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Human Factors Integration in Future ATM Systems - Design Concepts and Philosophies

HRS/HSP-003-REP-01

Edition	:	1.0
Edition Date	:	08.08.2000
Status	:	Released Issue
Class	:	EATMP

EUROPEAN AIR TRAFFIC MANAGEMENT PROGRAMME

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title			
Human Factors Integration in Future ATM Systems - Design Concepts and Philosophies			
EATMP HRS WORK PACKAGE REFERENCE NUMBER: HRS/HSP-003			
DELIVERABLE REFERENCE NUMBER:	**EDITION:**	1.0	
HRS/HSP-003-REP-01	**EDITION DATE:**	08.08.2000	

Abstract

This report is, within the EATMP* Human Resources Domain (HUM), the first in a series dealing with the integration of human factors in Air Traffic Management (ATM) systems. This report suggests that human factors should be integrated throughout the ATM system life cycle in order to reduce cost and make ATM systems safer and more effective.

The report will provide the reader with an awareness of the benefits from integrating human factors into the ATM system life cycle and the cost associated herewith. The module will accommodate an understanding of the effects of both taking specific human factors initiatives and the way in which cost develops over the lifetime of the system.

* European Air Traffic Management Programme (formerly EATCHIP or European Air Traffic Harmonisation and Integration Programme)

Keywords

ATM	Human factors	MANPRINT (Manpower, Personnel and Integration)	Standard
ATM systems	Human-centred design	Method	System development
Guidelines	Integration	Model	Usability
Human Factors Integration in Future ATM systems (HIFA)	Life-cycle		

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DOCUMENT STATUS AND TYPE

STATUS		CLASSIFICATION	
Working Draft	☐	General Public	☐
Draft	☐	EATMP	☑
Proposed Issue	☐	Restricted	☐
Released Issue	☑		

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME: G\Own_use\Delvrabl\Released\HFs\HIFA\HIFA1_1.doc

HOST SYSTEM	MEDIA	SOFTWARE
Microsoft Windows	Type:	**MicroSoft Office 97 (MS97)**
	Media Identification:	

DOCUMENT APPROVAL

The following table identifies all management authorities who have successively approved the present issue of this document.

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DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.1	19.00.1999	Working Draft	All
0.2	12.11.1999	Draft	All
0.3	10.03.2000	Proposed Issue	All
1.0	08.08.2000	Released Issue	All (document configuration)

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EXECUTIVE SUMMARY

This document is concerned with the integration of human factors in the design of Air Traffic Management (ATM) systems. In particular, it presents a review of relevant design concepts and philosophies for integrating human factors within the life cycle of ATM systems. The document constitutes the first part of a larger project entitled 'Human Factors Integration in Future ATM Systems (HIFA)'. The HIFA Project is being conducted within the ATM Human Resources Programme (HRS) of the European Air Traffic Management Programme (EATMP), formerly known as the European Air Traffic Harmonisation and Integration Programme (EATCHIP), under Work Package Number HRS/HSP-003.

The traditional role of human factors in the overall system design process has often been described as too little, too late. This problem has been recognised for many years by system designers and human factors practitioners alike. Although the importance of human factors is now more widely recognised, particularly as a consequence of the increasing use of computers and computer-based technology, the contribution and systematic integration of human factors throughout the ATM life cycle is still fragmentary.

The overall aim of the HIFA Project is to make users and stakeholders aware of the importance and benefits of integrating human factors in the ATM life cycle, and to give them the necessary knowledge to implement such programmes effectively within their organisation. To this end the project aims to provide appropriate and effective guidance material about human factors for users.

As currently planned the HIFA Project is being carried out in two Phases: in Phase 1 the basic guidance material will be prepared; subsequently, in Phase 2 this material will be made widely available through advanced information technology (such as Internet and CD-ROM). This document is the first report for Phase 1 of HIFA that aims to outline relevant design concepts and philosophies. The second report (EATMP, 2000) identifies tasks and development scenarios, while the third report (EATMP, not printed) outlines some useful methods and tools to be applied.

Chapter 1, **'**Introduction**'**, outlines the background to the project, and the objectives and scope of the report.

Chapter 2, **'**ATM Systems and Human Factors Research**'**, explains what is meant by an **'**ATM system**'** and describes the ATM system life cycle, contrasting it with a number of others that have been developed. The chapter includes a brief review of human factors research in ATM and lists seven current research topics.

Chapter 3, **'**System Development**'**, provides a wide-ranging and comprehensive review of different approaches to system design. The review covers system development models (e.g. waterfall, spiral, 'V' models) and system development methods (e.g. structured methods, Multiview, the Method for Usability Engineering (MUSE)).

Chapter 4, **'**Human Factors in System Development**'**, is concerned with the issue of how human factors is currently addressed and incorporated (but not necessarily 'integrated') within system development processes. The review covers such topics as the role of human factors, human factors guidance material (i.e. design guidelines and style guides), civil and military standards, and usability.

Chapter 5, **'**Human Factors Integration**'**, provides a wide-ranging review of different approaches to Human Factors Integration (HFI) in the system design life cycle. First, the general philosophy of **'**user-centred**'** design is considered as it underlies most other current approaches. The integration approaches in the space and nuclear industries are then briefly reviewed. The chapter concludes with a detailed look at the defence system acquisition processes in the US and UK, in particular recent developments that have built on the well-known MANPRINT (Manpower, Personnel and Integration) approach.

Chapter 6, **'**Human Factors Integration for ATM**'**, concentrates on HFI specifically in the ATM domain. The current approach in ATM industry is reviewed and particularly its focus on **'**human-centred automation**'** in aviation. The approaches adopted by ATM national administrations are considered and recent publications by the Federal Aviation Administration (FAA) are noted.

Finally, several issues concerning the development of HIFA are discussed; for example, how to build on existing approaches, system life cycle, methods and tools, and the need for high-level commitment to support and implement a HFI programme. An example of human factors activities required for various stages of the system life cycle is presented.

Chapter 7, **'**Conclusions**'**, presents the overall conclusions of the report.

Annexes contain an extensive list of References, a list of human factors information sources on the Internet, Abbreviations and Acronyms and a list of the Contributors to this document.

1. INTRODUCTION

1.1 Purpose

The purpose of this document is to present a review of relevant design concepts and philosophies for integrating human factors within the life cycle of ATM systems. The document constitutes the first part of a larger project entitled 'Human Factors Integration in Future ATM Systems (HIFA)' being carried out by the Human Factors and Manpower Unit of EUROCONTROL (in short DIS/HUM or HUM Unit; formerly known as the ATM Human Resources Unit) and contracted to the UK Defence Evaluation and Research Agency (DERA).

The HIFA Project is one of several human factors activities being conducted under the ATM Human Resources Programme (HRS), within the EATMP[1] Human Resources Domain (HUM). The projects accords well with the aim of the 'ATM Strategy for 2000+' (EATCHIP, 1998a) which states:

> *consideration of human factors issues must be part of the technology design and certification process and of the development of operating procedures, and be completed before technology is used operationally to avoid flawed human-technology interfaces which may cause operating problems and additional costs throughout the system life cycle.*

The Strategy Document (*op. cit.*) goes on to say:

> *ATM has a poor record for implementing change to time and within budget, and many major infrastructure projects have suffered delays and escalating costs. This indicates that there are fundamental problems in the development of complex ATM systems, and the relationships with equipment suppliers.*

Although the integration of human factors within the system development process does not by itself guarantee that ATM systems will avoid such problems in the future, the proper consideration of human factors issues is an essential part of the solution.

1.2 Scope of Document

This document is the first of three reports planned for Phase 1 of the HIFA Project. The document is intended to provide a wide-ranging and detailed review of literature concerned with human factors and system design. The

[1] European Air Traffic Management Programme (formerly EATCHIP which stood for the European Air Traffic Harmonisation and Integration Programme)

information sources for the review are largely in the public domain and include relevant EATMP documents. The second report (EATMP, 2000) identifies HFI tasks and development scenarios, while the third document (EATMP, not printed) will outline useful methods and tools.

It is not within the scope of the project to develop a new system design methodology, but rather to lay the foundation for developing a fresh approach to the integration of human factors in system design based on existing material.

1.3 Background to Project

The HIFA Project was initiated in 1997 as part of the ATM Human Resources Programme (HRS). The main events and milestones, within which HIFA fits, including those anticipated in the future, are as follows:

- Human Factors Module — March 1998
  Title: 'Human Factors in the Development of Air Traffic Management Systems' (EATCHIP, 1998b)
- Third EUROCONTROL Human Factors Workshop — October 1998
  Title: 'Integrating Human Factors into the Life Cycle of ATM Systems'. Held in Luxembourg, 7-9 October 1998 (see EATMP, 1999a)
- Human Factors Integration Guidance material — November 1999
  Guidance material for HFI in the ATM system development life cycle. Development work contracted out to the British Defence Evaluation and Research Agency (DERA) (see this report and EATMP [2000 & not printed])
- Human Factors Module — December 1999
  Title: 'A Business Case for Human Factors Investment' (EATMP, 1999b)
- Human Factors Integration E-Book — November 2000
  A handbook will be produced on the basis of the guidance material and will be made widely available through Internet and CD-ROM technology

1.4 Structure of the Document

Reviewing such complex and diverse subjects as system development, ATM systems, and human factors within one document presents a difficult task of how best to structure the information. Several different approaches could be taken. The approach adopted here is to structure the report so that the text progresses from the general to the specific and focuses, finally, on HFI for ATM systems.

Thus, following this Introduction the report is divided into six main chapters. It starts with general background information about ATM systems (see Chapter 2) and system development (see Chapter 3), then moves on to consider the role of human factors in system development (see Chapter 4). Next, several different approaches to incorporating HFI are reviewed (see Chapter 5), which leads to the final chapter on HFI specifically for ATM (see Chapter 6). The conclusions of the report are presented in Chapter 7.

The structure of the report is illustrated schematically in Figure 1.

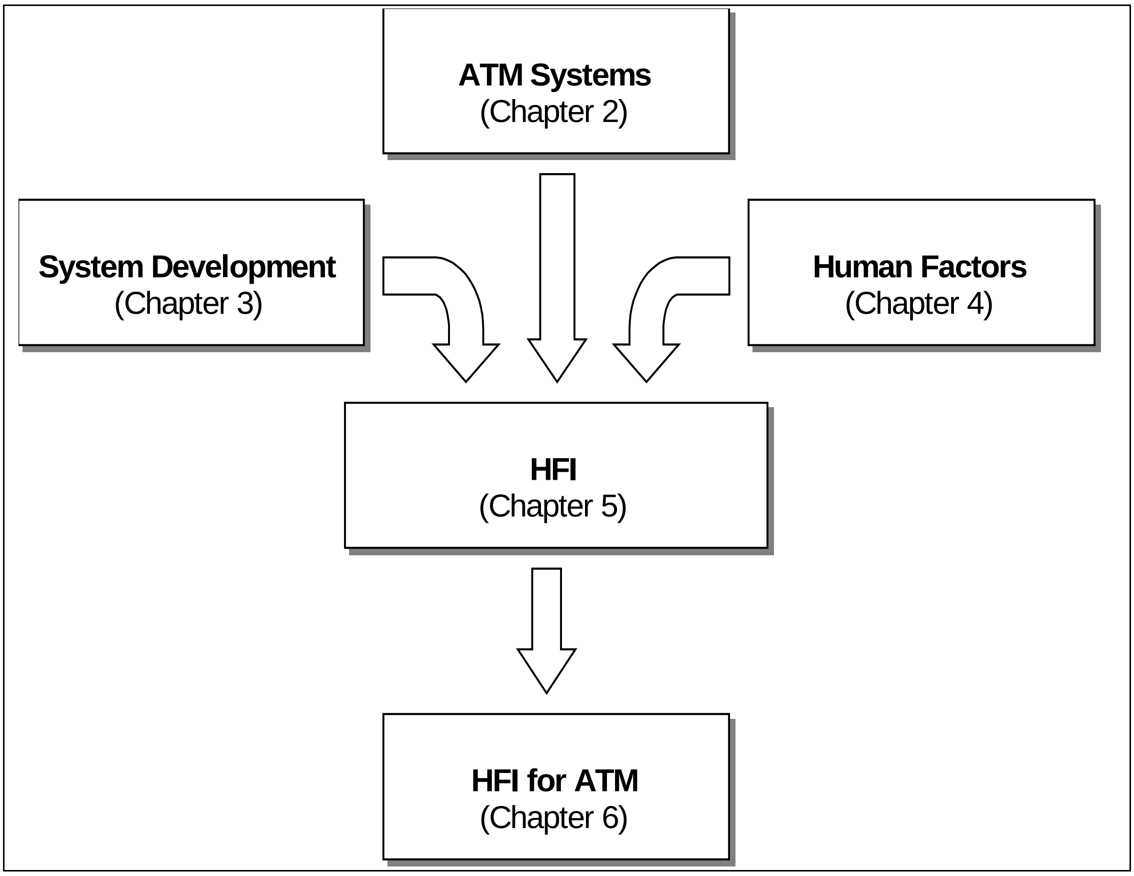

Figure 1: Schematic illustration of topics covered in the report

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2. ATM SYSTEMS AND HUMAN FACTORS RESEARCH

2.1 What is an ATM System?

Before examining the development and life cycle of ATM systems it is important to be clear what is meant by 'ATM system'. In general terms a system can be defined as a purposeful organisation of equipment, infrastructure, personnel, and procedures functioning together to achieve some specified result or goal. However, in today's complex technological age, a system is rarely, if ever, a single self-contained entity. Instead, any given system is but one part of some larger system and will itself be composed of many sub-systems.

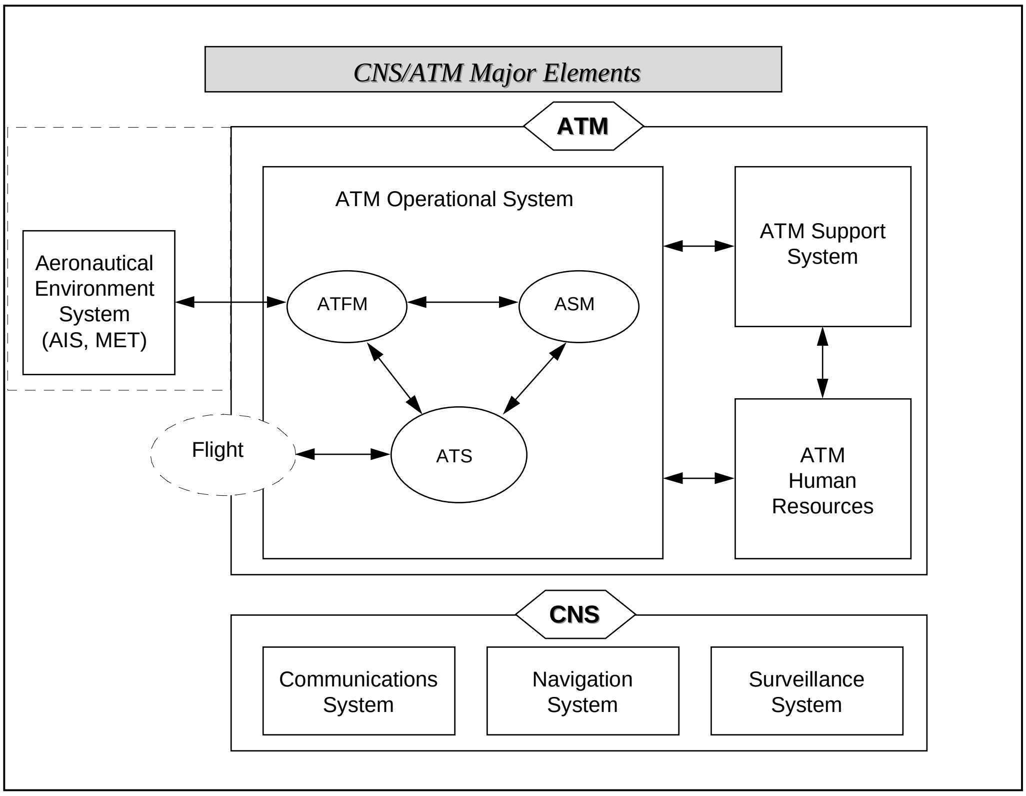

Figure 2: Major elements of CNS/ATM system

Viewed in these terms, we can define an ATM system as a complex network of ground-based and airborne sub-systems that together ensure the safe, orderly, expeditious and economic flow of air traffic through all phases of their flight. As shown in Figure 2 (see EATCHIP, 1997a), the main functional components of ground-based ATM are: Air Traffic Services (ATS), Airspace Management (ASM) and Air Traffic Flow Management (ATFM). The main component of ATS is Air Traffic Control (ATC) services, provided by ATC centres and their controllers, and associated flight information and alerting services.

It can also be seen from Figure 2 that an ATM system is one part of a larger 'CNS/ATM' system which, in accordance with description of EATMP (EATCHIP, 1997a), is composed of the following three major elements:

1. ATM System.
2. Communications, Navigation, Surveillance Systems.
3. Aeronautical Environment System.

An ATM system is a complex network of ground-based and airborne sub-systems which together ensure the safe, orderly, expeditious and economic flow of air traffic through all phases of their flight.

2.2 ATM System Life Cycle

The life cycle of a system is the sequence of stages or phases through which a system passes during its 'life'. Opinions differ on how many phases there are and what they are called, but a life cycle starting from initial planning through to construction, operation, potential in-service modifications, to final de-commissioning or disposal is generally agreed upon.

The ATM life cycle has recently been described by EUROCONTROL for the management of EATMP programmes and projects (EATCHIP, 1998c). The life cycle consists of eight phases as shown in Table 1. Whilst it can be seen that the EATMP life cycle is closely related to other descriptions of the life cycle (i.e. Table 2), it is also evident that the above EATMP life cycle is specifically aimed at the processes for project management.

The ATM system life cycle has also been considered at the recent EUROCONTROL human factors workshop concerned with HFI (EATMP, 1999a). Two items of particular interest are noted here:

- An "Augmented 'V' Model" of the software life cycle (Jackson, 1998). Essentially, this model expands the User Requirements phase into a number of layers each of which have specific human factors inputs (and consequences for the testing 'limb' of the 'V'.

- A further elaboration by Kirwan (1998) of the earlier Kirwan, Evans, Donohoe et al life cycle (shown in Table 2) to include an additional phase and some separation of the build/commissioning phases.

Table 1: EATMP Programme/Project life cycle

Life Cycle Phase	Objectives
1. Initiation	To initiate a new programme/project within the scope of the EATMP portfolio.
2. Planning	To gain approval for the detailed structure of the programme, i.e. its portfolio of projects, staffing and funding.
3. Feasibility	To test the technical, operational, and financial feasibility of different development options.
4. Development	To develop proposed specifications and standards for a well-functioning solution (including equipment, interfaces, etc.)
5. Pre-operational	To have an extra reality check on the proposed solution by building a pre-operational prototype and/or undertaking a real-time simulation to verify specifications.
6. Implementation planning	To have a detailed understanding of all the practicalities of a successful implementation of the proposed solution and to produce a coordinated implementation plan for all ECAC States and the affected airspace users.
7. Local implementation	To support the local States and the affected airspace users in the implementation: detailed design, development, integration, assembly and testing, publications, education, training, procedures, implementation, phase-in, phase-out.
8. Operations	To start operations of the final programme/ project output as part of the ATM system by the service providers and/or airspace users. To assess and record performance.

To the extent that an ATM system is the same as any other large, complex system (e.g. rail transport system, nuclear power system, defence system), its life cycle will broadly follow the well-known phases of system engineering development (see Chapter 3). Indeed, the few recent publications that have specifically addressed the ATM system life cycle reflect this perspective (see Table 2).

The possibility of adapting the EATMP life cycle for the purposes of human factors integration will be considered later in the report.

However, the following conclusions can be drawn:

⇨ First, as for other system life cycles, there is no explicit human factors phase; human factors is an implicit 'input' into each of the phases (assuming it is to be included in the first place). Determining exactly what those inputs are, and how they are made, is at the crux of human factors integration.

Table 2: Different views of ATM system life cycle[2]

Blom, Hendriks & Nijhuis (1995)	Kelly, Mann & Maltier (1996)	Kirwan, Evans, Donohoe et al (1997)
Conceptual	Mission	Concept development
	User requirements	
	Operational requirements	Preliminary design
Procurement	Functional description	Detailed design
	System requirements	
Transition	System implementation	Construction and Commissioning
Operation	Operation	Operation and Maintenance
	Maintenance	
	Transition	Modification
		De-commissioning

⇨ Second, from the earlier discussion about ATM systems (see Section 2.1) it is clear that the ATM system is composed of numerous sub-systems, each of which has a life cycle of its own, each of which evolves differently, and each of which requires different human factors inputs. To quote from the recent 'ATM Strategy for 2000+',

> *New ATM concepts will require greater inter-operability between the systems of aircraft, aircraft operators, airport operators and ATM service providers both on the ground and in the air. These systems will evolve at different rates and be replaced or upgraded at different times, but will need to progressively support increasing traffic levels. For a system of a typical life cycle of 15 years, this means being able to support a doubling of traffic through the smooth evolution of its capabilities.*

⇨ Third, although the ATM system life cycle is not radically different from other systems, from the viewpoint of human factors integration, the current structuring is not necessarily adequate. This is a matter to which we will

[2] In the table stages which are approximately equivalent are aligned horizontally. However, it should be noted that 'transition' has two meanings. In the first column the transition is from pre-operational to fully operational system; in the second column the transition is from existing operational system to new, successor system.

return in later chapters (see Chapter 6), but two important requirements are noted here:

1. The need for an Early Human Factors Analysis (EHFA) phase;

2. The consideration of system maintenance at an earlier (i.e. conceptual) stage.

The ATM life cycle is typically described in terms similar to other large complex industrial systems, i.e. composed of major phases of initial planning, through to construction, operation, potential in-service modifications, to final de-commissioning or disposal.

2.3 Human Factors Research in ATM

Although historically the emergence of human factors as a distinct discipline cannot be traced to any single event or year, the application of human factors to ATM can be said with some certainty to have started in 1951. In that year a National Research Council (NRC) report was published, concerned with the planning of a 'long-range research program on human factors in air-navigation and traffic control' (Fitts, 1951). The list of topics considered in that report were:

- the role of the human operator (manual vs. automatic);
- the division of responsibility between humans and machines[3];
- human performance characteristics (e.g. alertness, overloading, fallibility);
- the division of responsibility between human operators (as regards decision-making, workload-sharing);
- manpower and personnel problems (e.g. training, maintenance of skills);
- economic issues.

Nearly fifty years later these topics remain as relevant as ever. Indeed, a more recent NRC report (Wickens, Mavor & McGee, 1997) covers very similar subjects:

– tasks in ATC,
– performance assessment, selection and training,
– workload and vigilance,
– teamwork and communications,
– automation.

[3] This 'men versus machines' comparison was to became better known as the 'Fitts list'.

Since its origins in the early 1950s, the literature on human factors in ATM has grown enormously although much of it, as noted by Hopkin (1995) remains diffuse and rather inaccessible. Several comprehensive reviews of the field have been produced, most notably by Hopkin (1982; 1995). Other material produced by ICAO (1993; 1998), EATCHIP (1998b) and EATMP (1999) is further increasing awareness of human factors in ATM. It is inappropriate to review that literature here, but it is useful to mention some topics of human factors research for the purposes of illustrating the information that ultimately the human factors guidance material must address. Eight key such topics are:

1. Workload. The mental workload of the air traffic controller (or personnel) remains a key human factors consideration and attempts to assess it are a feature of most studies. A wide variety of workload measures have been developed (e.g. Costa, 1993; Foot, Chupeau, Biemans et al, 1996).

2. Workstation design. The controller's workstation is the prime means through which information about the aircraft he/she is monitoring, is conveyed. Much research has focused on the introduction of high-resolution colour displays and the replacement of paper flight progress strips by alternative electronic mechanisms and representations (e.g. Jackson & Pichancourt, 1995; Metcalfe & Reynolds, 1998).

3. Automation. One of the major issues facing future ATM systems is the impact of automation upon the human controller who, it is well recognised, will remain 'in the loop' for the foreseeable future. Although most research has focused upon the airborne side (see 6.2.2), the automation of ground-based ATC/ATM systems has also received considerable attention (e.g. Hollnagel et al, 1994; Hopkin, 1997; Wickens et al, 1998).

4. Safety. The safety of ATM has always been of prime importance. However, human factors aspects of safety has until recently been an implicit consideration only. The subject is now receiving a lot of attention (Farmer, Jorna, McIntyre et al., 1998; ICAO, 1999).

5. Human error. Although ATM systems (both aircraft and ground-based ATC) are very safe, concern about human error remains high. Air travel is often perceived to be risky by the public. However, studies of human error in the ATM environment are few (e.g. Langan-Fox & Empson, 1985) and most have either been in the context of investigating the effects of automation (Garland & Wise, 1993), or have been part of routine accident investigations by various regulatory authorities (Baker, 1993). The need for a better understanding of human error or procedural violations in ATM systems has become very apparent, and EUROCONTROL has begun work in this area (EATCHIP, 1998d) including most recently the HERA (Human Error in ATM) Project (EATMP, 1999c).

6. Situation awareness. Air traffic control and flying an aircraft are highly cognitive activities, and both the controller's mental **'**picture**'** and the pilot's Situation Awareness (SA) have been topics of much research (e.g. Whitfield & Jackson, 1982; Endsley & Bolstad, 1994). Interestingly, recent research is now focusing upon controllers' SA (e.g. Isaac, 1997).

7. Teamwork. Teamwork between controllers, between pilots, and between controllers and pilots, is critically important for the safety and efficiency of ATM systems. In aviation a lot of research has been devoted to Crew Resource Management (CRM). Under EATMP a type of CRM for air traffic controllers known as Team Resource Management (TRM) has been developed (EATCHIP, 1996). The second EUROCONTROL human factors workshop was also devoted to teamwork issues (EATCHIP, 1998e). The most recent review of team-related research in ATC is probably that conducted by Wickens et al (1997).

8. Human Factors Integration. As indicated by the research reviewed in this report, this is a major topic and the HIFA Project is one of the most recent initiatives to address it. HFI was also the focus of the third EUROCONTROL human factors workshop held in October 1998 (see EATMP, 1999a).

Human factors research in ATM is extensive and its origins go back several decades. Eight key topics of current research are:

- **workload**
- **workstation design**
- **automation**
- **safety**
- **human error**
- **situation awareness**
- **teamwork**
- **human factors integration**

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3. SYSTEM DEVELOPMENT

3.1 Introduction

A system may be defined as a collection of elements that are assembled together to fulfil some defined purpose or objective. A total system may include hardware, software and human elements, and may comprise a number of sub-systems. In addition, systems are not independent but exist in a physical, informational, social, organisational, legal, commercial and political environment containing many other systems.

A number of approaches to system development have been proposed from the early days of computing as a fledgling science through to today's disciplined approach to software engineering (Sommerville, 1995) and systems engineering (Stevens, Brook, Jackson & Arnold, 1998). These will be summarised below, together with their strengths and weaknesses. It is noted that although system development methodologies have been in existence for many decades they continue to evolve. Moreover, their efficacy is still debated (Malouin & Landry, 1983; Wynekoop & Russo, 1995). At the outset a number of principles of, or themes within, system development can be identified, which recur throughout this report:

- systems are assumed to include people, and therefore have human-machine (or human-computer) interfaces;
- systems are designed and built for a human purpose and understanding that purpose (or users' needs and wishes) is an essential step;
- system development, particularly of large complex systems, is typically a non-linear process involving much iteration;
- system development is driven by specifications and proceeds from the general to the specific.
- system development is a social process managed by, and for, people.

A distinction can be usefully made between system development models and methods. A model is a conceptual framework or philosophy within which the process and life cycle of system development can take place, whereas a method comprises a prescribed set of techniques, notations, symbologies and possible support tools detailing how a system may be developed. The rest of the design world makes extensive use of development models and methods. Certain models and methods are most suitable for specific classes of application, enabling and facilitating the practical expression, documentation and communication of appropriate design decisions and detail. Some are more amenable to Human Factors Integration (HFI), whereas others are less so.

The aim of this section is therefore to briefly survey common modelling approaches and methods, and to summarise their main features and criteria for selection.

3.2 System Development Models

3.2.1 Waterfall Model

The classic 'Waterfall Model' contains separate and distinct phases of specification and development, the development process 'flowing down' from one well defined stage to the next. The systems engineering process usually follows a Waterfall Model. This is partly due to industrial tradition and partly due to the practical need for parallel development of different component parts of the system. In the UK defence procurement has until very recently adopted this waterfall approach (see Section 5.6).

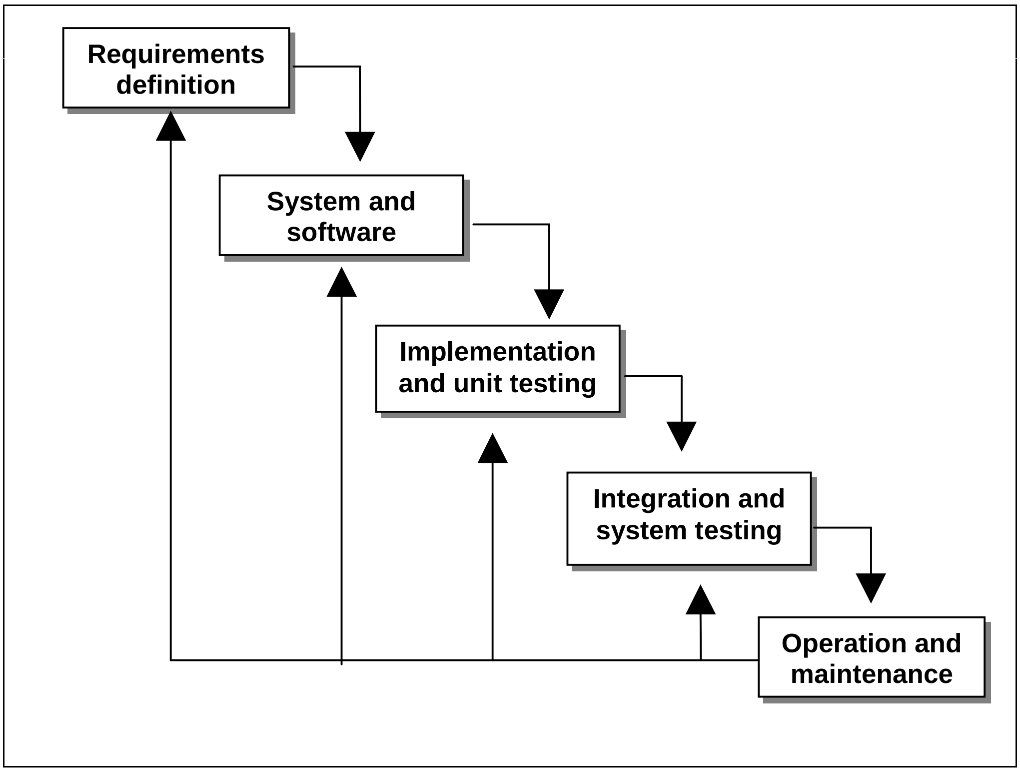

Figure 3: Waterfall Model

Sommerville (1995) notes that the drawback of the Waterfall Model is the difficulty of accommodating change after the process is underway. There is little scope for iteration between phases because hardware changes are very expensive – hence software may have to compensate for hardware problems. However, for linear systems development the clear stages of the model and the boundaries between the stages, each of which may be 'frozen' to form a baseline, has benefits over unstructured development. There is a high risk for new systems because of specification and design problems, but a low risk for well-understood developments using familiar technology.

The Waterfall Model has many strengths and does not preclude the inclusion of human factors and participative design, but due to the staged development approach the scope for iterative refinement (often based on user group reactions to the final product) once a baseline has been frozen is limited. The timescale for effective human factors input is therefore potentially restricted. It is ideally facilitated by user representatives as well as human factors specialists being part of a multidisciplinary development team from the earliest development stages.

3.2.2 'V' Model

In the classic 'V' Model of the software life cycle, development descends the **'**design limb**'** in well-defined stages from user and software requirements definition through design down to coding. The process then ascends the **'**testing limb**'** from coding through testing up to acceptance and final operation. There is heavy emphasis on software coding aspects, testing and acceptance/certification plans.

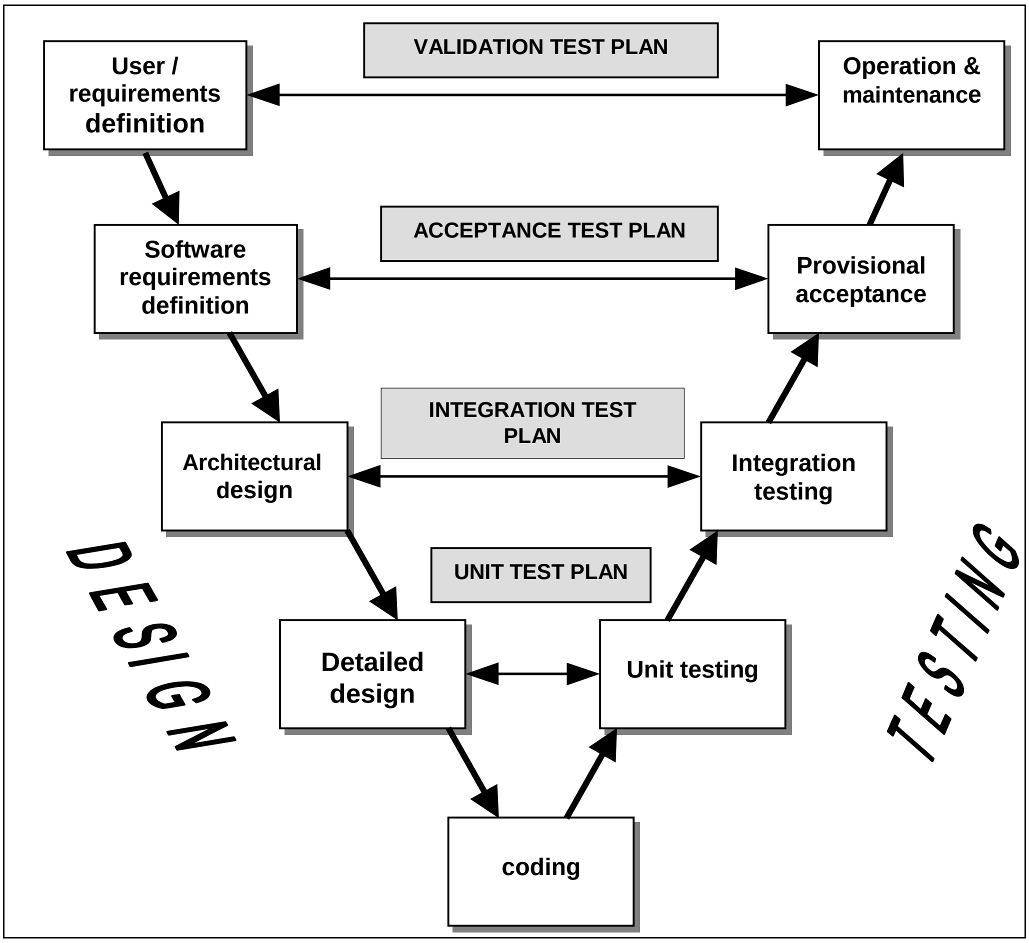

Figure 4: 'V' Model

As with the closely related Waterfall Model, the 'V' Model life cycle is adequate for well-defined linear systems, but its lack of feedback loops means it is weak for iterative system development. Jackson (1998) has, however, built on the strengths of the 'V' Model to propose an augmented 'V' Model reflecting a socio-technical perspective to include the potential for iteration at each level, with an enhanced opportunity for human factors contribution at the user requirements and pre-operational acceptance levels.

3.2.3 Evolutionary Development Model

In the Evolutionary Development Model specification and system development are interleaved. Two variants of prototyping underpin the evolutionary development approach: exploratory or throw away prototyping. In exploratory prototyping the objective is to work with customers to evolve a final system from an initial outline specification. Well-understood requirements are a prerequisite. In throwaway prototyping the objective is in itself to understand the system requirements, which are assumed to be poorly understood at system start-up.

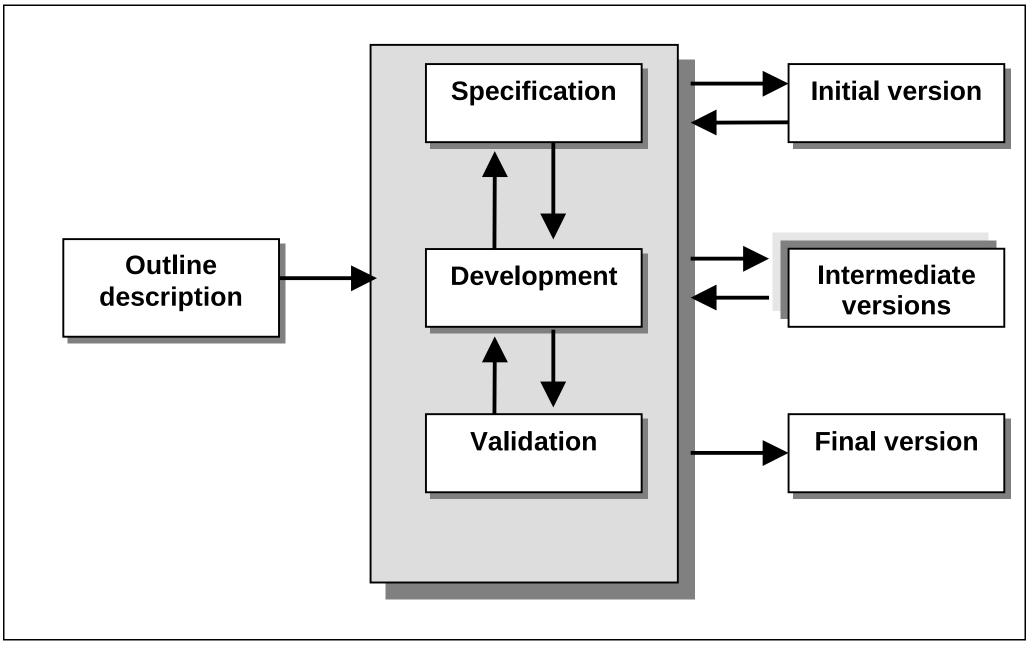

Figure 5: Evolutionary Development Model

Sommerville (1995) notes that evolutionary development is appropriate for small or medium-sized interactive systems, for parts (such as the user interface) of larger systems or for short-lifetime systems. There are potential problems and high risk in the lack of process visibility; resulting systems are often poorly structured and specialist skills (such as in programming languages for rapid prototyping) may be required. However, the strength of evolutionary development is in its ability to accommodate change and in its involvement of the user. New applications present a low risk because the specification and the developed system stay in step.

3.2.4 Hybrid / Spiral Model

Large systems are often made up of several sub-systems, and the same process model need not be used for all sub-systems. For example, the waterfall approach may be appropriate for well-understood sub-systems, but prototyping may be more appropriate for higher-risk, less well-known sub-systems. For safety-critical sub-systems with a stable requirement and complete specification then a Formal Transformation Model (see 3.2.5) may be best. The Hybrid/Spiral Model (Boehm, 1988) aims to achieve this flexibility. The model has a number of phases:

- objective setting for each phase of project spiral,
- risk identification, assessment and reduction,
- model development and validation,
- review and planning of next phase.

In these phases specific objectives for the project phases are identified. Key risks are then identified and analysed, and counter measures sought to reduce these risks. An appropriate development model is then chosen for the next phase of development of the project spiral. Finally, the project is reviewed and plans drawn up for the next round of the spiral. Development proceeds in a cyclic iterative manner, spiralling outward from initial concept through to final service, and the number of phases of the project spiral depending on the size, complexity and interactivity of the systems under development. Prototyping is an integral part of the development life cycle and there is scope for inclusion of human factors input.

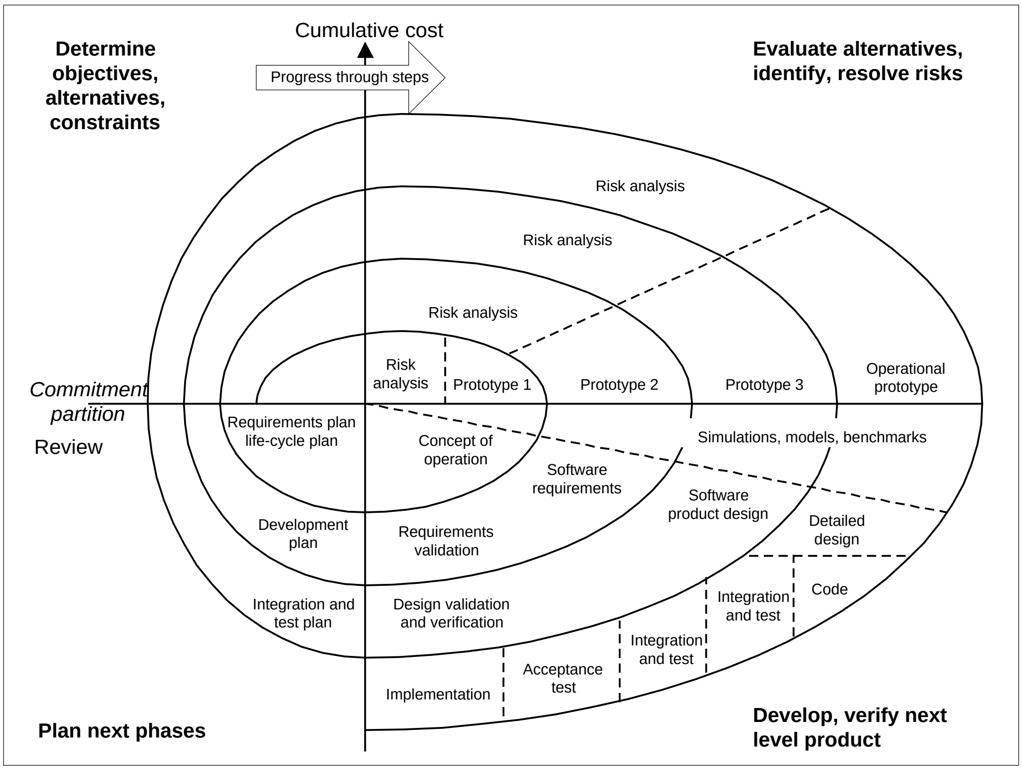

Figure 6: Hybrid/Spiral Model (Boehm, 1988)

Sommerville (1995) notes that the Hybrid/Spiral Model has a number of strengths. It focuses attention on re-use options, on early error elimination and on quality objectives. It also integrates development and maintenance, and provides a flexible framework for both hardware and software development. Against these advantages the model requires expertise in risk assessment and prototyping languages; it can be complex and needs refinement for general use. In practical terms, a single process model to be used may be mandated by the customer in advance.

3.2.5 Formal Transformation Model

Formal modelling is included here as it presents an alternative, rigorous and novel emerging framework for systems development. A mathematical language such as Z or VDM (Jones, 1986), LOTOS or Petri nets (Paterno, 1995) is used to build a precise model of a hardware or software system. The model is then formally checked, proven to meet the stated system requirements and finally transformed to an implementation.

Sommerville (1995) notes that this transformational process is currently high risk because of the need for advanced technology and specialist staff skills. The process is also not friendly to the user owing to the obtuse mathematical representations employed. Computer scientists with limited knowledge of real-world problems have also oversold the formal modelling approach in the past. However, small-scale systems can be developed which are mathematically consistent, formally complete and verifiable against the specification. The process of formal modelling provides insights into the software requirements and the design. In addition, the need to produce formal documents from each phase, for the process to continue, means that the model achieves good process visibility.

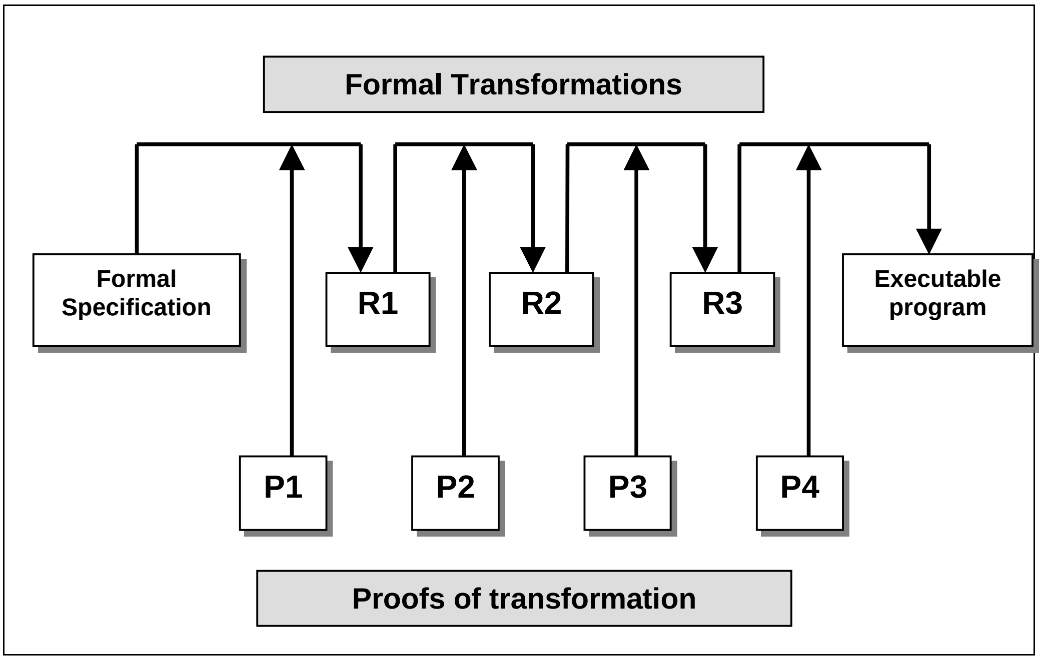

Figure 7: Formal Transformational Development Model

Formal mathematical models are still an active research area and have not found a wide industrial uptake other than in certain niche markets of safety critical systems or sub-systems. This situation may change, however, as the benefits of specific methods become known and reliable toolkit support becomes available. The Framework IV ESPRIT Project 'MEFISTO' is currently investigating ways of using formal techniques to model, specify and build user interfaces in safety critical en-route and airport ATC systems.

3.2.6 Summary of Models

It is not possible to recommend a single 'preferred' system development model, since the choice will depend very much on the application domain, the familiarity of the problem, the degree of user interaction, as well as the traditions and design precedents of the employing organisation.

Table 3: Summary of system development models

Model name	Strengths	Weaknesses	Characteristics	When to use
Waterfall Model	Commonplace, traditional, well-structured. Good process visibility.	Scope for iteration limited. High risk for novel systems.	Well-defined stages, linear flow.	Familiar and well-defined applications, e.g. databases.
V Model	Commonplace, traditional, well structured. Emphasis on software coding and testing. Good process visibility.	Scope for iteration limited (but see Jackson's enhanced V-Model). High risk for novel systems.	Well-defined stages, linear flow.	Familiar and well-defined applications, e.g. databases.
Evolutionary Development Model	Flexible: evolve system or refine requirements. Able to accommodate change and involve user.	Potential lack of process visibility and structure. Specialist skills required e.g. prototyping languages.	Concurrent activities. Flexibility. Exploratory or throwaway prototyping.	Novel applications. Small to medium sized interactive systems or sub-systems), e.g. user interfaces.
Hybrid/Spiral Model	Combined benefits of other model approaches. Defined stages. Also able to accommodate change and involve user. Good process visibility.	Specialist skills required e.g. risk assessment expertise, prototyping languages. May not be practical.	Flexibility. Cyclic, iterative refinement. Risk-driven.	Large to medium sized systems comprising sub-systems, e.g. including user interfaces.
Formal Transformation Model	Mathematically rigorous and provable. Informs the development process. Good process visibility.	Specialist skills required. Currently not widely used. Poor user involvement.	Radically different approach using mathematical modelling.	Small safety critical systems or sub-systems, e.g. user interfaces.

The survey has reflected an almost evolutionary process of model development from the traditional waterfall through prototyping to formal modelling approaches. Table 3 summarises the main strengths, weaknesses, characteristics and usage areas of the different models.

A system development model is a conceptual framework or philosophy within which the process and life cycle of system development takes place. Examples are Waterfall, 'V', Evolutionary and Hybrid/Spiral Models. It is not possible to recommend a single 'preferred' model; each has its own strengths and weaknesses. Some models are more amenable to human factors integration than others.

3.3 System Development Methods

3.3.1 Methods from Business and Management Theory

There is a generic collection of business system development methods arising from management theory. This alternative management science approach includes management information systems (Davis & Olson, 1985) and decision support systems (Sprague & Watson, 1986). Here the information system with its attendant user interface requirements is seen as part of a broader management and organisational development process. Professional systems development is as much to do with adopting appropriate management systems as well as information technology systems (Andersen, 1990). This approach fits well with the project and business management systems adopted by industry, government agencies such as DERA and international bodies such as EUROCONTROL (EATCHIP, 1998c). The scope for including human factors in such business management systems is described elsewhere (EATMP, 1999b).

3.3.2 General Structured Software Development Methods

A number of authors (Birrell & Ould, 1985; Avison & Fitzgerald, 1988) have charted the evolution of information systems methodologies, techniques and tools. The early 1970s were the era of structured top-down programming, but by the mid-1970s structured design techniques (Yourdon & Constantine, 1975) had begun to emerge. The late 1970s were characterised by similar structured analysis techniques such as Structured Systems Analysis and Design Method (SSADM), DeMarco's approach (1978) and the Gane and Sarson's method (1979), as well as database techniques. In the early 1980s Jackson System Development (JSD) (Jackson, 1983) appeared, also non-procedural languages and action diagrams.

By the late 1980s Information Engineering (Martin, 1989) was in vogue, together with data modelling, case techniques, support tools, rule-based systems, verification checking and automatic code generation. The 1990s saw the emergence of Object-Oriented Analysis and Design (OOA/D) methods (Yourdon & Coad, 1991; Booch, 1994), encompassing simplified representations of the real world through object classes and the concepts of inheritance and data encapsulation.

By the mid to late 1990s the Unified Modelling Language (UML) (Fowler & Scott, 1997; Booch, Rumbaugh & Jacobson, 1999) was created by the joint efforts of leading object-oriented practitioners and represents a convergence of several object-oriented analysis and design notations. Its emphasis on use cases together with several diagram types to represent different perspective views of the system has received broad-based industry support.

The basic tenet of all structured techniques includes the principles of abstraction, formality, decomposition, structure, modularity, hierarchical ordering, localisation, interfacing, consistency and logical completeness. The objectives of structured techniques can be summarised as:

- achieve high-quality programs of predictable behaviour,
- achieve software that is easily modified and maintained,
- simplify the program development process and programs,
- achieve predictability and control in the development process,
- achieve system development which is faster and cheaper.

Common themes include the need to take an overall systems approach, the importance of user involvement and the need for automated tool support. Many of the development methods embody similar philosophies and techniques, but use slightly different notations. The modularity OOA/D methods particularly suit the Augusta Ada Byron (ADA) and C++ programming languages, and also fits with human conceptual chunking.

The present day market leaders are Rational-Rose, using UML supported by their Teamwork toolkit. In general, these methods make no special provision for the user interface design component, implying a lack of opportunity for human factors input.

However, Damodaran (1991) reports early work at the Human Sciences and Advanced Technology (HUSAT) Research Institute[4] attempting to define a human factors strategy for information technology systems. The approach, known as Departmental Integrated Application Development Methodology (DIADEM)[5], aimed to provide human factors expertise as an integral part of SSADM and Project Resource Organisations Management and Planning Technique (PROMPT) methods used by the UK Department of Health and Social Security (DHSS) for first computerising its office systems.

[4] HUSAT Research Institute is part of the Science Faculty at Loughborough University.
[5] DIADEM also stands for 'Dialog Architecture and Design Method' which was developed by the French company Thomson-CSF.

Key human factors inputs to Information Technology (IT) design included in the management, technical and techniques development manuals were:

- user analysis / socio-technical systems analysis,
- user involvement in decision-making,
- user acceptability criteria,
- methods of user involvement,
- job design and work organisation,
- task allocation / job stream charts,
- Human-Computer Interface (HCI) design,
- prototyping,
- workplace and workstation design,
- user support,
- management of change,
- institutionalising human factors.

Evaluation studies were carried out, it is not known whether the DIADEM method was used in practice. Catterall (1991) compares and contrasts DIADEM with two other potential generic methods (HUFIT Toolset and MoD/DTI[6] Human Factors Guidelines) of inputting human factors into information technology systems design. The DIADEM Project did, however, provide many useful lessons on the successful strategies and pitfalls of introducing human factors into system development methods (Damodaran, 1991).

Finally, Hornby, Clegg, Robson et al (1992) compared fifteen ‘design methods’ (e.g. SSADM, ETHICS, USTM, etc.) as to the extent to which they incorporated consideration of a set of relevant ‘human and organisational issues’. The authors concluded:

> *… our findings suggest that no single method covers all phases of the life cycle. Coverage of human and organisational issues is patchy in the mainstream technical methods …*

3.3.3 Multiview Methodology

The Multiview methodology is a flexible framework for defining and developing information systems, popular in the late 1980s (Wood-Harper, Antill & Avison, 1985). Its strength is in its holistic breadth and non-prescriptive approach. Multiview consists of five phases:

1. Analysis of human activity systems (Soft systems methodology, Rich pictures).

2. Analysis of entities, functions, tasks and events (Information modelling).

3. Analysis and design of socio-technical system (Allocation of function).

[6] Ministry of Defence / Department of Trade and Industry

4. Design of user's HCI (specification and design).

5. Technical design.

There is scope for human factors involvement (depending on breadth of the definition of human factors) in each of Phases 1-4, as indicated above. The Soft Systems method can be used to conceptualise and iteratively refine for further evolution future ATM systems that do not yet exist. Rich pictures are a way of representing ATM system organisations and stakeholders, their views and concerns, and the communication channels and conflicts between them. Information modelling of a total system, employing SSAD techniques (covered in the previous section.) can equally well encompass the Human (Task Analysis: Kirwan & Ainsworth, 1992) as well as the technical components of a system.

Socio-technical systems analysis and design is able to consider and evaluate alternative options for ATC human roles and people tasks as well as computer task requirements. HCI design specifies the technical requirements to best support the user of the ATC system through appropriate interfaces, dialogues and user-centred prototypes.

The Multiview methodology has been used successfully in carrying out a systems analysis of the current UK ATC system as a precursor for identifying the requirements for the future new en-route ATC system (Goillau, 1990).

3.3.4 MUSE

The Method for Usability Engineering (MUSE) was developed by the Ergonomics and HCI Unit, University College, London (Lim & Long, 1994; Lim, 1996). The method defines the user interface design process by specifying the products to be generated and the procedures by which they are to be generated.

MUSE increases the degree to which human factors considerations are reflected in the development process and resultant designs. It reduces the requirement for re-work late in the development process by avoiding divergence of, and by promoting common understanding and discussion between, human factors and software engineering design teams. The ability to discuss design issues early in the design process results in the production of high-quality user interfaces by ensuring that the high-level design is appropriately specified before detailed design commences. Finally, the system of documentation specified by MUSE facilitates re-use of work from earlier projects, thus reducing the need for duplication of analyses. A table of detail, which also contains observations and speculations concerning design ideas, supports each MUSE diagram.

MUSE has three phases:

- Phase 1: information elicitation and analysis (extant systems analysis model, generalised task model) – This phase involves collecting and analysing information (using human factors techniques such as task analysis) concerning the existing tasks of users and the positive and negative features of the systems that they currently use.

- Phase 2: synthesis (statement of user needs, composite task model, system and user task model) – In this phase the human factors requirements of the design are established and the semantics of the task domain as it relates to the work system are analysed and recorded.

- Phase 3: design specification (interaction task model, interface model and display design stages) – Based on the specification of the on-line task a detailed and device-specific specification of the user interface is produced. The user interface is then assessed and refined in an iterative fashion. Once the interface is considered satisfactory, the products of the final stage are delivered to the software engineers for implementation.

Although developed as a generic method, MUSE has been integrated particularly with the JSD method (Lim, Long & Silcock, 1992). MUSE is gaining acceptance and has been applied in case studies such as domestic energy management requirements (Stork, Middlemass & Long, 1995). In addition to research use MUSE has been positively evaluated (BIUSEM, 1995) in industrial trials under the European Systems and Software Initiative (ESSI) Project to promote integration of human factors contributions with those of software engineering in structured software development methodologies and to incorporate human factors into otherwise complete software life cycles.

3.3.5 IMPACT

IMPACT is a EUROCONTROL sponsored theoretical design process for studying new ATM concepts (EATCHIP, 1998f). It proposes a generic life cycle that identifies the main activities for projects dealing with new ATM concepts, including their training implications and needs.

The stages of the IMPACT methodology comprise:

- Define the operational scenarios – analyse and formalise need:
  - produce the new system itself (parallel activities);
  - prepare the training tools and plan (parallel activities);
  - prepare the ergonomic validation tools and plan (parallel activities).

- Evaluate the new system – as a result of this activity, ‘upgraded air traffic controllers’ with adequate skills, achieved validation plan and tools, tested system.

- Validate the new system – study final report.

- Enrich the impact analysis knowledge base – provide new data for future Impact analyses.

IMPACT aims to identify processes and activities, and to guide the research of tools and techniques needed to provide methodological support. The stress is on IMPACT analysis activities. To identify an IMPACT is to manage the consequence of change in a predictive way, and because prediction involves risk management, dealing with the IMPACT can be thought of as managing the risk. IMPACT's strength is that it constitutes a generic theoretical view based on past practical ATM project experience. It is directive and top-down enough to allow compatibility with the waterfall cascade model, but flexible enough to permit a degree of backtracking between process stages. It also facilitates multidisciplinary design teams comprising operational air traffic controllers, human factors, systems and training experts. However, it has yet to be extensively validated.

3.3.6 Summary of Methods

As with development models, it is again not possible to recommend a single 'preferred' system development method, since the choice will depend very much on the application domain, the familiarity of the problem, the degree of user interaction, as well as the traditions and design precedents of the designing organisation.

Table 4: Summary of system development methods

Method name	Strengths	Weaknesses	Characteristics	When to use
Management science	Considers total business and management system perspective.	Distant from detailed engineering systems and user interfaces.	Strategic. Top-level project management / financial considerations.	Overall project and business management considerations.
Structured software development methods	Traditional software / hardware development methods.	Can be overly detailed. No special provision for user interface.	Classic systems development techniques.	Software and hardware systems development.
Multiview methodology	Flexible. Broad. Considers from concepts to final implementation.	Top level. May not be prescriptive enough.	'Pick and mix' method.	Total systems development.
MUSE method	Integrates task analysis with software engineering.	Very detailed and prescriptive.	Generic method. Specifically integrated with JSD.	Combined usability and software engineering.
IMPACT method	Generic EUROCONTROL in-house method. ATM specific. Risk management.	Couched in terms of training needs.	Bridges between ATM systems and training needs.	Systems with training requirements.

In terms of human factors integration the classic problem has been the failure of traditional software engineering methods adequately to support the design of the user interface with respect to user requirements. The first step towards a better user interface is realising that good design begins in the early requirements definition stage and not when prototyping or implementation is underway. Indeed, it can be argued that human factors input should inform the design of the entire **application,** not just the interface. However, mainstream software development methods historically have not given the required support or the scope within their specific method steps to include such support externally. The more recent methods (i.e. DIADEM, Multiview, MUSE and IMPACT) have attempted at least partial solutions to this dilemma.

Table 4 summarises the main strengths, weaknesses, characteristics and usage areas of the different methods.

A system development method is a prescribed set of techniques, notations, symbologies and possible support tools detailing how a system may be developed. It is not possible to recommend a single 'preferred' model; each has its own strengths and weaknesses. Some methods are more amenable to human factors integration than others.

4. HUMAN FACTORS IN SYSTEM DEVELOPMENT

4.1 Introduction

4.1.1 Definition of Human Factors

Human factors can be defined as an interdisciplinary science concerned with the application of knowledge about human psychology, physiology and anatomy to the design of the **things** we use (i.e. tools, machines, **'**systems**'**, etc.) and the **places** (or environments) in which we use them, so as to improve their effectiveness and usability, and increase our safety, comfort and satisfaction. In short, human factors is *designing for human use* (McCormick, 1976).

As the things that we use include, to an ever-increasing extent, computers and computer-based technology, this has given rise to Human-Computer Interaction (HCI) as a distinct, but closely related, scientific field (e.g. Helander, 1988). This interaction between humans and machines obviously occurs within a wider social and organisational context; therefore, human factors such as job design, selection and training, health and safety, and employment legislation, are also important.

4.1.2 Human Factors Data

The amount of human factors knowledge which has been accumulated over the years is quite enormous, as evidenced by such seminal texts as 'Human Factors Design Handbook' (Woodson, 1981), 'Engineering Data Compendium' (Boff & Lincoln, 1988), 'Handbook of Human Factors and Ergonomics' (Salvendy, 1997), 'International Encyclopedia of Ergonomics and Human Factors' (Karwowski, 2000), each of which cites hundreds of references. In addition, there are now many sources of human factors information available on the Internet (see Annex 'Information Sources on the Internet'). However, the application of this wealth of information to system development remains problematic.

4.1.3 Human Factors Techniques, Methods and Tools

Like any other scientific discipline, human factors has its own assortment of techniques, methods and tools[7]. For example, task analysis is a technique for analysing the behavioural implications of system design. There are several task analysis methods to choose from and probably the best known one is Hierarchical Task Analysis (HTA). However, EUROCONTROL has recently

[7] Technique is used here to mean a set or sets of analysis and measurement methods, e.g. observation techniques, questionnaire and survey techniques, prototyping techniques or workload assessment techniques. A method is a way of implementing the technique. Finally, a tool (usually computer-based) is a way of making it quicker or easier to perform.

reported (EATCHIP, 1998g) the development of a new approach known as Integrated Task Analysis (ITA) which, amongst other features, emphasises the cognitive aspects of air traffic control.

Many human factors methods have been developed over the years and there are many different types (see, for instance, Meister, 1985). If one includes HCI methods and tools as well (e.g. DTI, 1991), the pool of techniques is indeed very large and new tools are regularly being developed. However, it has to be said that the usability, availability, cost and general effectiveness of these tools vary a lot. It is also true that most tools are for application during the detailed design and evaluation phases of the system life cycle, which is one of the reasons why human factors as a profession has been so poorly integrated in the system development process (see 4.2 below).

Several detailed and comprehensive reviews of human factors methods and tools have been produced (e.g. Foot, Chupeau, Biemans et al, 1996), but the subject will be considered more fully in the third HIFA report (EATMP, not printed).

Human factors is an inter-disciplinary science concerned with 'designing for human use'. Over several decades it has accumulated an enormous amount of knowledge about human characteristics and behaviour for application to systems design. Like other scientific disciplines it has its own assortment of techniques, methods and tools.

4.2 Role of Human Factors in System Development

The proposition that human factors should be an integral part of system design is not a new idea and has been discussed and exhorted for several decades (e.g. Singleton, Easterby & Whitfield, 1967; Singleton, 1974). Unfortunately, the traditional role of human factors in the overall system design process has often been described as too little, too late. This problem has been recognised for many years by system designers and human factors practitioners alike. According to Rouse and Cody (1988) this lack of attention is due in part to an engineering-led focus on 'getting the technology to work', and in part to a lack of methods for considering humans' roles early in the process. This methodological limitation is addressed later (see Chapter 6).

There are a number of reasons for the inadequate treatment of human factors issues. It is not appropriate to discuss these in detail here, but suffice to say that some of the main reasons, which are common to all domains, are:

- Inherent problems of the system design process, particularly the differing perspectives of customers and producers of systems. As Rouse and Cody (1988) put it,

> *It appears to us that customers, particularly those in government, want 'good' products while being assured of a 'correct' design process. Producers, on the other hand, do not want to be required to produce better than 'correct' products (i.e. it is difficult to guarantee a classic design!), but want the freedom and pleasure of innovating in terms of 'good' design processes (i.e. rapid prototyping). This conflict may also be irresolvable, but it is easily understandable.*

- Attitudes towards human factors as a discipline – it is often perceived as 'just common sense' or as an extra (unwanted) project cost.

- Inadequate human factors methods and tools, and methodology – human factors components are seldom included as an integral part of the development techniques used by systems designers. However, as Chapanis (1996) observed, this is partly the fault of human factors professionals themselves. To quote,

> *human factors professionals have not understood how engineers go about their work, how systems are developed, and the kinds of things we can do to assist in that process (p.55).*

It is outside the scope of this report to examine this issue any further, but it is intended that the material presented within the report (and the HIFA Project as a whole) will lead to a significant improvement in the application of human factors within system development.

It is widely accepted that human factors should be an integral part of systems design from its earliest stages rather than 'too little, too late'. Reasons for the inadequate inclusion of human factors are discussed.

4.3 Human Factors Guidance Material

4.3.1 Style Guides and Design Guidelines

Consistency is a key issue in user interface design. Interfaces that are inconsistent in their operation and philosophy, their **'**look and feel**'**, can be difficult to use. However, consistent interfaces can aid usability considerably. Style guides are uniform collections of design principles and rules for developers to follow. Three categories are commercial style guides produced by hardware or software manufacturers, the corporate style guides (often modified from commercial style guides) produced by companies for their own internal use, and sets of generic design guidelines.

The IBM Report by Engel and Granada (1975) was the first widely recognised compilation of user interface design guidelines. Pew and Rollins' (1975) Report for Bolt Beranek and Newman represents an admirable attempt to propose design guidelines for one particular system application, though its recommendations can be readily generalised for broader application. Brown et al's (1983) Report for Lockheed is a good example of user interface guidelines developed as an in-house design standard, but which have been made available for public reference. The Apple (1992) Macintosh Style Guide is a classic example of a commercial style guide and many others also exist (e.g. Microsoft, 1992).

Although commercial style guides usually contain some high-level design principles, the bulk of the document is often made up of low-level design rules with graphical examples. Traditionally distributed in lengthy book form (over 600 pages typically), some style guides are available in a **'**soft**'** interactive version so that developers can actually see the styles resulting from their design decisions. This issue of usability of the style guide itself has implications for the subsequent stages of the present HIFA Project.

Generic human factors style guides are also available, independent of any hardware platform or software product. Smith and Mosier (1986) have collated a definitive set of 944 previously published user interface design guidelines, grouped under the headings of data entry, data display, sequence control, user guidance, data transmission and data protection. A searchable version called **'**HyperSAM**'** is also available for the Macintosh[8]. They usefully identify classes of potential user: systems analysts or software designers, managers, human factors practitioners, researchers, teachers or students. A further specific example is that of the British Telecom (1990) top-level generic design principles – **'**Ten ways to keep the user friendly**'**:

1. Use the user's model.
2. Introduce through experience.
3. Design the system to be user- centred.
4. Allow the user to observe and control the system.
5. Log activities.
6. Ensure consistency and uniformity.
7. Provide immediate feedback.
8. Avoid the unexpected.
9. Validate entered data where possible.
10. Provide help information.

In France a number of ergonomics guidelines have also been produced, for example by the National Institute for Research in Computer Science and Control (INRIA) and the National Centre for Scientific Research (CNRS); see Scapin (1986), Alezra et al (1987) and Ratier (1998). The latter document, issued by the CNRS Quality Bureau, is available on the Internet along with several other ergonomics guidelines[9].

[8] see also Internet addresses at annex.
[9] See http://www.dsi.cnrs.fr/bureau_qualite/ergonomie/ergonomie.htm

A number of independent ergonomics consultancies have also produced generic human factors guidelines. For example, Human Factors International Inc. has made available a set of thirty-four human factors 'Design Magic' interface design principles on the Internet[10], grouped according to colour, layout and wording principles. Whilst a useful overview, such consultancies may make information available as a means of securing consultancy or training business, pointing out that interpreting guidelines calls for specialist training and skills, coupled with extensive previous practical experience.

4.3.2 Human Factors Design Guides for ATM

A number of human factors design guides have been produced in recent years, primarily in the United States under the auspices of the FAA. These documents basically build upon existing human factors material with some tailoring of information specifically for ATM systems.

The FAA's Human Factors Design Guide (Wagner et al, 1996) – over thousand pages in length – provides human factors guidelines covering the following topics: automation, maintenance, human-equipment interfaces, human-computer interfaces, workplace design, user documentation, system security, personnel safety, environment and anthropometry.

A related FAA report by Cardosi and Murphy (1995) provides extensive literature review and guidelines on the following major topics:

- human capabilities (e.g. visual and auditory perception, speech),
- human information processing (e.g. attention, memory, etc.),
- issues in ATC automation,
- HCI (e.g. displays, input devices, etc.),
- workload and performance measurement,
- workstation and facility design and evaluation,
- human factors testing and evaluation.

In addition, the report includes a section on human factors in system acquisition that discusses at some length the development of a **'**human factors plan**'**. Interestingly, an electronic version of the guidance information in the report has also been developed[11]. Detailed human factors guidelines have been produced by some national authorities (e.g. Atkinson, Donohoe, Evans *et al*, 1997), the latter apparently now totalling some 1600 guidelines.

In contrast to the broad human factors guidance offered by the above FAA documents, specific guidance on the design of HMI's has been recently produced by EUROCONTROL. First, a description of a 'state-of-the-art' graphical interface for en-route ATC (Jackson & Pichancourt, 1995); second, an 'HMI Catalogue' and demonstration available on the Internet[12]. Although the guidance is very specific to the design of HMI's for future controller

[10] See http://www.humanfactors.com
[11] See http://www.hf.faa.gov/products/checklst/checklst.htm
[12] See http://www.eurocontrol.be/hmi/

workstations within the context of EATMP, it does contain human factors information of a more generic nature.

Finally, according to Amalberti (1998) two new human factors **'**harmonisation groups**'** in the aviation domain have recently been set up. The aim of the first of these, formed at the end of 1998, is to provide new human factors guidance material and regulations. The second harmonisation group (JAA/FAA HWG 1329)[13] is dealing with automation and autopilots.

Human factors guidance material for system development exists in a number of forms such as commercial or corporate style guides and generic design guidelines. Human factors design guides specifically for ATM have also been produced. Guidance material is traditionally in printed form, though some electronic media have appeared.

4.4 Standards

4.4.1 Civil Standards

Closely related to design guidelines, standards concern prescribed ways of communicating or presenting information or carrying out a process. Standards seek to achieve consistency across products of the same type, so ensuring user confidence and ease of use (Parsons, Shackel & Metz, 1995). Standards may be connected with a national body, for example the British Standards Institution (BSI) and Health and Safety Executive (HSE), or an international body, for example the International Organisation for Standardisation (ISO) and the International Electro-technical Commission (IEC). They may also be connected with a particular application domain (e.g. UK or US military), with a professional body (e.g. British Computer Society) or with a specific company's house standards (e.g. Apple Computer). Informal or *de facto* standards also exist (e.g. the QWERTY keyboard).

In the field of civil computing, a Joint Technical Committee (JTC1) between the ISO and IEC deals with standards in the field of information technology. The international standard series ISO9000 is concerned with general software quality (equivalent to British BS5750, European EN29000, American ANSI Q90-94). The European equivalent of ISO is the *Comité Européen de Normalisation (CEN).* Relating to human factors and user interface design the most relevant standards are ISO 9241, ISO/DIS 13407 (TC159/SC4) and ISO 14915.

ISO 9241 addresses the ergonomic requirements for office work with Visual Display Terminals (VDTs), both hardware and software, and is the most

[13] Joint Aviation Authorities/Federal Aviation Administration

relevant ISO standard to date. In addition to human-computer dialogue software aspects of display design, ISO 9241 includes guidance on Visual Display Unit (VDU) tasks in recognition of the fact that many problems attributed to poor equipment design stem in fact from poor job design.

The seventeen parts of ISO 9241 comprise:

1. General introduction.
2. Guidance on task requirements.
3. Visual display requirements.
4. Keyboard requirements.
5. Workstation layout and postural requirements.
6. Environmental requirements.
7. Display requirements with reflections.
8. Requirements for displayed colours.
9. Requirements for non-keyboard input devices.
10. Dialogue principles.
11. Guidance on usability specification and measures.
12. Presentation of information.
13. User guidance.
14. Menu dialogues.
15. Command dialogues.
16. Direct manipulation dialogues.
17. Form-filling dialogues.

ISO/DIS13407 will be concerned with human-centred design processes for interactive systems, i.e. the ergonomics of human-system interaction. It is still in its discussion stage. Its Working Groups TC159/SC4 comprise fundamentals of controls and signalling methods, visual display requirements, control workplace and environmental requirements, software ergonomics and human-computer dialogues, human-centred design processes for interactive systems, and ergonomic design of control centres. This is potentially a far-reaching standard, in that it will provide a means for establishing and auditing the process of HCI design rather than its detailed content.

ISO14915 will establish software ergonomics requirements and recommendations for interactive multimedia user interfaces that integrate and synchronise different media (text, graphics, images, audio, animation and video). It is still in its draft stage. Its four parts will be framework, multimedia control and navigation, selection of media and media combination, and domain specific interfaces. The standard will apply to presentation and interaction techniques for computer-based multimedia applications, ergonomic design issues and evaluation.

In addition, though not strictly a standard as such, the Council Directive from the European Community issued on 29 May 1990 addresses the minimum safety and health requirements for work with display screen equipment. Its impact on HCI design practice and standards of the future will be high. The technical annex to the Directive contains a number of very general minimum requirements for the workstation and users' tasks, including display screen, keyboard and operator/computer requirements.

4.4.2 Military Standards

In the military domain Defence Standard 00-25 (MoD, 1997) comprises human factors guidelines for designers of equipment:

- Part 1: Introduction.
- Part 2: Body size.
- Part 3: Body strength and stamina.
- Part 4: Workplace design.
- Part 5: Stresses and hazards.
- Part 6: Vision and lighting.
- Part 7: Visual displays.
- Part 8: Auditory information.
- Part 9: Voice communication.
- Part10: Controls.
- Part 11: Design for maintainability.
- Part 12: Systems.
- Part 13: Human-Computer Interaction (HCI).

Part 12 (MoD, 1989), concerned with systems aspects, and Part 13 (MoD, 1996), concerned with HCI aspects, are particularly relevant. There are also standards for human factors in naval project management (HMSO, 1993; 1994). For the US military the data sources by Boff, Kaufman and Thomas (1986), Boff (1988) and Lincoln (1988) fulfil a similar function along with MIL-STD-1472E (DoD, 1998)[14].

Standardisation has clear benefits in that it provides a common terminology, maintainability and evolvability, a common identity, and a potential reduction in training. However, a potential drawback in relation to the present HIFA Project is the large number of standards from which to choose.

In comparing standards versus guidelines for designing user interface software Smith (1986) notes that formal design standards may prove ineffective for aiding software design. He argues for the development of flexible design guidelines for user interface software, without the imposition of standards. He further comments that applying guidelines effectively will require a process of translation into system specific design rules, potentially incorporated as part of future computer-based design algorithms.

Standards relevant to human factors integration exist in both the civil and military domains, and are closely related to design guidelines. Their quantity, volume and inflexibility may offset the benefits of standards. Standards are traditionally in printed form, even if electronic media have begun to appear.

[14] MIL-STD 1472E is the most recent version of the standard which was first issued in the early 1970s.

4.5 Usability

4.5.1 Product Usability

Usability can be defined (Preece *et al*, 1994) as a measure of the ease with which a system can be learnt or used, its safety, effectiveness and efficiency, and the attitude of its users towards it. The ultimate goal of HCI is to produce systems that can be – and indeed are – used, as well as being safe and functional. To produce computer systems with good usability, HCI specialists attempt to understand the factors (psychological, ergonomic, organisational and social) that determine how people make use of computer technology. This understanding is translated into the development of techniques and tools to help system designers ensure that that computer systems are appropriate for the activities that people will use them for. Such development will help achieve efficient, effective and safe interaction for the individual or group.

Since the term **'**usability**'** was first coined in the 1980s there has been an explosion in the amount of the available literature (e.g. Helander, 1988; Shneiderman, 1992; Hix & Hartson, 1993; Rubin, 1994). In the early 1990s the usability movement received an impetus from the UK DTI: **'**Usability Now!**'** initiative (Benyon, Davies, Keller et al, 1990). The Internet now provides several information resource sites specifically concerned with usability and usability engineering, for example Jakob Nielsen's 'Usable Information Technology' web site amongst many others (see <u>list of Internet sites at annex</u>).

Often in the past focus has been on the engineering the usability of the user interface **product**, in terms of the design and evaluation in terms of measured usability of the total human-computer system. However, Gould (1988) notes that there are many components of usability which must be taken into account if the system is to be **'**good**'**: system performance, system functions, user interface, written materials, language translation, outreach program, customer tailorability, installation, field maintenance and serviceability, advertising, and user support group. It is straightforward to argue the case for engineering product usability (Whiteside et al, 1988) in terms of improved user performance, efficiency and job satisfaction, but economic justification for usability effort in interactive system development is also beginning to be established (Nielsen, 1993; Bias & Mayhew, 1994).

There has been little comparative study evaluating different strategies for including usability design techniques within system development methods. Shackel's comment (1984) that '*There is no comprehensive and generally accepted manual on how to design good human factors into computer systems*' remains arguably true fifteen years on.

4.5.2 Usability of Human Factors Data and Guidelines

When designers do choose to consider the human factors aspects of their systems it is commonly held that human factors guidelines, whilst a useful consciousness-raising starting point, are often hard to follow (Gould, 1988). Why should this be so? A number of common themes have emerged:

- the sheer volume of data and research findings is potentially intimidating, with guidelines running into hundreds or even thousands of pages;
- the research findings may be inconsistent and conflicting, depending on the specific nature of the experimental paradigm employed;
- the way the data is structured may be unhelpful for an individual user (different users having different needs);
- the data do not use the mental model and domain terminology of the user's application domain;
- a degree of interpretation is needed, as the research data rarely meet the exact specific requirements of the user, or are too general;
- there is a potential range of user **'**types**'** who may wish to consult the data (e.g. system designers, other technical personnel, end-users, human factors specialists, project managers, accountants and financiers, and other interested parties or stakeholders);
- much of the human factors source data is not readily accessible in the public domain;
- the data is only available at a price or at a considerable time investment;
- technology is advancing faster than the relevant human factors research studies.

Gould (1988) notes that you cannot design a good system from guidelines alone – there is not a handbook of operating characteristics for the human mind. He recommends that for the foreseeable future guidelines should be considered as a collection of suggestions, rather than distilled science or formal requirements. Understanding users, testing in operational contexts and iterative design remain indispensable, costly necessities.

Product usability is a key concept within human factors and more broadly within design. Despite the vast amount of research on usability, the process of designing human factors into computer systems remains something of an art. Human factors guidelines themselves are often not sufficient and are rarely usable by non human factors-specialists.

5. HUMAN FACTORS INTEGRATION

5.1 Introduction

In this chapter a number of different approaches to Human Factors Integration (HFI) are reviewed. First, the user-centred design approach is considered, since it underlies most other approaches.

Next, human factors activities within the space and nuclear industries are briefly examined to illustrate approaches taken in non-ATM domains.

The final parts of this chapter then take a more detailed look at the defence system acquisition processes in the US and UK governments. The justification for this is that the latter have undoubtedly done most to improve the position and role of human factors in the system design process – the US through its MANPRINT Programme, and the UK through its own HFI programme. HFI is a management and technical process that seeks to provide a balanced development of both the technical and human aspects of system procurement.

The approaches to HFI within the ATM domain are considered separately in Chapter 6.

5.2 User-centred Design Approach

As far as it is possible to trace the origin of particular terms, the term 'user-centred design' probably emerged in the early 1980s as part of the rapidly expanding fields of IT systems and HCI (e.g. Shneiderman, 1980; Eason, 1983). This emphasised the importance of understanding and taking account of the user's needs when designing systems. The term is most strongly associated with the book by Norman and Draper's (1986).

User-centred design represents a particular philosophy to systems design and it is important to consider it here as it underlies most of the approaches to human factors integration that have been developed. For instance, user-centred design is at the heart of the 'human-centred automation' approach in aviation that is discussed later in the report (see 6.2.2). The main principle of user-centred design is that *if a product, an environment or a system is intended for human use, then its design should be based upon the characteristics of its human users* (Pheasant, 1989, p. 81). In other words, designers must understand whom the users are, or will be, and what tasks they do or will be expected to carry out.

An interesting and highly pertinent example of the user-centred design approach is to be found in the human factors guidelines developed by the HUSAT Research Centre (Gardner & McKenzie, 1988; Gardner, 1991).

The guidelines are specifically stated to be user-centred because they focus on:

a) how to identify the users' purposes and how to represent the information gathered so that it can be used by a design team;

b) how to establish testable system goals from the point of view of the users;

c) how to involve users in decision-making;

d) identifying, and giving advice on, users' characteristics that are relevant to design.

Closely related to the user centred approach, which needs to be mentioned, are '**cognitive engineering**' and '**cognitive systems engineering**' (Hollnagel & Woods, 1983; Norman, 1986). The idea behind this approach is that, because of the ever-increasing growth in computerised systems, there is less emphasis required on human perceptual and motor skills, and more on cognition, i.e. problem-solving and decision-making. This requires a shift of emphasis in system design. As Hollnagel and Woods put it, *the central tenet of cognitive systems engineering is that an man-machine system needs to be conceived, designed, analysed and evaluated in terms of a cognitive system*' (p. 585). It is beyond the scope of this report to discuss this subject any further, but for more information consult Rasmussen, Pejtersen and Goodstein (1994).

Finally, an alternative term – use-centred approach – suggested by Flach and Dominguez (1995) appears to suggest a more traditional, task-centred rather than a user-centred approach.

User-centred design is an approach to systems design that emphasises that the purpose of the system is to serve the user. It is important to understand who the users are, and the tasks they do. User-centred design underlies most other approaches.

5.3 Space Industry Approach

Human factors influences may have been limited, though still significant, in space programmes. Data on human performance in manned space systems has not been gathered under controlled conditions and the limited availability. Data from performance in space that can be fed back into system design are limited.

As a consequence human factors issues have been based primarily on an extrapolation from data gained from ground-based studies and design standards. Concerns focus on spacecraft habitability, the humans' ability to perform physical and cognitive tasks in high acceleration and weightless conditions, crew station design, and the pathological effects of space travel (Hunt, 1987).

Terrestrial standards were, and continue to be, applied to manned space systems design because dedicated standards were unavailable. That position has been under long-term review. More recently, however, the National Aeronautics Space Administration's (NASA) Man-Systems Integration Standards (MSIS) has been developed to provide human factors guidance for the man-machine interface in manned space crew functions, though it has been based substantially on terrestrial standards (NASA, 1995). This standard also incorporates cross-cultural aspects of design, reflecting the increasing multinational nature of space exploration. Also the Human-Computer Interface Guide (SSP 30540) provides design guidance for information systems that affect human performance within the Space Station Freedom Programme (NASA, 1993). These standards are also being applied to human factors issues in the design of future lunar outpost.

5.4 Nuclear Industry Approach

In the aftermath of the **'**Three Mile Island**'** accident in 1979 the US Nuclear Regulatory Commission (NRC) prompted the nuclear industry to incorporate human factor safety aspects of the control and maintenance of nuclear power plants into their risk assessment programme. The NRC required that all licensees and applicants for commercial nuclear power plant operating licences conduct detailed control room design reviews, including reviews of remote shutdown panels, to identify and correct design deficiencies related to human factors. Extensive guidelines published as NUREG-0700, 'Guidelines for Control Room Design Reviews' were prepared to support these reviews. The guidelines, first issued in 1981, were recently revised to take into account the introduction of computer-based, human-computer interface technology (NRC, 1995). The Institute of Electrical and Electronics Engineers (IEEE) has also developed several related standards (IEEE, 1988a, 1998b).

Kirwan and Ainsworth (1992) made a comprehensive summary of task analytical methods that were available. Many of their examples related to applying general task analytical techniques to varying issues in the nuclear industry. These include applying:

- ergonomics checklists to ascertain whether a particular ergonomics requirement have been met within a task;
- interface surveys using a group of methods to assess specific physical aspects of the man-machine interface;
- task and function analyses to determine staffing levels for control rooms;
- a balance between human action and automation using techniques including hierarchical task analysis, timeline studies and workload assessments.

Kirwan (1994) outlined several human factor assessment methods that have been applied to the nuclear industry. Human reliability analysis has been used to predict human error probabilities, and probabilistic risk assessment has been used to identify potential areas of significant risk and indicate how they may be overcome.

5.5 Defence System Acquisition Process in the United States

The defence industries and governments in Western Europe, particularly the US, have done most to improve the position and role of human factors in the system design process. They had long realised that failure to recognise the importance of human element of a system resulted in higher life cycle costs and lower system performance levels than predicted. System users often had to compensate for poor design, resulting in high error rates, increased training costs, poor system effectiveness and job dissatisfaction.

The leading role of government in the development of systems engineering and the promotion of human factors is not surprising. Chapanis (1996) says:

> *The government is the largest purchaser and user of large systems. Everyone is familiar with the many military systems - aircraft, ships, tanks, missile systems [...] Developing those systems required a structured approach – a set of formal procedures to instruct and guide engineers and designers and to provide the means by which developments could be monitored. At the same time, the realisation that machines do not fight alone resulted in a number of stringent requirements that military systems be designed to make them usable by people with 'only-human' abilities and capacities. This total approach taken by government has been codified in numerous standards, specifications, and other documents. (p. 10)*

The US Department of Defense (DoD) has a tri-service directive to conduct a Human Systems Integration (HIS) Programme in materiel acquisition. Individual Services have their own version of HIS that is tailored to their own type of system acquisition. The US Army MANPRINT Programme has evolved since the mid-1980s and now has seven domains:

1. Personnel capabilities.
2. Manpower.
3. Training.
4. Human factors engineering.
5. System safety.
6. Health hazards.
7. Soldier survivability.

MANPRINT is a comprehensive management and technical initiative to enhance human performance and reliability during weapons system and equipment design, development and production. Its focus is to integrate technology, people and force structure to meet mission objectives under all environmental conditions at the lowest possible life cycle cost. Further information on MANPRINT can be found in the MANPRINT Practitioner's Guidebook, now available on the Internet[15].

In order to serve the growing needs of the HIS community in the US, an automated information system called Manpower and Training Research Information System (MATRIS) has been set up by the DoD Defense Technical Information Center (DTIC). MATRIS has produced a Directory of Design Support Methods (DDSM) which is also available on the Internet[16].

The US MANPRINT Programme has been particularly influential in improving the position of human factors in system development. Although it has itself evolved considerably, it has been adopted and modified in several domains including ATM and other non-military domains.

5.6 Defence System Acquisition Process in the United Kingdom

In the early 1990s the UK Ministry of Defence (MoD) introduced a modified version of the US MANPRINT Programme. Initially, this programme was developed on land-based systems but was then extended to become tri-service and is now known as HFI. As this programme probably represents the most advanced work currently on HFI, it is described below at some length.

5.6.1 Definition of Human Factors Integration

Human Factors Integration (HFI) is a management and technical process that seeks to provide a balanced development of both the technical and human aspects of system procurement. It provides a process that ensures the application of scientific knowledge about human characteristics through the specification, design, development and evaluation of systems. This defined process acts as a quality assurance function and gives the procurement authority an audit trail that human factors issues such as usability, safety and personnel-related whole life costs are adequately considered during the procurement process. The goal of HFI is to identify the most cost-effective trade-off between the six domains, which are described in Table 5 below.

5.6.2 Human Factors Integration Management

Since HFI is a process it needs to be managed in order to work effectively. It needs some method of enforcement otherwise it will be treated as an optional

[15] http://www.manprint.army.mil/manprint/index.html
[16] http://dticam.dtic.mil/hsi/index.html

extra. The enforcement should be authorised by someone in a high level of authority. In the UK MoD HFI process, this is achieved by the Chief of Defence Procurement Instruction (CDPI) (HMSO, 1998a). This is an auditable document that instructs the project manager to perform a number of tasks to initiate the HFI process.

These consist of making sure that HFI is a part of the procurement strategy, and informing relevant bodies who will be affected by decisions made in the HFI process. These bodies include finance staff who have to make provision in the long-term costing and principal personnel officers who need to know what impact the proposed system is likely to have on future recruitment criteria and trade group structures. Other tasks include assigning HFI roles and responsibilities, developing the HFI Plan and conducting an Early Human Factors Analysis (EHFA). These are discussed more fully in the sections below.

Table 5: Six HFI domains

HFI Domain	Description
Manpower	The numbers of personnel, which are required to operate, maintain, train and support the system.
Personnel	The aptitudes, experience and other human characteristics, including body size and strength, necessary to achieve optimum system performance.
Training	Specification and evaluation of the optimum combination of: instructional systems, education and On-the-Job Training (OJT) required to develop the knowledge, skills and abilities needed by the available personnel to operate, maintain and support systems to the specified level of effectiveness under the full range of operating conditions.
Task and Interface Design (TID)	Comprehensive integration of human characteristics into system design, including all aspects of interface (workstation and workspace) design and tasks.
System Safety	The process of applying human factor expertise to minimise safety risks occurring as a result of the system being operated or functioning in a normal or abnormal manner.
Health Hazard Assessment	The process of identifying and addressing conditions inherent in the operation or use of a system (e.g. vibration, toxic fumes, radiation, shock, recoil) which can cause death, injury, illness, disability or reduce the performance of personnel.

5.6.3 Human Factors Integration Roles and Responsibilities

The project manager has overall responsibility for HFI. The CDPI instructs the project manager to establish an HFI focus as part of the integrated project management team. In smaller projects the HFI focus may be the project manager. Neither the project manager nor the HFI focus will be qualified human factors experts. This expertise comes from either an MoD agency or an external contractor. Once the contract has been let there will also be human factors expertise from the industry partner(s).

5.6.4 Human Factors Integration Plan

The HFI plan set out the process of HFI management. It describes the HFI issues to be addressed in the project and actions to be taken to address each issue or risk (Hamilton, 1996). It proves a plan of action indicating the timing and duration of each activity, who will perform it, effort and resources required, dependencies on other project activities and methods for monitoring and controlling progress against the plan. It also references other related plans (such as the training plan, human engineering plan and safety plan).

5.6.5 Target Audience Description

The Target Audience Description (TAD) is the specification for the human element of the system, which includes operator, maintainers and support personnel. In the past, designers have tended to concentrate on a single operator and have neglected the needs of supervisors, maintainers and even the trainers of the system. These personnel contribute to the cost of ownership of the system. In addition, designers often assume that the capabilities and limitations of the potential users are similar to themselves. Often this is not the case. The TAD contains a description of the physical and mental characteristics of potential users, previous educational background and experience, a list of tasks, which they routinely perform, previous training and career structure. It should also include a list of high driver tasks – those, which are difficult, or costly in terms of time or error, training needs – and which should be designed out of the new system wherever possible. The TAD is used by a number of different people in the design process from human resources (recruitment and manning), trainers to designers and HFI practitioners.

It is important that the TAD portrays a detailed picture of all the users of the system in terms that can be easily understood by the people who will use it. It can reveal a number of unexpected characteristics – for example, operators may have colour deficient vision and be expected to view complex colour displays. They may have hearing deficits but have to listen to complex auditory information in noisy environments and may include women who are expected to perform heavy lifting tasks. The new system may introduce new tasks or duties, which are outside the present training schedules and may exclude roles that were essential in the career progression of the profession.

This could require redesign of training and career paths, which is a costly process.

5.6.6 Human Factors Integration Technical Process

The technical part of the HFI process consists mainly of a number of analyses that are performed early on in the system development. In addition to the usual human factors analyses (functional analysis, task analysis, etc.) these include:

- **Mission analysis**. This should be based on the predicted operational requirement to identify those factors that dictate the performance requirements of the man-machine system. These factors include the sequence and timing of major events, threat situations, communications, environmental conditions, etc. It should include system preparation, start-up, operation, degraded mode operation, maintenance and support activities.

- **Early Human Factors analysis**. The EHFA is a fundamental part of the HFI process. It identifies the human issues associated with a system from its early concept stage, logs them as potential risks which can be assessed and controlled in the same way as any other project risk and gives an early indication of the level of effort required to address human factors issues.

- **Early Comparability Analysis**. This can be part of the EHFA or a stand-alone analysis. Very few systems are completely new but are improvements to previous systems. The Early Comparability Analysis (ECA) is performed at the early stage of system design and is based on an analysis of operator, maintainer and support personnel tasks with those associated with a predecessor and/or reference system. The prime concern of the analysis is to determine which of the tasks from the predecessor system are ‘high drivers’, i.e. difficult to perform, prone to error, or manpower, personnel or training resource intensive. It is then the aim to eliminate these tasks from the new system, wherever possible.

- **Trade-off analyses**. A key feature of the HFI programme is to enable trade-off analyses to be made between the domains and other relevant aspects of system design. For example, a requirement to reduce manpower may increase workload in the Task and Interface Design (TID) domain and also increase training costs. Another requirement for reduced training costs may be met by the introduction of embedded training but this may also increase software and hardware costs. Re-design of the human interface may enable the number of task steps to be reduced; this may reduce training costs and improve system performance. No single domain is treated in isolation from the other domains and system design.

- **Training Needs Analysis**. This activity is usually undertaken as part of Integrated Logistic Support in a defence procurement programme. It is based on a task analysis and determines the training needs of the system, type of training required, time and resources needed and location (on-the-job versus training school, etc.). It also covers skill retention and frequency of refresher training.

- **Sensitivity Analysis**. A sensitivity analysis is performed at an early concept stage to determine the effects various concept options would have on system performance. For example, a larger number of lower skilled people versus a small number of higher skilled people and their effects on personnel and training costs as well as system performance. It is closely related to a trade-off analysis.

5.6.7 Human Factors Integration Guidance

A number of guidance documents have been produced to provide advice on HFI to key stakeholders in the process. These include the desk officer or project manager (DERA, 1998a), HFI practitioner (DERA, 1998b), the HFI representatives in industry (DERA, 1998c), The Chief of Defence Procurement Instruction (CDPI) and The Defence Procurement Management Guide (HMSO, 1998a), which gives more detailed guidance on using the CDPI. The last two documents provide guidance to the desk officer. There are other guidance documents to support specific activities, for instance the EHFA user guide (DSD Ltd., 1997).

5.6.8 Tools and Methods

There are many tools and methods which can be applied to HFI, but very few address the integration of human factors. Most concentrate on the human engineering domain, although a few address training and safety issues. Some of the tools that have been developed are for use by the procurement authority at the very early stages of the project life cycle. These are mostly HFI management tools, for example to determine manpower and costing requirements, project management and reporting, preparation of the TAD, and analysis tools such as the Key Issues Tool (KIT) for EHFA (McLeod & Walters, 1999).

5.6.9 Future Developments

Although there are a large number of standards that are applicable to human factors, there is currently no single standard that can be used for HFI. DERA is in the process of producing a draft standard for HFI which, it is proposed, will eventually replace DEF STAN 00-25. It will provide process and technical information, and will be used to specify and test against HFI requirements while providing technical guidance for the design of systems.

Currently work is being done on developing a Capability Maturity Model for HFI (Earthy & Sherwood-Jones, 1999). Capability refers to how well processes such as HFI are done. Capability Models have been used in Software and Systems engineering to assess, before contract award, whether a company is capable of performing to a required level of performance in a discipline which is too complex to assess by normal methods. The organisation is audited and is awarded a capability level. A capability level can be defined as points on an ordinal scale (of process capability) that represents increasing capability of the performed process. It is a method of quality assurance that gives the contractor the opportunity to prove a capability in the area and to show process improvement by increasing its capability level.

Work has been carried out to provide a methodology for conducting a human reliability analysis which is suitable for use as an integral part of the MoD's procurement process, from concept stage to decommissioning. The assessment helps to demonstrate that the risks identified in the analysis are 'As Low As Reasonably Practicable' (ALARP). The methodology includes instruction to allow the human risks associated with a system to be adequately addressed and, where relevant, guidance is given for the elimination or control of errors.

The Human Factors Integration (HFI) developed by the UK government is probably the most advanced programme in existence for the integration of human factors.

Key components of the programme are:

- **HFI management,**
- **HFI roles and responsibilities,**
- **HFI plan,**
- **target audience description,**
- **HFI technical process,**
- **HFI guidance,**
- **tools and methods.**

6. HUMAN FACTORS INTEGRATION FOR ATM

6.1 Introduction

In the preceding chapter some of the design concepts and philosophies for human factors integration which are relevant to ATM have been examined, including an overview of the latest research in the defence environment.

In Chapter 6 we draw together this information to propose a way forward for HFI in ATM which can be used in the context of the ATM system life cycle.

6.2 Current ATM Industry Approach

6.2.1 General Approach

The approach to human factors integration by ATM industry – ATM equipment suppliers, aircraft manufacturers, etc. – typically follows the approach taken by most other large industries. That is, system development uses its standard 'good engineering practices' and human factors is incorporated within that process to the extent that resources permit, or to the extent that designers are aware of the importance of human factors and involve human factors specialists as part of the design team. Too often, as in other industries, only a small amount of human factors integration takes place.

According to Amalberti (1998), the separation between industry and human factors research is extreme and he writes*:*

> *only two persons with a degree in academic human factors were employed in design & certification offices by the overall French aviation industry in 1992 (compared to over 10,000 employees in that area!). The situation was just a little better in US and in the rest of Europe ...*

However, Boeing would maintain that it regularly involves human factors experts in its design teams, and this was certainly the case claimed for the development of the Boeing 777 aircraft (Veitengruber & Rankin, 1995).

It has been recently reported (Casale & Marti, 1998) that Alenia, the Italian ATM service provider, is also actively incorporating human factors during the process of updating the design of its products. According to Casale and Marti (*op. cit.*),

> *the integration of human factors was particularly successful and valid in two recent projects. We think that the approach adopted in these projects can be generalised and exported to other projects.*

Finally, a **'**human factors requirements engineering methodology**'** was developed by Computer Technology Associates Inc., for use by the FAA in the context of specifying the controller-system interface requirements for the FAA's Advanced Automation System (AAS)[17] (Lenorovitz & Phillips, 1987). However, the methodology was focused only on the definition of those interface requirements and did not embrace any other aspects of the development life cycle.

6.2.2 Human-centred Automation

The human factors aspects and problems of automation, particularly on the flight deck, have long been a matter of concern for the aviation industry (Wiener, 1985). Traditionally, automation is introduced because it is technically possible, rather than by considering whether it is required necessarily, and has been viewed as the panacea to overcome all problems of human error. However, such automation limits the scope of the operator's authority and removes him further from the command loop. Without awareness of the systems' operation and management authority the controller has lost his authority over the whole operation. The result of that displacement is automation complacency at one extreme and a lack of trust and confidence in the system at the other extreme.

To counter the trend towards too much automation, a design approach known as **'**human-centred automation**'** has emerged (Billings, 1991) and received the endorsement of ICAO (1994). Human-centred automation is defined as automation designed to work cooperatively with human operators in pursuit of the stated objectives. Its aims are twofold.

1. To reduce the occurrence of accident and incidents. To do this effectively investigators need to differentiate between true human errors and those that are induced by a complex system of automation.

2. To reduce costs. The majority of costs are determined during early stages of concept design. If human factors not considered early there is a substantial risk that downstream costs (e.g. training, re-design) may multiply (also see Wheatley, 1994).

The human-centred approach forms a cornerstone of what human factors design is intended to achieve, i.e. aiding the human in his task through an intuitive system. As such it presents potential for better design and application if incorporated into a human factors integration programme. The principles of human-centred automation will be relevant to all areas of the procurement life cycle (e.g. to determine allocation of function between human and automation, and consideration of operator's situational awareness for possible reversionary control).

[17] The AAS was a major programme of technology enhancement that was initiated by the FAA in the 1980s. In 1994, following delays and other problems, the AAS was divided into smaller projects which dealt with the upgrading/replacement of ageing equipment rather than automation per se.

To be able to comply with their legal responsibilities pilots should remain in command of their flight and controllers should remain in command of air traffic. That command authority should be limited only for highly compelling reasons and after consultation with the users that will ultimately be affected; a human-centred approach to automation is required to assist the operators in achieving their tasks (Billings, 1996). Principles of human-centred automation are shown in Table 6.

The strength of the human-centred approach is that it is likely to:

- reduce the likelihood of human error encroaching on automated systems;
- keep the operators aware of the system operation and progress;
- present a context for system design by incorporating the users and what they have to achieve in the field;
- make system more intuitive to use;
- enhance the operators trust and confidence in the system.

However, potential weaknesses of the approach are:

- to improve the operator's situational awareness that his/her mental workload may increase;
- training requirements may be increased to include automated systems that previously removed the operator from the control loop;
- greater technological ingenuity may be required (see Bainbridge, 1982).

The application of these principles of human-centred automation is seen as central in the design of highly advanced, complex technological systems. The essential point is that:

> *automation is employed to assist human operators to undertake their responsibilities in the most efficient, effective, economical and safe manner*
>
> *ICAO, 1994, p. 22*

Interestingly, automation was the focus of a recent European Commission project called RHEA (Role of the Human in the Evolution of ATM Systems)[18]. In particular, the project looked at principles for the integration of automation support, and the roles of the controller in future ATM systems (Cox & Kirwan, 1999).

[18] European Commission DG VII (Transport), see http://www.cordis.lu/transport/src/rhea.htm

The human-centred automation design approach has been adopted by the aviation industry so as to improve the design of its highly complex flight deck systems. The application of the principles of human centred automation is seen as central both to reduce the occurrence of accidents and incidents, and also to reduce costs.

Table 6: Principles of human-centred automation

The human bears the ultimate responsibility for the safety of the aviation system. Therefore:
• The human must be in command *If they are to retain the responsibility for safe operation or separation of aircraft, pilots and controllers must retain the authority to command and control those operations.*
• To command effectively, the human must be involved *Without active involvement in the system the operator becomes remote from the system operation and inefficient at reacting to time-critical situations.*
• To be involved, the human must be informed *Information must be consistent with the operators' responsibilities and should be presented in a format meaningful to the controller in a given context. The designer needs to understand what information the controller needs and consider the broad spectrum of capabilities and cultures in the population of operators, not just the highly experienced experts. Automation must be comprehensible.*
• Functions must be automated only if there is good reason for doing so *Most tasks* ***can*** *be automated. The question to ask is* ***should*** *the task be automated? Automation should be undertaken only if there is a good reason to do so, its primary role being to enhance the operators' situational awareness.*
• The human must be able to monitor the automated system *The operator needs to be able to monitor the automation and understand what it is doing. They must have positive evidence that the system is doing what they intended it to do.*
• Automated systems must, therefore, be predictable *The operator must understand the automated system's normal operation if he is to detect any anomalies. Behaviour must be predictable to aid the evaluation of the systems' performance.*

Table 6: Principles of human-centred automation (continued)

The human bears the ultimate responsibility for the safety of the aviation system. Therefore:
• Automated systems must be able to monitor the human operator *Humans are not infallible and consequently need to be monitored. Automation capable of questioning certain classes of operator action that could potentially compromise safety should to be designed into the system.*
• Each element of the system must have knowledge of the others' intent *Cross-monitoring can only be effective if the monitoring agent knows what the monitored agent is doing. The intention of each agent (whether automation or human) must be clearly communicated. The communication of intent makes it possible to work cooperatively to solve any problem that may arise.*
• Automation must be designed to be simple to learn and operate *If a system is sufficiently simple, automation is unlikely to be necessary. However, automation is usually targeted at complex and time-critical tasks that the operator may not be able to perform effectively. If automation is applied, the principles of simplicity, clarity and intuitiveness should be applied to its design*.

6.3 Current ATM national Administration Approach

The approach to human factors integration by ATM national administrations is, with some exceptions, to rely on the ATM industries who, by and large, carry out the actual system development of ATM facilities and infrastructure. This is not surprising since the national administrations, which act primarily as regulatory bodies, often do not have the human resources to employ human factors specialists, or develop policies or guidelines for the application of human factors knowledge.

For example, in the UK, the contract for the system development of Civil Aviation Authority's (CAA) new en-route centre at Swanwick (the New En-Route Centre or NERC) was undertaken by Lockheed Martin and its various sub-contractors[19]. Consequently, even though the CAA specified the system requirements for the centre, the human factors integration during the system development was inevitably the responsibility of the contractors. According to Dupée, Schneider and Tomasi (1995), the system development approach adopted by the UK National Air Traffic Services (NATS) is controlled by its quality management procedures which describe the life cycle of major new ATM system projects in six phases:

[19] The contract for the definition of the software for the centre was awarded to IBM and Thomson-CSF in 1991. In 1992 the implementation contract was let to IBM, which was subsequently acquired by LORAL Corporation, which in turn was acquired by Lockheed Martin in 1996 (HMSO, 1998b).

1. Requirement determination.
2. Feasibility and options.
3. Project definition.
4. Procurement.
5. Installation and commissioning.
6. Transition to operational use.

Human factors is not mentioned at all in this report. Neither is human factors explicitly included in the ATS Safety Requirements regulations (CAA, 1999), with the exception of a few short references to the layout of operations rooms (… *must be ergonomically designed to assist the staff in their task*, p. B102), and the description of a method for specifying and testing the adequacy of the radar display human-machine interface (*A formal ergonomic evaluation shall be carried out* …, C246). However, Kirwan (1998) has provided a clearer picture of the sorts of human factors activities that a national administration undertakes – primarily project support and research.

Interestingly, in 1994 NATS commissioned a study (Wheatley, 1994) to examine the feasibility of a human factors integration programme, based on the US MANPRINT Programme, for its air traffic systems. Judging by the recent NATS paper on the subject (Kirwan, *op. cit*.), it would seem that such a programme has yet to be implemented. However, a number of projects are now gaining at least partial human factors integration at a range of design stages, including early ones (e.g. Evans, 1999).

An alternative approach taken by national administrations is to employ the services of EUROCONTROL itself. A good example of this is the current 'Denmark-Swedish Interface (DSI)'[20]. The project is collaboration between the Danish and Swedish CAA's with aim of developing an HMI prototype that will support the ongoing national projects (Control Centre Copenhagen in Denmark and System 2000 in Sweden). The HMI specifications are being prepared and elaborated at the EUROCONTROL Experimental Centre (EEC) by teams from both countries.

The FAA is probably unique in the importance it attaches to human factors in relation to aviation safety and effectiveness. Recognition of this importance by the agency resulted in the 'National Plan for Civil Aviation Human Factors: An Initiative for Research and Application' (FAA, 1995). This prescribes the central goals, objectives, progress, and challenges for the future of human factors research and application, and the required implementation activities arising from discussions within the public and private sectors of the aviation community. The plan is intended to encompass the whole aviation community, *including flight deck, aircraft cabin, air traffic control, airway facilities, aircraft maintenance, and commercial and general aviation operations, as well as the regulatory and organisational activities affecting these elements*. In the same vein as the National Plan, the FAA generated a 'Human Factors Policy' Order (FAA, 1993) which states:

[20] See http://www.eurocontrol.fr/projects/dsi

> *Human factors shall be systematically integrated into the planning and execution of the functions of all FAA elements and activities associated with system acquisitions and system operations. FAA endeavors shall emphasise human factors considerations to enhance system performance and capitalise upon the relative strengths of people and machines. These considerations shall be integrated at the earliest phases of FAA projects.*

Another FAA document is the ‘Human Factors Job Aid’ (FAA, 1999). The document describes a set of functions or processes *that must be accomplished to produce a successful human factors program* (p. i). It is a management process guide intended to serve as a desk reference for human factors integration. The document is based quite heavily on US military standards and handbooks. The eight processes are shown in Table 7.

The FAA is probably unique in the importance it attaches to human factors in relation to aviation safety and effectiveness. Its recently published Human Factors Job Aid, that builds on extensive military documentation, provides useful guidance material for a human factors integration programme in ATM.

Table 7: Processes within FAA Human Factors Job Aid

1.	Develop human factors inputs for acquisition documentation. *The purpose is to identify human factors inputs that are required in key system acquisition documents (e.g. Mission Need Statement)*
2.	Develop the human factors program. *The purpose is to establish the approach for applying human factors engineering to the system being acquired so as to increase system performance and reduce developmental and life cycle costs.*
3.	Formulate human factors in system specifications. *The purpose is to identify and define human performance considerations for incorporation into system specifications.*
4.	Generate human factors requirements in Statement of Work (SoW). *The purpose is to generate human factors requirements for incorporation in SoW to be placed on contractors developing the system.*
5.	Specify human factors in source selections. *The purpose is for a human factors specialist to prepare inputs (i.e. proposal evaluation criteria, Source Selection Plan) for the evaluation and eventual selection of contractors.*

Table 7: Processes within FAA Human Factors Job Aid (continued)

6. Integrate human factors in systems engineering. *The purpose is to contribute information relating to design enhancements, safety features, automation impacts, human-system performance trade-offs, ease of use, and workload.*
7. Determine human factors requirements in system testing. *The purpose is to provide human factors testing requirements to ensure that human factors are adequately integrated into the system acquisition testing programme.*
8. Coordinate with the Integrated Logistics Support (ILS) Programme. *The purpose is to coordinate the analyses and information content and flow between the human factors and ILS Programmes.*

6.4 Human Factors Integration in Future ATM Systems: Issues

6.4.1 Building on Existing Approaches

It is clearly evident from the preceding discussions in this report that a substantial amount of research and development work has been carried out on human factors integration. In particular, the approach to human factors integration developed over many years by government and defence industries, probably offers the most appropriate approach for the ATM domain. This echoes the conclusion of a related study carried out by DERA which examined the feasibility of a human factors integration, based on the US MANPRINT Programme, being applied to air traffic systems in the UK (Wheatley, 1994).

Human factors integration for ATM is likely to require a combined approach, taking appropriate activities from the UK defence and FAA processes. Both the FAA and UK defence versions of human factors integration have the same goals which are to optimise the total system performance and reduce developmental and life cycle costs by ensuring that the human element is addressed as an integral part of system design. Other relevant material has been produced by, for example, the French Organisations INRIA and CNRS.

However, it is believed that the use of the six HFI domains and identification and management of the human factors risks in the programme through the Early Human Factors Analysis (EHFA) makes a modified version of the UK HFI programme a more suitable approach for ATM. It is suggested that the HFI domains be modified for civilian use. It must address the issues of through-life costs, total system performance, and consider the maintainers and support people (e.g. system trainers) as well as operators, the organisational and career development structure.

6.4.2 ATM System Life Cycle

Human factors integration needs to be mapped onto the ATM process (life cycle) and integrated into other related processes. For example, the UK defence HFI and FAA HFI programmes integrate with ILS. If there is not an equivalent process for ILS in ATM, the activities that relate to, and are required by, HFI would have to be incorporated into the ATM HFI process.

It was suggested earlier when reviewing the EATMP life cycle (see 2.2) that the phases might need some adaptation for the purposes of HIFA. Several modifications at least would seem to be required:

1. The consideration of system maintenance at an early stage.
2. The need for an EHFA phase.
3. The inclusion of system modifications within the Operations phase.
4. The addition of a 're-cycling', de-commissioning phase.

These changes are illustrated in the example in 6.5.

6.4.3 High-level Commitment

In order to be successful human factors integration needs commitment at a high level in ATM. Unless this happens, it will be treated as an optional extra and is likely to be ignored. A management process for planning and control of HFI will have to be developed which is suitable for use in ATM.

HFI roles and responsibilities have to be assigned. Although all members of the project team have HFI responsibilities, there needs to be a single person such as the HFI focus who has overall responsibility for making HFI happen.

The HFI focus is responsible for integrating the HFI requirements and constraints across the HFI domains in order to identify where trade-offs may be required. Other responsibilities include maintaining the HFI plan, coordinating any necessary project support studies and ensuring that any HFI issues are reflected in procurement documents and decisions. The HFI focus does not necessarily have to be qualified in human factors but should have access to technical advice from a human factors specialist.

6.4.4 Human Factors Methods and Tools

The analyses and methods that are appropriate for use in ATM have to be identified. As a minimum, this should include the EHFA as this determines level of effort required for HFI throughout the project and a human reliability assessment because of the safety implications of ATM.

Some tools, which already support methods used in HFI for defence systems, may be suitable for use in the version of HFI adopted for ATM. Other tools may have to be developed or adapted, as appropriate.

6.4.5 Usability

It was noted earlier (see Section 4.5.2) that the usability of human factors data and guidelines is an important issue. To overcome the potential problems a number of usability guidelines for the human factors guidance material itself may be proposed:

- make the volume of 'visible' human factors guidance material approachable;
- pre-process conflicting human factors guidelines;
- the way the data is structured should be helpful for an individual user;
- where possible use the mental model and domain terminology of the user's application domain;
- state where a degree of interpretation is needed;
- identify and attempt to cater for the potential range of user 'types' who may wish to consult the data;
- summarise where the human factors source data is not readily accessible in the public domain;
- minimise the cost and time investment required of the user;
- acknowledge the practical limitations of the guidelines.

6.4.6 Costs

Human factors integration, to be achieved both fully and properly, has significant costs in terms of investment of time and money, often at an early stage. These costs must therefore be examined in terms of likely effort, delay, management overheads, and any other extra costs. A 'spend to save' philosophy will be realistic only where the saving is at least one order of magnitude larger than the extra spend. It is notoriously hard to quantify them, but the most likely and most evident savings come from manpower/personnel trade-offs or reductions in the cost of training (Wheatley, 1994).

Human factors costs are sometimes quoted as being a one-off cost (ICAO, 1994). This is probably an excessive claim because unanticipated factors (human and engineering) are likely to become manifest later in the design process, but the initial investment would reduce their extent. Human factors integration is no more the cure-all than automation (see 6.2.2), but it is a means of reducing risks involved with ill-conceived technology.

Human factors integration for ATM is likely to require a combined approach, taking appropriate activities from Europe (particularly the UK and France) and the FAA processes in the US. A modified version of the UK defence approach is likely to be best suited to ATM.

In order to be successful, human factors integration needs commitment at a high level in ATM. Unless this happens, it will be treated as an optional extra and is likely to be ignored. A management process for planning and control of human factors integration will have to be developed which is suitable for use in ATM. All need to be committed.

6.5 Human Factors Integration in Future ATM Systems: An Example

The example set out below illustrates how HFI activities could be incorporated into the ATM life cycle. At each stage, the activities are conducted mainly in parallel and are iterative. The plans, requirements, assumptions, etc., are revised and updated as the design develops.

Most of the analyses are conducted in the early design stages where design changes are relatively easy and cheaper to implement. Data collected from the analyses are stored in databases, and there is an audit trail that is managed throughout the system life cycle to link requirements to design decisions. The following is a list of HFI activities in a HFI programme for ATM.

1. INITIATION

- *Project manager.* Appoint HFI focus.
- *HFI focus.* Agree HFI strategy.
- *HFI focus*. Set up HFI working group, which includes users (size of group depends on complexity of project. It may not be necessary to have a representative for each domain).
- *Human factors expert.* Review available information on existing or similar system to identify human factors requirements and issues that need to be examined in current project.

  HFI focus to lead, analysis team to include human factors experts, covering all domains, and users as subject matter experts. Conduct Early Comparability Analysis (ECA) part of EHFA.

2. PLANNING

HFI focus (with advice from human factors experts):

- Review new system concept to identify any statements or assumptions relevant to six HFI domains.
- Describe new system concept as fully as possible in terms of domains, covering background information, requirements, constraints, assumptions, issues and risks.
- Note any likely HFI distinction between options under consideration.
- *Analysis team or Human Factors Integration Working Group (HFIWG).* Conduct EHFA and produce EHFA report.
- Determine HFI analysis baseline - discuss assumptions and outstanding issues on:
  - system concept of use,
  - human tasks,
  - human performance requirements (including human reliability),
  - technologies and associated human factors issues,
  - operational environment,
  - interoperability and supply policies,
  - policies, requirements, constraints, standards for all six domains,
  - maintenance policy.
- *HFI focus.* Initiate HFI plan and related plans.
- *HFI focus and human factors expert.* Initiate Target Audience Description (TAD) for operators, maintainers and support personnel.

3. FEASIBILITY

- *HFI focus and WG.* Revise HFI assumptions and issues in light of wider assumptions and decisions.
- Fixed constraints on performance, manning, training, potential technical solution and costs in consultation with relevant domain specialists.
- *HFI focus and expert.* Produce HFI requirements document containing:
  - HFI-related failings of present equipment;
  - numbers and organisation by grade of personnel required to operate, maintain and support new system under different operating conditions;
  - significant changes from present equipment in personnel cognitive requirements;
  - training policy;
  - maintenance policy;
  - human reliability (error) analyses;
  - performance requirements for critical user or maintainer tasks under specified operating and environmental conditions;
  - requirements for use of specified HMI technologies;
  - applicable standards for HMI design;
  - potential health and safety hazards and applicable policy and standards.
- *HFI focus.* Agree with project manager:
  - HFI assessment criteria in line with operational requirements;
  - planned assessment process which will enable proper testing of deliverables against HFI assessment criteria.
- *HFI focus and expert*. Update HFI plan and TAD.
- *HFI focus.* Update HFI issues register (from EHFA).
- *Human factors practitioner.* Trade-off performance, manning, training, potential technical solution and costs within fixed constraints until an overall set of policies, requirements and standards can be defined which is likely to be feasible and acceptable to all stakeholders.

4. DEVELOPMENT AND PRE-OPERATIONAL
• *HFI focus and expert.* Include HFI requirements in system specifications, sub-contracts, test plans and requirements traceability systems. • *HFI expert*. Ensure each requirement is testable. If this is not possible, identify the activity required to define the requirement. • *HFI focus*. Demonstrate through requirements that an integrated approach to HFI has been taken, proposed system designs have been evaluated across all HFI domains and appropriate trade-offs have been made. • *HFI focus*. Identify key project milestone which require HFI inputs. • *HFIWG.* Review emerging design specifications, drawings, model and prototypes. • *HFI expert.* Design HFI aspects of the system as appropriate. • *HFI expert.* Participate in design meetings and HFIWG meetings. • *HFI focus and WG.* Use HFI requirements and acceptance criteria to provide inputs to trade-off studies. • *HFI focus and expert*. Participate in design reviews. • *HFI focus.* Ensure results of HFI studies flow into appropriate design activities. • *HFI expert.* Produce interface designs for operations and support which: – promote effective task performance, – minimise training requirements, – minimise likelihood of errors, – ensure safe operation, – are compatible with the capabilities and limitations of expected users.

5. IMPLEMENTATION PLANNING
• *HFI focus and WG.* Review design documentation, models, prototypes, etc., of system operation and determine whether or not HFI issues/risks have been mitigated. • *Human factors expert and WG.* Identify any deficiencies or areas for further work. • *HFI focus and WG.* Conduct trade-offs to address conflicting requirements between domains. • *HFI focus.* Update **requirements** documents and test plans as required. • *HFI focus.* Update the audit **trail** that shows that HFI requirements have been included in the design.

6. LOCAL IMPLEMENTATION
• *HFI focus and WG.* Assess whether there are any unresolved HFI issues associated with local implementation of system. • *HFI focus and WG.* Conduct trade-off analyses to determine best ways of resolving issues and address conflicting requirements between domains. • *HFI focus.* Update TAD and issues register. • *HFI focus and WG.* Review proposed design changes, where necessary. • *HFI focus and WG*. Attend design review meetings. • *HFI focus and WG.* Review design documentation, models, prototypes, etc., of system operation and determine whether or not HFI issues/risks have been mitigated. • *Human factors expert and WG.* Identify any deficiencies or areas for further work. • *HFI focus*. Update requirements documents and test plans as required. • *HFI focus*. Update the audit trail that shows that HFI requirements have been included in the design.

7. OPERATIONS
• *Human factors expert.* Measurement of in-service performance: – workload measurement, – human reliability analysis, – training time, frequency of refresher training, training costs, – Mean Time To Repair (MTTR; including diagnostic time). • *Human factors expert.* Update TAD where there are differences in physical and mental characteristics of actual users compared with predicted users. • *Human factors expert.* Revise HFI issues for system disposal/upgrade. • For Mid-life upgrade or new system: Conduct EHFA, etc., as in planning.

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7. CONCLUSIONS

1. In fulfilment of the first part of the HIFA Project, a review of the extensive literature pertaining to system development, human factors and its role in system development, ATM systems, the ATM system life cycle, and human factors integration has been carried out.

2. An ATM system is defined (Chapter 2) as a complex network of ground-based and airborne sub-systems which together ensure the safe, orderly, expeditious and economic flow of air traffic through all phases of their flight. It is also one part of a larger 'CNS/ATM' system itself composed of the three major elements: ATM System, Communications, Navigation, Surveillance Systems, Aeronautical Environment System.

3. The ATM life cycle is typically described in terms similar to other large complex industrial systems, i.e. composed of major phases of initial planning, through to construction, operation, potential in-service modifications, to final de-commissioning or disposal.

4. The ATM life cycle to be used for human factors integration needs to include, at the very least, an Early Human Factors Analysis (EHFA) and consideration of maintenance at the conceptual phase.

5. Human factors research in ATM is reviewed (Chapter 2.3). Eight key topics are identified which are: workload, workstation design, automation, safety, human error, situation awareness, teamwork, and human factors integration.

6. The overview of system development (Chapter 3) covers a wide range of models (e.g. waterfall, 'V', spiral) and methods (e.g. structured software methods, Multiview, MUSE), from systems engineering, software engineering and management science perspectives. The amenability of these approaches to human factors integration has been considered.

7. The role of human factors in system development (Chapter 4.2) remains limited because of inherent problems in the system design process; because of attitudes towards human factors as a discipline; and because of inadequate human factors methods and tools.

8. Human factors guidance material for system development exists in a number of forms such as commercial or corporate style guides and generic design guidelines. Human factors design guides specifically for ATM have also been produced. Guidance material is traditionally in printed form, though some electronic media have appeared. (See Chapter 4.3)

9. A number of ATM human factors design guides have been produced in recent years, primarily in the United States under the auspices of the FAA.

These documents basically build upon existing human factors material, with some tailoring of information specifically for ATM systems.

10. Standards relevant to human factors integration exist in both the civil and military domains, and are closely related to design guidelines. Their quantity, volume and inflexibility may offset the benefits of standards. Standards are traditionally in printed form, but electronic media have begun to appear. (See Chapter 4.4)

11. Product usability is a key concept within human factors and design. Despite the vast amount of research on usability, the process of designing human factors into computer systems remains something of a 'black art'. Current human factors guidelines themselves are not sufficient and are rarely usable. (See Chapter 4.5)

12. The usability of both products and human factors guidelines themselves are considered. A number of guidelines for the usability of the human factors guidance material are proposed for subsequent phases of the HIFA Project.

13. Several approaches to human factors integration are reviewed. User-centred design is an approach to systems design that emphasises that the purpose of the system is to serve the user. It is important to understand who the users are, and the tasks they do. User-centred design underlies most other approaches. (See Chapter 5.2)

14. The US MANPRINT Programme has been particularly influential in improving the position of human factors in system development. Although it has itself evolved considerably, it has been adopted and modified in several other domains including ATM and other non-military domains. (See Chapter 5.5)

15. The human-centred automation design approach has been adopted by the aviation industry so as to improve the design of its highly complex flight deck systems. The application of the principles of human centred automation is seen as central both to reduce the occurrence of accidents and incidents, and also to reduce costs. (See Chapter 6.2)

16. The FAA is probably unique in the importance it attaches to human factors in relation to aviation safety and effectiveness. Its recently published Human Factors Job Aid, which builds on extensive military documentation, provides useful guidance material for a human factors integration programme in ATM.

17. The Human Factors Integration (HFI) developed by the UK government is probably the most advanced programme in existence for the integration of human factors (see Chapter 5.6). Key components of the programme are reviewed:

    - HFI management,
    - HFI roles and responsibilities,

- HFI plan,
- TAD,
- HFI technical process,
- HFI guidance,
- tools and methods.

18. Human factors integration for ATM is likely to require a combined approach, taking appropriate activities from the UK defence and FAA processes. However, a modified version of the former approach is likely to be best suited to ATM.

19. Human factors integration for ATM raises a number of issues: the ATM life cycle, high-level commitment, methods and tools, and costs.

20. In order to be successful, human factors integration needs commitment at a high level in ATM. Unless this happens, it will be treated as an optional extra and is likely to be ignored. A management process for planning and control of human factors integration will have to be developed which is suitable for use in ATM.

21. An example of how human factors integration activities could be incorporated into the ATM life cycle is provided covering the following 8 phases:

    - initiation,
    - planning,
    - feasibility,
    - development and pre-operational,
    - implementation,
    - operation and maintenance,
    - system modification,
    - re-cycling.

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REFERENCES

Alezra, C., Chrostol, J. Falzon, P., Mazoyer, B., Pinsky, L. and Salembier, P. (1987) L'ergonomie des logiciels. Un atout pour la conception des systèmes informatiques; *Les Cahiers 'Technologie Emploi Travail'*, No.4, October.

Amalberti, R. (1998) The Experiences of Human Factors Integration on the Flight-Deck; in *Third EUROCONTROL Human Factors Workshop - Integrating Human Factors into the Life Cycle of ATM Systems'*, 7-9 October, Luxembourg (see EATMP, 1999a).

Andersen, N.E. (1990) *Professional Systems Development*. London: Prentice Hall.

Apple Computer Inc (1992) *Macintosh Human Interface Guidelines* Reading, MA: Addison-Wesley.

Atkinson, T., Donohoe, L., Evans, A., Gorst, A., Kilner, A., Kirwan, B., Lamoureux, T. & MacKendrick, H. (1997) *Human factors guidelines for air traffic management systems*; NATS R&D Report 9737, NATS ATMDC, August.

Avison, D.E. & Fitzgerald, G. (1988 / 1995) *Information systems development – methodologies, techniques and tools*. 2nd edition. Oxford: Blackwell Scientific Publications.

Bainbridge, L. (1982) Ironies of automation, in, G. Johannsen & J.E. Rijnsdorp*, Analysis, Design and Evaluation of Man-Machine Systems*, Proc. of IFAC Conf., Baden-Baden, Germany, 129-135.

Baker, S. (1993) The role of incident investigation in system validation; in, J. Wise, V. David Hopkin & P. Stager*, Verification and Validation of Complex Systems: Human Factors Issues*, Springer-Verlag, 239-250.

Benyon, D., Davies, G., Keller, L., Preece, J. & Rogers, Y. (1990) *A guide to usability*. Open University / Department of Trade and Industry Usability Now! Initiative.

Bias, R.G. & Mayhew, D.J. (eds) (1994) *Cost justifying usability.* Boston: Academic Press.

Billings, C.E. (1991) *Human-centred Automation: A Concept and Guidelines*; NASA Technical Memorandum 103885.

Billings, C.E. (1996) *Aviation Automation: the Search for a Human-centred Approach*; Lawrence Erlbaum.

Birrell, N.D. & Ould, M.A. (1985) *A practical handbook for software development*. Cambridge: Cambridge University Press.

BIUSEM (1995) Benefits of Integrating Usability and Software Engineering Methods. CEC ESSI Project 10290, Final Report.

Blom, H., Hendriks, C. & Nijhuis, H. (1995) Assess necessary validation developments. EC DGVII VAPORETO Project Report No. VAP/NL/WPR/3/2.1, 16th October.

Boehm, B.W. (1988) A spiral model of software development and enhancement; *IEEE Computer*, **21**, 2, 61-72.

Boff, K.R., Kaufman, L. & Thomas, J.P. (eds) (1986) *Handbook of perception and human performance, Volumes 1 and 2.* New York: Wiley.

Boff, K.R & Lincoln, J.E. (1988*) Engineering Data Compendium. Human Perception and Performance, Volumes 1-3*; Harry G. Armstrong Aerospace Medical Research Laboratory.

Booch, G. (1994) *Object-oriented Analysis and Design – with Applications*. Redwood City: Benjamin/Cummings.

Booch, G., Rumbaugh, J., & Jacobson, I. (1999) *Unified Modelling Language User Guide.* Reading, Massachusetts: Addison-Wesley.

British Telecom (1990) *Ten ways to keep the user friendly – Design principles from ONA User Interface Style Guide.* British Telecom Cooperative Networking Architecture, PHME/4867/7/90.

Brown, C.M., Brown, D.B., Burkleo, H.V., Mangelsdorf, J.E., Olsen, R.A. & Perkins, R.D. (1983) *Human factors engineering standards for information processing systems.* Report LMSC-D877141. Sunnyvale, California: Lockheed Missiles and Space Company.

CAA (1999) *Air Traffic Services Safety Requirements.* Civil Aviation Authority, CAP 670, March.

Cardosi, K.M. & Murphy, E.D. (1995) *Human factors in the design and evaluation of air traffic control systems*; FAA Report No. DOT/FAA/RD-95/3.

Casale, G. & Marti, P. (1998) Human factors integration at Alenia; in, *Third EUROCONTROL Human Factors Workshop - Integrating Human Factors into the Life Cycle of ATM Systems*, 7-9 October, Luxembourg (See EATMP, 1999a).

Catterall, B.J. (1991) 'Three approaches to the input of human factors in IT systems design: DIADEM, the HUFIT Toolset and the MoD/DTI Human Factors Guidelines'. *Behaviour and Information Technology*, 10(5), pp.359-371.

Chapanis, A. (1996) *Human factors in systems engineering*; John Wiley & Sons, Inc.

Costa, G. (1993) Evaluation of workload in air traffic controller; *Ergonomics*, **36**, 9, 1111-1120.

Cox, M. & Kirwan, B. (1999) The future role of the air traffic controller: Design principles for human-centred automation; in, M.A. Hanson, E.J. Lovesey & S.A. Robertson, *Contemporary Ergonomics 1999*. Taylor & Francis.

Damodaran, L. (1991) Towards a human factors strategy for information technology systems; in, B. Shackel & S. Richardson (Eds.) *Human Factors for Informatics Usability*, Cambridge University Press, 291-324.

Davis, G.B. & Olson, M.H. (1985*) Management information systems: conceptual foundations, structure and development*, 2nd edition. New York: McGraw Hill.

DeMarco, T. (1978*) Structured Analysis and System Specification*. New Jersey: Prentice-Hall.

DERA (1998a) *Specifying human factors integration requirements* (version 1.0); Defence Evaluation Research Agency, 7th April.

DERA (1998b) *Integrating human factors with systems procurement* (version 3.0); Defence Evaluation and Research Agency, 9th April.

DERA (1998c) *Building human factors into systems design* (version 3.0); Defence Research and Evaluation Agency, 16th April.

DoD (1998) *Human engineering*; Military Standard MIL-STD-1472E, Washington DC: Department of Defense, 31st March.

DSD Ltd. (1997) *Early Human Factors Analysis*. User Guide.

DTI (1991) *HCI Tools & Methods Handbook*; UK Department of Trade and Industry.

Dupée, R.A., Schneider, J-Y. & Tomasi, J. (1995) WP2: Review relevant existing methodologies; EC DGVII VAPORETO Project, Report Ref. VAP/CA/WPR/20/07, 30th June.

Earthy, J. & Sherwood-Jones, B (1999) Proposal for Human Factors Integration capability Maturity Model Implementation Strategy; CHS 8117 Final Report. Version 1.1, May.

Eason, K. (1983) User centred design for information technology systems; *Physics in Technology*, **14**, 210-224.

EATCHIP Human Resources Team (1996) *Guidelines for Developing and Implementing Team Resource Management*. HUM.ET1.ST10.1000-GUI-01. Released Issue. Ed. 10. Brussels: EUROCONTROL.

EATCHIP (1997a) *Overall CNS/ATM Architecture for EATCHIP*. ASE.ET1.ST02-ADD-01-00. Brussels: EUROCONTROL.

EATCHIP (1998a) *ATM Strategy for 2000+*. Brussels: EUROCONTROL.

EATCHIP Human Resources Team (1998b) *Human Factors Module - Human Factors in the Development of Air Traffic Management Systems*. HUM.ET1.ST13.4000-REP-02. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATCHIP (1998c) *EATCHIP Management Handbook*. EATCHIP\EATMP Programme//Project Life Cycle. Brussels: EUROCONTROL.

EATCHIP Human Resources Team (1998d) *Human Factors Module - Human Factors in the Investigation of Accidents and Incidents*. HUM.ET1.ST13.3000-REP-02. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATCHIP Human Resources Team (1998e) *Proceedings of the Second EUROCONTROL Human Factors - Teamwork in Air Traffic Services.* HUM.ET1.ST13.000-REP-02 (held in Luxembourg in May 1997) Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATCHIP (1998f) *A Theoretical Design Process for Studying New ATM Concepts*. IMPACT Project Technical Note, TN97005. Proposed Issue. Bretigny, France: EUROCONTROL Experimental Centre.

EATCHIP Human Resources Team (1998g) *Integrated Task and Job Analysis of Air Traffic Controllers - Phase 1: Development of Methods*. HUM.ET1.ST01.1000-REP-03. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATMP Human Resources Team (1999a). *Proceedings of the Third EUROCONTROL Human Factors Workshop - Integrating Human Factors into the Life Cycle of ATM Systems*. HUM.ET1.ST13.000-REP-03. (held in Luxembourg on 7-9 October) Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATMP Human Resources Team (1999b) *Human Factors Module - A Business Case for Human Factors Investment.* HUM.ET1.ST13.4000-REP-02. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATMP Human Resources Team (1999c) *Technical Review of Human Performance Models and Taxonomies of Human Error in Air Traffic Management.* HRS/HSP-002-REP-01. Proposed Issue. Ed. 0.3. Brussels: EUROCONTROL.

EATMP Human Resources Team (2000) *Human Factors Integration in Future ATM Systems – Identification of Tasks and Development Scenarios.* HRS/HSP-003-REP-02. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

EATMP Human Resources Team (not printed, due in 2000) *Human Factors Integration in Future ATM Systems – Methods and Tools.* HRS/HSP-003-REP-03. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

Endsley, M.R. & Bolstad, C.A. (1994) Individual differences in pilot situation awareness*; The Int. J. of Aviation Psych*., **4**, 3, 241-264.

Engel, S.E. & Granada, R.E. (1975) Guidelines for Man/Display Interfaces. Technical report TR00.2720. Poughkeepsie, New York: IBM.

Evans, A. (1999) Human factors in the design lifecycle of NATS future systems; Paper presented at the EUROCONTROL/FAA Technical Interchange Meeting (TIM), 27-29th April, Toulouse, France.

FAA (1993) Order 9550.8, Human Factors Policy. Federal Aviation Administration, 27th October.

FAA (1995) National plan for civil aviation human factors: An initiative for research and application. Federal Aviation Administration, March.

FAA (1999) Human Factors Job Aid; Federal Aviation Administration, 4th March.

Farmer, E., Jorna, P., McIntyre, H., Samel, A., Kelly, C. & Rejman, M, (1998) Human factors and air safety policy. Final report of the AIRSAFE Project; EC DGVII.

Fitts (1951) Human engineering for an effective air navigation and traffic control system; National Research Council, Committee on Aviation Psychology.

Flach, J.M. & Dominguez, C.O. (1995) Use-centred design: Integrating the user, instrumentation and goal; *Ergonomics in Design*, 19-24.

Fowler, M. & Scott, K. (1997) *UML distilled.* Reading, Massachusetts: Addison-Wesley.

Foot, P., Chupeau, F. Biemans, M., Tremblay, B. & Goillau, P. (1996) Criteria and applicability of evaluation methods; EC DGVII RHEA Project Report, Ref. RHEA/DRA/WPR/4/1.2, 9th December.

Gane, C. & Sarson, T. (1979) *Structured Systems Analysis: Tools and Techniques*. New York: Prentice-Hall.

Gardner, A. (1991) An approach to formalised procedures for user-centred system design; in, B. Shackel & S. Richardson (Eds.) *Human Factors for Informatics Usability*, Cambridge University Press, 133-150.

Gardner, A. & McKenzie, J. (1988) Human factors guidelines for the design of computer-based systems (Parts 1-6), Issue 1; HUSAT Research Centre, Loughborough.

Garland, D.J. & Wise, J.A. (1993) *Human factors and advanced aviation technologies*; Embry-Riddle Aeronautical University Press.

Goillau, P.J. (1990) A systems analysis study of air traffic control: Identification of future ATC computer assistance concepts for NERC; DERA ATC Systems Group, Working paper AD4/89/10/01, October.

Gould, J.D. (1988) How to design usable systems. In Helander, M. (Ed) (1988) *Handbook of Human-Computer Interaction.* Amsterdam: North-Holland / Elsevier Science Publishers.

Hamilton, I. (1996) The Human Factors Integration Management Plan and its Role within Procurement. Vol 2: The Plan; Human Engineering Ltd., HEL/NE/9508/RT3, 16th September.

Helander, M. (1988) *Handbook of human-computer interaction*; Elsevier Science.

Hix, D. & Hartson, H.R. (1993*) Developing user interfaces: ensuring usability through product and process*. New York: Wiley.

HMSO (1993) Warship project manager's guide for human factors integration plans; MoD Sea Systems Controllerate Publication No.10, SSCP 10, Issue 1, July.

HMSO (1994) Human factors guide for management and design in Royal Navy combat systems; MoD Sea Systems Controllerate Publication No.11, SSCP 11, April.

HMSO (1998a). Defence Procurement Management Guide. Managing Human Factors Integration; DPMG/TECH/330 Issue 1.0 (Jun 98).

HMSO (1998b) Environment, Transport and Regional Affairs Committee. Fourth Report. Air Traffic Control; London: The Stationery Office.

Hollnagel, E., Cacciabue, P.C. & Bagnara, S. (1994) Workshop report. The limits of automation in air traffic control; *Int. J. Human-Computer Studies*, 40, 561-566.

Hollnagel, E. & Woods, D. (1983) Cognitive systems engineering: new wine in new bottles*; Int. J. Man-machine Studies*, **18**, 583-600.

Hopkin V.D. (1982) Human factors in air traffic control; Advisory Group for Aerospace Research and Development, AGARD-AG-275, April.

Hopkin, V.D. (1995) *Human factors in air traffic control*; Taylor & Francis.

Hopkin, V.D. (1997) Automation in air-traffic control: Recent advances and major issues; in, M. Mouloua & J.M. Koonce (Eds), *Human-Automation Interaction. Research and Practice*, Lawrence Erlbaum Associates, 250-257.

Hornby, P., Clegg, C., Robson, J., Maclaren, C.R., Richardson, S.C. & O'Brien, P. (1992) Human and organisational issues in information systems development; *Behaviour & Information Technology*, **11**, 3, 160-174.

Hunt, S.R. (1987) Human engineering for space; in, G. Salvendy (Ed), *Handbook of Human Factors*, John Wiley & Sons, 708-721.

ICAO (1993) Human Factors Digest No.8. Human factors in air traffic control; International Civil Aviation Organization, ICAO Circular 241-AN/145.

ICAO (1994) Human Factors Digest No.11. Human factors in CNS/ATM systems. The development of human-centred automation and advances technology in future aviation systems; International Civil Aviation Organization, ICAO Circular 249-AN/149.

ICAO (1998) Human Factors Training Manual; International Civil Aviation Organization, Doc 9683-AN/950, First Edition.

ICAO (1999) Proceedings of the Fourth Global Flight Safety and Human Factors Symposium; Santiago, Chile, 12-15 April, International Civil Aviation Organization.

IEEE (1988) Guide for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations; Institute of Electrical and Electronic Engineers, IEEE Std. 1023.

IEEE (1998) Guide for the Application of Human Factors Engineering in the Design of Computer-Based Monitoring and Control Displays for Nuclear Power Generating Stations; Institute of Electrical and Electronic Engineers, IEEE Std. 1289.

Isaac, A.R. (1997) Situation awareness in air traffic control: human cognition and advanced technology; in, D. Harris, *Engineering Psychology and Cognitive Ergonomics Volume 1*, Ashgate, 185-191.

ISO 9241 Ergonomic requirements for office work with Visual Display Terminals (VDTs). Geneva, Switzerland: ISO Publications.

ISO ISO/DIS 13407 Human-centred design processes for interactive systems. Geneva, Switzerland: ISO Publications.

ISO 14915 Multimedia User Interface Design – Ergonomic requirements for human-centred multimedia interfaces. Geneva, Switzerland: ISO Publications.

Jackson, A. (1998) Human Factors Integration within Concept Development, Design and Pre-operational Evaluation Phases: A Pragmatic Approach; in, *Third EUROCONTROL Human Factors Workshop - Integrating Human Factors into the Life Cycle of ATM Systems*. 7-9 October, Luxembourg (see EATMP, 1999a).

Jackson, M.A. (1983) *Systems Development*. New Jersey: Prentice-Hall.

Jackson, A. & Pichancourt, I. (1995) A human-machine interface reference system for en-route air traffic control; EUROCONTROL Experimental Centre EEC Report No. 292, December.

Jones, C.B. (1986) *Systematic software development using VDM*. London: Prentice-Hall International.

Kelly, C.J., Mann, J. & Maltier, L. (1996) Scope of validation. EC DGVII GENOVA Project, Report No. GEN/DRA/WPR/1/1.1, 15th August.

Karwowski, W. (2000) *International Encylcopedia of Ergonomics and Human Factors*; Taylor & Francis.

Kirwan, B. (1994), *Practical Human Reliability Assessment*, Taylor & Francis.

Kirwan, B. (1998) Human Factors Techniques in the NATS ATM System Development Process; in, *Third EUROCONTROL Human Factors Workshop - Integrating Human Factors into the Life Cycle of ATM Systems*, 7-9 October, Luxembourg (see EATMP, 1999a).

Kirwan, B. & Ainsworth, L.K. (1992) (eds) *A guide to task analysis*. London: Taylor & Francis.

Kirwan, B., Evans, A., Donohoe, L., Kilner, A., Lamoureux, T., Atkinson, T. & MacKendrick, H. (1997) Human factors in the ATM system design life cycle; FAA/EUROCONTROL ATM R&D seminar, 16th –20th June, Paris.

Langan-Fox, C.P. & Empson, J.A.C. (1985) ‘Actions not as planned’ in military air-traffic control; *Ergonomics*, **28**, 11, 1509-1521.

Lenorovitz, D.R. & Phillips, M.D. (1987) Human factors requirements engineering for air traffic control systems; in, G. Salvendy (Ed), *Handbook of Human Factors*, John Wiley & Sons, 1771-1789.

Lim, K.Y. (1996) Structured task analysis: an instantiation of the MUSE method for usability engineering’, *Interacting With Computers*, vol 8 no 1 pp 31-50.

Lim, K.Y. & Long, J. (1994) *The MUSE method for usability engineering*; Cambridge University Press.

Lim K.Y., Long, J.B., & Silcock, N. (1992). Integrating human factors with the Jackson System Development method: an illustrated overview.; *Ergonomics* vol 35 no 10 pp 1135-1161.

Malouin, J-L & Landry, M. (1983) The mirage of universal methods in system design, *J. of Applied Systems Analysis*, **10**, 47-62.

Martin, J. (1989) *Information Engineering. New Jersey*: Prentice-Hall.

McCormick, E.J. (1976) *Human factors in engineering and design* (4th Ed.); McGraw-Hill.

McLeod, R.W. & Walters H. (1999) The human factors integration key issues tool; in, D. Harris (ed.), *Engineering Psychology and Cognitive Ergonomics Volume Four*. Ashgate Publishing, 361-367.

Meister, D. (1985) *Behavioral Analysis and Measurement Methods*; John Wiley & Sons.

Metcalfe, C. & Reynolds, L. (1998) NATS standard for the use of colour on air traffic control displays; National Air Traffic Services, R&D Report 9834, December.

Microsoft (1992) The Windows Interface: an application design guide. Seattle: Microsoft Press.

MoD (1997) *UK defence standards.* Directorate of Standardisation, UK Ministry of Defence (PE) DSTAN CD ROM. Issue 2, December 1997.

MoD (1989) *Def Stan 00-25 Human Factors for designers of equipment, Part 12: Systems.* Issue 1, July 1989, pp. 74. Directorate of Standardisation, UK Ministry of Defence (PE). DSTAN CD ROM. UK defence standards, Issue 2, December 1997.

MoD (1996) *Def Stan 00-25 Human Factors for designers of equipment, Part 13: Human Computer Interaction.* Issue 1, May 1996, pp. 40. Directorate of Standardisation, UK Ministry of Defence (PE) DSTAN CD ROM. UK defence standards, Issue 2, December 1997.

NASA (1993) Human computer interface guide. Revision A; NASA Report NASA-TM-109708, SSP-30540-REV-A, 1st July.

NASA (1995) Man-Systems Integration Standards, NASA-STD-3000 Volume I, Revision B, July.

Nielsen, J. (1993) *Usability Engineering*; Academic Press.

NRC (1995) Human-System Interface Design Review Guideline; U. S. Nuclear Regulatory Commission, NUREG-0700, Revision 1, January 1995.

Norman, D.A. (1986) Cognitive engineering; in, Norman D.A. & Draper, S.W. (1986) *User centred systems design*; Lawrence Erlbaum Associates, 31-61.

Norman D.A. & Draper, S.W. (1986) *User centred systems design*; Lawrence Erlbaum Associates.

Parsons, K.C., Shackel, B. & Metz, B. (1995) Ergonomics and international standards. History, organisational structure and method of development; *Applied Ergonomics*, **26**, 4, 249-258.

Paterno, F. (1995) Interactive systems: design, specification and verification. Berlin: Springer-Verlag.

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., Carey, T. (1994) Human-Computer Interaction. Wokingham: Addison-Wesley / Open University.

Pew, R.W. & Rollins, A.M. (1975) Dialog specification procedures. Report 3129. Cambridge, Ma: Bolt, Berenek & Newman.

Pheasant, S. (1989) User-centred design – an ergonomist's viewpoint; in, A.S. Nicholson & J.E. Ridd, (Eds.) *Health, Safety and Ergonomics*, Butterworths, 73-96.

Rasmussen, J., Pejtersen, A.M. & Goodstein, L.P. (1994) *Cognitive systems engineering*; John Wiley & Sons.

Ratier, C. (1998) Ergonomie des logiciels: Application a la DSI; National Centre for Scientific Research. CNRS Bureau Qualité, 9th June.

Rouse, W.B. & Cody, W.J. (1988) On the design of man-machine systems: principles, practices & prospects; Automatica, **24**, 2, 227-238.

Rubin, J. (1994) Handbook of usability testing. New York: Wiley.

Salvendy, G. (1997) *Handbook of Human Factors & Ergonomics*, 2nd Ed.; John Wiley & Sons, Inc.

Scapin, D.L. (1986) *Guide ergonomique de conception des interfaces homme-ordinateur (Ergonomic guidelines for the design of human-computer interfaces)*; INRIA Report No. RT-0077, October.

Shackel, B. (1984) Information technology – a challenge to ergonomics & design. *Behaviour & Information Technology*, 3, pp.263-275.

Shneiderman, B. (1980) *Software psychology. Human factors in computer & information systems*; Winthrop Publishers.

Shneiderman, B. (1992) Designing the user interface – strategies for effective Human-Computer Interaction, 2nd edition. Reading, Ma: Addison-Wesley.

Singleton, W.T. (1974) *Man-machine systems*; Penguin Books.

Singleton, W.T., Easterby, R.S. & Whitfield, D.C. (1967) The human operator in complex systems; Taylor & Francis Ltd.

Smith, S.L. (1986) Standards versus guidelines for designing user interface software. *Behaviour & Information Technology*, 5, 47-61.

Smith, S.L. & Mosier, J.N. (1986) Guidelines for designing user interface software. Bedford Mass: MITRE Corporation. Report ESD-TR-86-278. Technical Report NTIS No. A177 198.

Sommerville, I. (1995) Software Engineering, 5th edition. Wokingham: Addison-Wesley.

Sprague, R.H. & Watson, H.J. (1986) Decision support systems: putting theory into practice. London: Prentice Hall International.

Stevens, R., Brook,P., Jackson, K., & Arnold, A. (1998) Systems Engineering – Coping with complexity. London: Prentice Hall Europe.

Stork, A., Middlemass, J., & Long, J. (1995) 'Applying a structured method for usability engineering to domestic energy management user requirements: a successful case study'. In Kirby, M.A.R., Dix, A.J. & Finlay, J.E. (1995) *People & Computers X: Proceedings of the HCI'95 Conference*, pp.367-385. Cambridge: Cambridge University Press.

Veitengruber, J.E. & Rankin, W.L. (1995) Use of crew-centred design philosophy allows the introduction of new capabilities & technology; ICAO Journal, March, 20-22.

Wagner, D., Birt, J.A., Snyder, M. & Duncanson, J.P. (1996) Human factors design guide; FAA Report No. DOT/FAA/CT-96/1, 15th January.

Wheatley, E.H.I. (1994) A human factors integration programme for NATS' systems; Defence Evaluation & Research Agency, Report No. DRA/CHS/CR94001/1.0, July.

Whiteside, J., Bennett, J., Holtzblatt, K. (1988) Usability engineering – our experience & evolution. In Helander, M. (Ed) (1988) *Handbook of Human-Computer Interaction*. Amsterdam: North-Holland / Elsevier Science Publishers.

Whitfield, D. & Jackson, A. (1982) The air traffic controller's picture as an example of a mental model; in, G. Johannsen & J.E. Rijnsdorp*, Analysis, Design & Evaluation of Man-Machine Systems*, Proc. of IFAC Conf., Baden-Baden, Germany.

Wickens, C.D., Mavor, A.S. & McGee, J.P. (1997) *Flight to the future. Human factors in air traffic control*. Commission on Behavioral & Social Sciences, National Research Council, National Academy Press.

Wickens, C.D., Mavor, S.A., Parasuraman, R. & McGee, J.P. (1998) *The future of air traffic control. Human operators & automation*. Commission on Behavioral & Social Sciences, National Research Council, National Academy Press.

Wiener, E. (1985) Beyond the sterile cockpit; *Human Factors*, **27**, 1, 75-90.

Wood-Harper, Antill & Avison (1985) *Information Systems Development: The Multiview Approach.* Oxford: Blackwell Scientific Publications.

Woodson, W.E. (1981) *Human Factors Design Handbook*; McGraw-Hill.

Wynekoop & Russo (1995) Systems development methodologies: unanswered questions, J. of Info. Technology, **10**, 65-73.

Yourdon, E. & Coad, P. (1991) *Object-Oriented Analysis and Design.* New Jersey: Prentice-Hall.

Yourdon & Constantine, L. (1975) *Structured Design*. New Jersey: Prentice-Hall.

INFORMATION SOURCES ON THE INTERNET

INFORMATION SOURCE	INTERNET ADDRESS
Association Francophone d'Interaction Homme-Machine (AFIHM)	http://www-ihm.lri.fr/afihm
ATC electronic checklist	http://www.hf.faa.gov/products/checklst/checklst.htm
ATC Webring	http://users.forthnet.gr/ath/mpang/wrframes.htm
ATM R&D seminars (FAA & EUROCONTROL)	http://atm-seminar-2000.eurocontrol.fr
Aviation medicine & other links	http://pw1.netcom.com/~nuance/airlift/medicine.html
Aviation safety links	http://www.aviation.org/links.htm
CENA (Toulouse)	http://www.cenatls.cena.dgac.fr
Cognitive & Psychological sciences	http://www-psych.stanford.edu/cogsci
CNRS Ergonomie	http://www.dsi.cnrs.fr/bureau_qualite/ergonomie/ergonomie.htm
CSERIAC	http://cseriac.flight.wpafb.af.mil
Defence Standards (UK)	http://www.dstan.mod.uk
EATCHIP HMI web site	http://www.eurocontrol.be/hmi
Ergonomic Resources	http://www.geocities.com/CapeCanaveral/1129
Ergonomics Information Analysis Centre	http://www.bham.ac.uk/manmecheng/ieg/eiac.html
Ergonomics Society (UK)	http://www.ergonomics.org.uk
ErgoWeb	http://www.ergoweb.com/Pub/ewhome.shtml
Ergoworld	http://www.interface-analysis.com/ergoworld
FAA Human Factors	http://www.hf.faa.gov
Human Factors & Ergonomics Society	http://hfes.org
Human Factors International Inc	http://www.humanfactors.com
HCI sites	http://www.acm.org/sigchi/hci-sites
HCI resources on the net	http://www.ida.liu.se/labs/aslab/groups/um/hci
HyperSAM	http://www.dstc.edu.au/RDU/staff/ri/hyperSAM.html
IFIP Technical Committee 13 (HCI)	http://www.csd.uu.se/ifip_tc13/index.shtml
INRIA	http://www.inria.fr/welcome.html
International Ergonomics	http://www-iea.me.tut.fi

Association	
International Standards Organisation	http://www.iso.ch
Inventory of tools & methods	http://www.megataq.mcg.gla.ac.uk/sumi.html
MANPRINT	http://www.manprint.army.mil/manprint/index.html
MATRIS Directory of Design Support Methods	http://dticam.dtic.mil/hsi/index.html
MEFISTO (EC DGIII Project)	http://www.cnuce.cnr.it/mefisto.html
NASA Ames Research Centre	http://human-factors.arc.nasa.gov
NASA Human Factors	http://olias.arc.nasa.gov/home-page.html
NASA Man-Systems Integration Standard NASA-STD-3000	http://www-sa.jsc.nasa.gov/FCSD/CrewStationBranchMsis/msis_home.htm
Smith & Mosier 1986 guidelines	ftp://ftp.cis.ohio-state.edu/pub/hci/Guidelines
University College Cork HFRG	http://www.ucc.ie/hfrg
Usability engineering resources	http://inf2.pira.co.uk/jzus1.htm
Usability for Software Engineers	http://www.otal.umd.edu/guse
Useable Information Technology (Jacob Nielsen's website)	http://www.useit.com
Usability, software engineering for (Quebec Telecommunications Multimedia)	http://www.crim.ca/hci/indiv/hayne_seu/SE_for_usability.html
User-centred design	http://inf2.pira.co.uk/use-bck.htm

ABBREVIATIONS AND ACRONYMS

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

AAS	Advanced Automation System
ADA	Augusta Ada Byron *(programming language)*
AFIHM	French Association of Human-Machine Interaction *(France)* *Association francophone d'intéraction homme-machine*
ALARP	As Low As Reasonably Practicable
ANSI	American National S
ASM	Airspace Management
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Services
BIUSEM	Benefits of Integrating Usability and Software Engineering Methods
BSI	British Standards Institution
CAA	Civil Aviation Authority
CDPI	Chief of Defence Procurement Instruction
CEN	Comité Européen de Normalisation
CENA	Air Navigation Study Centre *(France)* *Centre d'etudes de la navigation aérienne*
CNRS	National Centre for Scientific Research *(France)* *Centre national de recherche scientifique*
CNS	Communications, Navigation, Surveillance
CoE	Centre of Expertise
DDSM	Directory of Design Support Methods
DERA	Defence Evaluation and Research Agency *(UK)*
DHSS	Department of Health and Social Security *(UK)*
DIADEM	Departmental Integrated Application Development Methodology

DIADEM	Dialog Architecture and Design Method
DIS	Director(ate) Infrastructure, ATC Systems & Support (*EUROCONTROL, EATMP, SDE)*
DIS	Draft International Standard
DIS/HUM	See ‘HUM Unit’
DoD	Department of Defense *(US)*
DTI	Department of Trade and Industry *(UK)*
DTIC	Defense Technical Information Center *(US)*
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(now EATMP)*
EATMP	European Air Traffic Management Programme *(formerly EATCHIP)*
EATMS	European Air Traffic Management System
ECA	Early Comparability Analysis
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre *(France)*
EHFA	Early Human Factors Analysis
ESSI	European Systems and Software Initiative
ET	Executive Task *(EATCHIP)*
FAA	Federal Aviation Administration
GUI	Guidelines *(EATCHIP/EATMP)*
HCI	Human-Computer Interface / Interaction
HERA	Human ERror in ATM
HFI	Human Factors Integration
HFIWG	Human Factors Integration Working Group
HIFA	Human factors Integration in Future ATM Systems
HIS	Human Systems Integration
HMI	Human-Machine Interface (or Interaction)
HMSO	Her (or His) Majesty’s Stationery Office
HRS	ATM Human Resources Programme *(EATMP, HUM)*
HRT	Human Resources Team *(EATCHIP/EATMP, HUM)*
HSE	Health and Safety Executive

HSP	Human Factors Sub-Programme *(EATMP, HUM, HRS)*
HTA	Hierarchical Task Analysis
HUFIT	HUman Factors into Information Technology
HUM (Domain)	HUMan Resources Domain *(EATCHIP/EATMP)*
HUM Unit	HUMan Factors and Manpower Unit *(EUROCONTROL, EATMP, SDE, DIS; also known as DIS/HUM; formerly stood for 'ATM Human Resources Unit')*
HUSAT	HUman Sciences and Advanced Technology
HWG	Harmonisation Working Group
ICAO	International Civil Aviation Organization
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFIP	International Federation for Information Processing
ILS	Integrated Logistics Support
IMPACT	Methods and Tools to assess the impact of future ATM systems on the controller's job
INRIA	National Institute for Research In Computer Science and Control *(France)* *Institut national de recherche en Informatique et en automatique*
ISO	International Standardisation Organisation *(usual designation)* International Organization for Standardization *(official designation)*
IT	Information Technology
ITA	Integrated Task Analysis
JAA	Joint Aviation Authorities
JSD	Jackson System Development
JTC	Joint Technical Committee
KIT	Key Issues Tool
MANPRINT	MANpower, PeRsonnel and INTegration
MATRIS	MAnpower and Training Research Information System
MET	Meteorology
MoD	Ministry of Defence *(UK)*

MSIS	Man-Systems Integration Standard
MUSE	Method for USability Engineering
NASA	National Aeronautics and Space Administration *(US)*
NATS	National Air Traffic Services *(UK)*
NERC	New En-Route Centre
NRC	National Research Council
NRC	Nuclear Regulatory Commission *(US)*
OJT	On-the-Job Training
OOA/D	Object-Oriented Analysis and Design
PROMPT	Project Resource Organisations Management and Planning Technique
R&D	Research and Development
REP	Report *(EATCHIP/EATMP)*
RHEA	Role of the Human in the Evolution of ATM Systems
SA	Situation Awareness
SDE	Senior Director, Principal EATMP Directorate *(EUROCONTROL)*
SSADM	Structured System Analysis and Design Methodology
ST	Specialist Task *(EATCHIP)*
STD	Standard
TAD	Target Audience Description
TID	Task and Interface Design
TNA	Training Needs Analysis
UML	Unified Modelling Language
VDT	Visual Display Terminal
VDU	Visual Display Unit
WG	Working Group
WP	Working Package *(EATCHIP, EATMP)*

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