Human Factors in the ATM System Design Life Cycle

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ABSTRACT

Development of effective and usable Air Traffic Management (ATM) systems requires Human Factors input throughout the design life cycle, from concept formulation, through detailed design, to implementation and operation. This paper outlines existing and developing Human Factors inputs that will help to ensure that good Human Factors enters the design of future ATM systems.

At the early stages, a profile of the user, together with task analyses of user functions, enables the new ATM system concept to be formulated. Prototyping tools then allow early testing of the concept, via simulation methods that predict controller interactions and workload, and small−scale simulation prototyping exercises allow on−line evaluations with samples of real prospective users. Both of these approaches allow insights into the degree of usability and performance with the new system concept before detailed design, and will be likely to improve the overall design concept. During detailed design, there is much supportive Human Factors data and many techniques that can enable the system to become highly usable, particularly if a user−centred design philosophy is adopted. Prior to implementation and operation of the system, real−time simulation is an invaluable tool to detect any residual problems, and to determine the workload and error impacts of the system on real controllers under realistic operational conditions. Measures currently under development and evaluation, such as Situation Awareness, and Eye Movement Tracking, are expected to enhance what can be learned during both prototyping and real−time simulations. Additionally, aspects such as team design need to be reviewed. These current and developing Human Factors inputs to the design process are outlined in the paper. They are then presented in a preliminary framework for integrating Human Factors into the design life cycle of ATM systems.

1. Introduction

This paper is concerned with achieving a high degree of Human Factors in the design of Air Traffic Management (ATM) systems. It is based on the premise that ATM systems currently, and in the forseeable future, will retain human Air Traffic Controllers (ATCOs) in the ATM system. This premise appears valid for a number of reasons. First, (human) ATCOs have achieved a very high degree of safety, reliability and expeditiousness of traffic management in the past. Second, humans are good optimisers and problem solvers, and the projected increasing traffic densities and complexities means that keeping the human in the loop enables ATM to utilise such unique attributes. Third, whereas automation can in theory replace certain functions in the future, it will be some time before the reliability and efficiency of such automation has been experienced, and hence the human should stay in the loop in case things go wrong. Given that humans will continue to dominate ATM for the forseeable future, it is sensible to optimise the human's performance in the system, which means achieving good Human Factors in the design and operation of that system.

ATM systems are however undergoing significant change at present, to accommodate continuing increases of air traffic. Such changes include new sectorisation procedures, advanced new generation displays, and the transition to electronic flight strips. There are also a range of potential ATCO automated aids which are nearing the time when they could be implemented in the ATM work system. ATM interface technology is therefore currently accelerating, after having remained relatively stable for many years, and the human must not be left behind. This is therefore a challenge to Human Factors professionals in ATM, since it is not merely a matter of applying well−tried databases of Human Factors information and tools to the new interface technologies − instead, in certain cases new or at least innovative methods must be developed. Human Factors data and techniques (which can be thought of as 'Human Factors *Technology*'), must themselves develop to keep up with the changes in interface technology.

This paper therefore discusses methods used to develop a good Human Factors design during the system design life cycle. These methods, however, fall into two categories: those currently in use, and those under development and evaluation. It is the latter techniques that in part reflect the need for different approaches given the changes that are occurring and may occur in the future of ATM. These latter methods are therefore being developed/evaluated as part of a Research and Development (R&D) programme of work, being carried out by the Human Factors Unit based at the Air Traffic Management Development Centre (ATMDC) at Bournemouth Airport in the UK. The Unit has the following remit:

- Ensure adequacy of systems about to be implemented, in terms of ATCO workload, via support to the Real−Time simulation programme at ATMDC;
- Carry out R&D to enhance the safety and efficiency of ATM via enhanced Human Factors;
- Help existing or developing systems with Human Factors issues.

The work described in this paper feeds into all three of these objectives, since it includes real−time simulations, represents the core of the Human Factors R&D programme (Kirwan, 1997), and is aimed at helping existing and future ATM systems development.

Some of the approaches under consideration reflect the fact that ATM could involve fundamental changes for the role of the ATCO, e.g. with respect to what is known as 'the picture', and how potential future automation will affect this picture. Such 'deeper' issues are of more long term concern, and may seem more academic in nature, but they are not. The picture is currently central to successful ATM, and to the performance of the ATCO. Human Factors in ATM must therefore attempt to understand the picture better, as the degree of change soon to impact on ATM systems may change the picture. If Human Factors is to support ATM systems development, and ensure that the human continues to perform with high reliability, a better understanding of the picture, how it is built, maintained, and lost, is essential.

The paper therefore firstly reviews Human Factors in the System Design Life Cycle (SDLC) for ATM systems development, in general terms. It then reviews current approaches for evaluating Human Factors in the SDLC. Methods that are currently under development and/or evaluation are next considered before placing all of these into a potential future framework for achieving good Human Factors in system design.

2. Objectives

2.1 To review the techniques and approaches currently in use to achieve good Human Factors in ATM systems design

2.2 To outline ongoing research and development of future techniques and approaches

2.3 To show how such techniques and approaches might look in an integrated Human Factors System Design Framework

3. ATM, Human Factors, and the System Design Life Cycle

Before considering the approaches in use, it is useful to outline the major Human Factors areas of concern in ATM, and to outline the System Design Life Cycle and its relationship to Human Factors.

3.1 Human Factors in ATM

Some of the major Human Factors areas in ATM are as follows:

- **Interface design & workplace layout −** *ensuring a good interface for the ATCO*
- **Environmental considerations −** *adequate lighting noise, thermal, and air conditioning aspects*
- **Communications aspects −** *ensuring reliable communications (e.g. R/T, etc.)*
- **Job and team design −** *facilitating high motivation and teamwork*
- **Selection, training and procedures −** *the right person for the job, and proper training and aids*
- **Human error & recovery −** *detecting and correcting or avoiding the consequences of human errors, and ensuring the human can detect and correct machine errors/failures*

Human Factors is concerned with designing for human use, and essentially comprises **data**, **principles** and **techniques**. The data concern human attributes which determine how to achieve good performance, e.g. anthropometric data on body dimensions, or visual data on colour perception, both of which are useful when designing interfaces to ‘fit’ people and help them make sense of what the interface is trying to tell them. Principles may similarly concern how to develop a windows−based environment that is user−friendly rather than cluttered and opaque to the user. Techniques are used to determine detailed aspects of system design, and may be concerned with how to select people for the particular job (e.g. an ATCO), or what tasks may be susceptible to error, etc. The Human Factors professional’s main task is therefore applying generalised data, principles and techniques to the specific context being studies, in this case ATM. The Human Factors professional must therefore tailor these data etc. to ATM, and carry out detailed analyses on human performance in the specific context in ATM. However, in order to achieve impact on the interface design, job design, etc., Human Factors analyses and inputs must occur at the appropriate stages in the System Design Life Cycle, as defined next.

3.2 Human Factors in the System Design Life Cycle

ATM systems evolve as any other systems do. Typical stages in an industrial project life cycle are as follows:

1. **Concept** − initial idea of the system, its nature and benefits

2. **Preliminary Design −** enough design to prove the feasibility of developing the system
3. **Detailed Design −** complete design of the system, all of its components and controls and displays, etc., down to the precise location and colour of everything
4. **Final Design Phase** − leading to Construction and Commissioning − finalising the details of the design, building the system and getting it to work
5. **Operation & Maintenance − running and maintaining the system for its useful lifetime**
6. **Modification** − evolving the system as necessary or advisable as technology, economics and/or operational experience warrants it
7. **Decommissioning** − dismantling and disposing of the system

Typically, Human Factors is brought in at stage 3 (and fairly late within this stage) or 4, and sometimes not until 5 or 6. However, this does not harness the full utility of Human Factors in developing usable systems, i.e. systems where operational performance will be maximised.

Table 1 shows the type of involvements Human Factors can have in the life cycle for ATM systems. These involvements start at the beginning, at the Concept stage.

Human Factors can therefore support activities in every stage of the Life Cycle of a new or existing ATM project. The degree of involvement depends on a number of factors, e.g. how critical human involvement is (e.g. safety critical functions), the novelty of the design, and the degree to which the system requires human interaction (during normal operations). These three factors would appear to be maximised for ATM systems, as ATM is highly human−interactive systems, it depends on human intervention for safety of operations, and as ATM is currently evolving rapidly, there is a high degree of ‘novelty’ due to advancing technology.

The timing of Human Factors involvement is important − if it occurs late, then either the impacts of the human−system configuration on performance may not be fully analysed, or else alterations will be required at a later stage than is desirable, i.e. incurring delays to the programme or extra cost in re−design, or both. This was the experience in the nuclear power industries in the past decade, and more recently in the offshore oil and gas industries, and so now both these industries incorporate Human Factors earlier into the life cycle, at appropriate points.

Table 1 − Typical Human Factors Inputs to the System Life Cycle (not industry−specific)

Life Cycle Stage	**System/HF Issues**	**HF Inputs**
Concept	• What should the human do, what should the machine do, what functions should they share?	• Information on the relative merits of human vs. machine (human operating parameters) • Human−machine joint operation configurations • Human−Centred Automation principles
Preliminary Design	• How many staff, what arrangement of staff ? • What basic layout of the workplace and equipment ?	• Task Analysis of likely operations to determine staff numbers and workload • Research and **prototyping** technology and facilities to

	• What types of displays and controls ?	develop effective new displays and controls to achieve the concept intent
Detailed Design	• Exact dimensions of workplace • User−friendly design of all interface aspects and the working environment • Human Reliability Assessment (error analysis) with proposed configuration	• Detailed Human Machine Interface (HMI) guidance on user interface characteristics • Environmental measurement and prediction techniques • HRA technology (qualitative and quantitative)
Construction and Commissioning	• Training content for staff • Procedural aspects • Details of job design • Final usability trials/testing • Human Reliability Assessment of operations	• Task analysis of operations • Job design principles and theory • Training and Procedures design guidance • **Real−time simulation** and on−line testing • HRA technology
Operation and Maintenance	• Assisting with initial implementation and start−up problems (system 'teething' problems) • Problem resolution during operations and maintenance • Human Reliability Assessment as system evolves • Monitoring/analysis of operational performance and incidents to determine improvements, and/or 'next generation' concepts	• Task analysis and subjective analysis techniques − real−time simulation methods • Human Factors technology • HRA technology • Incident Analysis approaches
Modification	• Determination and management of impact of system changes to human performance and workload • HRA inputs to Safety Analysis of impact of changes	• Real−time simulation methods • HRA approaches • Task Analysis & Human Factors techniques

Decommissioning	• Determination of re−training or adaptation requirements	• Task Analysis

As well as the potential costs of not involving Human Factors in a timely fashion, there are significant benefits if Human Factors is used at the appropriate times. The primary benefit is a usable system, one that will achieve, and possibly exceed the original intentions of the design. Usability should not be under−estimated as a concept. A usable system does not mean merely one that works, it means one that works well. If a human is given a good, well−designed and usable tool, that man or woman often not only accomplishes the task with it, but also learns how to maximise its usage. This is because humans are naturally creative and adaptive, but only if motivated, and if not bogged down using all their ingenuity just trying to get the system to work at all. A usable system will therefore result in optimised performance, and a high degree of error correction when things go wrong. A system that does not possess usability, is not usable. The controllers will probably get such a system to work, but it will hardly be an optimised system, and [system design−induced] errors will be frequent.

This paper is largely concerned with the phases of the SDLC leading up to operation, i.e. getting the system design right prior to it being implemented in a real operational setting. The techniques used currently are discussed in the next section.

4. Current Human Factors Approaches

The main current approaches to achieving good Human Factors in ATM systems development are as follows (see Evans et al, 1997; Gorst et al, 1997):

1. Use of various Human Factors databases by qualified Human Factors practitioners
2. User−centred design philosophy
3. Task analysis
4. Predictive workload modelling (PUMA system)
5. Prototyping and evaluation (including walk−throughs and checklists)
6. Real−time simulation (including subjective workload measurement)
7. Interviews, questionnaires, and debriefs

4.1 Human Factors databases and Prototyping Simulations

The **Human Factors databases** are accessible references and standards as used by Human Factors professionals worldwide, and comprise Human Factors data and principles (e.g. Pheasant, 1988; Sanders and McCormick, 1992; Cardosi and Murphy, 1995). Guidance from such sources can be applied both to design studies, and during **prototyping simulations**, where a prototype is tested with real controllers, who are interviewed extensively afterwards.

4.2 User−Centred Design

User−centred design philosophy means the key involvement of a number of ATCOs in the design process and at key decision points. In particular user groups may be included in the prototyping phase of the SDLC, where a prototype is developed and tested with prospective operators, sometimes in ‘slow time’, where the user can walk−through the task slowly and comment on its design adequacy and usability, and sometimes (usually later) in real−time where the user can gain a better ‘feel’ for how it will operate in reality. Human Factors data and checklists are also usually applied during such evaluations, and interviews, questionnaires and debriefs are used in these as well as the real−time simulations.

4.3 Task Analysis

Task analysis (e.g. Hierarchical Task Analysis, Shepherd, 1989), has been carried out extensively for certain ATCO tasks (e.g. Cox 1994), although little task analysis to date has apparently influenced design decisions, except via prototyping simulation studies and the PUMA system (see below).

4.4 Predictive Workload Assessment

The **PUMA (Performance and Usability Modelling in ATM)** Toolset was developed for NATS by Roke Manor Research Limited. It is a toolset designed to enable the prediction and description of controller workload for ATC scenarios. The motivation for using PUMA stems from the fact that real time simulation is resource intensive, requiring a lot of manpower to plan, prepare for, conduct, analyse and report each trial. It is therefore highly useful to apply the PUMA 'coarse filter' to new operational concepts before expensive real time simulation. This allows the more promising and the less promising options to be identified, before proceeding with the better options, to full simulation. PUMA is capable of assessing the effect on controller workload of various computer assistance tools.

PUMA uses observational task analysis to try to capture all the relevant information about cognitive activities in a task, usually based on video analysis of someone (i.e. an ATCO) performing the task. Each task or activity is then classified by a PUMA analyst and its impact on workload calculated as a function of its usage of cognitive resources, and as a function of other activities' (competing) resource requirements. Some tasks or activities will conflict more with each other as they are demanding the same cognitive resources, as defined in a 'conflict matrix' within PUMA. Central to the PUMA methodology is a workload prediction algorithm, which calculates how different task types will impact on workload alone, and together. This algorithm is based on the Wickens (1992) multiple resource theory. The output is a prediction of MWL as it changes throughout the overall task (see Figure 1).

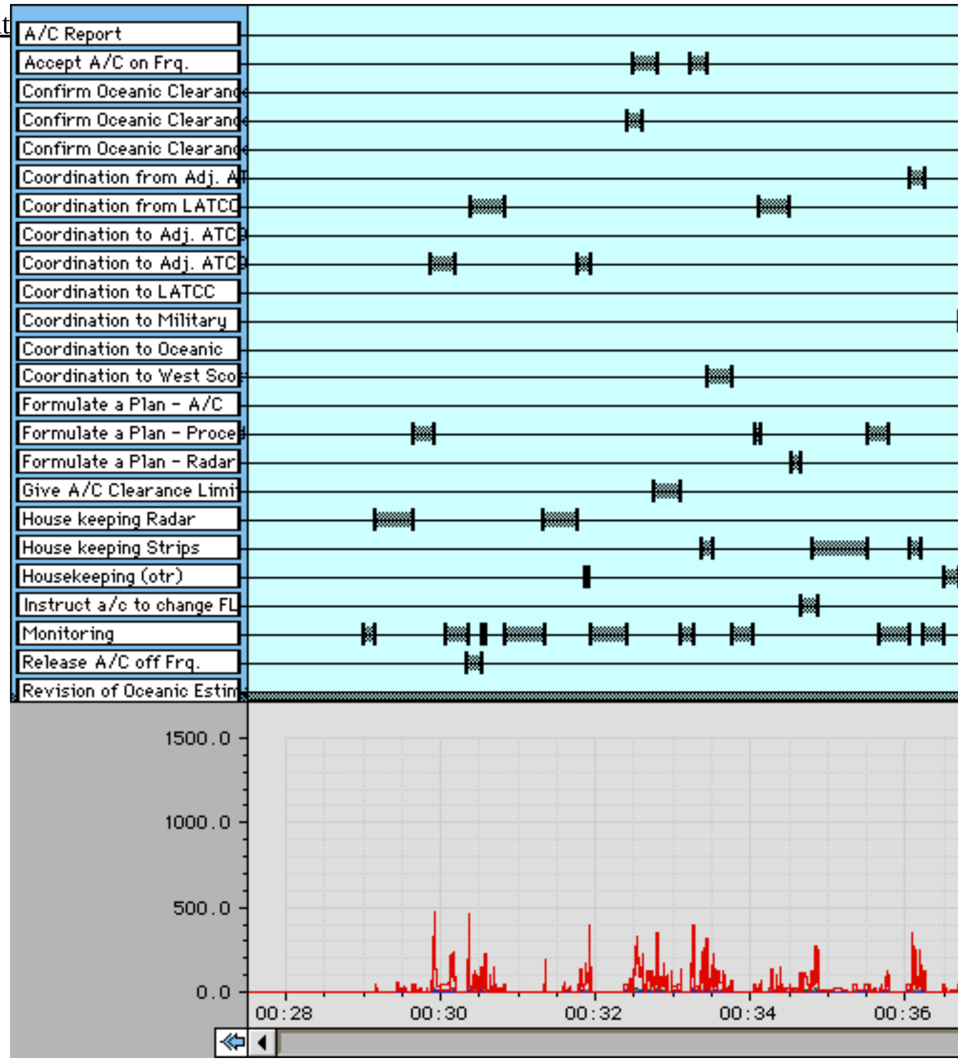
PUMA has been applied to a number of future operational concepts, providing useful information in terms of their likely workload impacts, and potential improvements in the designs of future tools for the ATCO.

4.5 Real−Time Simulations

The Human Factors involvements during **real−time simulation** studies fulfil a number of functions, with the main ones as follows:

1. Determining the adequacy of ATCO workload and performance given a new ATM system (ATMS) configuration
1. Gaining subjective information on user−acceptance of a new ATMS configuration
1. Investigating error potential with a new system configuration
1. Investigating the usability of a new ATMS configuration

Figure1: Example of PUMA output



The configuration could be new in a number of ways, e.g.:

- evaluating alterations to existing sectors
- testing a vertical sectorisation system
- evaluating new interfaces
- etc.

Whatever the change that is being evaluated, it is critically important that it does not have adverse effects on the system, and from the Human Factors perspective, this means the ATCO−system relationship. Although design can usually predict with a degree of confidence whether adverse effects will be found, there always remains a degree of uncertainty. A real−time simulation offers a sound, and possibly the last, chance to detect problems before a new configuration is implemented. Real−time simulations are therefore an important preventive measure or barrier to failure in the real environment.

The most frequently used measure of mental workload in real−time simulations is the Instantaneous Self Assessment (**ISA**) technique. This measurement method was developed at the ATMDC to assess mental workload in real time. During each exercise, participants are asked to record their perceived level of workload every two minutes using a small keypad. It is important that the manner in which workload is recorded does not interfere with the primary task and, thus, add to the level of workload artificially. The measure has been designed to be as quick and unobtrusive as possible to avoid this. The recordings obtained from this measurement allow the levels of workload experienced as a result of new equipment, procedures or other system attributes to be assessed. It also indicates the way in which workload varies over time.

The ISA measure consists of a panel with five numbered and colour coded buttons. Each of the buttons represents a level of workload (as defined below in Table 2). At either side of the buttons

Table 2 − ISA Workload Categories

Level	Workload Heading	Spare Capacity	Description
5	Excessive	None	Behind on tasks; losing track of the full picture
4	High	Very Little	Non essential tasks suffering. Could not work at this level very long.
3	Comfortable Busy Pace	Some	All tasks well in hand. Busy but stimulating pace. Could keep going continuously at this level.
2	Relaxed	Ample	More than enough time for all tasks. Active on ATC task less than 50% of the time.
1	Under− Utilised	Very Much	Nothing to do. Rather boring.

are two LED lights. Every two minutes during an exercise, the two lights flash indicating that an input is required. The participant presses the button corresponding to the level of workload being experienced at that particular moment. Once an input has been registered the flashing of the lights will stop. The lights will flash for thirty seconds.

As controllers input their workload the scores are displayed in real−time on a PC at the HF analysts desk in the operations room. The real time display allows the analyst to see when something interesting is happening. It provides the opportunity to observe possible causal events as they are happening. This also allows the HFU to debrief controllers soon after the event whilst relevant information is still fresh. Other subjective measures of mental workload are also used occasionally, e.g. **NASA−TLX** and **SWAT** (see Wickens, 1992).

5. Human Factors Approaches Under Development & Evaluation

5.1 Human Centred Automation Principles

The problems of clumsy automation in the aviation world have been elucidated in a number of texts (e.g. see Billings, 1996; Parasuraman and Mouloua, 1996). Typical problems are as follows:

- *Too many modes − unclear to the operator what the mode is*
- *Unclear what the intention of the system is, particularly when in an abnormal event*
- *Over−riding the system tends to occur too late*
- *Some systems are over−trusted, some under−trusted*
- *Lack of transparency about the system's mechanisms and processes (its 'reasoning')*
- *Dramatic changing of the role of the operator: e.g. 'pilot' becomes 'information manager'*
- *Unclear where the edges of the 'envelope' of the automated system are*
- *Latent errors may be extremely difficult to find (e.g. navigation programming errors)*
- *Human error detection and correction potential decreases*
- *Job satisfaction decreases*
- *etc.*

The above are a handful of some of the problems experienced, many of which have led to fatal accidents. Although in some clear cut cases (e.g. automated landings) the automation has proved itself in risk terms, there have been far more automation−related accidents than anticipated. The problem for the designers and risk analysts is one of anticipating novel problems and interactions with automated systems, for which by definition we have very little experience. Aviation, and the public, have therefore learned automation lessons at quite a price. The ATM industry does not want to learn the hard way.

The aviation experience has led to the concept of Human−Centred Automation (HCA: e.g. Billings, 1996). However, at present the 'principles of HCA' are rather high level, and difficult for a designer to implement. One near−future research project of the Human Factors Unit is therefore to examine the lessons that can be learned from aviation, and render them into useful and practicable guidelines for ATMS development. If this can be achieved, then it will help in the allocation of function, and more closely set the parameters of the role of the operator in future systems. If this cannot be achieved, then there is a risk of ATMS development being technology−led, as arguably occurred with aviation, with some concomitant and undesirable negative consequences for the industry.

5.2 Development of a Target Audience Description (TAD)

To successfully control air traffic it is necessary that controllers posses particular skills and abilities. Human performance depends upon perception, motor skills and cognitive abilities. It is also affected by factors like personality, motivation and attitudes. If performance of the ATC task is to be safe and effective controllers need to make accurate and timely use of particular skills. As a first step towards understanding the relationship between controllers' abilities and performance, a description of controller characteristics is being constructed. The description is called a **Target Audience Description** (**TAD**), a term which derives from MANPRINT, the US Army's programme for integration of Human Factors into system procurement (Walters, 1992, Wheatley 1994). The TAD is a structured description of the characteristics of a system user in terms of both physical and psychological characteristics and covers, cognitive abilities, personal attributes anthropometrics and demographic data.

A task analysis of UK air traffic control, which is also part of the NATS Human Factors research programme, will provide a detailed analysis of how controllers carry out their task. This will be used to identify the skills and which are used in the ATC task. MANPRINT has an associated methodology called cognitive requirements analysis which can be used in conjunction with a task analysis to assess which tasks create the greatest cognitive loading. This will be attempted using the ATC task analysis.

When the TAD is complete it will provide a profile of controllers which will indicate their strengths and weaknesses. The cognitive requirements analysis, carried out using the task analysis, will also indicate which tasks make the most demands on controllers. This information can be used to inform system design to produce optimum system performance by matching the design of HCI, procedures, equipment and automation to the abilities of the controllers. Automation strategies can be shaped to assist in tasks which require abilities that are not strong in the controller population and for tasks which are cognitively most demanding.

5.3 Task Analysis (re−visited) and Cognitive Task Analysis

Task analysis is a fundamental approach describing and analysing how the operator interacts with a system, and with other personnel within that system (Kirwan and Ainsworth, 1992). In particular, task analysis describes what an operator is required to do, in terms of actions and/or cognitive processes, to achieve a system goal. Task analysis methods can also detail the displays which cue the operator to perform or cease an operation, and the controls with which such operations are achieved. As such, task analysis is a fundamental input to the design of the interface, to procedural and training systems development, and to error analysis studies. The first primary aim of task analysis, however, is to create a detailed picture of human involvement, with all the necessary information for carrying out the task(s).

The technique of Hierarchical Task Analysis (HTA: Shepherd, 1989) has been chosen as the means to describe the task of ATC (see Figure 2). HTA's are being completed for all ATC domains in the UK, including: Area Control; Terminal Control; Airfield Operations; Military Operations; and Oceanic Operations. HTA's that are produced will provide an intimate picture of the task of the controller, allowing critical tasks, bottlenecks, and incompatibilities to be identified and rectified. As a hypothetical example, HTA may identify that the controller must maintain a watching brief on the radar for aircraft climbing past their assigned flight level. However, the system display may not facilitate this task. Such a discrepancy is readily identified through doing an HTA and can subsequently be addressed.

The Task Analysis programme is anticipated to feed into most future work undertaken by the NATS Human Factors Unit, including: design of new systems (including automated tools); writing new procedures; assigning roles and responsibilities; fine−tuning information presentation; ensuring control display compatibility; construction of a Target Audience Description and defining team resource management training. All of these applications aim to facilitate the controller's task and eliminate ambiguities that may lead to mistakes or accidents.

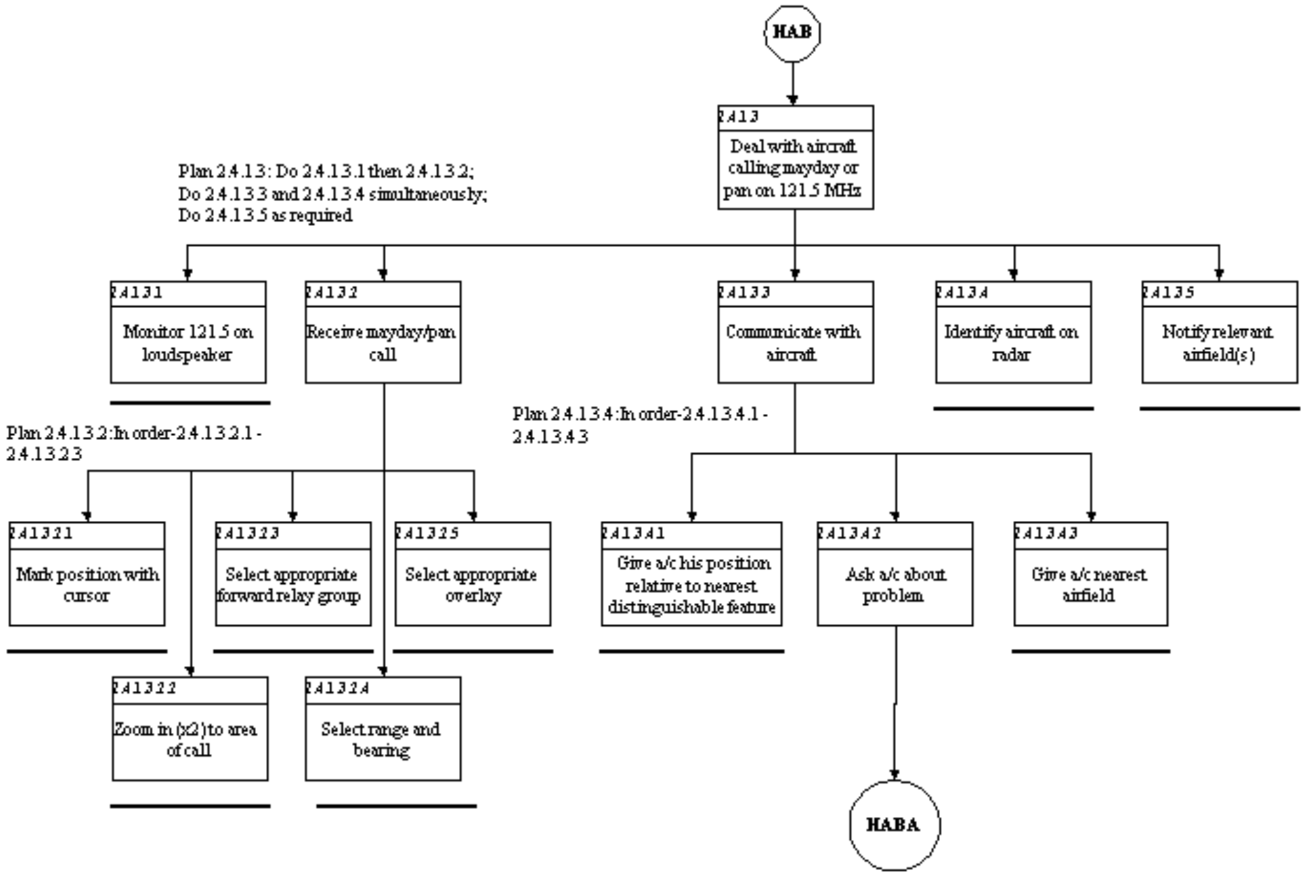


Figure 2: Excerpt from HTA of UK Distress and Diversion Operations.

Furthermore, the need for a **Cognitive Task Analysis (CTA)** tool has been identified which can define the cognitive and less overt processes in ATC. This is because it is these activities that dominate ATC performance by ATCOs, rather than physical movements etc. However, CTA methods are still in their infancy, with few if any methods currently being able to usefully analyse dynamic tasks such as ATC. Nevertheless, the formulation of a CTA methodology is important for future HF inputs to ATC. By gaining a complete understanding of the Controller's strategies and heuristics, as well as understanding their search patterns, information use and communications, more detailed input can be made to design of new systems.

5.4 Additional and Improved Workload Measurement Methods

The NATS HFU places a great emphasis on ensuring the workload experienced by system users is appropriate for their task. Using a combination of the workload measures above, a detailed picture of controller workload can be recorded and analysed. This allows assessments of any potential changes in workload associated with new procedures or HMI tools. Whilst the measures used are either valid measures of workload, or have a degree of face validity, there are, of course, questions arising out of the specific application of the measure to ATC. NASA−TLX for example was not developed for use in ATM, and some evidence exists to suggest that the time period in which it is applied is critical. However, these hypothesised methodological problems arise are being addressed by the HFU in order to improve the service they provide to customers: the ATM service providers.

The review of these methodologies is wide in scope and currently addresses how workload is recorded, measured and analysed during human−in−the−loop simulations. This has involved an independent review of the workload measures currently used and some guidance on how they could be amended. In order that NATS incorporates a broad range of appropriate workload measurements in its simulations, the following research areas are to be addressed:

- The investigation of the practical utility of certain **psychophysiological measures** (e.g. blink rate)
- Considerations of how appropriate the demands contained in **NASA−TLX** are for the ATC environment
- Review of the textual anchors used with **ISA**
- Improvement of the **PUMA** algorithm.

This research will enable the approach to workload measurement to be refined in order to provide an accurate assessment of task−load, subjective workload and an effective method of task analytic workload assessment. In turn this will ensure that where new procedures, HMI tools or equipment are to be introduced in the ATM workplace, the effects on workload can be clarified and quantified to ensure optimum workload levels are maintained.

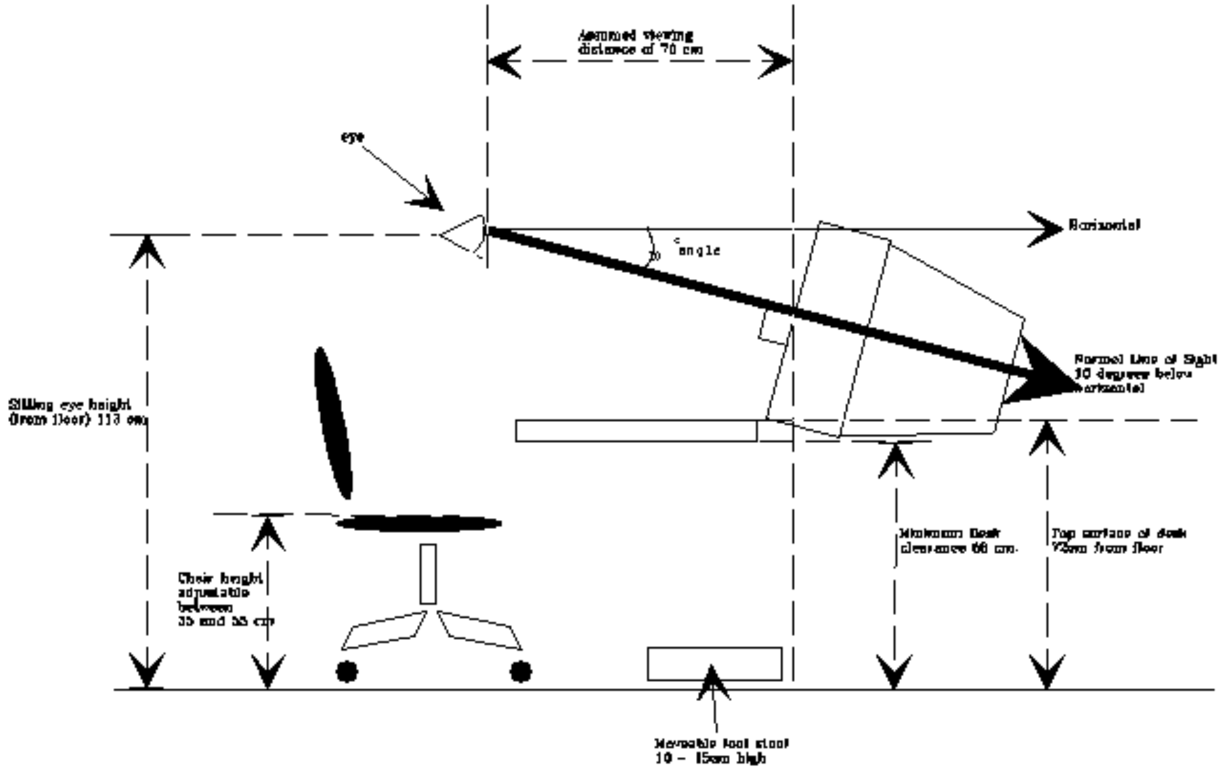
5.5 Human Machine Interface Design Guidelines

The Human Factors Unit at ATMDC is developing an ATC−specific database of human machine interface (HMI) guidelines that can be used for reference and support by developers, designers and engineers. This database will allow good HF practice to be implemented at very early stages of system development and throughout the system life−cycle (e.g. see Figure 3).

During the design phase of a project the guidelines will be used to: ensure consistency, usability, efficiency and safety in HMI design; decrease costs (since post hoc alterations should not have to be made) and reduce the risk of timescale overrun.

For existing systems the guidelines will be used to: provide an independent/objective route to audit existing system integrity; highlight areas of concern and provide guidance for remedial action; support system changes, alterations and mid−term upgrades; ensure that HF is not confined solely to the design process; raise the profile and reputation of HF within the organisational culture.

Figure 3: Example of Recommended Dimensions for an ATC Workstation



The guidelines are gleaned from a variety of sources including existing military, nuclear, petro−chemical and ATC related texts. The guidelines will appear in the form of a ‘living document’ to be upgraded to meet the needs and requirements of users and designers as technology becomes more sophisticated.

The use of tools such as the HMI guidelines, will allow designers, contractors and users to realise the benefits of early HF input. This will result from reduced project costs, a reduction in the need for post hoc design modifications and more user friendly systems that fully support the changing role of the user. Furthermore, because the guidelines can be adapted and upgraded, this will allow the HFU to continuously accommodate and support new developments within the realm of ATC technology.

5.6 Learning from Incidents & Near−Incidents[1]

The purpose of research in this area is to discover whether it is feasible to enhance the mitigation measures which are taken after incidents and in the design of future systems, by using a theory−driven approach to analyse existing incident data. The recent growth in theories which set out the underlying psychological processes involved in human error means that incident data can be interpreted with reference to such processes. If it is possible to describe the psychological causal mechanisms which lead to ATC incidents, in terms of their nature and frequency, then guidance to counter operator tendencies to make error would be available to shape mitigation measures. Such information would also be of use if included in strategies for future automation. Designers of automated tools could make use of the information to produce tools which would help to reduce the incidence of human error. If the theory−driven approach is found to be successful it may also lead to a recommendation that theory−driven analysis is carried out as part of future incident investigations.

A classification system will be developed to capture the important contributory factors in incidents. Additionally, the use of the Critical Incident Technique, which focuses on the larger set of near−incidents (i.e.

non−reportable events which nevertheless could have been incidents in other circumstances), will be explored. Accident theory suggests that for every actual incident there were probably 30 near−incidents. The point is that it may be easier to learn from such near−incidents than actual incidents (due to their higher frequency), and in fact some would go further and argue that there is more to learn from them.

1Incidents are currently analysed by the Human Factors members at the Safety Regulation Group (SRG). The incident analysis referred to here would be in addition to the mainstream incident investigation work of SRG.

5.7 Error Analysis and Human Reliability Assessment (HRA)

As well as learning retrospectively from incidents, it is desirable to predict errors if possible before their potential negative consequences are experienced. This requires a method of predicting errors and, in some cases, an approach to determining their likely frequency. The analysis of errors may be carried out qualitatively, e.g. to identify vulnerabilities in a system (e.g. see Figure 4, which shows a schematic of an analysis of communication vulnerabilities in an ATM co−ordination task), or may be quantitative. The latter may be required, for example, when trying to determine whether a new ATCO support tool for planning approach sequences will help reduce risk or enhance it. Such prediction of human error probabilities is called Human Reliability Assessment (HRA) and usually occurs within a larger risk assessment of a system (see Kirwan, 1994).

A new method and associated taxonomy of classifying errors may therefore be developed specifically for ATC. The aim is to classify the human errors in psychological terms and to define the psychological error mechanisms underpinning those errors, a number of which will relate to design parameters (e.g. memory load problems), so that the error analysis can feed in to the design process. The human error identification method will also identify factors which shaped the operators performance towards making an error. Examples of such performance shaping factors are poor communications, poor interface design, workload which is too high or too low and skill level of the controller or pilot etc. An understanding of the psychological basis of errors will permit recommendations for system changes to be based on this information and perhaps to be more specific than recommendations which are made without this information.

An example of the types of errors that might be identified for future automation considerations, as an example, is shown in Table 3, together with a hypothetical extract from a human error analysis in Table 4.

Table 3 − Example Cognitive Error Mode Guidewords Associated with ATM Automation

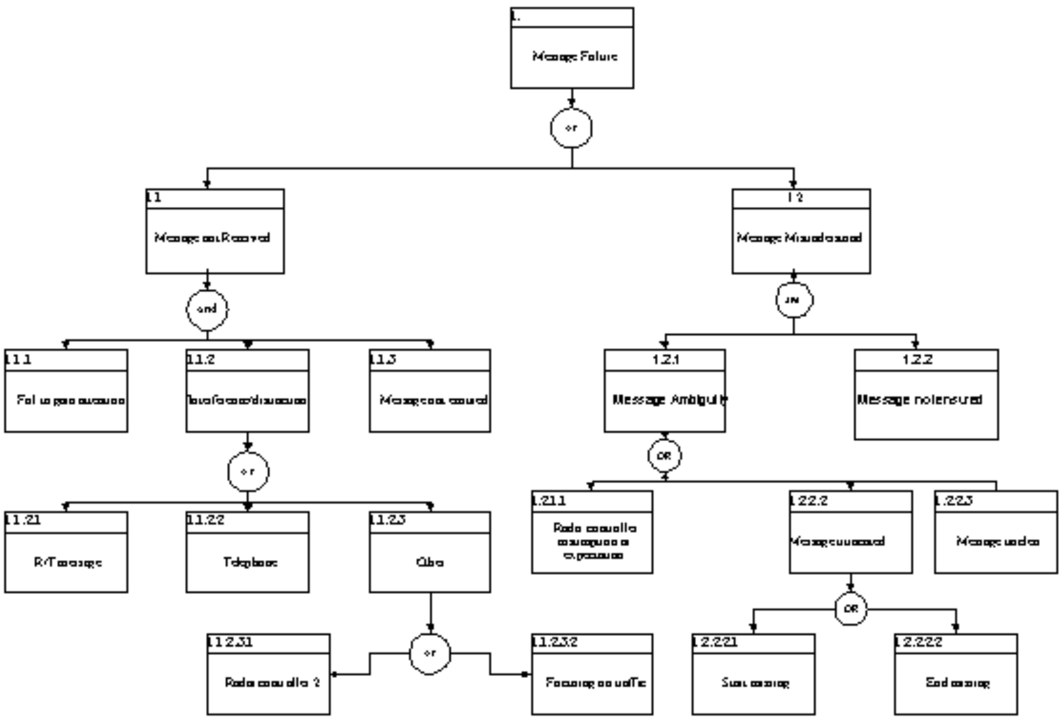
Loss of picture Rejecting a correct machine action or proposal Accepting an incorrect machine action or proposal Unable to resume control Role confusion (believe machine in control of a particular task, when in fact the ATCO is in control of the task, or vice versa) Control conflict (reluctance [by ATCO

or pilot] to accept delegated tasks) Fail to realise need to take over or over−ride Fail to detect machine error Non−fluent control (on take−over or over−ride) Loss of mode awareness Request wrong task or information Apply wrong tool Process (evaluate) wrong information Evaluate information in the wrong way Missing parameters from evaluation Specify with insufficient precision Ignore computer advice Focus on wrong aircraft (right action, wrong aircraft) Wrong action, right aircraft Instruct aircraft in wrong direction/altitude/speed/approach/other Co−ordination failure (fail to co−ordinate)

Table 4 − Extract from Cognitive Error Analysis

Task Step	Potential Cognitive Error	Factors Influencing failure	Recovery Factors	Consequences
Identify conflicts as indicated by the cognitive tools (CT)	Fails to monitor CT, or monitors too late or infrequently (low sampling rate by ATCO)	Busy; distracted; lack of trust in system; slack period resulting in assumption of no conflicts.	Other ATCOs; supervisor (if any)	Conflict may develop.

Figure 4 SCHEMATIC FAULT TREE OF COORDINATOR-RADAR CONTROLLER COMMUNICATIONS PROCESS



The Human Factors Unit has also recently studied the feasibility of collecting quantitative human error probability data for En Route ATM, with some success. It is hoped to expand this work in the future, so that risk assessments which quantify human error impacts can be made more accurate.

5.8 Team Resource Management (TRM)

Air Traffic Controllers work in teams with other controllers, support staff, pilots and with the computer system to achieve their task of controlling traffic. Teamwork is one of the most important human factors in maintaining safe and efficient air traffic control. Although a great deal of effort and expertise is devoted to training controllers in the technical skills required for the ATC task, little, if any, effort has been employed to train controllers to function as effective team members.

As part of the European programme for the harmonisation of air traffic control, a project has been initiated which involves NATS, along with other Eurocontrol member states, developing and implementing a training course aimed to improve team−working amongst operational air traffic controllers. This **Team Resource Management (TRM)** course is based on the concepts and principles of its forerunner, Cockpit Resource Management (CRM) from the aviation industry. It aims to highlight the importance of the team in the safe and efficient conduct of air traffic control and provide a means of improving ATC team working skills, and therefore safety by reducing the likelihood of incidents as a result of human error. TRM consists of training in basic human factors areas including: communication, decision making, team working, situation awareness, stress management and leadership.

Different means of communication (e.g. data link, electronic strips) and decision making (e.g. automation tools) are likely to affect the way controllers work together. Such changes could introduce new sources of error and misunderstanding within the team if they are not taken into account. The way information is communicated, shared and used within the ATC team will need to be re−considered to ensure that the team are able to maintain a safe and efficient role within the system. This may reduce the likelihood that automation will interfere with the team structure that the controllers work within.

5.9 Situation Awareness

Automation can reduce the controllers need to interact with the system, thus reducing workload, however, it may also reduce awareness of the control situation (Porter, 1996). If air traffic controllers are to maintain an active role within a more automated ATM system, it is necessary that they are able to use the automation tools within the system without losing situation awareness vital to their ability to safely and effectively carry out the control task. Automation should *support* the controller. For this to happen, it is important that the right tasks within the controller's job are automated and that the consequences automation for the controller, are understood.

Situation awareness is therefore a key research issue which aims to determine what the controller needs to be aware of within the ATC task. Situation awareness is commonly defined as 'the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future' (Garland and Endsley, 1995) and, is a process rather than a novel construct, which involves several cognitive processes used to perceive, process and utilise information, all of which are vital to the task of ATC.

Investigation of situation awareness will allow appreciation of the accuracy of a controller's mental picture of the ATC task and of the information needed to maintain the level of awareness required to safely control the traffic. By measuring situation awareness in a simulated environment, a controller's performance can be tracked over time and occasions when performance is challenged can be identified. If the causes of performance difficulties experienced by the controller can be identified, this information can be passed to designers of future system so that these causes can be eliminated.

Over the next three years a situation awareness approach will be developed and evaluated in terms of its robustness and utility for ATM Human Factors. It is believed that such a measure may yield more useful information in dynamic situations, in terms of what is causing awareness problems, and how to resolve them, than is currently the case with workload measurement techniques. The latter may tell us where there may be a problem, but may yield little information on the contextual causes of the problem and what to do about it. Overall therefore, Situation Awareness may be a more useful diagnostic measure than workload measurement. Whether this hypothesis is true remains to be seen.

5.10 Eye Movement Tracking

The Air Traffic Control task is highly visual in nature, with the need for constant reference to radar displays and flight progress strips. Any technique which can provide a greater insight into the visual aspects of the task, and the impact of this on the controller's planning, awareness of the situation and job performance, merits examination. Eye movement tracking is an obvious candidate technique for human Factors investigations into scanning patterns, and the usability of the interface and its displays by the ATCO. It can also be used to investigate more 'deeper' issues such as how the picture is built and maintained, and the narrowing of attentional focus on the radar display as may occur in some conflict resolution scenarios.

Analysis of eye movements may also provide an indication of the workload state of the controller. Various aspects of eye movements, e.g. saccade size and blink rate, have been linked to workload. These will be reviewed and tested in parallel with other measures of workload, to find out if these measures are reliable.

6. A Framework for Integrating Human Factors into the ATM System Design Life Cycle

Table 5 shows a potential framework for integrating Human Factors into the System Design Life Cycle, based on an integration of methods currently in use, and those under development (the latter in italics).

This framework will enable the development of systems which embody good Human Factors practice. The new methods will enable deeper insight into how new systems will affect the ATCO's picture, the ATCO's situation awareness, and the impacts of new interfaces on the cognitive performance and strategies ATCO team. Clearly this represents more intensive study than for previous systems development, but this recognises that increasing traffic density may make ATM more complex for the ATCO, or may lead to more automation that changes the ATCO's picture. More intensive and insightful Human Factors methods and support activities, during the SDLC, will help ensure that the high degree of human reliability currently seen in ATM continues.

Table 5: Integration of Human Factors into the ATM SDLC (*italicised* items are under development and evaluation)

Life cycle stage	Method
Concept	• *Human Centred Automation Design Principles* • *Task Analysis & cognitive task analysis* • *Error Analysis* • *Target Audience Description (user profile)* • *(Future) user population interviews/groups (user−centred design)*
Preliminary Design	• HMI design principles • Task Analysis & *cognitive task analysis* • *Human Reliability Assessment* • Fast−time simulation (PUMA) • (Future) user population interviews
Detailed Design	• Prototyping Evaluation • − *Eye movement tracking studies* • − *Situation Awareness Evaluations* • HMI guidelines evaluation • Task Analysis & *cognitive task analysis* • Fast−time simulation • Prototyping simulation and performance data collection • Risk assessment (including *HRA*) • User trials
Final Design Phase [2]	• Real−time simulation

	• − *new workload measures* • − *eye tracking* • − *situation awareness* • *Team Resource Management* • Task Analysis & *cognitive task analysis* • Risk Assessment (including *HRA*) • Usability & System Performance Demonstration trials
Operation	• *Incident & near−incident analysis* • *User groups* • *Task Analysis & cognitive task analysis* • *Risk Analysis (including HRA)*

[2] Leading up to and oncluding construction and commissioning

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