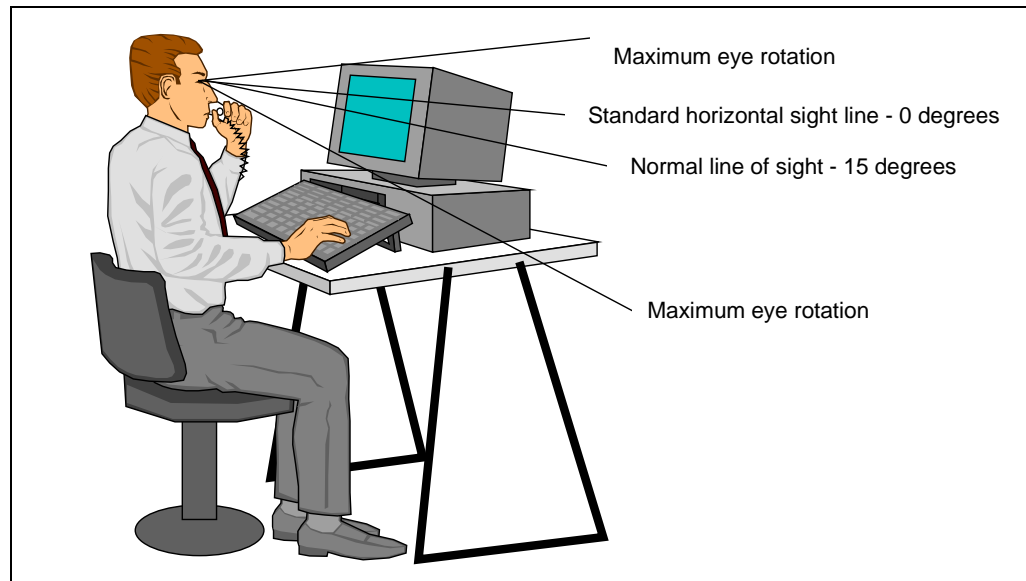


Figure 6: Visibility of controls and displays

2.3 Teamwork and Human-Machine Interaction

Most tasks need some kind of co-ordination between human beings, and between humans and machines. Sub-chapters 2.3.1 and 2.3.2 provide a short introduction to some of these concerns.

2.3.1 Teamwork

Operators form part of many teams at the same time. The teams may be made up of other individuals from the same work shift, from adjacent sectors, in cockpits of the aircraft under control, etc.

The performance of these different teams depends on a number of factors:

- ♦ understanding the nature of roles in the teams;
- ♦ good communication among team members;
- ♦ staying aware of own situation as well as the situation of others;
- ♦ understanding decision-making strategies and individual differences within them;
- ♦ appreciating different controlling styles which both leaders and followers can support;
- ♦ recognising own as well as others' stressors.

Shared Traffic Picture

To achieve an effective interaction among humans, and between human beings and machines, it is important to have a common reference and shared understanding, as shown in [Figure 7](#). Humans working together with computers need to share the traffic picture in order to provide a primary basis for understanding it.

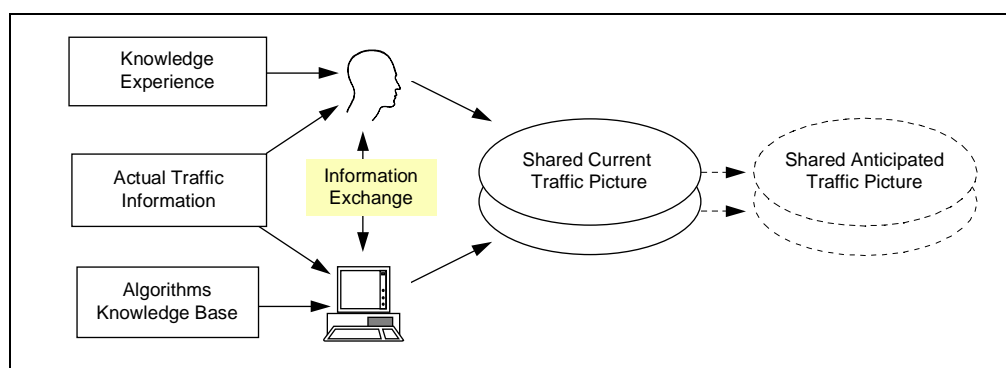


Figure 7: Shared human-machine situational awareness

2.3.2

Task Sharing between Human and Machine

The allocation of tasks between humans and machines should look at the role each must play and the requirements from the tasks, as well as the strengths and limitations for each to perform the task. A list of strengths has been developed by Fitts (1951). A modified version of this list is shown in [Table 1](#).

Table 1: Strengths of humans and machines (modified from Fitts, 1951)

Humans are better at:	Machines are better at:
<ul style="list-style-type: none"> ♦ Detecting small amounts of visual, auditory or chemical energy ♦ Being sensitive to an extremely wide variety of stimuli ♦ Perceiving patterns and making generalisations about them ♦ Improvising and using flexible procedures ♦ Storing information for long periods of time, and recalling appropriate parts ♦ Reasoning inductively ♦ Exercising judgement 	<ul style="list-style-type: none"> ♦ Monitoring (both humans and machines) ♦ Performing routine or repetitive tasks ♦ Storing and recalling large amounts of information rapidly ♦ Responding quickly to control signals ♦ Reasoning deductively ♦ Doing many complex operations at once

3. COSTS AND BENEFITS OF HUMAN FACTORS INTEGRATION

'Pay now - or pay more later'

Experience gained from the design of large power plants, chemical processes, aircraft, and other large and complex systems has shown the importance of integrating the systems inhabitants, the humans, from the beginning and throughout. Many systems have been designed and built as ingenious masterpieces, only to present multiple problems for the people operating them, which consequently results in low performance and productivity, or worse, infringement of safety.

Two concepts are of key importance in the assessment of any given system:

1. **Usability:** Refers to whether a system is easy to use, easy to learn and efficient for the human to apply for performing a certain task.
2. **Acceptability:** Refers to whether the humans coming into contact with the system accept its existence and the way in which it operates.

Integrating human factors in the system life-cycle will maximise the acceptability of the system and considerably improve its usability.

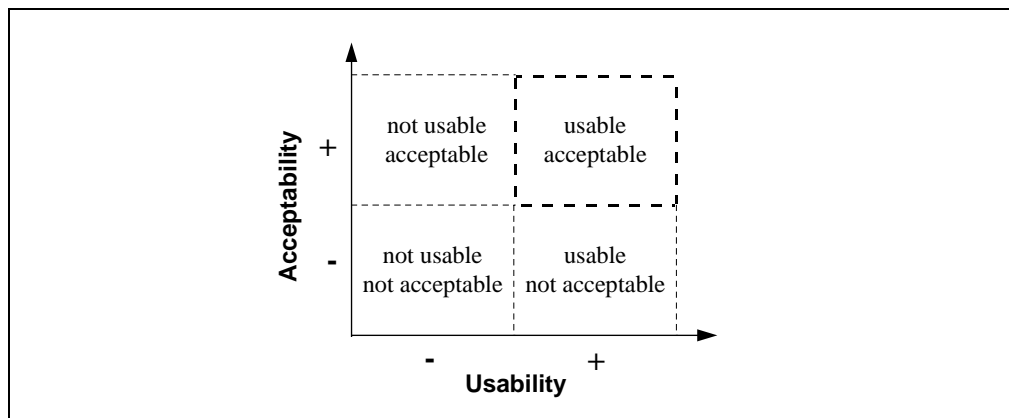


Figure 8: Designing for acceptability and usability

Sub-chapters 3.1 and 3.2 will look in more detail at some of the benefits and costs of integrating human factors in the development process.

3.1 The Cost of Human Factors Integration

It is generally believed that the decisions made during the first stages of a system design determine the main body (more than 80%) of a system's life-cycle cost. In an increasingly competitive world of privatised air traffic service providers and national administrations under tight budget control, it is

therefore important to pay extra attention to these first steps when initiating the acquisition of a new system or when modifying an existing one.

An awareness and concern for human factors in the system development will increase the attention towards human performance in the system. With good planning for human factors integration and a qualified application of philosophies, guidelines and techniques, most of the problems related with human performance will be detected in the early phases of the system development. This situation, shown in [Figure 9A](#), will support an early detection of the problems and as a consequence lower the human performance problems later in the system life-cycle, such as during operation.

If no attention is paid to these issues early in the development, as depicted with a dotted line in [Figure 9A](#), the problems are merely postponed to the later stages of the system life-cycle.

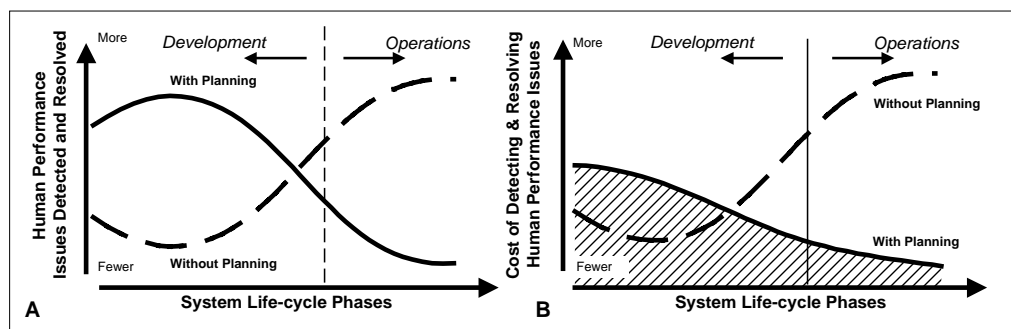


Figure 9: The cost of detecting and resolving human performance issues (adapted from Cardosi and Murphy, 1995)

While it may appear to be costly to solve the human performance problems early in the development, it is actually cheaper in the long run as can be seen from [Figure 9B](#). Detecting a problem during development simply means facing it up front. If the problem is lying dormant it will surface later and cause even more problems. If the problem is left unresolved until after the system has been brought into operation, it will not only pose a cost in terms of lower performance, but the cost of mending it is much higher. The cost of solving human performance issues will decline rapidly with the integration of human factors (see [Figure 9B](#)). If the problems are left to the operation of the system, the cost of fixing them will increase throughout the life-time of the system.

To put it briefly, it is a matter of either paying now for detecting and resolving the problems - or paying more later, which by all accounts will be significantly more costly.

3.2 The Benefits of Human Factors Integration

Integrating human factors in the system design will result in benefits on the two following levels:

1. The development cycle, from the development of the initial concept of the system to its installation, will benefit from issues such as more effective product testing, improved training and selection, and better system documentation.
2. At the working position level, human factors integration will contribute to reduced fatigue and physical stress, a reduction in monotony and boredom, improved comfort for the humans, an improved working environment and a reduction in human errors.

These factors will at the overall system level provide the benefits of increased efficiency and productivity, improved maintainability, increased system reliability and increased safety, as shown in [Figure 10](#).

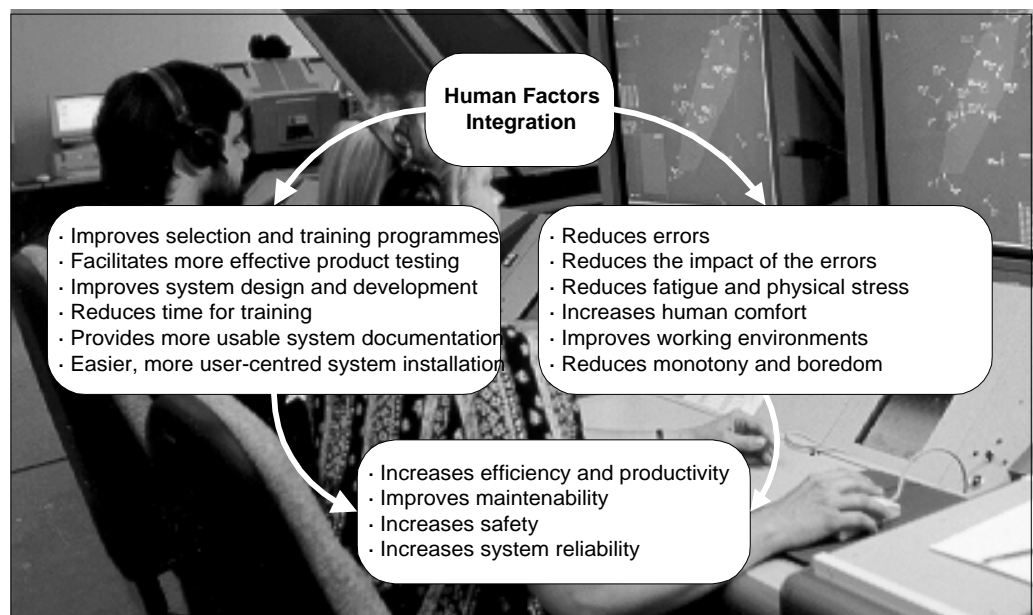


Figure 10: Some benefits of human factors integration

The benefits of employing human factors integration can be summarised as follows:

- reduced overall cost of system development, implementation, maintenance and operation.
- increased human efficiency and productivity through adequate design.
- increased safety through better integration of humans and improved system reliability.

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4. INTEGRATING HUMAN FACTORS IN THE SYSTEM LIFE-CYCLE

'The captain and first officer did not sufficiently understand the FD (Flight Director) mode change and the AP (AutoPilot) override function. It is considered that unclear descriptions of the AFS (Automatic Flight System) in the FCOM (Flight Crew Operating Manual) prepared by the aircraft manufacturer contributed to this'.

(Excerpt from aircraft accident report - MoT, 1996)

4.1 Introduction

The development of systems traditionally tends to concern itself primarily with technological aspects. This chapter approaches the development process from a different perspective.

We need to concern ourselves not only with the development process, but with the entire life-cycle of the system. In the first life-cycle phases during which the organisation prepares for the system, there is a need for concern for the people who will be affected by the changes. This process requires management and a network of people needs to be established. Sub-chapter 4.4 presents a model of the system life-cycle and associate some important milestones with the phases, together with some major questions to be answered.

4.2 Management of Change

A well-known problem connected with the introduction of a new system (or even changes to an existing system) is that people in the workplace may feel threatened, alienated or otherwise uncomfortable with the change. It is therefore crucial to *manage the change* and to make sure that its introduction is successful. A number of key activities are related to such implementation:

- ♦ **Provide help to face up to change:** It is important to help people to face up to the change and take them through the crisis stages towards an acceptance of the need to change. Experience shows, however, that approximately 10% of the people in an organisation will have serious doubts concerning the benefits of the change process and will resist it.
- ♦ **Communicate as you have never communicated before:** Communication becomes a key activity in the change process. It is important to inform, to the maximum extent possible, in order to avoid uncertainty among employees. Rumours can be detrimental to the change process. It is equally important to receive feedback during the

change process to obtain an accurate feeling of how things are being received and to improve implementation.

- ♦ **Gaining energetic commitment to the change:** In the short-term commitment can be gained from a focus on the survival of the organisation. In the long-term the commitment has to come from system reward structures, employment policies and management practices.
- ♦ **Early involvement:** Early involvement of the affected people in the formulation of the change will go a long way towards reducing behavioural resistance during implementation. It will considerably reduce the amount of energy that has to be expended on coercion and power strategies to enforce compliance. The involvement of the end-user operators in the preliminary design phase is an involvement at an early stage, which will support the basic acceptance from the end-users.
- ♦ **Turn perception of 'threat' into opportunity:** A change process is likely to be seen as a threat by people. Experience shows that an organisation which can change this perception so that the change is seen as an opportunity is more likely to succeed. The change process should be viewed by people as natural, continuing and opportunity-providing.
- ♦ **Avoid over-organising:** The change process should be well thought-out before it takes place, but it should be recognised that the process is very organic in nature. One should not stick to the plan just because it is there, but rather learn from the situations as they develop - remember, a change process is a learning process.
- ♦ **Train for the change:** People's perception of the change may transform significantly if they have an opportunity to understand better what will be required of them. Training sessions can significantly reduce the resistance to the change.



4.3 Organising the Integration of Human Factors

The approach taken here would see the development team comprising roughly of people with the following profiles:

- ♦ system developers, typically software engineers;
- ♦ end-users, usually the operational controllers, supervisors and maintenance engineers;
- ♦ managers responsible for directing the development process;
- ♦ human factors specialists, who participate to ensure the integration of human factors.

4.3.1 Designation of Person Responsible for Human Factors

It is important that a person responsible for human factors is nominated for the system development. The nomination should be made at the earliest possible stage of the development process. As argued in Sub-chapter 3.1, the earlier human factors are taken into account, the less the system will cost in the long-term. The person responsible for human factors should participate in the planning and management throughout the life-cycle of the system.

The person responsible should be a human factors specialist with good qualifications and experience from applying human factors principles and methods. If the human factors specialist does not have a background in ATM, it is important that he or she receives a proper training and exposure to an operational environment.

David Hopkin describes the objective of the specialist as follows:

'An important function of the human factors specialist during system design is ... to ensure that designers understand the relevance of human factors contributions enough to allow the human factors recommendations to be integrated into the design process.'

(Hopkin, 1995)

4.3.2 Users' Group

An important step in organising the process of system development is the establishment of a users' group. While users may not always be the best judge of what will provide the best operational performance, their feedback, interaction and commitment are imperative. The users' group is also a key element in the change process and in obtaining acceptance of the system as well as improving the future system and incorporating past experience.

The composition of the users' group may change between the initial phases of the system life-cycle and the long-term operational phase. While the development process may require a relatively stable operator group to ensure continuity, the operational phase may call for the operators to be changed to retain the dynamics of the process.



The users' group should have a suitable balance of operational, technical, systems and support personnel. The representatives should be experienced and well qualified in their profession with operational experience from the air traffic centre. The selected representatives should also be respected by their peers.

4.4 Human Factors in the System Life-Cycle

We shall use the entire life-cycle of a system as defined by Barry Kirwan and his colleagues (Kirwan et al., 1997). According to them, the (generic) system life-cycle can be divided into a number of phases:

- ♦ **Concept development:** Development and assessment of initial ideas and philosophies.
- ♦ **Preliminary design:** Sufficient design to prove the feasibility of developing the system.
- ♦ **Detailed design:** Complete design of the system, all of its components, controls and displays, etc., down to the precise location and including ergonomic design.
- ♦ **Construction and commissioning:** Building the system, making it work and introducing the humans to it.
- ♦ **Operation and maintenance:** Running and maintaining the system.
- ♦ **System modification:** Modifying the system as necessitated by technological, economic and/or operational experience.
- ♦ **Re-cycling:** Dismantling and disposing of the system, and re-using the human resources.

Figure 11 summarises the system life-cycle phases and some important issues to consider.

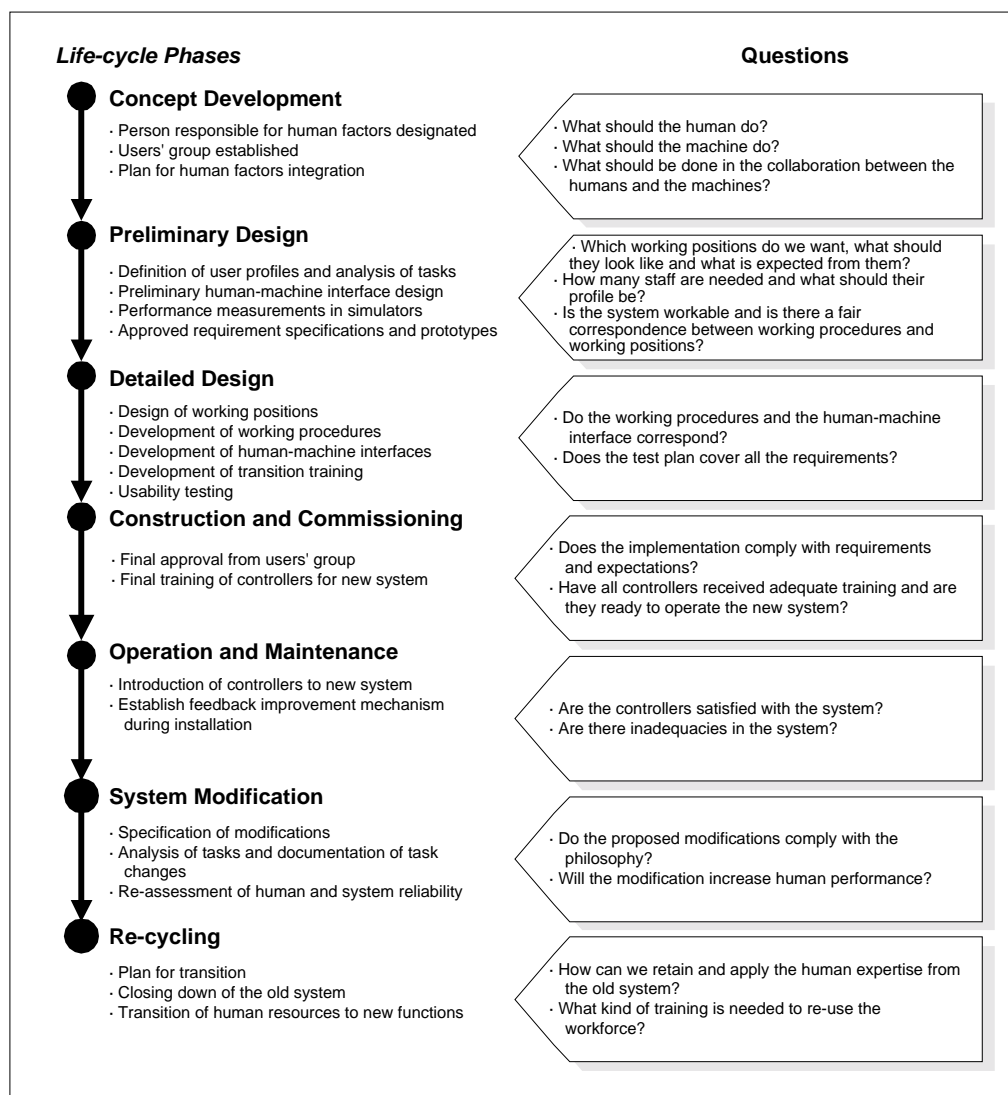


Figure 11: Human factors in the system life-cycle

Sub-chapters 4.4.1 to 4.4.7 each describe one of these phases. For each phase, a summarising checklist is provided in the form of a table at the end of every sub-chapter.

4.4.1

Concept Development

During the concept development phase the first, typically tentative and ambiguous, steps are taken. Major principles to guide the system development and the philosophy for allocation of tasks between humans and machines are defined. This is also the phase that will see the first formalisation of human factors integration, through the designation of a person responsible for human factors and the establishment of a users' group.

The person responsible for human factors should draw up a plan on how to integrate human factors into the development process in collaboration with the users' group and with the approval of the project managers.

The initial specification of the system concept should answer basic questions as to what the human would do, what the machine should do, and how they should work together and share tasks. At this phase, principles for system automation, such as those outlined in [Annex B](#), should be consulted.

The initial specification and plan should be evaluated by the users' group for comments and approval.

Table 2: Checklist for the concept development phase

Milestones	Questions
<ul style="list-style-type: none"> ♦ Person responsible for human factors designated ♦ Users' group established ♦ Plan for integration of human factors 	<ul style="list-style-type: none"> ♦ What should the humans do? ♦ What should be done by machines? ♦ What should be done in collaboration between the humans and the machines?

4.4.2

Preliminary Design

The preliminary design phase sets out to sketch the design through early design, mock-up systems and prototypes. This phase should see a substantial involvement of the users' group. The design should address the analysis of tasks to be performed, the basic layout of the workplace, human-machine interface and equipment, considerations of how many people are needed to operate the system, and the type of displays and consoles.

A profile of the users (ATCOs, supervisors, maintenance engineers, etc.) should be drawn up to identify the basic skills needed by the new system. A task analysis should be made for each of the working positions that are considered, providing some details of the composition of the work and an analysis of the interaction between the humans as well as among the humans and the computers.

Consideration should be given as to the kind of training required and whether new recruits should be taken on. The availability of adequate staff should be ensured early on in the process, as training development and recruitment in particular can be long-term processes. (Some estimate the average lead time from the decision to recruit up to the establishment of a fully operational controller to be approximately 3.5 years.)

In this phase, mock-ups and prototypes of the working positions and systems should be made. The prototype systems should have usability tests and enable the operators to get a 'look-and-feel' for the system. Simulations under

realistic traffic conditions should be carried out and measures of human performance made. The latter should be based on a model of cognition, such as the one described in [Sub-chapter 2.1](#), and would typically focus on issues such as situational awareness, workload, co-ordination of activity and communication.

The result of this phase should be a detailed requirement specification and prototypes of the system approved by the end-users involved.

Table 3: Checklist for the preliminary design phase

Milestones	Questions
<ul style="list-style-type: none">♦ Definition of user profiles and analysis of tasks♦ Preliminary Human-Machine Interface design♦ Performance measurements in simulators♦ Approved requirement specifications and prototypes	<ul style="list-style-type: none">♦ Which working positions do we want, what should they look like and what is expected from them?♦ How many staff are needed and what should their profile be?♦ Is the system workable and is there a fair correspondence between working procedures and working positions?

4.4.3

Detailed Design

The detailed design phase should cater for specifications elaborate enough to enable construction of the system, requiring all aspects of the system to be described in minute detail.

The detailed design should cover items ranging from working procedures to the workplace and the training of operators. This means that the final working procedures and the contents of the transition training should be finalised. Furthermore, it means that the dimensions and ergonomics of the workplace have to be defined, as well as user-friendly human-machine interfaces and other aspects of the working environment. To support the design of the human-machine interface, guidelines such as those outlined in [Annex D](#) may be applied.

The usability of the system in regard to the working procedures needs to be carefully analysed and the correspondence with the human-machine interfaces has to be studied. Usability testing of the system should therefore be applied rigorously to ensure that the design is sound and that no inadequate features remain.

A plan for testing and evaluating the system should be finalised. The test plan should ensure that all requirements are being dealt with adequately. Aspects related with human performance should be a integrated component of the test plan.

Table 4: Checklist for the detailed design phase

Milestones	Questions
<ul style="list-style-type: none"> ♦ Design of working positions ♦ Development of working procedures ♦ Development of human-machine interfaces ♦ Development of transition training ♦ Usability testing 	<ul style="list-style-type: none"> ♦ Do the working procedures and the human-machine interface correspond? ♦ Does the test plan cover all the requirements?

4.4.4 Construction and Commissioning

During the construction of the system the users' group should be kept involved and should participate in regular project meetings with the contracted developers. Changes are bound to occur during the construction and the developers will need the feedback from end-users. The involvement of the group will also ensure that the intentions from the first phases of the system development are carried out and that the system implementation will conform to the requirements.

In parallel with the implementation of the system the operators required for its future operation need to complete their training before taking up their duties in operating it or before they start operating it.

Table 5: Checklist for the construction and commissioning phase

Milestones	Questions
<ul style="list-style-type: none"> ♦ Final approval from users' group ♦ Final training of operators for new system 	<ul style="list-style-type: none"> ♦ Does the implementation comply with requirements and expectations? ♦ Have all operators received adequate training and are they ready to operate the new system?

4.4.5 Operation and Maintenance

The introduction of the operators to the new system will inevitably be a critical point in the system life-cycle. It is a crucial point in the change process as the operators will encounter the real system for the first time. They should already feel acquainted with the system because of the early prototypes and their training. It is, however, the first time that they will encounter the system in a real working context. This first encounter may be stressful as the operators struggle to come up to speed with the tasks and the system.

It is important in this phase to devise mechanisms to take feedback from the operators into account. While the operators on the one hand have to accustom themselves with the new system and its working procedures, they can on the other hand provide significant feedback on inadequacies early on in its operation.

The users' group will play a vital role in the normal operation and maintenance of the system and should stimulate the ongoing concern for human factors.

Table 6: Checklist for the operation and maintenance phase

Milestones	Questions
<ul style="list-style-type: none">♦ Introduction of operators to new system♦ Establish feedback improvement mechanism during installation	<ul style="list-style-type: none">♦ Are the operators satisfied with the system?♦ Are there inadequacies in the system?

4.4.6

System Modification

Modifications to operating systems are a fact of life; they may occur out of necessity or as an opportunity to improve the system. The person responsible for human factors and the users' group will have to investigate carefully whether the modifications comply with the initial philosophy as outlined during the concept development phase.

Whenever changes to the system are planned, it is vital to analyse the impact on human performance and workload. In order to do so task analysis and simulations may be performed.

While modifications may be minor and could seem irrelevant they may, if altering the operation of the system in a significant way, need substantial consideration. If the modifications are large, such as making a transition to a strip-less operator environment, it may be necessary to treat the new functions in the system through the same optic outlined in this module as used when considering an entirely new system.

Table 7: Checklist for the system modifications

Milestones	Questions
<ul style="list-style-type: none">♦ Specification of modifications♦ Analysis of tasks and documentation of task changes♦ Re-assessment of human and system reliability	<ul style="list-style-type: none">♦ Does the proposed modification comply with the philosophy?♦ Will the modification increase human performance?

4.4.7 Re-cycling

At the end of the systems lifetime, it is necessary to consider how the system functions and how the resources around it may be re-used. The transition phase should be planned well in advance. Consideration should be given at to how the humans previously operating or maintaining the system can be brought to best use in a new working context.

Table 8: Checklist for the re-cycling phase

Milestones	Questions
<ul style="list-style-type: none">♦ Plan for transition♦ Closing down of the old system♦ Transition of human resources to new functions	<ul style="list-style-type: none">♦ How can we retain and apply the human expertise from the old system?♦ What kind of training is needed to re-use the workforce?

5. HUMAN FACTORS METHODS

In order to tackle the study, analysis and application of human factors, various techniques and methods are available although further research and development are needed in specific areas. This chapter gives an overview of some commonly used methods without trying to be exhaustive.

5.1 Human Error Analysis

Errors are an intrinsic characteristic of human activity. We act and we occasionally fail (Cicero would even claim that this is the hallmark of a human). We do not fail randomly and the patterns in our errors reveal a great deal about our limitations as humans. When dealing with human errors we should, however, remind ourselves that as humans we are unmatched in our flexibility in controlling systems.

Incident Report Analysis

A primary source in the identification of human errors in ATM is incident reports. While accidents are normally investigated thoroughly and accident reports consequently very detailed, incidents provide a much larger variety and quantity of data. Analysis of incident reports may give a good overview of the problems and shortcomings encountered in the work of an operator. Such problems may range from system malfunctions and inadequate system design to behavioural slips and cognitive mistakes. An overview of some of the issues in incident reporting and analysis is given in 'Human Factors Module - Human Factors in the Investigation of Accidents and Incidents' (EATCHIP, 1998a).



Human Reliability Assessment (HRA)

Embraces the identification of errors, the quantification of errors and the prevention of errors (Hollnagel, 1997). The means to achieve this assessment is gained through tools such as fault trees and statistical analysis.

5.2 Task and Workload Analysis

Task analysis may be applied to break activity down into its constituent parts in order to describe these parts as well as the ways in which they are organised. Task analysis can be applied for many purposes, such as identifying training requirements or designing human-computer dialogues. The techniques are many and include elements such as observation, verbal protocol analysis and videotaping of operational activity.

Hierarchical Task Analysis (HTA)

A popular technique for analysing and representing tasks. Application of this technique will develop a tree-like structure, describing the hierarchical organisation of higher-level tasks down to lower-level tasks (see [Figure 12](#)). An excellent example of a HTA of an ATCO's tasks has been developed by Cox (1994).

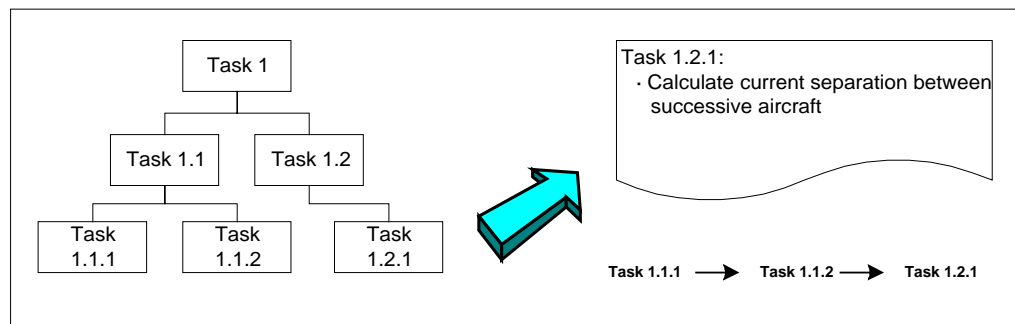


Figure 12: Hierarchical Task Analysis

Cognitive Task Analysis (CTA)

An increasingly popular set of task analysis techniques. The CTA techniques focus on the cognitive aspect of tasks with increased emphasis on understanding constructs, such as situational awareness, decision-making and planning. A task analysis method has been developed within EATCHIP (1998b) integrating elements from HTA with a method for CTA.

Workload Analysis

Questions such as: 'How busy is the operator?', 'How complex are the tasks?' are typically asked as part of the system development process or when evaluating jobs. Measurement of especially mental workload has received increased interest. Some commonly used methods are the Instantaneous Self-Assessment (ISA) (Evans, 1994) or the Subjective Workload Assessment Technique (SWAT) (Hendy et al., 1993).

5.3 Simulation and Field Studies

The inherent complexity of ATM systems requires data is to be collected and analysed as part of the system development process and experiments to be

conducted to test particular system designs. Various types of simulations and data collection methods can be applied.

Fast-time Simulations

Fast-time simulations are conducted primarily using mathematical or software-based techniques. By varying the input to the simulation, relations with different outputs are generated and consequently an overview of the total system performance is produced. Fast-time simulations can be applied early on in the development process, when the real-time simulations are still too demanding in terms of external interaction. Fast-time simulations are typically technically-oriented, but some concern for human factor variables, such as workload, may be included.

Real-time Simulations

Real-time simulations are often used at major milestones to demonstrate the design of a particular airspace or ATC system. Due to the lack of a theoretical basis, real-time simulations are often trying to answer relatively simple questions simulating the operational context as accurately as possible. These simulations can be large and complex to organise and execute, sometimes involving as many as 30 working positions and including pilots in cockpit simulators. Real-time simulations are good vehicles for assessments and analysis of human-machine interfaces, workload, situational awareness, communication and teamwork.



Field Studies

Nothing beats reality and investigations in the field can provide a rich picture of phenomena in the operational environment. Despite the benefits of real-time simulations, various phenomena can only be studied in their natural setting, such as in the operations-room. While field studies can provide rich data, great discipline is required of the researcher and the studies have to be designed to encompass the uncontrolled nature of real operations.

5.4 Design Concepts and Guidelines

Rapid Prototyping

To provide the end-users and developers with a common reference point and to get a feel for the final system, rapid prototypes can be built. Rapid prototypes will only mimic certain aspects of the final system's behaviour and may choose to ignore interaction with other systems. Rapid prototypes are used, for example, when designing human-machine interfaces.

Human-centred System Design

The human-centred system design philosophy guides the design of systems in a way that both enhances system safety and efficiency, and optimises the contribution of the human operators. The increased introduction of automation in air traffic systems has caused the development of a number of guidelines for human-centred system design, as outlined in [Annex B](#).

Usability Engineering

Usability Engineering (Nielsen, 1993) is based on the human-centred system design philosophy and comprises a number of methods and techniques to ensure that a system is easy to learn, pleasant to use, error free and error-forgiving, easy to remember and efficient.

Human-Machine Interface Design

The concerns are many when developing the human-machine interfaces. As an aide during the design process, various guidelines have been developed for imposing good interface design practice. One such guideline for ensuring system usability (Karat et al., 1992) is outlined in [Annex D](#).

ANNEX A. SYSTEM DEVELOPMENT CHECKLIST

Milestones	Questions
Concept Development <ul style="list-style-type: none"> ♦ Person responsible for human factors designated ♦ Users' group established ♦ Plan for integration of human factors 	<ul style="list-style-type: none"> ♦ What should the humans do? ♦ What should be done by machines? ♦ What should be done in collaboration between the humans and the machines?
Preliminary Design <ul style="list-style-type: none"> ♦ Definition of user profiles and analysis of tasks ♦ Preliminary human-machine interface design ♦ Performance measurements in simulators ♦ Approved requirement specifications and prototypes 	<ul style="list-style-type: none"> ♦ Which working positions do we want, what should they look like and what is expected from them? ♦ How many staff are needed and what should their profile be? ♦ Is the system workable and is there a fair fit between working procedures and working positions?
Detailed Design <ul style="list-style-type: none"> ♦ Design of working positions ♦ Development of working procedures ♦ Development of human-machine interfaces ♦ Development of transition training ♦ Usability testing 	<ul style="list-style-type: none"> ♦ Do the working procedures and the human-machine interface correspond? ♦ Does the test plan cover all the requirements?

Milestones	Questions
Construction and Commissioning <ul style="list-style-type: none"> ♦ Final approval from users' group ♦ Final training of operators for new system 	<ul style="list-style-type: none"> ♦ Does the implementation comply with requirements and expectations? ♦ Have all operators received adequate training and are they ready to operate the new system?
Operation and Maintenance <ul style="list-style-type: none"> ♦ Introduction of operators to new system ♦ Establish feedback improvement mechanism during installation 	<ul style="list-style-type: none"> ♦ Are the operators satisfied with the system? ♦ Are there inadequacies in the system?
System Modification <ul style="list-style-type: none"> ♦ Specification of modifications ♦ Analysis of tasks and documentation of task changes ♦ Re-assessment of human and system reliability 	<ul style="list-style-type: none"> ♦ Does the proposed modification comply with the philosophy? ♦ Will the modification increase human performance?
Re-cycling <ul style="list-style-type: none"> ♦ Plan for transition ♦ Closing down of the old system ♦ Transition of human resources to new functions 	<ul style="list-style-type: none"> ♦ How can we retain and apply the human expertise from the old system? ♦ What kind of training is needed to re-use the workforce?

ANNEX B. AUTOMATION OF TASKS

The expected increase in air traffic will be met with advanced information technology and in particular by the automation of tasks that were previously done by the human operators. While advances in information technology have provided a vast potential for improving the handling of high levels of traffic, it is important to consider the interaction and interface with the human operators. Experience from other domains, such as nuclear power plants and flight decks, has shown very clearly that while the potential of automation is great, it has to be applied with caution and insight.

Automation of tasks should not be seen as an either/or situation, but rather as something that is running on a continuum. Figure 13 provides some interpretation of an allocation of control between the human and the automatic functions performed by a computer.

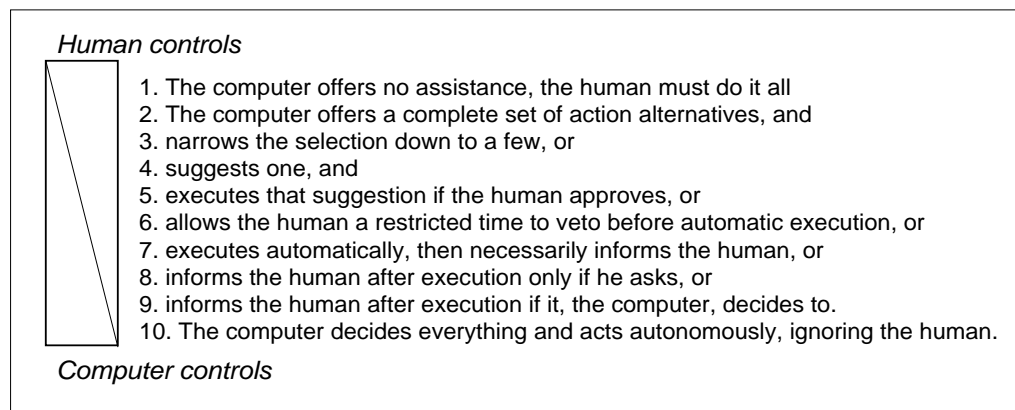


Figure 13: Levels of Automation (Sheridan, 1992)

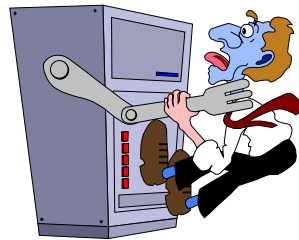
In principle, humans and automation should be allocated tasks for which they are suited. Billings (1996) has developed some general principles for the use of automation and the role of humans. According to these principles, the human bears the ultimate responsibility for the safety of the aviation system. Therefore:

- ♦ **The human must be in command:** It is essential that the human remains the final authority in the carrying-out of the tasks, and the human operator consequently needs to be in command.
- ♦ **To command effectively, the human must be involved:** If we want the human operator to elicit a good effectiveness in his command of the system, the operator has to be involved in the process.
- ♦ **To be involved, the human must be informed:** The human operator needs to be well informed about the state of the process as well as about the environmental factors involved in the process.

- ♦ **The human must be able to monitor the automated system:** In addition to the need for the human to be informed about the process itself, the human needs to be informed about the automated system and to be able to monitor its state.
- ♦ **Automated systems must be predictable:** The automated system should enable the human operator to be forewarned on the basis of observation or experience. To put it another way, it should be possible for the human operator to build a reliable mental model of the automated system.
- ♦ **Automated systems must be able to monitor the human operator:** To avoid conflict between the automated system and the human operator over the control, the automated system must be able to monitor the activity the human operator.
- ♦ **Each element of the system must have knowledge of the other's intent:** Monitoring or co-ordination of activity can only be effective if the elements have knowledge about the other's intent.
- ♦ **Functions must be automated only if there is a good reason for doing so:** The crucial question in a particular design is which tasks to automate. Technologically many tasks can be automated, but it is important to remember to ask why a particular task is automated.
- ♦ **Automation must be designed to be simple to learn and operate:** A complex system need not be complex to operate. A system which is based on a clear philosophy and which is well thought-out will require only a relatively simple and clear mental model to operate. The benefits of this will be many; the system will be easy to learn, easy to operate and will consequently provide the operator with an improved basis for achieving a good performance.

ANNEX C. EFFECTS OF AUTOMATION

Experience from other domains has shown that the introduction of automation will significantly influence and change the role of the human operator and his work. The automation of tasks and functions may result in some cost in terms of human performance.



Below is a non-exhaustive list of some negative effects experienced when tasks are automated:

- ♦ **New error forms:** While automation can reduce or eliminate certain kinds of human error, it may also produce new forms of error. These may not necessarily represent a failure of the automation, but may be by-products of the introduction of the automation. One example of new error forms is the mode-confusion, in which the automation is controlled in a number of modes and the human inadvertently operates the system in the wrong mode.
- ♦ **Cognitive influence:** The human cognition may be influenced as a result of automating tasks and altering the role of the operator. The influences can be many, such as decision biases, loss of situational awareness, increased mental workload, increased monitoring demands and cognitive overload.
- ♦ **Trust (mistrust and overtrust):** Mistrust in automation may develop from annoyance about false alarms, for example. While system tools such as Short-Term Conflict Detection (STCD) have generally received widespread acceptance among operators, it is crucial for the operator to develop trust in the system. High trust (overtrust or complacency) in automation may on the other hand lead operators to abandon vigilant monitoring of their displays and instruments.
- ♦ **Skill degradation:** When certain aspects of a task are automated, the human operator will no longer experience the daily on-the-line handling of the task, and this may consequently result in a reduced performance of the skill involved. This skill degradation may become crucial if the operator is supposed to take over from the automation in critical or emergency situations.

- ♦ **Loss of team co-operation:** The change in the role of the human operator towards increased monitoring and away from interaction may undermine the co-operation in a team of operators.

ANNEX D. HUMAN-MACHINE INTERFACE DESIGN GUIDELINES

The following design guidelines have been developed by Karat, Campbell and Fiegel (Karat et al, 1992) to ensure the usability of human-machine interfaces:

- ♦ **Use a simple and natural dialogue:** The dialogue between the system and the human should be simple and natural. The ambiguity that may arise from different contextual interpretations of the same communications should be taken into account during the design.
- ♦ **Provide an intuitive visual layout:** The visual layout of an interface should be intuitive and provide the user with an instant understanding of how to operate it.
- ♦ **Speak the user's language:** The user's understanding of communication can be greatly reduced if the language used by the system is different from that the users. The most typical example is when the computer informs the human operator about its internal state in highly technical terms, which are completely incomprehensible to the user.
- ♦ **Be consistent:** Consistency at all levels should be emphasised. Use of colours and other visual means should be consistent. Terms used in communication should be consistent to avoid misunderstandings. Windows and labels for input and output should be consistent, and changes in system models should not alter the way in which the system is operated.
- ♦ **Provide feedback:** It is important to provide the user with feedback. Feedback will enhance the human's understanding of the system's state and help him to build a mental picture of the situation. In a longer time-frame feedback will also provide the user with a better understanding of the dynamics of the system, and thereby improve his performance in less well-defined situations.
- ♦ **Provide clearly marked exits:** Computer displays should have clearly marked exits so as to remove the frustration the user may have in leaving a specific facility of the system.
- ♦ **Provide shortcuts:** Situations should be avoided where the user navigates through tedious sequences of menus or command inputs to arrive at a common and much-used function of the system. Shortcuts should be provided to make the navigation easier and smoother.

- ♦ **Provide assistance:** The system should provide adequate assistance to the user, such as on-line help functions. Adequate assistance will make difficulties with the system easier to overcome and will support the user in the performance of his work.
- ♦ **Allow user customisation:** Although systems are developed with a certain kind of operation in mind, variations should be accounted for. Customisations of the system should be available to the user to make sure that its operation fit the user's needs.
- ♦ **Minimise the use of effects of modes:** It is tempting to design a system to operate in different modes as it may for example simplify the Human-Machine Interface. The user may forget the mode change or the mode change may occur unnoticed by the user. The consequences of operating the system with a different model of the system in mind will in the best instance be erroneous and in the worst disastrous.
- ♦ **Support input device continuity:** The constant changing of input devices can be disruptive for the user. The system should emphasise a limited number of input devices, such as keyboard, mouse or track-ball, and keep to them in a consistent way.

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GLOSSARY

For the purposes of this document, the following glossary of terms shall apply:

Cognition: Human thought processes and their components, such as perception, memory and decision-making.

Cognitive model: Occasionally (more correctly) called 'model of cognition'. A model of cognition can take many forms, such as a paper model showing the relationships between cognitive processes and behaviour or simulation models of cognition for interaction analysis, etc.

Cognitive psychology: A general approach to psychology which emphasises the internal mental processes including thinking and perception.

Cognitive Task Analysis (CTA): Methods focusing on the cognitive aspect of tasks with increased emphasis for understanding constructs, such as situational awareness, decision-making and planning.

Decision-making: One of the basic functions of ATC. Decision-making is an active cognitive process which selects one out of a set of possible courses of action. Decision-making requires a weighing up of the pros and cons of different alternatives.

Hierarchical Task Analysis (HTA): Technique for analysing and representing tasks hierarchically.

Human-centred design (approach): As opposed to technology-centred (or driven) approach. Provides the human with automated assistance that saves time and effort; the operator's task performance is supported, not managed, by computing machinery.

Human factors: Multi-disciplinary effort to compile and generate knowledge about people at work and apply that knowledge to the functional relationships between people, tasks, technologies and environment in order to produce safe and efficient human performance.

Human factors engineering: Discipline that applies knowledge of human capabilities and limitations to the design of technological systems.

Human factors plan: Plan for the integration of human factors in the system life-cycle.

Human factors specialist: The term 'human factors specialist' is used widely and should be considered with caution, as there is no protection on this title. A human factors specialist usually has one of the following backgrounds:

- ♦ a degree in industrial psychology or cognitive psychology and some practical experience of human factors application;
- ♦ an engineering degree with some additional study in industrial or cognitive psychology and some practical experience of human factors application;
- ♦ an operational background with additional human factors training, and some practical experience.

Human performance: The extent to which goals for speed, accuracy, quality, and other criteria are met by people functioning in working environments.

Human Reliability Assessment (HRA): Is concerned with the identification, the quantification and the prevention of errors.

Human supervisory control: One or more human operators are continually programming and receiving information from a computer that interconnects through artificial effectors and sensors to the controlled process or task environment.

Long-term memory: One of the four components of the structural model of the cognitive processes of ATC. It stores the mental model, information, information processing routines and programmes.

Mental model: Cognitive process/representation whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states and predictions about future system states (according to Rouse and Morris, 1986).

Mental picture: The actual mental picture of a situation represents a moment-to-moment snapshot of the actual situation based on the mental model and the actually perceived external cues. A series of mental pictures represents the actual mental model including the actual parametrisation.

Situational awareness: The 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 (Endsley, 1988). This also means the continuous extraction of environmental information, the integration of this information with previous knowledge to form a coherent mental picture and the use of that picture in directing further perception and anticipating future events.

Task analysis: Method for breaking down activity into its constituent parts in order to describe the parts as well as the ways in which they are organised within the task.

Usability engineering: Comprises a number of methods and techniques to ensure that a system is easy to learn, pleasant to use, error-free and error-forgiving, easy to remember and efficient.

Working memory: One of the four components of the structural model of the cognitive processes of ATC. It is a short-term buffer with a limited capacity for new incoming data and information. It can only handle a set of about five to nine elements or combined elements (called chunks) at the same time. Without active rehearsal procedures, memory traces fade within a few seconds.

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ABBREVIATIONS AND ACRONYMS

For the purposes of this document, the following abbreviations and acronyms shall apply:

AFS	Automatic Flight System
AP	AutoPilot
ATC	Air Traffic Control
ATCO	Air Traffic Controller/Air Traffic Control Officer (US/UK)
ATM	Air Traffic Management
CTA	Cognitive Task Analysis
CWP	Controller Working Position
DED	Directorate EATCHIP Development
DEL	Deliverable
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme
ET	Executive Task
EWP	EATCHIP Work Programme
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FD	Flight Director
FMC	Flight Management Computer
FMS	Flight Management System
GPWS	Ground Proximity Warning System
HMI	Human-Machine Interface
HRA	Human Reliability Assessment
HTA	Hierarchical Task Analysis
HUM	Human Resources (Domain)

ISA	Instantaneous Self-Assessment
MoT	Ministry of Transport
REP	Report
R/T	RadioTelephony
ST	Specialist Task
STCD	Short-Term Conflict Detection
SWAT	Subjective Workload Assessment Technique