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Human Factors Integration in Future ATM Systems - Methods and Tools

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Abstract

Human factors is traditionally not well integrated within systems design. The Human factors Integration in Future ATM systems (HIFA) Project aims to redress this situation with respect to ATM projects. This report provides a comprehensive review of human factors methods and tools. A total of 39 ‘core’ methods is identified and described. The main characteristics of each method (its aim, procedure, requirements, outputs) are covered along with its advantages and disadvantages. Some 72 supporting human factors tools are also listed and described briefly. An extensive list of information sources on the Internet is included.

Keywords

Analysis	HIFA	Life cycle	Task analysis
Data collection	Human factors	Method	Task evaluation
Descriptive methods	Human reliability	Questionnaire	Tool
European Air Traffic Management Programme (EATMP)	Integration	Standards	Usability

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EXECUTIVE SUMMARY

This document is concerned with human factors in systems design and in particular making users and stakeholders aware of the importance and benefits of integrating human factors in the ATM life cycle. The report provides a wide-ranging review of human factors methods and tools relevant to the life cycle of ATM systems design.

The report constitutes the second part of the larger Human Factors Integration in Future ATM Systems (HIFA) Project being carried out by the UK Defence Evaluation and Research Agency (DERA) on behalf of the Human Factors and Manpower Unit of EUROCONTROL (formerly the ATM Human Resources Unit). As currently planned the HIFA Project is being carried out in two Phases: in Phase 1 the basic guidance material is being prepared; subsequently, in Phase 2 this material will be made widely available through appropriate electronic media (e.g. Internet).

This document is the third report for Phase 1 of HIFA. The first report (EATMP, 2000a) for Phase 1 is a comprehensive literature review of design concepts and philosophies for the role of human factors within ATM systems development. The second report (EATMP, 2000b) identifies the key integration issues, and specifies the human factors tasks to carry out and the checklist questions to ask. The roles and responsibilities required to implement the HIFA process are also detailed.

Chapter 1, ‘Introduction’, outlines the background to the project, and the objectives and scope of the report.

Chapter 2, ‘Human Factors Methods’, provides the bulk of this report and itemises the major human factors methods, and lists their associated tools used in human factors analyses during system design, development and integration.

Chapter 3, ‘Human Factors Tools’, lists and briefly describes the nature of the tools.

Chapter 4, ‘Human factors Methods and Life Cycle Integration’, briefly illustrates how human factors activities have been incorporated into the EATMP life cycle.

The final sections of the report provide References, Sources of Information on the Internet, a glossary of the Abbreviations and Acronyms used in the report, and a list of the Contributors to this document.

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1. INTRODUCTION

1.1 Purpose

The purpose of this document is to present a review of relevant human factors methods and tools used in system design. The document constitutes the third 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 British 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

The document is the third 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 methods and tools.

[1] European Air Traffic Management Programme (formerly 'EATCHIP', standing for 'European Air Traffic Harmonisation and Integration Programme')

The purpose of the report is as follows:

- to identify methods and tools to integrate human factors into future ATM systems;
- to describe those methods and tools;
- to provide guidance on the resource costs (e.g. time and effort) associated with the methods.

1.3 Background to Project

Current activities for integrating human factors within the life cycle of ATM systems were initiated in 1997 as part of the Human Resources Work Programme. The main events and milestones within which the present HIFA Project fits and including those events anticipated in the future are as follows:

• Human Factors Module Title: 'Human Factors in the Development of Air Traffic Management Systems' (EATCHIP, 1998b)	March 1998
• Third EUROCONTROL Human Factors Workshop Title: 'Integrating Human Factors into the Life Cycle of ATM Systems'. Held in Luxembourg on 7-9 October 1998 (see EATMP, 1999a)	October 1998
• Human Factors Integration (HFI) Guidance material Guidance material for HFI in the ATM system development life cycle. Development work contracted out to DERA (see this report and EATMP [2000a & 2000b])	November 1999
• Human Factors Module Title: 'A Business Case for Human Factors Investment' (EATMP, 1999b)	December 1999
• Human Factors Integration E-Book A handbook will be produced on the basis of the guidance material and will be made widely available through Internet and CD-ROM technology	November 2000

1.4 Structure of the Document

The document is divided into four main chapters, excluding the extensive literature references, and the Internet links given at the end of the report and other annexes. The structure of the report is intended to introduce the reader to the variety of human factors methods that are available and place them into a realistic context of when they are likely to be most useful through the system life cycle.

Following the Introduction (Chapter 1), some 39 human factors methods are described in detail in Chapter 2. Included in each description is a list of relevant tools and examples of key references in the literature. An extensive list of 72 tools is described briefly in Chapter 3. Finally, the relationship between the methods and the system development life cycle is discussed in Chapter 4, and example methods are given for each phase of the life cycle.

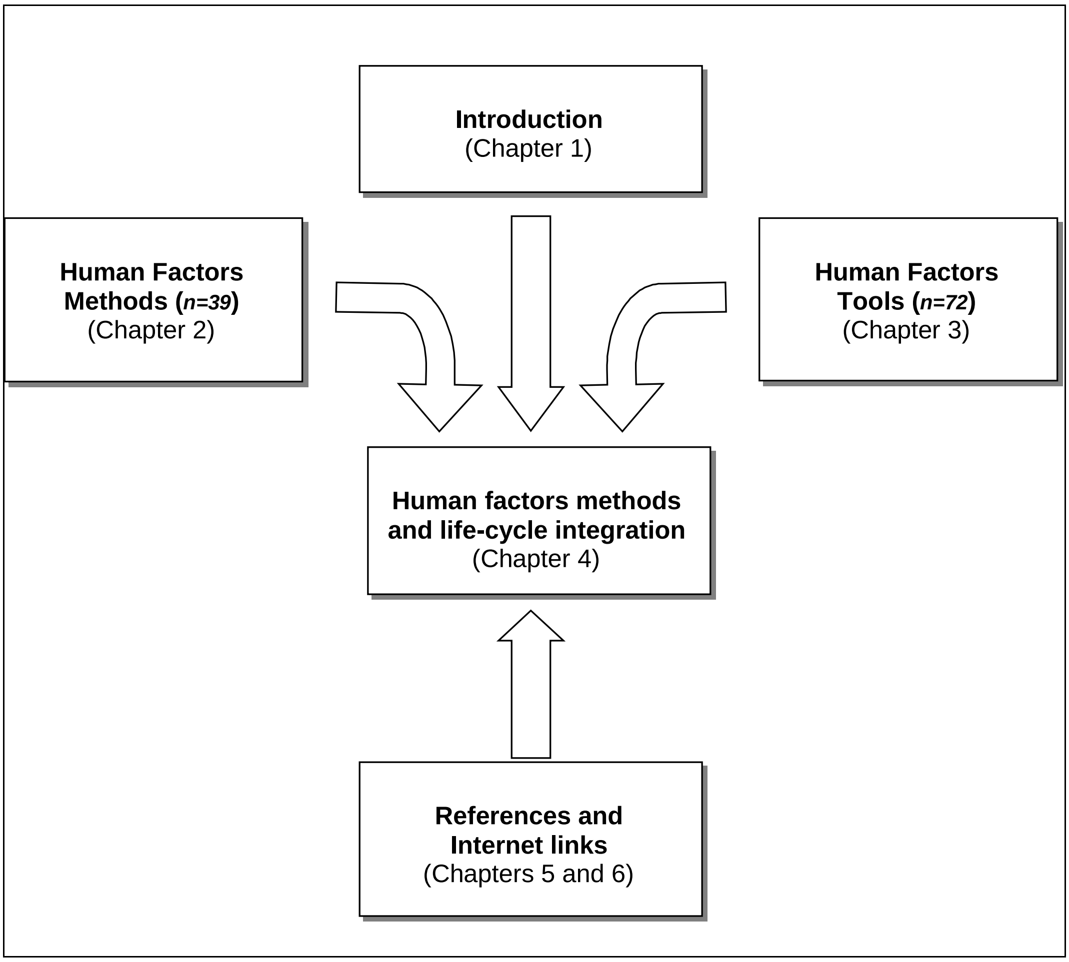

Figure 1: Schematic illustration of topics covered in the report

1.5 Definitions

The term 'method' is defined as a system of principles, practices and procedures applied to accomplishing anything. The term 'tool' is defined as anything (e.g. an instrument) used in the performance of an operation.

To clarify the distinction between the two terms; A method provides the underlying principles or rules that need to be applied in completing an operation, whereas a tool is a specific instrument that is based within a method to achieve a particular aim. Tools can be designed from scratch to achieve a novel aim not covered by existing tools.

For example, task analysis provides the broad methodology to investigate a wide range of issues (e.g. workload, training needs). Within that method are specific tools such as GOMS (Goals, Operators, Methods and Selection rules) designed to focus on cognitive aspects of working with computer-based equipment. Similarly, checklists can be used for a variety of purposes such as equipment design and conformance to procedures.

2. HUMAN FACTORS METHODS

2.1 Introduction

2.1.1 Scope and Selection Criteria

This chapter forms the bulk of this report. Its purpose is to provide a comprehensive overview of the methods available to address human factors issues in systems design. These method descriptions are supplemented with a list of their associated tools. However, it is beyond the scope of the present study to present a critical evaluation of each method and tool. The aim here is to provide an overview and guide to appropriate methods for a given situation, not to present an exhaustive listing of methods, their nature and application.

It is evident that there are many human factors methods and tools in existence as evidenced by reviews by Kirwan and Ainsworth (1992), Foot *et al* (1996), Beaujard *et al* (1997), and Dean (1997). Also, given the multi-disciplinary nature of human factors, which overlaps with such fields as computer science, systems engineering, occupational psychology, the list of methods and tools that could potentially be included is very large. Clearly, some selection of the most appropriate methods and tools is necessary.

With regard to the choice of methods, the main criterion is to provide a set of methods that covers the broad range of human factors activities throughout the system development life cycle. Thus, methods other than the traditional engineering ones should be included. The set of methods chosen is summarised in Sections 2.1.2 and 2.1.3 below.

With regard to the choice of tools the main criteria are:

- the tools should be well developed and should not be prototype or research products that have been little used or tested;
- the tools should be well documented, preferably with information on the Internet, and readily available from a clearly identified source or reference;
- the tools should, as far as possible, represent the latest in tool developments; they should be up-to-date and should not include obscure or rarely used examples.

Based on these criteria a selection of some seventy-two tools is identified and described in Chapter 3.

2.1.2 Description of the Methods

A simple tabular format is used for the presentations that follow. Each table describes the following:

- the title of the method,
- the appropriate phase(s) in the ATM life cycle,
- a definition of the method and its objective,
- the broad procedure associated with the method,
- the method's inputs and outputs,
- an outline of the costs, advantages and disadvantages of the method,
- a list of the tools associated with the method,
- a key reference about the method and/or tool.

2.1.3 Categories of Methods

To a certain extent all human factors methods are basically analysis methods of one form or another. However, it is useful to group the methods particularly for the purpose (within HIFA) of linking the methods to phases of the design life cycle.

Eight broad categories of methods are distinguished. These are listed below and form the structure for this chapter:

1. Data collection methods.
2. Task/system analysis methods.
3. Data analysis methods.
4. Equipment and environment design methods.
5. Evaluation methods.
6. Human resources methods.
7. Performance assessment methods.
8. Human reliability assessment methods.

The number of individual methods for each of the above categories varies from between two to seven. The total number of 'core' methods identified is thirty-nine. A complete listing of all of the methods is shown in Table 1.

Table 1: List and categorisation of human factors methods

Category of method	Methods (and report section)	Report Page No.
Data collection	2.2.1. Activity Analysis 2.2.2. Operational Analysis 2.2.3. Observational Techniques 2.2.4. Questionnaires 2.2.5. Structured Interviews 2.2.6. Psychometric Scaling 2.2.7. Charting and Network Methods	10 12 13 14 16 17 18
Task/system analysis	2.3.1. Early Human Factors Analysis 2.3.2. Task Analysis 2.3.3. Cognitive Task Analysis 2.3.4. Integrated Task Analysis 2.3.5. Method for Usability Engineering	21 22 24 25 26
Data analysis	2.4.1. Critical Incident Analysis 2.4.2. Functional Allocation 2.4.3. Operational Sequence Analysis 2.4.4. Timeline Analysis 2.4.5. Influence Diagrams	28 29 31 32 34
Equipment and environment design	2.5.1. Anthropometry 2.5.2. Body Strength and Stamina 2.5.3. Workspace and Workplace Design 2.5.4. Link Analysis	35 36 37 39
Evaluation	2.6.1. Checklists 2.6.2. Verbal Protocols 2.6.3. Cognitive Walkthrough 2.6.4. Real-time Simulation 2.6.5. Usability	41 42 44 45 47
Human resources	2.7.1. Selection 2.7.2. Training Needs Analysis 2.7.3. Training 2.7.4. Manpower Planning	49 51 52 54
Performance assessment	2.8.1. Objective Performance Measurement 2.8.2. Objective Workload Assessment 2.8.3. Subjective Workload Assessment 2.8.4. Physiological Workload Assessment	56 57 58 60
Human reliability assessment	2.9.1. Event Trees 2.9.2. Fault Trees 2.9.3. Failure Mode and Effects Analysis 2.9.4. Hazard and Operability Analysis 2.9.5. Cognitive Reliability and Error Analysis	62 63 64 65 67

2.2 Data Collection Methods

A common starting point for human factors analysis is to describe the tasks being investigated. This forms the basis for subsequent, detailed analysis of the characteristics of those tasks. The relevant methods here are:

2.2.1. Activity Analysis.
2.2.2. Operational Analysis.
2.2.3. Observational Techniques.
2.2.4. Questionnaires.
2.2.5. Structured Interviews.
2.2.6. Psychometric Scaling.
2.2.7. Charting and Network Methods.

2.2.1 Activity Analysis

Life cycle phase: Early phases.

Definition: An objective analysis based on measurement and quantification, of the task behaviours (or activities) engaged in by an operator being observed.

Aim: To determine the proportion of time an operator spends on different activities.

Procedure

This method requires the activities to be observable and distinguishable, and the sampling must be able to keep pace with the tasks. The four phases required are:

1. **Categorising activities**. Observe the task to determine what the expected activities will be. Determine the distinctive activities. Categorise and define the expected activities (to a maximum of twenty activities) and the limits of each activity (the start and end points).

2. **Develop a sampling schedule**. The sampling interval must be less than or equal to half the duration of the shortest activity to ensure all relevant data is captured. Determine how long the sampling should continue for. Sampling schedules can be fixed interval (in which samples are taken at regular intervals) or random sampling.

3. **Data collection and recording**. Train the observers in the data collection requirements. Consider completing a pilot study to check the activity criteria and data recording techniques. Two types of data record can be used:

   a) A tally records a frequency without indicating the activities sequence or duration.

   b) A sequential sample in which activities are marked in a time sequence.

4. **Analysis**. Calculate each activity's frequency, duration and sequence.

Resources required/Information requirements: Subject matter experts to prepare the data collection formats, and analysts/observers to collect the data, timing equipment, data record sheets, video recorders and a sample of normal operator activities.

Outputs: Record of relative frequencies, duration and sequence of activities. Estimates of staff requirements, skill levels, workload, stresses, and problem areas can then be derived.

Advantages

- The method is objective.
- Pre-determined data tabulation reduces the need for interpretation in data collection.
- The method is non-intrusive; the observers have a passive role in data collection.
- Administering the method is simple and requires few resources.
- The method is useful when numerous activities occur in no particular order.
- The method can reveal whether a significant time is used on unanticipated activities.

Disadvantages

- Setting up the method may be difficult and resource intensive, depending on the nature of the activity observed.
- Analytical skill is required to set up a relevant and targeted data collection tool.
- Complex activities can require increased time for data collection.
- Cognitive aspects of tasks are not addressed (e.g. decision-making activities).
- High-task frequency may not relate to task importance. This risks misinterpretation.

Tools

- Observer (http://www.noldus.com)
- Continuous Safety Sampling Methodology (CSSM)

References

- Meister (1985)
- Chapanis (1996)
- Quintana & Nair (1997)

2.2.2 Operational Analysis

Life cycle phase: Early phases.

Definition: The analysis of projected operations to obtain information about situations or events that will confront operators of a new system.

Aim: To generate a top-level statement of operational needs and concepts for a new system.

Procedure

Documents are reviewed and subject matter experts consulted to generate descriptions of scenarios, events, environments, assumptions, and constraints, and the consequences and implications for operators and maintainers.

Resources required/Information requirements: Documentation (statement of requirement, planning documents), and consultation with subject matter experts and the customer.

Outputs: Descriptions of scenarios, events, environments and assumptions, their implications for operators and maintainers, and foreseeable constraints and their consequences.

Advantage

The method provides a broad perspective and structure for later analyses (e.g. a hierarchical task analysis and a more detailed task analysis of the scenarios).

Disadvantages

- The method may lack detail necessary for detailed specification of a complex system and may need to be supplemented by further analysis.
- Can be time-consuming and requires subject matter experts to be available.

Tools

Key Issues Tool (KIT)

References

- Chapanis (1996)
- McLeod & Walters (1999)

2.2.3 Observational Methods

Life cycle phase: Any phase.

Definition: Methods that are used in research to assist in making accurate observations of events.

Aim: To obtain data by directly observing the activity or behaviour being investigated.

Procedure

Non-intrusive observation can be achieved by recording visual and audible events using an observer in the field, or recording those events on appropriate media for later transcription into a format that is meaningful to the analysis required.

Participative observation has the observer playing an active role in the task along with the operators. This may be useful in complex, skilled tasks where a certain amount of automatic activity is undertaken where the operator may have difficulty in explaining how the task is being achieved.

Resources required / information requirements: The following resources can be used: suitably trained observers, recorders (audio and visual), a means of transcribing those recording into meaningful data, cameras, timers and checklists. This method can be used in conjunction with the analysis of similar systems, structured interviewing and verbal protocols.

Output: This technique provides the specific data needed to the particular issue.

Advantages

- Some data can only be recorded by observation (e.g. social interactions and environmental influences).
- These methods are useful pilot studies to identify useful areas for further research.
- They increase the observers’ familiarity with the task under investigation.
- The method is objective.
- Participative methods can demonstrate team and organisational aspects of tasks.

Disadvantages

- The method is somewhat crude and so requires significant structuring to ensure the meaningful data are recorded.
- The method is non-intrusive but observable behaviours may be affected if operators know they are being observed.
- Cognitive processes cannot be analysed through this technique.

- Complex, high-quality observation methods can be expensive and difficult to set up.

Tools

- Continuous Safety Sampling Methodology (CSSM)
- DRUM (http://www.usability.serco.com/msexplorer/index.html)
- Observer (http://www.noldus.com)
- MacSHAPA (http://iac.dtic.mil/cseriac/products/macshapa.html)

References

- Drury (1990)
- Baber & Stanton (1996)
- Quintana & Nair (1997)
- Dray (1998)
- Ratier (1998a)

2.2.4 Questionnaires

Life cycle phase: Any phases.

Definition: A set of pre-determined, formatted questions administered to any number of people to elicit their views, for example as part of a survey.

Aim: To collect from a selected group of people their knowledge of, or opinions about, or attitudes towards specific things (including themselves) or events; to collect specific items of data in an economic and structured way.

Procedure

Four overriding issues must be considered in questionnaire design:

1. **Questions**. The primary design principles are simplicity and clarity while avoiding technical terms, negatives and leading questions. This will ensure all respondents interpret the items in the same way and avoid misinterpretation. Allow for a broad range of responses.
2. **Question types**. These are dependent on the type of data required. The range of types includes multiple choice questions, rating scales, paired comparisons, ranking according to a given criteria (all of which produce quantitative data), and open ended questions (producing qualitative data).
3. **Administration**. The appropriate population must be identified and an appropriate sampling strategy determined. Administration methods include self-completion questionnaires and structured interviews.
4. **Confidentiality**. The respondents' data must be retained in confidence.

Resources required/Information requirements: Printed material, return envelopes and postage costs (self-completion questionnaire), trained staff to administer the questionnaire (for interview structure).

Output: Structured data.

Advantages

- Questionnaires are economical to administer to large populations simultaneously.
- Closed questions can focus the survey on the issues in question rather than having respondents being distracted by secondary issues.
- A properly constructed questionnaire can be a robust, valid and reliable method.
- This method is closely linked with the structured interview method to give structured data.

Disadvantages

- Respondents may be influenced to provide answers they think are required or to leave a particular impression, rather than present a true response.
- Questions that are not clearly defined may lead to respondents applying different meanings may be given to same questions.
- Self-completion questionnaires have low response rates, so need a large sample pool. Using questionnaires for structured interviews can enhance the response rate.
- Some subjective interpretation is required in open-ended questions.

Tools

- Fleishman Job Analysis Survey (F-JAS)
- Position Analysis Questionnaire (PAQ)
- Questionnaire for User Interface Satisfaction (QUIS)
- Software Usability Measurement Inventory (SUMI)
- SAGAT
- Website Analysis and Measurement Inventory (WAMMI)

References

- Fleishman (1992)
- Fleishman & Mumford (1991)
- Sinclair (1975)
- Oppenheim (1986)
- Charlton (1996)
- Ratier (1998b)
- Allendoerfer & Galushka (1999)

2.2.5 Structured Interviews

Life cycle phase: All phases.

Definition: A meeting arranged for a particular purpose using a pre-determined sequence of interview questions.

Aim: The systematic collection of task-based data.

Procedure

An information interview generates general information on issue in question whereas a survey interview has a more specific goal and is more systematic.

Prior to the interview, the objectives of the study must be defined. Design the interview format with the analysis in mind to determine the type of data required (e.g. quantitative, qualitative, nominal, interval, etc.). Administer the interview in an environment that is likely to elicit response, usually an environment familiar to the interviewee or linked to the task under investigation.

The interview data must be kept confidential and the interviewer informed of that. A rapport must be established to facilitate and elicit response with the interviewer presenting a confident and competent manner.

During the interview the relevance of the process must be maintained and the interviewer should guide that process.

Resources required/Information requirements: Appropriate surroundings to facilitate the interview, trained interviewers, recording devices (audio and/or visual), a data collection format or pro-forma, and interviewer's knowledge of the task in question (if relevant).

Outputs: Recordings and transcriptions of the interviews, and quantitative and qualitative data.

Advantages

- Interviewing provides a natural means of data gathering that is relatively economic.
- Interviews can supplement other methods (e.g. critical incident and questionnaires).
- They are flexible in allowing interesting and unexpected information to be explored.
- Structuring the interview imposes consistency and standardisation to the process.
- This method can be used at any stage of task analysis.

Disadvantages

- Although generally economic this process can be time-consuming and labour intensive. Questionnaires may be a useful and cheaper alternative.
- The information required for the interview may not be easily recalled by the interviewer, or may be difficult to explain satisfactorily.
- The interviewer may bias the interview by inadvertently suggesting required answers.

Tools

- Ethnograph
- Decision Explorer
- Repertory Grid Analysis

References

- Meister (1985)
- Rubin & Rubin (1995)
- Baber (1996)

- http://www.qualisresearch.com
- http://tiger.cpsc.ucalgary.ca/WebGrid/WebGrid.html
- http://www.banxia.com/demain.html

2.2.6 Psychometric Scaling

Life cycle phase: All phases.

Definition: Subjective measurement technique using paired comparisons, ranking, sorting or rating to evaluate or measure things or events.

Aim: The aim of scaling is to quantify, both in degree and direction, subjects' views about the things or events in question.

Procedure

A rating scale consists, usually, of a straight line with five, seven or nine equal divisions along which a series of adjectives (with or without a number) which describe the stimulus attribute, are positioned. This Likert-type of rating scale, as it is known, is the one most practitioners are familiar with.

Resources required/Information requirements: All that is required, at its simplest, is a sheet of paper with the scales to be scored (alongside the relevant questions). Presentation of the material on a computer is also possible particularly to facilitate later data analyses.

Outputs: Data sheets with subjects' ratings. Analysing the collected data can then be carried out to derive additional statistical relationships.

Advantages

- Simple to construct and administer.
- Can be applied to almost anything. The use of rating scales is by far the most frequently employed subjective measurement technique.

Disadvantages

- Data analysis can be time-consuming without computer support.
- Valid and reliable scales require careful development. (Apparent simplicity of psychometric scaling can be misleading.)

Tools

- Bedford scale
- Cooper-Harper scale
- Defence Research Agency Workload Scale (DRAWS)
- Fleishman Job Analysis Survey (F-JAS)
- Subjective Workload Assessment Techniques (SWAT)
- SART
- MACE
- NASA TLX
- Observer Rating Form

References

- Fleishman (1992)
- Fleishman & Mumford (1991)
- Oborne (1976)
- Meister (1985)
- Aiken (1996)
- Sollenberger, Stein & Gromelski (1997)

2.2.7 Charting and Network Methods

Life cycle phase: Early phases.

Definition: Graphic descriptions used to describe tasks within a system.

Aim: To use the formal graphical representation of the task which is easier to understand than a textual description of the task.

Procedure: Charts

1. **Input/output diagrams**. A very simple representation of a task as an input-output diagram. The relevant tasks are selected and the inputs and outputs identified. These can be linked according to functions chains expected in task sequences.

2. **Process charts**. A simple, top-down flow diagram of a task. Each behaviour element within the task is represented by a symbol with particular characteristics (e.g. operation, inspection). This method is useful in representing semi-manual tasks.
3. **Functional flow diagrams**. This method presents block diagrams the represent the relationships between functions. Each function within the system is identified, and placed in the sequence that best represents their interrelationships. This method can be used as a simple form of indicating function order allocation within a system.
4. **Information flowchart or decision-action analysis**. This method considers task according to their decisions and actions. The format presents decisions as diamond shapes and actions as blocks within a line flowchart. Probabilities may be allocated to each item (e.g. event tree).

Procedure: Networks

1. **Critical path analysis**. A method usually used to determine management schedules. Tasks are listed and represented as nodes, links made between dependent tasks, and task durations are linked to the nodes so potential problems can be identified.
2. **Petri nets**. This method shows the conditions, which are connected by events, which alter the system's state. It is not linked to a timeline and can be used to show complex plans and control systems.
3. **Signal flow graphs**. Based on electrical flow diagrams, this method identifies important task variables, and how they relate within the system. Output variables are targeted and all the variables that could influence them are identified.

Resources required/Information requirements: Data and documents outlining the systems being investigated, subject matter experts familiar with using the methods, and observation methods.

Output: A clear and understandable system representation.

Advantages

- This method presents a concise and understandable representation of the tasks.
- Charts and networks incorporate a time element suitable for timeline analysis and creating operational procedures in training needs.
- The information can be used to categorise human tasks and systems functions when considering allocation of function issues.
- Charts can be used to identify criteria to identify task closure (e.g. for task analysis).
- These methods are also linked with fault and event tree analyses and hierarchical task analysis.

Disadvantages

- Charts and networks are limited in the amount of information they can convey.
- Complex systems can result in complex charts.
- At the early stages of the system life cycle the tasks and cognitive processes involved with using the system may be broad and without tight criteria that can be modelled.

Tools

- ATLAS
- FAST
- Micro Saint
- Traffic Organisation and Perturbation Analyzer (TOPAZ)

References

- Singleton (1974)
- Laughery & Laughery (1987)

- http://www.maad.com/msabout.html
- http://www.nlr.nl/public/facilities/f151-01/index.html
- http://www.humaneng.co.uk

2.3 Task/System Analysis Methods

These methods provide the focus of effort for analysing systems, reflected by the array of methods available for task analysis:

2.3.1. Early Human Factors Analysis (EHFA).
2.3.2. Task Analysis.
2.3.3. Cognitive Task Analysis.
2.3.4. Integrated Task Analysis (ITA).
2.3.5. Method for Usability Engineering (MUSE).
2.3.6. Influence Diagrams.

2.3.1 Early Human Factors Analysis

Life cycle phase: Initiation phase and early phases.

Definition: A method, integral to the early stages of a project, to raise awareness of issues (risks) that may affect the project.

Aim: To identify and track key human factors issues at life cycle stages when little information is available.

Procedure

Early human factors analysis (EFHA) begins with the top-level requirements of the process targeted at key stakeholders within the life cycle. The methods are allocated to specific phases of the life cycle and linked to the key stakeholder who will undertake those analyses. There are seven steps:

1. Document the Project Baseline for the analysis (documents, concept options, requirements, constraints, etc.).
2. Document Assumptions including those arising from baseline material as well as others that become apparent during the analysis.
3. Identify Concerns that might represent risks to the project. Encourage stakeholders to make concerns explicit rather than taking them for granted, or assuming they are not important.
4. Review the Concerns. Those that need further analysis are treated as key Issues (or requirements). There should be relatively few key Issues.
5. Analyse the key issues, ensuring that they are expressed unambiguously and that associated assumptions have been identified and checked.
6. Estimate Risks associated with key issues in terms of the likelihood and dimensions of Impact. The result is an input to the project risk register.
7. Identify Strategies to reduce serious risks. Strategies provide the basis for planning a work programme to reduce human-related risks.

Resources required/Information requirements: Project sponsor, subject matter experts, human factors analysis co-ordinator and documentation.

Outputs: Human Factors Integration Management Plan, Issues Register, Assumptions Register and Issues Log.

Advantages

- Simple and intuitive.
- Maintains an audit trail for key issues identified early in the development process.
- The method is well integrated into the whole life cycle process.

Disadvantages

- The method can be taxing on resources to maintain the output documents.
- The project sponsor must have an appreciation of human factors to be able to initiate the method.

Tool

Key Issues Tool (KIT)

References

- McLeod & Walters (1999)
- http://www.nickleby.com

2.3.2 Task Analysis

Life cycle phase: Early phases.

Definition: A broad method establishing the conditions required for a hierarchy of subtasks to carry out to achieve a system's goal.

Aim: To develop a system description in a task hierarchy from general processes down to specific details that merit further description.

Procedure

Task analysis is a very broad methodology, encompassing both descriptive and analytical techniques, and generally forms the basis of many subsequent analyses. The most well known method is Hierarchical Task Analysis (HTA). HTA is the common starting point for describing task structures prior to more detailed analysis. Individual HTAs vary in their implementation, but some basic principles apply. HTAs provide a set of rules for task description. Three core concepts apply:

1. A goal defines the top of the task hierarchy; it is a desired state of a system that is under control (e.g. system start-up).
2. A task is the method applied to achieve that goal (e.g. read checklist, initiate actions, etc.).
3. An operation is the base unit of behaviour that the person does to achieve the goal (e.g. actuate ON switch, etc.).

The goals are broken down into tasks and sub-tasks until the required level of performance criteria have been achieved. The criteria depend on what is necessary for the analysis. A common stopping tool is the P*C rule (see below).

The resulting HTA can be presented in several ways:

1. Hierarchical diagrams are used to convey the overall task structure or hierarchy. They provide an easy method of presenting the task structure information.
2. Number systems allocate the number 0 (zero) to the top-level goal. The tasks required for that goal are numbered from 1 to n (the number of tasks). Operations are numbered according to its related super-ordinate task (e.g. tasks 1.1-n). Sub-operations are numbered according to their subordinate operations in the same format as its operation (e.g. operation 1.1 is subdivided into operations 1.1.1-n).
3. Tabular formats allow further information and comments to be added to the task description by adding columns to the table.

Resources required/Information requirements: Subject matter experts, interview structures, stopping criteria.

Outputs: A hierarchy of operations or goals to be achieved within the system, and plans which state the conditions required before the operations can be undertaken.

Advantages

- This method provides the basis for many other human factors methods, especially more detailed performance, workload, and error analyses.
- It is economical because one researcher can complete it and only the parts requiring justification under the stopping rules need be addressed.
- The overall structure indicates the context in which individual tasks occur.
- The method allows rapid insight to be gained about the system processes.
- The method can form the basis for checking procedures later in the system life cycle.

Disadvantages

- It can be difficult to identify a suitable level of descriptive detail (i.e. when to stop).
- The method is not simple and may require training and/or experience in its use.
- The method requires collaboration to derive the information from the varied sources (e.g. operators, management).

Tools

- ATLAS
- Integrated Performance Modelling Environment (IPME)
- GOMS
- FAST
- WinCrew

References

- Card, Moran & Newell (1983)
- Diaper (1989)
- MOD (1989)
- Kirwan & Ainsworth (1992)
- Johnson & Johnson (1991)
- Sebillotte & Scapin (1994)
- Richardson, Ormerod & Shepherd (1998)

2.3.3 Cognitive Task Analysis

Life cycle phase: Detailed design.

Definition: A task analysis method that covers a range of approaches addressing cognitive, internal events or knowledge structures.

Aim: To investigate the cognitive aspects of tasks with an emphasis on constructs including situational awareness, decision-making and planning.

Procedure

The procedure will follow that of general task analysis. Once the task structure has been established, the supplementary information will be based on the constructs of interest to the investigation in question (e.g. situational awareness, decision-making and planning).

Resources required/Information requirements: Subject matter experts and documents (manuals, standard operating procedures, specification documents). Emphasis is placed on information requirements, evaluations and decisions.

Output: An ordered list of tasks with supplementary information about the cognitive requirements of the task structures (especially information processing, decision-making and planning processes).

Advantage

The method can be used to identify training needs and information requirements.

Disadvantage

Establishing the constructs can rely on subjective interpretation.

Tools

- Complex Cognitive Assessment Battery (CCAB)
- Applied Cognitive Task Analysis (ACTA)
- ATLAS

References

- Diaper (1989)
- Hamilton (2000)
- Militello et al (1997)
- Seamster, Redding & Kaempf (1997)
- Schraagen, Chipman & Shalin (2000)

2.3.4 Integrated Task Analysis (ITA)

Life cycle phase: Early phases and system evaluation process.

Definition: A task analysis method that covers different approaches addressing the behavioural and the cognitive aspects of the air traffic controller's tasks in order to compare different positions and service provisions (en-route, arrival/ departure and aerodrome).

Aim: To investigate the cognitive aspects with an emphasis on the cognitive processes and working style of air traffic controllers.

Procedure

The task analysis is conducted by applying a standardised set of methods comprising of:

1. A cognitive interview.
2. A set of behavioural observations.
3. A post observational interview.
4. A method of flight strip reconstruction.
5. Several complementary questionnaires on strain and stress.

Resources required/Information requirements: Subject matters experts (air traffic controllers), trained analysts (familiar with interview techniques and a fair background in ATC) and the ITA methods documents (interview guide, observation grids and questionnaires; and data processing scales).

Outputs

- Cognitive processes, cognitive profiles and working styles of the specific position/Unit.
- Users' needs identification.

Advantages

- The methods are easy to use and take about five hours by controller/position.
- The methods are adjustable and adaptable for specific purposes.
- Reference material is available on the cognitive processes of air traffic controllers and working style.
- The results allow before/after or previous/new system comparison.

Disadvantages

- The data processing is time-consuming.
- Analysts need a basic training.
- No computerised tools available for the data collection and processing.

Tools

No computer support yet developed.

References

- EATCHIP (1998c)
- EATMP (1999c, 2000c and 2000d)

2.3.5 Method for Usability Engineering

Life cycle phase: Early.

Definition: An analysis and design method focusing upon the integration of human factors with structured software engineering methods.

Aim: The method for usability engineering (MUSE) aims to improve the effectiveness of the human factors input into system development, particularly to facilitate an active and explicit involvement in system specification (as opposed to system evaluation only).

Procedure

MUSE has three phases:

1. Phase 1 (Information elicitation and analysis) involves collecting and analysing information concerning the existing tasks of users and the positive and negative features of the systems that they currently use.
2. Phase 2 (Synthesis) during which 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.
3. Phase 3 (Design specification) during which a detailed and device-specific specification of the user interface is produced.

Resources required/Information requirements

- A separate Software Engineering Method (such as JSD or SSADM) is required.
- The method requires that certain products are checked against those of the SE design team to promote implementability of the final design.

Outputs: Extant systems analysis, statement of user needs and various task models. In addition, a table concerning aspects of the diagrams as well as observations and speculations concerning design ideas supports each MUSE product.

Advantages

- Promotes common understanding and discussion between human factors and software engineering design teams.
- Consideration of design issues early in system development.
- Facilitates re-use of work from earlier projects, thus reducing the need for duplication of analyses.
- MUSE has wide application and documented case studies.

Disadvantages

- MUSE is a sophisticated method and has a steep a learning curve.
- It is best integrated with a system development method, usually Jackson System Development (JSD).

Tool

Toolkit support is available for MUSE (for example, MUSE*/JSD)

References

- Lim & Long (1994)
- http://euserver3.psychol.ucl.ac.uk/RESEARCH/muse.html

2.4 Data Analysis Methods

These methods are more specific than task analysis methods and cover investigation of important and safety critical tasks and/or events (critical incidents), sequencing issues (timeline analysis) and appropriate allocation between human and machine (function allocation). The relevant methods are:

2.4.1. Critical Incident Analysis.
2.4.2. Functional Allocation.
2.4.3. Operational Sequence Analysis.
2.4.4. Timeline Analysis.
2.4.5. Influence Diagrams.

2.4.1 Critical Incident Analysis

Life cycle phase: Early and Operations phases.

Definition: A method of identifying the sources of operator-system and maintainer-system difficulties in operational or simulated systems.

Aim: The collection of data about incidents within a working environment which have potentially important effects on system objectives.

Procedure

There is a presumption that incidents are memorable and so easily recalled for detailed analysis. The severity of events attracting the label ‘critical’ must be clearly defined at the start. Two broad approaches are available:

- The **‘open ended technique’** uses simple open-ended questions to elicit data in a free recall approach for later classification.

- The **‘systematic approach’** uses the following guiding principles:

  1. Determine general aims of activity. This determines the effective behaviours against which to assess the incident.
  2. Specify criteria for effective and ineffective behaviours. The situation in which the incident occurred must be specified so the incident can be related to the original system objectives.
  3. Collect data. Using individual/group interviews, questionnaires or checklists can complete this. A standardised format has economic benefits for data collection.

Resources required/Information requirements: The following resources can be used: trained analysts, subject matter experts, accident/incident investigation, interviews, questionnaires, observation techniques and verbal protocols.

Outputs: The identification of human-system difficulties in the operation of a system. Hypotheses about their causes may be made and solutions to those difficulties may be produced.

Advantages

- The method identifies system features that are potential human factors problems.
- It can contribute to the reduction of human error.
- Rare but critical events can be identified that may not be identified in other methods.
- The method has high face validity.
- It provides an economic use of resources if used at the early stages of design.
- It links with fault and event tree methods, and with HAZOP analysis.

Disadvantages

- The method relies on accurate and truthful reporting of events by operators.
- Memory is subject to distortion and forgetting.
- Good interviewer-interviewee rapport is required to elicit truthful, confidential reports.
- More regular but less memorable incidents may not be captured by this method.

Tools

- Procedural Event Analysis Tool (PEAT)
- Maintenance Error Decision Aid (MEDA)

References

- Flanagan (1954)
- Chapanis (1996)
- Ratier (1998a)

- http://www.boeing.com/news/techissues/peat/index.htm
- http://www.boeing.com/commercial/aeromagazine/aero_03/m/m01/index.html

2.4.2 Functional Allocation

Life cycle phase: Design phases.

Definition: A method for assigning functions, actions and decisions to hardware, software, human, or a combination of them.

Aim: To allocate functions between the components of hardware, software and the human operator to aid the completion of the system's goals.

Procedure

This method links closely to task description and analysis. Identify all the functions that are to be allocated. Remove the functions to be allocated to operators or equipment for reasons of safety, capability limitations, or system requirements. Prepare description of the remaining functions.

Define the various options between manual control and automation for each function. Establish weighting criteria to compare those alternatives. Compare the effectiveness of those options in achieving the required function. Select the option that meets the performance criteria and provide a cost-effective means of achieving the system functions. Cost effectiveness of an option may depend on manning levels, training needs, workload issues and standard operating procedures.

Resources required/Information requirements: Documentation review of functional flow analysis, decision-action analysis, action-information analysis, data from other human factors databases, consultation with subject matter experts.

Output: Function allocations between hardware, software, operators, maintainers or a combination of those elements.

Advantages

- The method does not result in a design freeze. The allocation of functions is a flexible process that can be altered through the system's life cycle.
- The method encourages designers to consider the detail of how and why functions are allocated between system and operator and consult widely on the matter rather than basing the allocation on intuition from a limited source of experience.

Disadvantages

- The method is not very precise because it relies to some degree on judgements in determining the selection criteria and the weightings.
- There is a risk that too many functions may be allocated to operators. This may arise if there is mistrust in an immature system and operators are unwilling to relinquish any level of control to automation.

Tools

- Integrated Performance Modelling Environment (IPME)
- Man-Machine Integration Design and Analysis Systems (MIDAS)
- FAST

References

- Price (1985)
- Chapanis (1996)
- Beevis & Essens (1997)

2.4.3 Operational Sequence Analysis

Life cycle phase: Design phases.

Definition: A method combining events, information, actions, decisions, and data to provide a graphic representation of the sequence of operator tasks.

Aim: To identify the operations associated with a task and their order of performance.

Procedure

In its basic form, the sequence diagram is formatted as follows:

1. A time scale is placed down the left column,
2. Additional columns are then included, as required, to show inputs, outputs, machinery, and operators, etc.
3. The flow of events is plotted from top to bottom against the time scale.
4. Interactions between the events are identified and plotted.

The interactions can be further tailored for specific objectives:

- **Temporal operational sequence**. The time for each task is represented on the vertical axis rather than a simple ordering of tasks.
- **Partitioned operational sequence**. This form allows different dimensions of a task to be presented in different columns of the diagram (e.g. sensory modalities).
- **Spatial operational sequence**. This format represents the spatial links between tasks by representing all tasks in one diagram and imposing the sequence of those tasks onto the map.

Resources required/Information requirements: Data from link, timeline, fault, task and function analyses, and simulation studies.

Output: Time-based chart representing the functional relationships between tasks.

Advantages

- Operational sequence diagrams are an inexpensive means of task simulation.
- They provide a representation of relationships between tasks that is easier to understand than textual reports.
- The method can incorporate multi-crew environments.
- The method does not rely on hardware.
- The method is also relevant to link analysis.

Disadvantages

- The method can be cumbersome and expensive to implement, despite being a cheap means of simulation.
- No single format of sequence diagram can convey all task information that can be represented by the different individual diagrams.
- The diagrams can become cluttered, especially when representing complex operations.

Tools

No specific computer support tools are known, but there are a number of commercially available drawing/graphics packages which would probably support the method.

References

- Kurke (1961)
- Kirwan & Ainsworth (1992)
- Chapanis (1996)

2.4.4 Timeline Analysis

Life cycle phase: Design phases.

Definition: A method deriving human performance requirements which incorporates the functional and temporal loads for a set of tasks.

Aim: To chart the sequence of operations, duration of tasks, the times at which tasks should occur, and multi-crew interactions.

Procedure

A timeline is a representative line with a length proportional to the task's duration. Data is derived from task analysis, observation and performance data of the tasks. A basic timeline describes the time-on-task as a staggered line on a two-axis chart; one axis for the time, the other for the function sequences. Additional task information can be displayed by shading or adding text to the bars, and using a vertical format rather than a horizontal format because several columns can be added without cluttering the diagram.

1. A horizontal axis timeline presents a horizontal bar to the right of its associated task. For a horizontal time axis each timeline is shown as a horizontal.
2. A vertical axis timeline presents the timelines as a continuous vertical bar with task identifications in a column alongside.

Alternatively, the timeline can be converted into a series of histograms, the height of each bar relating to a quantitative variable that varies over time.

Resources required/Information requirements: Data from task analyses, observation and performance metrics.

Output: A simple, graphical representation of the tasks' duration, temporal interaction between a set of tasks.

Advantages

- The method is economical because little training and few resources are required.
- Multi-person timelines can be represented to assess the effectiveness of task allocation between group members and identifying communications requirements.
- The method also links to the task analysis method.
- The output is easily understandable by non-experts.

Disadvantages

- The method only shows temporal relations of when events occur and their duration. Better assessment of interrelationships between events would require using methods such as charting or sequencing.
- Assessment of the associated cognitive processes would require additional analysis.
- Objective data may be difficult to establish.

Tools

- ATLAS
- Micro Saint
- PUMA

References

- Laughery & Laughery (1987)
- Kirwan & Ainsworth (1992)
- Chapanis (1996)

2.4.5 Influence Diagrams

Life cycle phase: Implementation and operational phases.

Definition: A method of representing graphically the factors that are likely to influence directly the occurrence of specific events.

Aim: To define target events and conditions that lead up to a specific task.

Procedure

The relevant scenario for investigation is identified. Select the appropriate experts for the investigation. Define the target tasks and describe the conditions leading up to each of them. The quality of influence information may be broken down to describe its quality, for example, the list of influences for a specific task may be categorised as good/bad or meaningful/not meaningful. Each influence factor can then be quantified to generate probability values for each.

Resources required/Information requirements: Judgements of subject matter experts.

Output: A graphical representation of factors that influence specific events.

Advantages

- Organisational influences can be incorporated into the analysis.
- No assumptions are made about the influence of conditions on task success/failure.
- The quantitative analysis can target important influence for cost effective modifications.

Disadvantages

- The method may be labour intensive and time consuming because a wide variety of subject matter experts may be required. High costs may result.
- It may be difficult to understand the concept of linked influences, especially when trying to quantify those influences.

Tools

- Analytica
- Decision Explorer

References

- http://www.lumina.com/software/index.html
- http://www.banxia.com/index.html

2.5 Equipment and Environment Design Methods

These methods are concerned with the equipment (i.e. workstations, consoles, tools and devices, etc.) that people operate or interact with, and the working environment in which they carry out their tasks. The main considerations are:

2.5.1. Anthropometry.
2.5.2. Body Strength and Stamina.
2.5.3. Workspace and Workplace Design.
2.5.4. Link Analysis.

2.5.1 Anthropometry

Life cycle phase: Preliminary and detailed design.

Definition: The study of the dimensions of the human body.

Aim: To incorporate functional body dimensions and their interrelationships in the design of workstation layouts and equipment.

Procedure

It is usually more cost-effective to design one system to accommodate all personnel likely to use it. There are therefore three fundamental anthropometric considerations for workspace design:

1. **Human variation**. Workspaces need to be designed to accommodate a range of individuals. These ranges are described as percentiles whereby, for example, short dimensions are towards the 3rd percentile and longer dimensions are towards the 97th percentile. Selecting dimensions for the average man may not be appropriate. It is therefore common to specify a range of dimensions to be incorporated into workspace design (e.g. the 3rd to 97th percentile range).
2. **Structural anthropometry**. This concerns the dimensions taken with the body in a rigid, standard posture. The basic measures used are body dimensions (standing and sitting), breadth and span dimensions, functional reaches, hand and foot dimensions, head dimensions, and weight. Data are available that allow adjustments to be made for clothes.
3. **Functional anthropometry**. This concerns the dimensions of the workplace needed by a person as they perform their job. It uses dynamic measurements that account for varying work positions. The basic measuring techniques are formal reach dimensions (from the standard body postures), dynamic reach dimensions (where the operator adopts whatever position is advantageous for completing the job), head and eye-pointing boundaries, and the accessibility of confined workspaces.

There are three broad approaches that can be taken to accommodate the above considerations: the single standard size approach, the adjustable system design, and the option to make different sizes and/or versions of a system or equipment.

Resources required/Information requirements: Relevant standards and related documentation, systems specification documents, subject matter experts.

Output: Anthropometric data required for the system design.

Advantage

The method provides a set of dimensions to generate a functional and effective workspace.

Disadvantages

- The variation in individuals' dimensions makes standardisation difficult to achieve.
- Any specified percentile range must be applied to each dimension. Consequently the more measures that are considered the smaller the total population that can be accommodated. For example, when considering the 3^{rd}-97^{th} percentile on three dimensions, the total population accommodated becomes 87%.

Tools

- BMD-HMS
- CADA
- Digital Anthropometric Video Imaging Device (DAVID)
- COMBIMAN
- Jack
- ManneQuinPRO
- Standards
- U-MAN

References

- Pheasant (1996)
- MOD (1997a)

- http://www.boeing.com/assocproducts/hms
- http://iac.dtic.mil/cseriac/products/cada/cada.html
- http://www.dstan.mod.uk
- http://www.syseca.thomson-csf.com/simulation/uman.htm
- http://iac.dtic.mil/cseriac/products/cada/cada.html
- http://www.nexgenergo.com/ergonomics/mqpro.htm

2.5.2 Body Strength and Stamina

Life cycle phase: Preliminary and detailed design.

Definition: Body strength is the measure of force that the body can apply to external objects, and stamina is the capacity of an individual to perform continuous physical exercise.

Aim: To incorporate functional body strength and stamina capabilities and their interrelationships in the design of workstation layouts and equipment.

Procedure

Design consideration needs to be given to the work rate and energy expenditure required for different types of effort, ranging from light to heavy work. Human factors standards such as Defence Standard 00-25, provides guidance on such matter. Guidance is also provided on the appropriate duration for different levels of work, the fatigue effects and rest periods for different levels of work, and the effects of posture and ergonomic equipment design on work capacity.

Resources required/Information requirements: Relevant standards and related documentation, systems specification documents, subject matter experts.

Output: Human strength and stamina estimates required for the system design.

Advantage

A set of dimensions to generate a functional and effective workspace.

Disadvantage

There is limited data on female strength and stamina.

Tools

Standards

References

- MOD (1997b)
- http://www.dstan.mod.uk

2.5.3 Workspace and Workplace Design

Life cycle phase: Preliminary and detailed design.

Definition: The application of human factors guidelines and practices to the design of equipment, workstations, and the working environment.

Aim: To ensure efficient and reliable operation of equipment in a safe and comfortable working environment by taking into account human capabilities and limitations.

Procedure

Workspace. The workstation for an air traffic controller, for example, must contain all the facilities needed for the whole range of duties at that position, including computers, other information displays, data input devices and communications (R/T and land-line telephone). The design of the human-computer interface (HCI) is critical. Moreover, the components of the workstation must meet all the anthropometric requirements of reach and viewing distances, and accessibility (i.e. based on relevant data).

The general layout of the workspace needs to accounts for factors such as visual requirement (fields of view), auditory requirements (communications and alarms), and control requirements (types of control, restrictions, handedness and clearance). The control room layout must allow for regular maintenance and cleaning to be done while services remains fully operational. (Air traffic control, for example, provides a continuous, 24-hr service and it is seldom possible to close down a facility.)

Workplace. Environmental factors should consider physiological factors (e.g. habitability, noise, vibration and fatigue inducing activity) and psychological factors (e.g. logical and functional arrangements, easy and intuitive operation). Contrasts between different operating conditions may also be addressed at this stage (e.g. between day and night operations). Air traffic control workplaces require good acoustic and visual properties. For example, an ATC unit located within an airport requires extensive sound insulation so that noise does not impair speech intelligibility. Proper lighting of the workspace is also very important.

The layout of an air traffic control room must accommodate all those who work there at the peak planned staffing level, including assistants, supervisors and other staff. There should be ample room in the workplace for watch hand-overs, for on-the-job training, and for back-up equipment used in emergencies.

Resources required/Information requirements: Relevant standards and related documentation, systems specification documents, subject matter experts.

Output: A functional and effective workspace design for the target population.

Advantages

- The method provides a design that should require minimal modification.
- Downstream costs may be significantly reduced if an appropriate design of produced early in the system life cycle.

Disadvantage

The process may be time-consuming and expensive depending on the complexity and size of the workstation being designed.

Tools

- CASHE:PVS
- Ergonomics guidelines
- Human Factors Design Guide (HFDG)
- MIDAS
- OIA
- Standards

References

- Smith & Mosier (1986)
- MOD (1991, 1992a, 1992b, 1996 & 1997c)
- Scapin (1986)
- Salvendy (1987)
- Sebillotte & Scapin (1994)
- Hopkin (1995)

- http://www.tc.faa.gov/hfbranch/hfdg
- http://www.dstan.mod.uk
- http://iac.dtic.mil/cseriac/products/cashe/cashe.html

2.5.4 Link Analysis

Life cycle phase: Design phases.

Definition: A method for arranging the physical layout of workstations to meet certain objectives.

Aim: To identify links between individuals and parts of the system in workstation operations (e.g. communications links).

Procedure

Common examples of this application are communications analyses and layout assessment for multi-crew environments. The basic process runs as follows:

1. Collate background information about the parts of the system in question.
2. List personnel and items to be linked.
3. Determine frequencies of links between operators, items, or operators and items.
4. Determine importance of links.
5. Calculate frequency-importance ratings for each link. Those ratings can be represented in a tabular format, or in a link diagram.
6. Rank the ratings in order of decreasing importance.
7. Fit and evaluate the layout.

Resources required/Information requirements: An appropriate sample of subject matter experts and operators; activity analysis, task analysis, observation studies or activity sampling data.

Output: Recordings of the frequency and importance of links and/or layout recommendations.

Advantages

- This method does not rely on hardware and so can be combined with other methods to investigate concepts (with defined tasks), existing systems or simulated systems.
- The method is objective and does not rely on subjective interpretation.
- Little training is required to implement the method.
- It is inexpensive to implement.
- This method closely links with network and operational sequence diagrams.

Disadvantages

- The method relies initially on data from other sources (e.g. task analysis).
- The method is not sensitive to organisational relationships or task duration.
- It may be difficult to represent the data from a complex system simply.

Tools

No computer support tools are known.

References

- Kirwan & Ainsworth (1992)
- Chapanis (1996)
- Stanton (1999)

2.6 Evaluation Methods

It is important, as a matter of quality control, to evaluate human-machine performance against the intended design criteria. This can be achieved by a variety of means, from simple checklists and surveys, to detailed usability assessments or to complex simulation methods. The main methods considered in this section are as follows:

2.6.1. Checklists.
2.6.2. Verbal Protocols.
2.6.3. Cognitive Walkthrough.
2.6.4. Real-time Simulation.
2.6.5. Usability.

2.6.1 Checklists

Life cycle phase: All phases.

Definition: Ergonomics checklists that can be used to check whether specified ergonomics criteria for a task are being met or whether a system is adequate for doing the task it was designed for.

Aim: To check whether the system complies with accepted ergonomics criteria.

Procedure

Checklist design. Some off the shelf checklists are available (see below), but new ones can be designed. Checklist design is usually set in a three-column format. Select the criteria against which the assessment will be made. The first column states the criteria should be clear and unambiguous. The second column provides a simple box check system. The third column allows for additional comments to be made.

Administering the checklist. Complex checklists will require a subject matter expert (human factors specialist) to complete. Each item is checked, marked and any relevant comments noted.

Analysis. The checklist highlights deficiencies in the system being assessed against its required specification. Items that fail become the subject of closer examination to establish their importance and the seriousness of the error.

Resources required/Information requirements: The relevant checklist, time, subject matter experts for administering the method.

Output: Traceable document detailing the status of system design against its requirement.

Advantages

- Checklists provide an easy reference against which a design can be compared.
- The method can be made a contractual requirement or a referenced standard.
- The method provides a traceable means of system development.
- Checklists ensure that no items are omitted by reliance on memory.

Disadvantages

- Administration of the method requires a subject matter expert (e.g. a human factors specialist) because the underlying human factors principles need to be understood.
- This method does not usually incorporate priorities of requirements with the criteria.
- The method cannot account for the context in which tasks are completed. Although a system may not meet strict requirements, its context of use may make minor non-compliance acceptable.

Tools

- ATC electronic checklist
- CRT display checklist
- ERNAP maintenance checklist
- Standards
- NUREG-0700
- VDU workstation checklist
- Ravden & Johnson checklist

References

- Kirwan & Ainsworth (1992)
- Ravden & Johnson (1989)
- Aiken (1996)

- http://www.hf.faa.gov/products/checklst/checklst.htm
- http://www.hfskyway.com/skyway.htm
- http://www.open.gov.uk/hse/hsehome.htm

2.6.2 Verbal Protocols

Life cycle phase: All phases.

Definition: Verbalisations about a task made by a person while carrying out a task which forms a commentary of their actions and reasoning.

Aim: To compile a commentary of the person's actions and reasons behind them.

Procedure

This method overlaps with the observation technique. The observer establishes a rapport with the subject. The subject provides a continuous commentary of his actions and reasoning while doing a task. Practice will be required to become familiar with this process.

The observer ensures recording is non-intrusive and notes events in the timeline. The first protocol should not be interrupted. For supplementary data the observer may ask the subject to clarify or expand on some points through a subsequent protocol.

The analysis involves:

1. Transcribing the protocol accurately.
2. Subsequent transcripts are used to produce a standardised protocol.
3. The content of the revised protocols can then be analysed.

Resources required/Information requirements: Audio recorder, resources to record corroborative data sources, staff to transcribe the data.

Output: A recording and transcript of the verbal commentary.

Advantages

- This method provides insight into the psychological processes involved doing a task.
- Data collection is relatively rapid; marginally longer that the task being observed.
- The method can be applied without special training.

Disadvantages

- Interpret data with care. Some mental processes cannot be verbalised directly.
- It requires some practice to be able to verbalise effectively and in a timely manner.
- The narration may interfere with the task being investigated. Corroboration of the data from other sources will be required.
- The process of setting up the protocol and corroborative data sources, transcription, and analysis may be time-consuming.

Tools

No computer support tools are known.

References

- Ericsson & Simon (1985)
- Ratier (1998a)

2.6.3 Cognitive Walkthrough

Life cycle phase: Early stages of development.

Definition: Cognitive walkthrough is a qualitative technique whereby system designers construct task scenarios from a system specification or early prototype and then role play (or ‘walk through’) the part of a user working with that interface.

Aim: To detect potential problems early on in the design process so that they may be avoided. Usability aspects of a user interface may therefore be assessed even before it is built.

Procedure

The cognitive walkthrough is based on the program code review method of software engineering. Commence evaluating by ‘walking through’ a system specification in terms of the tasks users will perform with that system, identifying the user’s goals and purpose for each task. Top-level goals are broken down into sub-goals and finer levels of granularity. Each goal or sub-goal will require cognitive (thinking) activity to manifest it. During the walkthrough, identify goal-task mismatches or problems arising in attaining the goals. Each step the user would take is scrutinised in detail: impasses where the interface blocks the ‘user’ from completing the task indicate that the interface is lacking. Similarly, convoluted, circuitous paths through function sequences indicate that the interface needs a new function to simplify the task and collapse the function sequence.

Resources required/Information requirements

A system specification and task breakdown is required to a fine level of detail, together with system designers who are able to represent the prospective user population.

Outputs

- Qualitative usability assessment of conceptual or prototype user interface.
- Informal feedback on problems likely to be encountered.
- Resulting refinement of specification and task descriptions.

Advantages

- Firm theoretical foundations – the walkthrough process is structured around specific questions that embody cognitive psychology theory.
- Hand simulation of cognitive activities of a user – the technique is good for assessing how well the interface meets the cognitive needs of the users.
- Strongly cognitive stance – closely mirrors cognitive task analysis.
- Highly-detailed, micro-level approach.

Disadvantages

- Lack of user input. No actual users are involved in the classic walkthrough approach, rather system designers estimating expected user responses. This argument for gaining feedback by designers using their own interfaces is somewhat circular.
- Classic walkthroughs can be overly formal and inflexible and take an academic as opposed to a real-world stance.
- The evidence on which to make reliable predictions of end user behaviour may not be available, particularly for novel system interfaces.
- The behaviour of single user rather than user teams are predicted.

These limitations have to some extent been overcome by pragmatic domain-specific extensions to the classic walkthrough approach such as the Malvern Cognitive Applied Walkthrough (MACAW) technique for ATM systems (Goillau et al, 1998).

Tools

Computer support tools are not applicable.

References

- Polson et al (1992)
- Wharton et al (1994)
- Rowley & Rhoades (1992)
- Goillau et al (1998)

2.6.4 Real-time Simulation

Life cycle phase: All phases.

Definition: Simulation is an engineering method used to predict a system's performance and to assess working methods, layouts, risk identification, and training needs.

Aim: To produce an environment that represents pertinent features of the realistic environment in which the system will operate, to be able to predict the systems operational performance.

Procedure

1. Determine the tasks to be investigated and the level of fidelity required.
2. Build a suitable simulation. This could range from a pen and paper system (e.g. mock-up), PC-based system, part-task simulation (where a specific aspect of the task is investigated), to full-task simulation (simulating the entire operational task environment).
3. Establish the parameters to be recorded for analysis and the recording processes (e.g. performance data from a part task simulation).
4. Incorporate the required inputs and operators.
5. The validity of stimuli, realism of control responses, stimulus-response relationships between displays and controls, task complexity, temporal representation, environmental conditions, situational pay-off (should the simulator be built to represent the task or provide a safe area for simulation?), social environment, and the control the investigator has over the simulation conditions.
6. Train the operators in the task requirements.
7. Perform a pre-determined task structure and collate the data for analysis.

Resources required/Information requirements: The resources required would depend on the nature and fidelity of the simulation. This could range from a pen and paper simulation to one that requires hardware, software, defined functions and tasks, operating procedures, and suitable subjects. Experimental design methods, and statistical analysis of data also needs to be considered.

Output: Data in system performance that allows the investigator to assess workload, predict system performance, evaluate alternatives, evaluate layout and procedures, identify training needs, and identify potential risks.

Advantages

- In large scale system (e.g. aircraft and ATM networks) simulation provides an economical alternative to live trials on operational systems.
- Functional fidelity rather than absolute fidelity can be used.
- Operator activities that cannot easily be observed can be assessed (e.g. accurate performance metrics, situational awareness, workload). This provides a close link with the behavioural assessment methods and also with the observational, interview and questionnaire methods that can be used to extract relevant data.
- Real-time simulations provide a major milestone to demonstrate a system design.

Disadvantages

- The activities assessed may not be fully representative of those in the actual system.
- Full simulation studies that aspire to high fidelity are extremely expensive.
- This method can produce large quantities of data that will need filtering and careful analysis.

Tools

Real-time simulation facilities are available throughout Europe, for example:

CENA	http://www.tls.cena.fr/divisions/ESV
DERA	http://www.dera.gov.uk//html/products/aerospce/atm/atmfacil.htm
DLR	http://www.dlr.de/FF-FL/24/atmos/atmos.html
EUROCONTROL	http://www.eurocontrol.fr/coe/ops/opspage/index.html
NATS	http://www.atmdc.nats.co.uk/b/svc/1/1%2D1.htm
NLR	http://www.nlr.nl/public/facilities/f75-05/index.html

ATCS Performance database

References

- Allendoerfer & Galushka (1999)
- Hadley, Guttman & Stringer (1997)
- Coolican (1994)
- Schick (1994 & 1998)
- EATMP (1999d)
- http://www.tc.faa.gov/hfbranch/atcpmdb

2.6.5 Usability

Life cycle phase: Early stages of development.

Definition: A user-centred design method for improving the effectiveness of 'ease-of-use' of modern technology by focusing on users' requirements and the measurement of users' performance with prototype systems.

Aim: Generally speaking, to improve the quality of interaction (between humans and 'machines') from the users' point of view.

Procedure

There is no single usability method, as it comprises a number of different activities as part of a general approach. Thus, focus groups, interviews (see 2.2.5), surveys or questionnaires (see 2.2.4), and walkthroughs (see 2.6.3) can all be used to gather users' opinions in response to specific questions at different stages of the design process. However, the key aspect of the usability method is the observation and measurement of users interacting with the equipment/product under being developed (or evaluated). This testing needs to be carried out under controlled conditions so that statistically valid data can be collected. Usability laboratories are frequently employed.

Where time and resources do not allow elaborate usability testing, shortcut usability heuristics can be used. The most well-known are those by Nielsen (1993) and consist of advice such as: *the system should always keep users informed about what is going on, through appropriate feedback within reasonable time* and *error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution*.

Resources required/Information requirements: Prototypes (or operational version) of equipment/product under evaluation; questionnaires; audio/video recording equipment; usability laboratory.

Output: Data and statistics on users' views and users' performance with equipment or product.

Advantages

- Overall effectiveness of product is improved.
- Users acceptance ('likeability') of product is increased.
- Cost benefits in the long term.

Disadvantage

Can be labour and time intensive to carry out full-blown evaluations.

Tools

- DRUM http://www.usability.serco.com/msexplorer/index.html
- SUMI http://www.ucc.ie/hfrg/questionnaires/sumi/index.html
- QUIS http://www.lap.umd.edu/QUIS/index.html
- WAMMI http://www.ucc.ie/hfrg/questionnaires/wammi/index.html
- Ergonomics guidelines
- Usability heuristics

References

- Ravden & Johnson (1989)
- Nielsen (1994)
- Jordan (1998)

2.7 Human Resources Methods

These methods are concerned with the many issues that could be grouped under the headings of Occupational or Personnel Psychology. The methods are concerned with recruitment, selection and training of people to perform operational tasks, and manpower planning, but they also embrace job design, personnel testing and related matters. However, as suggested earlier (see 2.1.1) it is beyond the remit of this report to cover all such methods. The four main methods to be briefly considered here are:

2.7.1. Selection.
2.7.2. Training Needs Analysis.
2.7.3. Training.
2.7.4. Manpower Planning.

2.7.1 Selection

Life cycle phase: Early phases.

Definition: A method for identifying and choosing the most appropriate personnel to meet the manning requirements of a system.

Aim: To select those personnel who, with appropriate training, are capable of becoming successful air traffic controllers.

Procedure

The selection process, based on a project called CAST (Consequences of future ATM systems for ATCO Selection and Training), comprises four phases:

1. **Recruitment.** This phase creates a relevant field of potential candidates for selection. As Hopkin (1995) has remarked, effective selection is impossible without suitable applicants.
2. **Pre-Filter.** This phase ensures that unsuitable candidates are excluded as soon as possible, on the basis of general criteria. In addition, relevant information about the personal qualities of those initially retained can be elicited efficiently for use later in the selection process.
3. **Pre-Selection.** This phase aims to ensure only the most suitable candidates will progress onto the final stage of selection. Performance in relation to core cognitive criteria can be used as a basis from which a decision can be made as to whether a candidate is suitable to progress further.
4. **Selection**. Having evaluated candidates' abilities on core criteria, this stage allows an assessment to be made to the extent to which candidates can apply their cognitive abilities in situations that are highly job related. Candidates for training should be selected on the basis of abilities and

characteristics they possess which are appropriate to the job (not training), and which the training process can develop to the standard required.

Detailed selection guidelines, practical advise and description of tools for all recruitment and selection stages is given in EATCHIP (1996, 1998d, 1998e and 1998f).

Resources required/Information requirements: Selection policy document, selection criteria, methods and media, pool of potential candidates, sponsor's funding endorsement of available training places post-selection. Criteria for air traffic controller selection can be described in categories of:

- general requirements (medical, education, age restrictions, nationality obligations, security, teamwork, flexibility);
- cognitive abilities (memory, scanning and vigilance, problem solving, prioritising, planning, perceptual ability, multitasking, verbal communication, mathematical ability);
- personality characteristics (relations, thinking style, emotional aspects, teamwork, flexibility).

Outputs: Selection report and audit trail, pool of relevant candidates for subsequent training.

Advantages

- The (CAST) method is comprehensive and follows defined stages.
- Consistency in selection criteria.
- Current and future ATM systems.
- Selection decisions are traceable and auditable.
- Should ensure a more reliable selection of controllers.

Disadvantages

- Subjective judgement still plays a large part in rating candidates against selection criteria.
- CAST method is recent and requires more extensive validation.

Tools

See tools for Questionnaires, Structured Interviews, Psychometric scaling, Psychological Tests (not included in current report). See also EATCHIP (1997a) for a description of some available tools; updated and extended documentation of available selection tools will be provided by EATMP.

References

- EATMP (2000e)
- Hopkin (1995)
- Broach & Manning (1998)
- CAST consortium (1999)
- http://www.nlr.nl/public/hosted-sites/cast/cast.htm

2.7.2 Training Needs Analysis

Life cycle phase: Initiated at early phases.

Definition: A method of identifying the training requirements of a system and a cost-effective means of meeting those requirements.

Aim: To identify cost-effective training methods for task requirements and provide an audit trail for training decision.

Procedure

The training policy, existing training and assumptions need to be addressed at the start of the process. TNA has three main phases:

1. **Scoping study.** This is completed by the sponsor. This is a preliminary outline of training requirements and solutions from a variety of information sources. Its coverage includes, amongst other things, the assumptions, influencing factors, job descriptions, design of the operational equipment, and available funding.

2. **Training needs activities.** These comprise three parts.

   - **Task analysis**. This provides a description of the job and its characteristics. The output is a task inventory which details the job's tasks and duties, the circumstances in which they are performed, who is to perform them, and the standard to which they should be performed.

   - **Training gap analysis**. The aim is to identify the training needed to take the personnel from their existing performance levels to the performance standard required in the new system. The output is a training objectives report which specifies the training required of each target personnel, the courses that are relevant, and the category of training (see 2.7.3).

   - **Training methods and media analysis**. The defined training regimes are then assessed according to a cost-benefit analysis to reconcile their effectiveness against the available resources (e.g. time, cost, equipment). The output is a combined training effectiveness and investment appraisal.

3. **Training needs analysis update (if required)**. This should be a continuous process of re-examination. As large projects develop and mature, the assumptions and requirements may need to be revised. These updates may affect all aspects of the TNA process, especially the documents outlined above), and an auditable configuration control mechanism must be in place.

Resources required/Information requirements: Subject matter experts, the sponsor, task analysis, the scoping study report, task analysis and training evaluation for current systems.

Outputs: Scoping report, task inventory, training objectives, a cost-benefit analysis for the options and review documents.

Advantages

- The method is an aid to determining cost effective training systems, standard operating procedures, and training costs of the options early in the design life cycle.
- The development decisions are traceable and revisable.

Disadvantages

- Early TNA is only as good as the limited information available relevant to the system.
- Large and complex systems may produce equally complex TNAs that will require significant effort. However, that cost may be relative to the size of the overall programme.

Tools

- MIDAS
- TRADAM

References

- Tri-service Guide: Training Needs Analysis (1997)
- EATCHIP (1997b)
- ICAO (1998)
- http://www.nlr.nl/public/hosted-sites/cast/cast.htm
- http://www.ott.navy.mil/refs/tradam.htm

2.7.3 Training

Life cycle phase: Early stages of development, Operations.

Definition: The process(es) by which instruction and guided learning, necessary for job performance, is given and its effectiveness assessed.

Aim: To impart job-related knowledge and skills at a level and in a manner appropriate to the needs of the individual and the task or job to be performed.

Procedure

Training starts with the preparation of a training plan to meet the training objectives. It is an essential part of the planning for an extensive training programme. A training plan will show: **who** needs training; **what** subjects you are going to train people on; **how** you are going to train them; **when** you are going to train them; and, **how long** the training will take. Two aspects of the training plan will be considered here: training phases and training methods.

Training phases. Training proceeds through several distinct, sequential phases from initial training of new recruits to refresher training of experienced staff. Three phases can be distinguished:

- ***Ab initio* training** (including basic or routine training). Designed to impart fundamental knowledge and skills to new recruits.
- **Operational training** (including transition training). Given in an operational environment and consolidated under the supervision of a qualified instructor in a ‘live’ situation.
- **Continuation training** (including conversion, upgrade and refresher training). Designed to increase knowledge and skills and/or to prepare for the introduction of new technologies (or procedures).

Training methods. There are a number of different training methods that can be employed to meet the training objectives:

- **Classroom training** (including lectures, tutoring, demonstrations, etc.). Can be regarded as the traditional method of training.
- **Simulation training** (including part-task and full-task training). Provides realistic representations of the operational system and is the traditional method of teaching operational procedures.
- **On-the-Job Training** (OJT). Designed to provide practice in real operating conditions.
- **Computer-based Training** (CBT) or ‘teachware’ (including interactive guided learning). The training material is presented to the trainee through the use of a computer.

Resources required / Information requirements: In addition to standard classroom materials (e.g. syllabi, textbooks, videos, audio-visual aids, etc.) and the computers and software for CBT, resources include all kinds of simulators. Key resource is also training instructors (who require training too).

Output: Performance and test results of trainees (paper and/or computer files).

Advantages

- Classroom teaching allows interaction and discussion between student and teacher.
- Simulation training allows risk-free practice of all required skills in real-time.
- CBT allows students to proceed at their own pace and repeat certain points as they wish; it is non-threatening.

- OJT provides essential practice in ‘live’ situation.

Disadvantages

- Simulators are labour and time-intensive.
- CBT can be very costly, particularly initial development costs.
- CBT is not necessarily a good method where team interactions are important.
- OJT training requires OJT Instructors (OJTIs) who have to be taken off normal operational duties; OJTIs require training too which is expensive.

Tools

- TRAINDEV
- Training simulators, e.g.:
  - DFS: http://www.dfs.de/e/job/flugsicherungsakademie/main_akademie.htm
  - ENAC: http://www.enac.fr

References

- EATCHIP (1997c)
- EATMP (1999d and 1999e)

2.7.4 Manpower Planning

Life cycle phase: Early stages of development.

Definition: The process(es) by which the required staff resources are determined, and future staff shortages or surpluses or skill categories are estimated and plans formulated.

Aim: To provide a sufficient number of qualified personnel, on a timely basis, so as to ensure the provision of the required services (e.g. ATC services).

Procedure

The following procedure is taken from the EUROCONTROL guidelines for air traffic controller manpower planning, but the principles are relevant to the provision of other services. The core process is the balancing of Operational manning Requirements (ORs) with the number of staff (e.g. air traffic controllers) available for the planning period. Two activities are required:

1. Estimating the manning requirement, which involves analysing air traffic demand to determine ORs and estimating the numbers of air traffic controllers required. Two formulas are used. The ‘multiplication factor calculation’ establishes the absolute minimum number of staff required to run a stable roster for any given OR. The ‘manning calculation method’ establishes a maximum number of staff. The true number of staff needed will be somewhere in between the two figures.

2. Estimating the number of air traffic controllers available by analysing the in-flow, through-flow and out-flow of air traffic controllers. The number of *Ab Initios* in the recruitment and selection stages of training, and OJT phases determines the number of controllers flowing into the system. The difference between the projected air traffic controllers required and the expected air traffic controllers available provides the recruitment requirement. If this number of people are trained (traffic growth and training success rate being as expected), the supply and demand of operational controllers should be in balance in the future.
3. With 1 and 2 above the number of required and available controllers is derived. However, at the strategic level the impact of changes which affect the job of the controllers (i.e., the introduction of new technology, privatisation) needs to be assessed. A process to manage this is outlined in EATMP guidelines (EATMP, 2000f).

Resources required/Information requirements: Job descriptions, training success rates; quantitative estimates of staff numbers (in-flow, through-flow, out-flow), air traffic statistics and predictions (growth or decline).

Output: Estimated numbers of staff required to maintain services.

Advantages

- Better matching of staffing levels to requirements, so ensuring better provision of services.
- Cost benefits in the long term.

Disadvantages

- Manpower planning is a difficult task as it requires juggling many factors in order to arrive at a balanced view of manpower estimates.
- Requires tool support to be done efficiently.

Tool

LAMPS

Reference

EATMP (2000f)

2.8 Performance Assessment Methods

These methods are concerned with measuring aspects of human performance. The data collected can be either objective (quantitative) or subjective (qualitative). In the case of workload a separate category of physiological data is usually distinguished. These methods link closely with the evaluation methods (see 2.6).

The approach to workload assessment depends on the level of detail required and the type of workload being investigated. This may range from a simple mental workload estimates of a decision-making process to a comprehensive assessment of objective, subjective and physiological workload in a full simulation study. The main methods are as follows:

2.8.1. Objective Performance Measurement.
2.8.2. Objective Workload Assessment.
2.8.3. Subjective Workload Assessment.
2.8.4. Physiological Workload Assessment.

2.8.1 Objective Performance Measurement

Life cycle phase: Pre-operational and operational.

Definition: The evaluation of operator/team performance by means of objective measures such as timing and counting of events.

Aim: To obtain quantitative data on operator/team performance, but without the extreme subjectivity of observation and judgement.

Procedure

In a system of reasonable size the number of performance indicators that could be measured is enormous. However, when considered in terms of their similarity, they reduce to a few generic measures:

1. Time (e.g. reaction time, duration).
2. Frequency (e.g. number of responses, observations, communications, etc.).
3. Accuracy (e.g. correctness of responses, observations, errors made, etc.).
4. Quantity (e.g. response magnitude or quantity achieved and/or used).
5. Behavioural state (e.g. situation awareness).

Resources required/Information requirements: Task simulation or actual task environment; methods for recording performance data (e.g. data sheets, pen and paper, computer-based data-logging).

Output: Quantitative data (timings, errors, etc.).

Advantages

- Especially suited to the measurement of task and job performance (as opposed to non-task behaviours, attitudes and traits).
- Usually simple procedure to gather data.
- Does not require specialist skills to take measurements.

Disadvantages

- Often provide much less information than subjective measures (because they measure only relatively simple, although fundamental, dimensions).
- In many cases the only observable measures in performance are time and errors.

Tools

(Computer software designed to log direct objective metrics during simulation)

- ATCS Performance Measurement Database
- CASHE:PVS
- Observer Rating Form
- SAGAT
- SART
- SPAM

References

- Hadley, Guttman & Stringer (1999)
- Coolican (1994)

2.8.2 Objective Workload Assessment

Life cycle phase: Pre-operational and operational.

Definition: A method for appraising operators' task loads and/or their ability to carry out the required tasks in the required time.

Aim: To investigate whether the operators can achieve the goals within a specified time within defined limits.

Procedure

Objective measurements are centred on task performance. As such, any task output (e.g. time, accuracy, quantity) can be used under experimental circumstances to reflect workload (see 2.8.1 above). Workload can also be measured objectively through the use of 'secondary loading' tasks. While performing his/her main (primary) task the operator is given an additional (secondary) task to undertake. Performance on the latter task theoretically decreases as the attentional demand of the primary task increases.

Resources required/Information requirements: Task simulation or actual task environment, methods for recording workload data ranging from pen and paper or computer-based metrics (e.g. performance metrics recorded during task simulation).

Output: Quantitative data (e.g. timings, accuracy, etc.) indicating the level of workload experienced by the operators.

Advantages

- A range of simple metrics is available to investigate performance.
- Workload estimates can be applied to early task analyses as a simple, initial predictor of workload.

Disadvantages

- Often provide much less information than subjective measures (because they measure only relatively simple, although fundamental, dimensions).
- Secondary task measures make certain assumptions about performance which are not necessarily validate.

Tools

(Computer software designed to log direct objective metrics during simulation)

- WinCrew
- ATCS Performance Measurement Database

References

- Hadley, Guttman & Stringer (1999)
- Coolican (1994)

2.8.3 Subjective Workload Assessment

Life cycle phase: Pre-operational and operational.

Definition: A method for appraising operators' task loads and/or their ability to carry out the required tasks in the required time.

Aim: To investigate whether the operators can achieve the goals within a specified time within defined limits.

Procedure

Subjective measures provide a self-assessed estimate of workload reported by the operators themselves. Consequently, subjective metrics give relative rather than absolute data. There are a variety of simple tools that can be used to take measurements either during a task or after it, and other more complex tools that need to be administered after a task:

1. Uni-dimensional measures of the workload based on a single scale or flowchart scale (e.g. Bedford Scale). They can be completed while the tasks are being undertaken.

2. Multi-dimensional measures which provide diagnostic information about the nature and relative contribution of each dimension in influencing overall operator workload (e.g. NASA TLX).
3. Operator debriefing (e.g. structured interview). This provides insight into operators decision processes and prioritising when dealing with high-workload situations.

Resources required/Information requirements: Task simulation or actual task environment, methods for recording workload data (ranging from pen and paper (e.g. NASA TLX) or computer-based approaches.

Output(s): Quantitative data (e.g. ratings) and/or qualitative data (e.g. decision processes derived during debriefing) indicating the level of workload experienced by the operators.

Advantages

- A range of methods are available for investigating different the characteristics of workload.
- Workload assessment can be applied to early task analyses as a simple, initial predictor of workload, or to simulation studies to gain realistic insight to operator workload.
- Simple workload estimates are a cost-effective method of assessing design at the early stages of development.
- Subjective measures are generally easy to apply.

Disadvantages

- Workload is nebulous concept and no one metric alone can define it.
- Subjective reports of workload (e.g. mental workload) may be difficult to quantify accurately.
- Comprehensive workload analysis can be expensive.

Tools

- Cooper Harper Scale
- Bedford Scale
- Defence Research Agency Workload Scale (DRAWS)
- Instantaneous Self Assessment of workload (ISA)
- Malvern Capacity Estimate (MACE)
- NASA Task Load Index (NASA-TLX)
- SWAT

References

- Hadley, Guttman & Stringer (1999)
- http://www.tc.faa.gov/hfbranch/atcpmdb

2.8.4 Physiological Workload Assessment

Life cycle phase: Pre-operational and operational.

Definition: A method for appraising operators' task loads and/or their ability to carry out the required tasks in the required time.

Aim: To investigate whether the operators can achieve the goals within a specified time within defined limits.

Procedure

These metrics are a branch of objective metrics that focus specifically on human physiological reactions to situations (e.g. high workload). A variety of physiological metrics can be taken that reflect workload effects:

1. Heart rate.
2. Heart-Rate Variability (HRV). This is the standard deviation of the inter-beat interval which relates to mental effort and spectral analysis breaks down the HRV into a number of frequency bands associated with different biological control mechanisms.
3. Measuring levels of catecolamines.
4. Measuring levels of cortisol from saliva swabs.
5. Electro-encephalography.
6. Eye blink rate.

Resources required/Information requirements: Task simulation or actual task environment, methods for recording workload data (ranging from pen and paper or computer-based metrics (e.g. Electro-encephalography).

Output: Quantitative data (e.g. heart-rate variability) indicating the workload level experiences by the operators in operating the system.

Advantages

- A range of methods and tools are available for investigating different the characteristics of workload.
- Workload assessment can be applied to early task analyses as a simple, initial predictor of workload, or to simulation studies to gain realistic insight to operator workload.
- Simple workload estimates are a cost-effective method of assessing design at the early stages of development.

Disadvantages

- Workload is nebulous concept and no one metric alone can defined it.
- Comprehensive workload analysis can be expensive.

Tools

- Cognitive Neurometric System (CNS)
- MacLab
- CCAB

References

- Miller & Rokicki (1996)
- Cabon *et al* (1999)

2.9 Human Reliability Evaluation Methods

These methods allow human performance to be formally reviewed, and the evaluation of human-machine performance against the intended design criteria. This typically completed through human reliability assessments and analysing events. These methods are also linked with the task evaluation methods (below). The main methods are as follows:

2.9.1. Event Trees.
2.9.2. Fault Trees.
2.9.3. Failure Mode and Effects Analysis (FMEA).
2.9.4. Hazard and Operability Analysis (HAZOP).
2.9.5. Cognitive Reliability and Error Analysis Method.

2.9.1 Event Trees

Life cycle phase: Design and operational phases.

Definition: An event tree is a task analytical method that produces a tree-diagram that represents tasks, task sequences and their consequences.

Aim: To investigate the potential sequences of events during system operation, and identify the potential consequences associated with each sequence.

Procedure

Each task in a task structure is symbolised as a node. Lines leading horizontally from that node to a secondary node represent all potential outcomes from that task. Each node in turn is then linked to its consequences until the events result in a success/failure option. Probabilities can be linked to each node. Many tools have been developed, all largely derived from the classical approach known as the Technique for Human Error Rate Prediction, or THERP, (Swain and Guttman, 1983).

Resources required/Information requirements: Subject matter experts may be required to generate suitable detail and structure for the event tree.

Outputs: A graphical representation of event sequences and the outcomes associated with those individual event sequences.

Advantages

- The method provides a useful technique for cross-discipline systems analysis (e.g. with engineers).
- The method derives tasks and error that may have a critical impact on system functioning.
- It can be used to diagnosis system difficulties.

- The method also links with HAZOP, task description methods, questionnaires, simulations and failure analyses.

Disadvantages

- The method may have difficulty in dealing with long task sequences.
- Event tree present a simple representation of tasks that cannot model the cognitive aspects of task completion (e.g. varying workloads, prioritisation and task shedding).

Tools

- Accident Sequence Evaluation Programme (ASEP)
- Generic Error Modelling System (GEMS)
- Human Error Assessment and Reduction Technique (HEART)
- Justification of Human Error Data Identification (JHEDI)
- MEDA

References

- Kirwan & Ainsworth (1992)
- Kirwan (1997)

2.9.2 Fault Trees

Life cycle phase: Design and operational phases.

Definition: A fault tree is a tree diagram that identifies combinations of event that could cause specific failures.

Aim: The analyse errors to determine their cause and consequences.

Procedure

An undesirable event is defined and placed at the top of the fault tree. Determine the cause of the fault and any linkages it has to other faults. For each of the causes, their individual causes and any linkages to other faults are also determined. The fault tree uses AND and OR gates to represent the nature of the linkages between faults. An AND gate indicates that a faults above the gate will only occur if all faults below that gate occur. An OR gate indicates that a fault underneath that gate can cause the fault above the gate.

Resources required/Information requirements: Documentation review of critical incident analyses, charts and network analyses, task analysis, and consultation with subject matter experts.

Outputs: Probabilities of faults, the event sequences that would precipitate them, and indicators of how to deal with the fault.

Advantages

- The method can identify tasks that are critical to the system function.
- The method provides a useful technique for cross-discipline systems analysis (e.g. with engineers).
- Quantitative analysis can be undertaken with this method by linking probabilities to the individual faults.
- The method also links with HAZOP, observation, interview, and task analysis methods.

Disadvantages

- The logic of the fault linkages can be difficult to construct.
- The large list of potential consequences for some tasks can produce long and complex fault trees.
- Training will be required to apply this method effectively.

Tools

- Generic Error Modelling System (GEMS)
- SAM 2000
- FaultrEASE™

References

- Kirwan & Ainsworth (1992)
- Kirwan (1994)
- Chapanis (1996)
- http://www.yse-ltd.co.uk

2.9.3 Failure Mode and Effects Analysis

Life cycle phase: Design and operational phases.

Definition: A method for deducing the consequences for system performance of a failure in one or more components and the probabilities of those consequences.

Aim: The analysis the cause and effects of component failures on systems. The components are the operators.

Procedure

Identify the types of human errors that can occur. Estimate their probabilities and the consequences of each error type. If the consequences are serious then modification or coping strategies may be investigated to mitigate the effect of those errors. A tabular format would cover task type, error type, recovery step, psychological mechanisms, causes, effects, and recommendations for mitigation.

Resources required/Information requirements: Documentation review of activity analysis, task analysis, critical incident analysis, and consultation with subject matter experts.

Outputs: A list of failures that have a critical effect on system operation; the probabilities of the failures and the tasks that required modification as a consequence.

Advantages

- This method is easy to understand and interpret.
- The level of detail incorporated can be varied to suit the analysis.
- Qualitative data about the causes and effects can be incorporated to the analysis.
- The consequences of the errors are used to indicate the most important risks.
- The method can be applied in a short timescale.

Disadvantages

- A skilled analyst is required to administer the method.
- Error description can become lengthy.

Tool

SAM 2000

References

- Kirwan & Ainsworth (1992)
- Chapanis (1996)
- http://www.yse-ltd.co.uk

2.9.4 Hazard and Operability Analysis

Life cycle phase: Initiation and early design phases.

Definition: A method that uses appropriately experienced subject matter experts to make a systematic appraisal of potential risks in a system's design and operation.

Aim: The systematic description identification of potential problems in a system's design and operation.

Procedure

HAZOP. From design documents, operating instructions, flow diagrams, task analysis data, interviews, questionnaires and subject matter experts develop an overall understanding of the process. When considering a flow or instrument diagram, *property words* that describe the characteristics of functions are investigated as well as *guide words* that describe deviations that can result in errors. The potential causes for and consequences of those deviations are identified. Preventive and corrective measures for the potential difficulties are considered, costed and incorporated at the design stage of development.

Human HAZOP. This method uses the same format as above but concentrates on identifying human errors, understanding their causes, and developing means of reducing the associated risks.

Resources required/Information requirements: Subject matter experts from a variety of relevant disciplines, a means of recording the information generated, tasks analysis data, design documents.

Output: A checklist of required design modifications.

Advantages

- The method attempts to identify the full range of potential hazards in a system.
- It provides a means of assessing hazards before a system goes into production.
- The method aids the derivation of corrective and preventive measures that may be incorporated into the system.

Disadvantages

- The method is labour intensive and time-consuming in that many subject matter experts from across disciplines are required.
- Human failures are at risk of being considered as risks, rather than their underlying causes. Hence, a human factors specialist needs to be included in the process.
- The method may not be able to provide adequate design solutions to the human error problems it highlights.

Tools

- SAM 2000
- PHA-Pro 5
- TRACEr

References

- Kletz (1999)
- Kirwan (1994)
- Clare, Chudleigh & Catmur (1994)
- Shorrock & Kirwan (1999)

- http://www.yse-ltd.co.uk
- http://www.dyadem.com/home.html

2.9.5 Cognitive Reliability and Error Analysis Method

Life cycle phase: Early design stages and Operations.

Definition: Analytical method for the (retrospective) analysis of accidents or incidents and/or the (predictive) analysis of human performance. It comprises an explicit method, cognitive model, and classification scheme of error modes.

Aim: The basic aim of CREAM is to find the likely cause for a given accident or event, or to identify potential error-inducing task steps or events.

Procedure

The retrospective analysis is composed of the following steps:

1. Determine or describe the context, i.e. the situation that existed at the time the event occurred. In CREAM this is done using the notion of Common Performance Conditions (CPC).
2. Describe the possible error modes.
3. Describe the probable error causes.
4. Perform a more detailed analysis of main task steps.

The general method for performance prediction has six main steps:

1. Detailed task analysis (cognitive or otherwise) of the application and situation.
2. Description of context or common performance conditions.
3. Specification of initiating events, i.e. the starting point for the particular set of event paths that requires analysis.
4. Qualitative prediction of performance, i.e. generation of most likely event tree(s).
5. Selection of task steps for analysis.
6. Prediction of quantitative performance

Resources required/Information requirements: Detailed description account of accident/incident; task analysis of events and/or system under development; analysts with specialist knowledge.

Outputs

- Identification of causes of errors.
- Overall assessment of the performance reliability that may be expected for a task.

Advantages

- Provides clear and systematic approach to quantification.
- Analysis is neutral with regard to where the ‘root’ cause of an accident or incident will be found, i.e. it is not assumed that ‘human error’ is more likely than other types of error.
- Includes explicit ‘stop-rules’ for the analysis.
- Method is well documented.

Disadvantages

- Method is time-consuming even for basic analyses.
- Requires detailed task analysis (e.g. HTA) to have been carried out.
- Might require specialist human factors or cognitive ergonomics knowledge.
- Simplification of method can risk losing important information.

Tool

Some (prototype) computer support has been developed.

References

Hollnagel (1993 & 1998).

3. HUMAN FACTORS TOOLS

This chapter describes the tools that were identified in the previous chapter. The tools are listed in alphabetical order and general descriptions of the aims, nature and method of each is given. A cross-reference to the relevant human factors method(s) is also given.

As stated earlier, the main criteria for the choice of tools are that:

- the tools should be well-developed and should not be prototype or research products that have been little used or tested;
- the tools should be well-documented, preferably with information on the Internet, and readily available from a clearly identified source or reference;
- the tools should as far as possible represent the latest in tool developments; they should be up-to-date and should not include obscure or rarely used examples.

Based on these criteria a selection of some seventy-two tools is identified and described below. The selection is not intended to be exhaustive, but does provide a comprehensive coverage of existing human factors tools. Other tools can be found in literature reviews (now a little out of date) by Beaujard et al (1997), Foot et al (1996) and Dean (1997), and databases such as those maintained by the International Council on System Engineering (INCOSE), the proGAMMA Software Information Bank (SIByl) and the Computers in Teaching Initiative (CTI) Psychology Centre[2].

The tools have been variously developed by academic, governmental or commercial organisations, and in many cases a combination of two or all three parties. It should be noted that the inclusion of any particular tool in this list does not signify an endorsement by EUROCONTROL as to its quality, accuracy or effectiveness. The list of tools is primarily for the purposes of informing the ATM community what is currently available.

3.1 Accident Sequence Evaluation Programme (ASEP)

This tool is based on the Technique for Human Error Rate Prediction (Swain & Guttman, 1983). ASEP comprises pre-accident screening with nominal human reliability analysis, and post-accident screening and nominal human reliability analysis facilities. ASEP provides a shorter route to human reliability analysis than THERP by requiring less training to use the tool, less expertise for screening estimates, and less time to complete the analysis.

Refs: Swain, 1987; Kirwan, 1994

Human factors method(s): 2.9.1

[2] See Internet links in Chapter 0.

3.2 Analytica®

Analytica® is a sophisticated, commercially available software tool that uses influence diagrams to show qualitative structure of models and intelligent arrays with the power to scale simple models up to handle large problems.

Ref.: http://www.lumina.com/software/index.html

Human factors method(s): 2.4.5.

3.3 Applied Cognitive Task Analysis (ACTA)

ACTA is a PC-based software tool for practitioners to identify the cognitive skills needed in task performance. The characteristics of these factors include problem solving and decision-making strategies. This tool is most useful for decision-based design approach.

Refs: Dean, 1997; Militello, 1997; Seamster, Redding & Kaempf, 1997

Human factors method(s): 2.3.3

3.4 ATC Electronic Checklist

The ATC Electronic Checklist, developed by the Volpe Center and the FAA, provides a checklist of human factors issues that should be considered in the design and evaluation of air traffic control systems and equipment. The checklist points controllers and other operations specialists to questions that they may wish to consider in the evaluation of new systems or subsystems or a new component of an existing system.

Ref.: http://www.hf.faa.gov/products/checklst/checklst.htm

Human factors method(s): 2.6.1

3.5 ATCS Performance Measurement Database

The Air Traffic Control Specialist (ATCS) Performance Measurement Database provides a compilation of performance measures and measurement techniques that have been proven effective for use in human factor research related to air traffic control. The database is a tool that can be used in conjunction with ATC simulators, generic sector configurations and scenarios, and other procedures used in assessing ATC system safety and effectiveness.

Refs: - Hadley, Guttman & Stringer, 1999
- http://www.tc.faa.gov/hfbranch/atcpmdb

Human factors method(s): 2.6.4, 2.8.1, 2.8.2

3.6 ATLAS

ATLAS is a software package for use in support of systems design and analysis work. it combines the best elements of graphically-based task analysis with the advantages of a database. ATLAS supports a variety of conventional task analysis methods and incorporates more than sixty human performance, workload, and human reliability algorithms.

Refs: - Hamilton, 2000
- http://www.humaneng.co.uk

Human factors method(s): 2.3.2, 2.4.4

3.7 Bedford Scale

The Bedford Scale is a uni-dimensional rating scale designed to identify operator's spare mental capacity while completing a task. The single dimension is assessed using a hierarchical decision tree that guides the operator through a ten-point rating scale, each point of which is accompanied by a descriptor of the associated level of workload. It is simple, quick and easy to apply in situ to assess task load in high workload environments, but it does not have a diagnostic capability.

Ref.: Roscoe & Ellis, 1990

Human factors method(s): 2.2.6, 2.8.3

3.8 Boeing McDonnell Douglas Human Modeling System (BMD-HMS)

The Boeing McDonnell Douglas Human Modelling System (BMD-HMS) is a sophisticated software model of a human manikin for use in virtual reality simulations. BMD-HMS is delivered with a variety of tools (e.g. reach algorithms, vision, collision detection) that can be utilised for analyzing assembly and maintenance tasks. It has been used, for example, in aircraft cockpit design to make sure that pilots will be able to reach controls; to check that all aircraft parts will accessible for maintenance and assembly tasks; and for simulation of zero gravity extra-vehicular operations on space craft.

Ref.: http://www.boeing.com/assocproducts/hms

Human factors method(s): 2.5.1

3.9 CASHE:PVS

The Computer Aided Systems Human Engineering: Performance Visualization System (CASHE:PVS) is a software product (on CD-ROM) that provides an encyclopaedic ergonomics database covering more than seventy areas in human perception and performance. CASHE:PVS is based on the seminal work of Boff and Lincoln (1988), and includes a specialised visualisation toolset called the Perception & Performance Prototyper. CASHE:PVS is available from the U.S. CSERIAC centre.

Ref.: http://iac.dtic.mil/hsiac/products/cashe/cashe.html

Human factors method(s): 2.5.3, 2.8.1

3.10 CSERIAC Anthropometric Data Analysis (CADA) Files

The CSERIAC[3] anthropometry data files offer designers and engineers data useful for resolving human accommodation issues during equipment design. The CSERIAC anthropometric data files are a collection of civilian and military surveys spanning over fifty years of research. Formerly archived by the US Air Force Armstrong Laboratory, CSERIAC has now made these database files available for general use.

Ref.: http://iac.dtic.mil/hsiac/products/cada/cada.html

Human factors method(s): 2.5.1

3.11 Cognitive Neurometric System (CNS)

The CNS is a small portable unit used to measure brainwave activity and so quantify the mental workload and alertness of operators. It may also link to the selection and training needs of a task. CNS provides real-time, objective data, but requires the connectors to record the data, an appropriate activity, and a processing unit to analyse the data collected.

Ref.: Dean, 1997

Human factors method(s): 2.8.4

3.12 Combiman

The COMputerized Biomechanical MAN-model (COMBIMAN) system of programs was developed to assist in the design and analysis phases of work station development. COMBIMAN allows the designer to perform operability analyses and correct design defects while the system is still in the early design stage. As a tool that represents geometric and physical properties of an operator, it can be used to evaluate both existing and conceptual work stations.

Ref.: http://iac.dtic.mil/hsiac/products/combiman.html

Human factors method(s): 2.5.1

[3] CSERIAC has recently been re-named HSIAC (Human Systems Information Analysis Center).

3.13 Complex Cognitive Assessment Battery (CCAB)

CCAB is a PC-based battery of nine tests of higher cognitive function. The test battery can be adapted to a variety of configurations and levels of difficulty to suit a required scenario. The battery is reported as being useful in, for example, sleep deprivation studies.

Ref.: Dean, 1997

Human factors method(s): 2.3.3, 2.8.4

3.14 Continuous Safety Sampling Methodology (CSSM)

This is a form of hazard analysis that uses observation and sampling techniques to determine and maintain a pre-set level of the operator's physical safety within constraints of cost, time, and operational effectiveness. This tool is used to determine whether activities are within tolerable limits. If outside tolerable limits, corrective action is then derived. However, it may focus more on industrial injury.

Ref.: Quintana & Nair, 1997

Human factors method(s): 2.2.1, 2.2.3

3.15 Cooper-Harper Scale

A uni-dimesional rating scale used to assess workload qualities. It is simple, quick and easy to apply in situ.

Refs: Cooper & Harper, 1969; Wierwille & Casali, 1983

Human factors method(s): 2.2.6, 2.8.3

3.16 CRT Display Checklist

This checklist forms Appendix A to NUREG/CR-3557. It provides subjective comparisons of methods for displaying screen information but is also used as a design checklist.

Refs: Kirwan & Aisworth, 1992; Blackman et al, 1983

Human factors method(s): 2.6.1

3.17 Decision Explorer

Decision Explorer is a commercially available software tool for managing 'soft' issues – the qualitative information that surrounds complex or uncertain situations. Reported areas of application include, amongst many, interview analysis, structured brainstorming, stakeholder analysis and influence diagrams.

Ref.: http://www.banxia.com/demain.html

Human factors method(s): 2.2.5, 2.4.5

3.18 Defence Research Agency Workload Scale (DRAWS)

DRAWS is a multi-dimensional tool used to gain a subjective assessment of workload from operators. The rating scales are input demand (demand from the acquisition of information from external sources), central demand (demand from mental operations), output demand (demand from the responses required by the task), and time pressure (demand from the rate at which tasks must be performed). DRAWS offers ease of data collection and ratings can be obtained during task performance by asking respondent to call out ratings (from 0 to 100) to verbal prompts. This can also provide a workload profile through a task sequence.

Refs: Farmer et al, 1995; Jordan et al, 1995

Human factors method(s): 2.2.6, 2.8.3

3.19 Digital Anthropometric Video Imaging Device (DAVID)

DAVID is a PC-based method of obtaining human body measurements that can interface with modelling software in a computer aided design process. It may easy to use but it may also be expensive to implement because it requires ‘frame-grabbing hardware’ required to generate the data. It is useful as an anthropometric survey tool.

Ref.: Dean, 1997

Human factors method(s): 2.5.1

3.20 Diagnostic Recorder for Usability Measurement (DRUM)

The Diagnostic Recorder for Usability Measurement (DRUM) is a software tool which assists the analysis of video recordings of usability evaluation sessions. DRUM connects with a video recorder and enables the evaluator to build a log of interesting events linked to the time-code recorded on the tape. DRUM was developed as part of an EC ESPRIT project (MUSiC, 5429), and has been in use in commercial organisations since 1992.

Refs: - Macleod & Rengger, 1993
- http://www.usability.serco.com/msexplorer/index.html

Human factors method(s): 2.2.3, 2.6.5

3.21 Ergonomics Audit Program (ERNAP) Checklist

The Ergonomics Audit Program (ERNAP) is a computerized checklist to help managers design and/or evaluate procedures for aviation maintenance and inspection. ERNAP is simple to use and evaluates existing and proposed tasks and set-ups by applying ergonomic principles. ERNAP allows the auditor to maintain Audits for further reference. ERNAP was developed under the auspices of the FAA, and can be downloaded from the Human Factors in Aviation Maintenance and Inspection (HFAMI) website.

Ref.: http://www.hfskyway.com/jobaids.htm

Human factors method(s): 2.6.1

3.22 Ergonomics Guidelines

Several ergonomics guidelines are available which provide guidance on the design of the human-machine interface (HMI) or human-computer interface (HCI). The guidelines are similar, but vary in the amount of detail given, and the extent to which they cover recent technological developments (e.g. the Internet). The main guidelines are listed here.

Refs:

- Smith & Mosier, 1986; Scapin, 1986; Cardosi & Murphy, 1995; Cardosi & Hannon, 1999
- ftp://ftp.cis.ohio-state.edu/pub/hci/Guidelines
- ftp://ftp.info.fundp.ac.be/pub/users/jvd/guidelin/scapin.zip
- http://www-3.ibm.com/ibm/easy/eou_ext.nsf/publish/572
- http://www.eng.buffalo.edu/~ramam_m/au_fr.html

Human factors method(s): 2.5.3, 2.6.5

3.23 Ethnograph

Ethnograph is a commercially available software tool designed to make the analysis of data collected during qualitative research easier, more efficient, and more effective.

Ref.: http://www.qualisresearch.com

Human factors method(s): 2.2.5

3.24 FaultrEASE

This is an interactive software program for editing and evaluating fault trees. It is designed to make fault tree construction and editing as easy as possible. The program has the ability to adjust the graphical display of the fault tree so as to fit all the symbols in the smallest area without overlapping, and without changing the connection logic of the tree.

Ref.: http://www.process-safety.com/software/ftrease.htm

Human factors method(s): 2.9.2

3.25 Fleishman Job Analysis Survey (F-JAS)

The Fleishman Job Analysis Survey (F-JAS) is a job analysis methodology for rating job tasks in terms of their ability requirements. The methodology developed involved presenting very carefully defined abilities, based on the best factor analysis research information about the ability, and a series of rating scales containing empirically derived task anchors representative of that ability at different points on each scale. The positions of these anchors on each scale were obtained empirically. Fifty-two such scales were developed covering the abilities in the cognitive, sensory-perceptual, psychomotor, and physical domains of human performance. These rating scales have been combined into the F-JAS.

Refs: Fleishman, 1992; Fleishman & Mumford, 1991

Human factors method(s): 2.2.4, 2.2.6

3.26 Functional Analysis System Technique (FAST)

This tool is used in the early stages of design to investigate system functions in a hierarchical format and to analyse and structure problems (e.g. in allocation of function). The aim of FAST is to understand how systems work and how cost effective modification can be incorporated. It asks '*how*' a sub-tasks link to tasks higher up the task hierarchy, and '*why*' the super-ordinate tasks are dependent one the sub-tasks. FAST has been developed and promoted over several decades by the Society of American Value Engineers (SAVE).

Refs: - Creasy, 1980; Kirwan & Ainsworth, 1992; Adams & Lenzer, 1997
- http://www.value-eng.com

Human factors method(s): 2.2.7, 2.3.2, 2.4.2

3.27 Generic Error Modelling System (GEMS)

GEMS is an error classification model that is designed to provide insight as to why an operator may move between skill-based or automatic rule-based behaviour and rule or knowledge-based diagnosis. Errors are categorised as slips/lapses (frequently skill-based errors) and mistakes (usually knowledge-based errors). The result of GEMS is a taxonomy of error types that can be used to identify cognitive determinants in error sensitive environments. GEMS relies on the analyst either having insight to the tasks under scrutiny or the collaboration of a subject matter expert, and an appreciation of the psychological determinants of error.

Ref.: Reason, 1990

Human factors method(s): 2.9.1, 2.9.2

3.28 Goals, Operators, Methods and Systems (GOMS)

GOMS is a task modelling method to describe how operators interact with their systems. Goals and sub-goals are described in a hierarchy. Operations describe the perceptual, motor and cognitive acts required to complete the tasks. The methods describe the procedures expected to complete the tasks. The selection rules predict which method will be selected by the operator in completing the task in a given environment. GOMS is mainly used in addressing human-computer interaction and considers only sequential tasks. GOMS requires some training and familiarity with the approach to be used effectively.

Refs: - Card, Moran & Newell, 1983
- http://www.usabilityfirst.com/goms/index.html

Human factors method(s): 2.3.2

3.29 Hiser Element™ Toolkit

The Hiser Element toolkit was developed by the Hiser Group, a user interface consultancy based in Australia. Serco distributes it in Europe. It provides step-by-step instructions and support tools for involving users throughout the development of human computer interfaces, ensuring a user-centred process is followed. For example, it provides checklists to gather information during site visits, design memos for documenting user design, log sheets for logging user issues during usability testing, questionnaires and report templates. It is available on-line or in hard copy, and 'just in time' training for use of the toolkit is available.

Refs:
- http://www.hiser.com.au/world/services/toolkits.html
- http://www.usability.serco.com/nonframe/products.html#hiser

Human factors method(s): 2.6.5

3.30 Human Error Assessment and Reduction Technique (HEART)

HEART is an error quantification process that is quick to use. The process defines a set of generic error probabilities for the types of tasks being examined and identifies the error producing conditions associated with them. For each of the error producing conditions the human error probability is multiplied by the error producing condition multiplier. The tool also provides some guidance on approaches towards error reduction.

Refs: Kirwan, 1994, 1997; Williams, 1986

Human factors method(s): 2.9.1

3.31 Human Factors Design Guide

The Human Factors Design Guide for Acquisition of Commercial Off-the-Shelf Subsystems, Non-Developmental Items, and Developmental Systems (HFDG) provides the most exhaustive compilation of human factors practices and principles integral to the procurement, design, development, and testing of FAA systems, facilities, and equipment. The HFDG draws heavily from human factors information published by the US Department of Defense, NASA, and Department of Energy.

Refs: - Wagner et al, 1998
- http://www.tc.faa.gov/hfbranch/hfdg
- http://www.hf.faa.gov/acquire/design_guide/design_guide.html

Human factors method(s): 2.5.3

3.32 Instantaneous Self-assessment of Workload (ISA)

ISA was developed as a tool that an operator could use to estimate their perceived workload during real-time simulations. The operator is prompted at regular intervals to give a rating of one to five of how busy he is (one means utilised, five means excessively busy). These data can be used to compare operators' perceived workload, for example, with and without a particular tool, or between different systems.

Ref.: Jordan, 1992

Human factors method(s): 2.8.3

3.33 Integrated Performance Modelling Environment (IPME)

IPME is a Unix/Silicon Graphics based software tool providing a suite of tools to aid human factors practitioner in understanding human-system performance. IPME incorporates mission analysis, function analysis, function allocation, task analysis, and workload/performance analysis and prediction. It is designed to provide a realistic representation of the human in a complex environment, interoperability with other model components, and a user-friendly graphical interface. IPME provide and environment to represent tasks, the human operator, the physical environment, threats and human performance. Human performance is represented in IPME using environment/operator models, micro-models of human performance, and performance shaping factors. Environment/operator models represent the physical environment, threat environment, and the operator's state and traits. Micro-models of human performance consider choice reaction times, eye-fixation times, and speech. The performance shaping factors provide a functional relationship between the operator and vigilance, perception, cognition, motor output, and speech. It is a tool that does require training in the use of the tool and can be time-consuming to use in complex models.

Refs: - Dahn et al, 1997
- http://www.maad.com/MaadWeb/products/ipme/ipmema.htm

Human factors method(s): 2.3.2, 2.4.2

3.34 Jack

Jack provides a 3D interactive environment for controlling articulated figures. It features a detailed human model and includes realistic behavioural controls, anthropometric scaling, task animation and evaluation systems, view analysis, automatic reach and grasp, collision detection and avoidance, and many other useful tools for a wide range of applications.

Ref.: http://www.cis.upenn.edu/~hms/jack.html

Human factors method(s): 2.5.1

3.35 Justification of Human Error Data Information (JHEDI)

JHEDI is derived from the Human Reliability Management System (HMRS) and is a quick form of human reliability analysis that requires little training to apply. The tool consists of a scenario description, task analysis, human error identification, a quantification process, and performance shaping factors and assumptions. JEDHI is a moderate, flexible and auditable tool for use in human reliability analysis. Some expert knowledge of the system under scrutiny is required.

Ref.: Kirwan, 1994

Human factors method(s): 2.9.1

3.36 Key Issues Tool (KIT)

KIT is a software tool designed to support the EHFA (see 2.3.1). It makes the EHFA process easier by providing structure and supporting the difficult aspects of tracking and linking many items. The output from KIT acts as an input to a project's overall risk register, allowing the project manager to see the human factors integration (HFI) risks in a manner which is comparable to other areas of project risk. The tool provides a full record of the analysis conducted on any issue over the life of a project.

Refs: - McLeod & Walters, 1999
- http://www.nickleby.com

Human factors method(s): 2.3.1

3.37 LAMPS

LAMPS (Long-term ATCO Manpower Planning Simulation) is a generic prototype dynamic simulation model of air traffic controller manpower which has as its core a PC-based gaming interface that uses graphs and tables to show the results of interactive simulation of various air traffic controller manpower scenarios.

The model takes into account all variables influencing the in-flow, through-flow and out-flow of air traffic controller's over time. In addition, the model allows the controller traffic handling capacity to be modelled, thus indicating the number of controllers needed taking into account training requirements, refresher training, quality aspects, availability of technical environment, etc., over a chosen time horizon.

Ref.: EATMP (2000f)

Human factors method(s): 2.7.4

3.38 MacLab

MacLab[4] is a package comprising hardware and software, which produces multi-channel, continuous data recording and analysis systems for the Life Sciences. Experimental data can be drawn from any measuring equipment or instrumentation that has an analogue output (e.g. spectrophotometers, colorimeters, fluorimeters, luminometers, calorimeters, or pH, dissolved oxygen and conductivity meters). Data can be sampled as fast as 100,000 samples per second, or as slow as 12 samples per hour. This data can then be manipulated, computed and stored, or can be transferred to other software packages for report generation. Applications of the MacLab system include:

- Physiology – ECG, cardiovascular studies, voice, respiration, gastrointestinal studies, haemodynamics, and ion channel analysis.
- Neurophysiology – Neuromonitoring studies, sleep studies, extracellular and intracellular recording, EEG, EMG, nerve conduction, and cortical evoked responses.
- Pharmacology – Dose response studies in smooth, cardiac, and skeletal muscle, agonist and neurally evoked response, multiple indicator dilution studies, and cardiovascular medicine.
- Psychology – Galvanic skin response and drug tolerance studies.

Ref.: http://www.adinstruments.com/cust/products/software/software.html

Human factors method(s): 2.8.4

[4] MacLab is now known as Powerlab.

3.39 Malvern Capacity Estimate (MACE)

MACE is designed as a quick simple and direct measure of maximum capacity. It is designed to provide a direct measure of air traffic controllers' subjective estimates of their own aircraft handling capacity. MACE is applied at the end of a work sequence (e.g. simulation trial) and provides capacity estimates in aircraft per hour. Applications have typically been in simulation environments.

Ref.: Goillau & Kelly, 1996

Human factors method(s): 2.2.6, 2.8.3

3.40 Man-Machine Integration Design and Analysis Systems (MIDAS)

MIDAS is a Silicon Graphics software tool designed to aid the application of human factors principles and performance models to the design of complex systems. It is intended for use at the earliest stages of the design process and consequently is likely to reduce some of the costs of simulation and prototyping. Initially aimed at rotorcraft design, its application is reported as being sufficiently generic to address different work environments, such as the design of large-scale, complex control rooms and emergency vehicles. MIDAS describes a system's operating environment and procedures, and incorporates human performance models into the design process. Consequently design engineers can incorporate human factors issues, anticipate function allocation, automation needs, and training needs.

Refs: - Dean, 1997
- http://ccf.arc.nasa.gov/af/aff/midas/MIDAS_home_page.html

Human factors method(s): 2.4.2, 2.7.2

3.41 Maintenance Error Decision Aid (MEDA)

Boeing has invested decades of research in maintenance error. It has developed a widely used maintenance error decision aid (MEDA) which is an attempt to systematise evaluation of events, problems and potential problems by using a repeatable, structured evaluation program. The company has been encouraging its customers to employ the technique.

Refs: - Allen & Rankin, 1996
- http://www.boeing.com/commercial/aeromagazine/aero_03/m/m01/index.html

Human factors method(s): 2.4.1, 2.9.1

3.42 ManneQuinPRO

ManneQuinPRO is a PC-based, commercial product for anthropometric design of equipment and facilities. It incorporates an extensive anthropometric database for the creation of 3-D 'mannequins'.

Ref.: http://www.nexgenergo.com/ergonomics/mqpro.html

Human factors method(s): 2.5.1

3.43 Micro Saint

Micro-Saint is a discrete-event task network-modelling tool that can be described by flow diagrams can be analysed to test, for example, alternative solutions or options, assess workload, function allocation, and temporal analysis (albeit based on time estimates). The analysis process requires input from subject matter experts on the task under investigation, training and familiarity with using the tool, and it can be difficult and time-consuming to use.

Refs: - Dean, 1997
- http://www.maad.com/MaadWeb/microsaint/msaintma.htm

Human factors method(s): 2.2.7, 2.4.4

3.44 NASA Task Load Index (NASA TLX)

The NASA TLX is a multi-dimensional rating scale for operators to report their mental workload. It uses six dimensions of workload to provide diagnostic information about the nature and relative contribution of each dimension in influencing overall operator workload. Operators rate the contribution made by each of six dimensions of workload to identify the intensity of the perceived workload. The dimensions are 'Mental demands', 'Physical demands', 'Temporal demands', 'Performance', 'Effort' and 'Frustration'. A paired comparisons procedure, in which the operator compares each of the six sub-scales with each of the others in turn, is used to identify the relative importance (weighting) of each dimension in contributing to perceived workload. Overall workload is then calculated by multiplying each rating by the weighting attributed to that dimension by the operator and the sum of the weighted ratings is then divided by fifteen (the number of paired comparisons). Because the TLX is more intrusive to administer than the Bedford it is appropriate for use after the simulation trials as part of the post-simulation debriefing procedure. It is simple, quick and easy to apply.

Refs: - Hart & Staveland, 1988
- http://iac.dtic.mil/hsiac/products/tlx/tlx.html

Human factors method(s): 2.2.6, 2.8.2

3.45 NUREG-0700

US Nuclear Regulation Commission (NRC) has produced several human factors guidance documents. NUREG-0700 is a detailed checklist for control room design (or more precisely, design review) in the nuclear power industry. The checklist addresses individual instruments, so using this checklist is time-consuming process because of its detail. The guidelines, first issued in 1981, were recently revised to take into account the introduction of computer-based, human-computer interface technology (NRC, 1995).

Refs: NRC, 1981, 1995; Kirwan & Ainsworth, 1992

Human factors method(s): 2.6.1

3.46 Observer

Observer is a PC-based software tool for the collection, analysis and management of observation data. Data is collected by a human factors practitioner using a video system linked to a PC. Events are entered into the computer or code events are identified from data (e.g. from a video sequence). Data entry may be time-consuming depending on the assessment being made, but the subsequent analysis tool available in the tool are reported as being quick and easy to use.

Refs: - Dean, 1997
- http://www.noldus.com

Human factors method(s): 2.2.1, 2.2.3

3.47 Observer Rating Form

The Observer Rating Form is a paper form consisting of 24 rating scales, developed by the FAA for use in research and possibly operational testing. The scales focus on observable actions that trained air traffic control specialists (observers) could identify to make behaviourally-based ratings of controllers' performance.

Refs: Sollenberger, Stein & Gromelski, 1997; Allendoerfer & Galushka, 1999.

Human factors method(s): 2.2.6

3.48 Objet Interactifs Abstraits (OIA)

Objet Interactifs Abstrait (OIA) is a software tool for examining the principal concepts underlying the structure of the human-computer interface, and the elementary software components ('abstract interaction objects') of which they are composed. OIA was developed as part of the TRIDENT project by the University of Namur.

Refs.: - ftp://ftp.info.fundp.ac.be/pub/users/jvd/guidelin/oia.zip
- http://www.info.fundp.ac.be/~emb/Trident.html

3.49 PEAT

Procedural Event Analysis Tool (PEAT) is a structured, cognitively-based analytic tool designed to help airline safety officers investigate and analyse serious incidents involving flight-crew procedural deviations. The objective of PEAT is to help airlines develop effective remedial measures to prevent the occurrence of future similar errors. The PEAT process relies on a non-punitive approach to identify key contributing factors to crew decisions. Using this process, the airline safety officer would be able to provide recommendations aimed at controlling the effect of contributing factors. PEAT includes database storage, analysis, and reporting capabilities.

Ref.: http://www.boeing.com/news/techissues/peat/index.htm

Human factors method(s): 2.4.1

3.50 PHA-Pro 5

PHA-Pro 5 is a commercially available software package, designed to support a number of safety/risk, or Process Hazards Analysis, techniques, namely: Hazard and Operability Studies (HAZOP), Preliminary Hazard Analysis (PHA), What If and FMEA.

Ref.: http://www.dyadem.com/home.html

Human factors method(s): 2.9.4

3.51 Position Analysis Questionnaire (PAQ)

This is a specific questionnaire designed to identify job characteristics. The characteristics consider information input, mental processes, work output, relationships with co-workers, job context, amongst others. The data can be used for personnel specification and skills identification for training.

Refs: - McCormick *et al*, 1972; Kirwan & Ainsworth, 1992
- http://www.paq.com

Human factors method(s): 2.2.4

3.52 PUMA

Performance and Usability Modelling in ATM (PUMA) is a prototyping and evaluation tool that predicts air traffic controller's workload as a function of discrete human behaviours and available human processing 'resources'. It is used to assess how operator workload would be affected by changes to his or her tasks. This has implications for validating new concepts relating to en-route capacity that aim to increase en-route capacity by decreasing controller workload. PUMA can be applied most effectively during the concept and design phases of the life cycle. It is a PC-based software tool that is non-intrusive to apply but is expensive to buy and requires training to use.

Refs: - Gouweleeuw et al 1996; Day *et al*, 1993; Rose, Kilner & Hook, 1997
- http://www.atmdc.nats.co.uk/C/PRJ/0023/0023-1.htm

Human factors method(s): 2.2.7, 2.4.4, 2.8.2

3.53 Questionnaire for User Interface Satisfaction (QUIS)

QUIS has pen and paper and PC software versions for administration. Operators use a nine-point scale to rate twenty-one items that relating to the system's usability. These ratings produce data for the overall reaction to a system's usability on six factors. It is easy to use and analyse.

Refs: - Chin et al, 1988; Foot et al, 1996
- http://www.lap.umd.edu/QUIS/index.html

Human factors method(s): 2.2.4

3.54 Ravden and Johnson Checklist

This is a comprehensive checklist of items that evaluate the usability of human-computer interfaces. It is easy to administer but its 156 questions make it somewhat lengthy. It generates much data on interface factors including visual clarity, consistency, compatibility, feedback, explicitness, functionality, control, error management, help facilities, and the usability of help facilities.

Ref.: Ravden & Johnson, 1988

Human factors method(s): 2.6.1

3.55 Repertory Grid Analysis

Based in clinical psychology and personality theory, Repertory Grid Analysis is a structured and theoretical form of interview method. Subjects group concepts and justify how the groups are similar and dissimilar. Although a simple technique it does require some familiarity for effective application.

Refs: - Baber, 1996
- WebGrid http://tiger.cpsc.ucalgary.ca
- Enquire Within™ http://www.enquirewithin.co.nz/default.htm

Human factors method(s): 2.2.5

3.56 SAM 2000

SAM 2000 is a commercially available software tool for supporting safety analyses. SAM 2000 incorporates a suite of editors (e.g. Hazard Log editor, HAZOP editor, FMEA editor and Fault Tree Analysis editor) and other functions in its 'toolset'. The tool is used by a wide variety of government departments and leading international companies in the fields of aerospace, defence, transport, and engineering. Its application to ATM was recently investigated as part of a European Commission DGVII project[5].

Refs.: - Wilson *et al*, 1997
- http://www.yse-ltd.co.uk

Human factors method(s): 2.9.2, 2.9.3, 2.9.4

3.57 Situation Awareness Global Assessment Technique (SAGAT)

SAGAT is a specialised questionnaire for querying subjects about their knowledge of the environment. This knowledge can be at several levels of cognition, from the most basic of facts to complicated predictions of future states. It is administered within the context of high fidelity and medium fidelity part-task simulations, and requires freezing the simulation at random times.

Most known uses of SAGAT have been in the context of fighter aircraft although its application within the ATM domain has also been investigated.

Refs: - Endsley, 1995; Endsley, 1997; Endsley & Garland, 2000
- http://atm-seminar-97.eurocontrol.fr/endsley.htm

Human factors method(s): 2.2.4, 2.8.1

3.58 Situational Awareness Rating Technique (SART)

A multi-dimensional rating scale for operators enables operators to report their perceived situational awareness. It examines the key areas of SA: understanding, supply and demand. These areas are further broken down into the fourteen dimensions. From the ratings given on each of the dimensions situational awareness is calculated by using the equation SA =U-(D-S) where U is summed understanding, D is summed demand and S is summed supply. It is simple, quick and easy to apply.

Ref.: Selcon & Taylor, 1989

Human factors method(s): 2.2.6

[5] European Commission DGVII project called 'ARIBA' conducted under the EC's 4th Framework Programme. See EC web site at http://www.cordis.lu/transport/src/ariba.htm and NLR hosted site at http://www.nlr.nl/public/hosted-sites.

3.59 Situation-Present Assessment Method (SPAM)

SPAM is a method of measuring Situation Awareness (SA). In contrast to SAGAT, the SPAM method uses response latency as the primary dependent variable and does not require a memory component. It acknowledges that SA may sometimes involve simply knowing where in the environment to find some information, rather than remembering what that information is exactly.

Ref.: Durso et al (1998)

Human factors method(s): 2.8.1

3.60 Standards

Several detailed human factors standards are available, particularly those produced for aiding the design of military systems. These standards also incorporate some checklists that can be applied through the design process.

Refs: - ISO 9241; Def. Standard 00-25 (MOD, 1989-1997); NASA-STD-3000;
- http://www.dstan.mod.uk
- http://www.iso.ch
- http://jsc-web-pub.jsc.nasa.gov/fpd/SHFB/Msis/MSIS_home.htm

Human factors method(s): 2.5.1, 2.5.2, 2.5.3

3.61 Subjective Workload Assessment Techniques (SWAT)

SWAT is a subjective scale of workload that can be administered easily in operation situations and is available as a PC-based software tool. It is a multi-dimensional tool incorporating factors of temporal load, mental effort and psychological stress. SWAT has two stages: The respondent ranks the levels of the three workload scales in order from the lowest to highest workload prior to the trial, and rates each of the scales during the trial. It was originally designed to assess aircraft cockpit and other crew-station environments to assess the workload associated with the operators' activities.

Refs: Reid & Nygren, 1988; Dean 1997

Human factors method(s): 2.2.6, 2.8.2

3.62 System Usability Measurement Inventory (SUMI)

SUMI is a questionnaire for the assessment of the usability of a software product or prototype, and can assist with the detection of usability flaws. Respondents are required to rate their views on fifty questions that generate scores on five factors (e.g. their perceived control, productivity).

SUMI is the only commercially available questionnaire for the assessment of the usability of software that has been developed, validated, and standardised on an international basis. SUMI has been hailed as the *de facto* industry standard questionnaire for analysing users' responses to software and is mentioned in the ISO 9241 standard as a recognised method of testing *user satisfaction*.

Refs: - Kirakowski et al, 1992
- http://www.ucc.ie/hfrg/questionnaires/sumi/index.html

Human factors method(s): 2.2.4

3.63 TRACEr (Technique for the Retrospective Analysis of Cognitive Errors)

TRACEr provides a human error identification technique specifically for use in the air traffic control domain. It builds on error models in other fields and integrates Wickens' (1992) model of information processing in ATC. TRACEr is represented in a series of decision flow diagrams. The method marks a shift away from knowledge-based errors in other error analysis tools to better reflect the visual and auditory nature of ATM. It has proved successful in analysing errors in AIRPROX reports to derive measures for reducing errors and their adverse effects.

Ref.: Shorrock & Kirwan, 1999

Human factors method(s): 2.9.4

3.64 Training Delivery Assessment Model (TRADAM)

TRADAM is a PC-based tool developed by the US Navy aimed at producing a cost-effective training system without compromising the training's effectiveness. The drive for developing this tool was a decline in defence resources. It is a modular application that is used to select potential courses, assess the training delivery alternatives against training needs, and undertakes an economics analysis of the alternative regimes. It was designed to allow a quick analysis of the potential for making savings by implementing appropriate advanced training courses.

Refs: - Dean, 1997
- http://www.ott.navy.mil/refs/tradam.htm

Human factors method(s): 2.7.2

3.65 TOPAZ (Traffic Organisation and Perturbation AnalyZer)

TOPAZ is a suite of analytic model-based software modules (primarily a high-level Petri-net based simulation and mathematical packages) used to evaluate ATM safety/capacity for a specific operational concept during either a specific flight phase or various flight phases. TOPAZ consists of three steps:

1. Assess the frequency of safety-critical non-nominal event sequences by Monte Carlo simulations.

2. Evaluate the probability of fatal ATM-related accidents.

3. Use a spreadsheet to combine these results into relevant ATM safety measures.

A large amount of input is required for this analysis (e.g. the operational ATM concept, statistical characteristics of the air traffic scenarios, identified hazards, parameter ranges for critical influences). TOPAZ produces an evaluation of safety characteristics of the operational concept. This tool is complex, requires expertise in modelling, human factors, and ATC, and is time-consuming to complete.

Refs: - Bakker, 1994
- http://www.nlr.nl/public/facilities/f151-01/index.html

Human factors method(s): 2.2.7

3.66 TRAINDEV (Training Development)

TRAINDEV (Training Development) is a dedicated training tool, developed by EUROCONTROL, to support the development of curricula for air traffic controller basic and rating training. The tool uses database techniques to maintain unity of the information and to establish links between tasks and objectives, links between objectives and their prerequisites, and finally to group the objectives as a part of a same lesson or of a same test. The benefits are the reduction of documentation volume and time necessary to record it. This tool also improves the quality control of the document and enables the conduct of several processes (such as mixing subject-driven and task analysis driven designs).

3.67 U-MAN

U-MAN is an anthropometric human model produced by Syseca. It is part of a larger software environment (known as 'EO') used for developing for applications in virtual reality, real-time 3D graphic simulation, and computer aided design (CAD). A motion-captured sequence can be played back on the body, giving a realism unattainable through mere calculation. The captured sequence need only consist of the movement of extremities, because the body computes the likely motion of the intermediate joints. An example of the use of

U-MAN would be in the design of a car. The model also has a module which lets the user experience the world as if he or she were in the physical location of another person.

Ref.: http://www.syseca.thomson-csf.com/simulation/uman.htm

Human factors method(s): 2.5.1

3.68 Usability Heuristic Evaluation

Usability heuristic evaluation is a usability inspection method for finding the usability problems in a human-computer interface design so that they can be attended to as part of an iterative design process. Heuristic evaluation involves having a small set of evaluators examine the interface and judge its compliance with recognised usability principles (the 'heuristics'). Heuristic evaluation is the most popular of the usability methods, particularly as it is quick, easy and cheap.

Refs:- Nielsen, 1994
- http://www.useit.com/papers/heuristic/heuristic_evaluation.html

Human factors method(s): 2.6.5

3.69 VDU Workstation Checklist

This checklist is taken from one of the many Health & Safety Executive (HSE) publications. It consists of a checklist for assessing the risk factors associated with visual display units (VDU), i.e. workstations.

Refs: - HSE, 1989; 1994
- http://www.open.gov.uk/hse/hsehome.htm

Human factors method(s): 2.6.1

3.70 WAMMI

WAMMI (Web site Analysis And MeasureMent Inventory) is a tool for evaluating web site usability, developed by the Human Factors Research Group in Cork (Ireland) and Nomos Management AB in Stockholm (Sweden). It consists of an extensively validated questionnaire refined to ascertain user's subjective rating of the ease of use of a web site. The questionnaire consists of multiple choice and open questions, and takes users about ten minutes to complete. It can be tailored to customer requirements and is currently available in about ten European languages. It can be used for predicting usability (before launch of the web site), monitoring (why do people not return to the site?), and benchmarking (how does the site's usability compare to other sites?).

Refs: - http://www.nomos.se/wammi/index.html
- http://www.ucc.ie/hfrg/questionnaires/wammi/index.html

Human factors method(s): 2.6.5

3.71 W-SDA (Web-Site Design Audit)

The Web Sit Design Audit (W-SDA) is a list of 101 web-site design guidelines. It covers issues ranging from the use of colour, animation and font size, to the use of links and how to make your site locatable via different search engines. W-SDA is available free online, and presented as an easy to use structured questionnaire. The W-SDA site also contains links to other sources of information on web site design. Maya Murthy of the University of Maryland created the site in 1997.

Ref.: http://www.eng.buffalo.edu/~ramam_m/au_fr.html

Human factors method(s): 2.6.5

3.72 WinCrew

WinCrew is a task and workload analysis tool that is designed to predict system performance as a function of human performance. Data input uses task and function times and sequences, error consequences, function allocation, crew-station design and workload data. These data are used to assess and predict system performance variations from varying function allocation, crew complement, and high workload. This is a software tool that will be most effectively used by a human factors practitioner. It is available from Internet.

Refs: - Archer & Lockett, 1997; Dean, 1997
- http://www.maad.com/MaadWeb/products/wincrew/wincrwma.htm

Human factors method(s): 2.3.2, 2.8.2

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4. HUMAN FACTORS METHODS AND LIFE CYCLE INTEGRATION

4.1 EATMP Life Cycle and Human Factors Methods

The EATMP life cycle in Figure 1 is the primary life cycle applicable to the HIFA project (Kelly *et al*, 1999) to keep it within the scope of the EATMP portfolio. The EATMP life cycle defines, generally, the distinctive stages of design, development and procurement cycle.

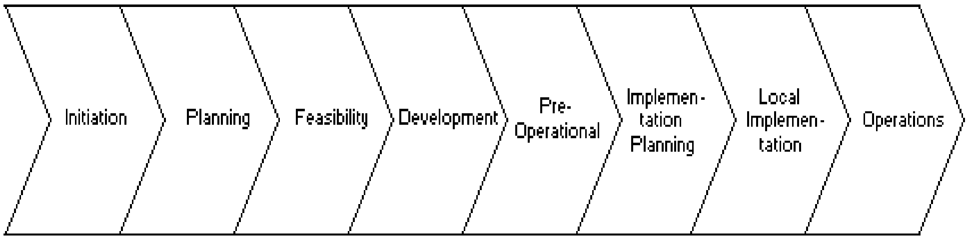

Figure 2. The EATMP life cycle (EATCHIP, 1998)

4.2 Application of Human Factors Methods and Tools

Just as the ATM design process has a life cycle, the application of human factors methods has a particular sequence which usually occurs. For example, a task analysis occurs before a Training Needs Analysis (TNA). Chapanis (1996) described the broad sequence of analysis methods that are typical through the design life cycle (Figure 2). He also explains that this sequence is flexible because of the iterative nature of the process. Consequently, the same method may be applied at several phases of the design life cycle and should not necessarily be fixed to a specific phase.

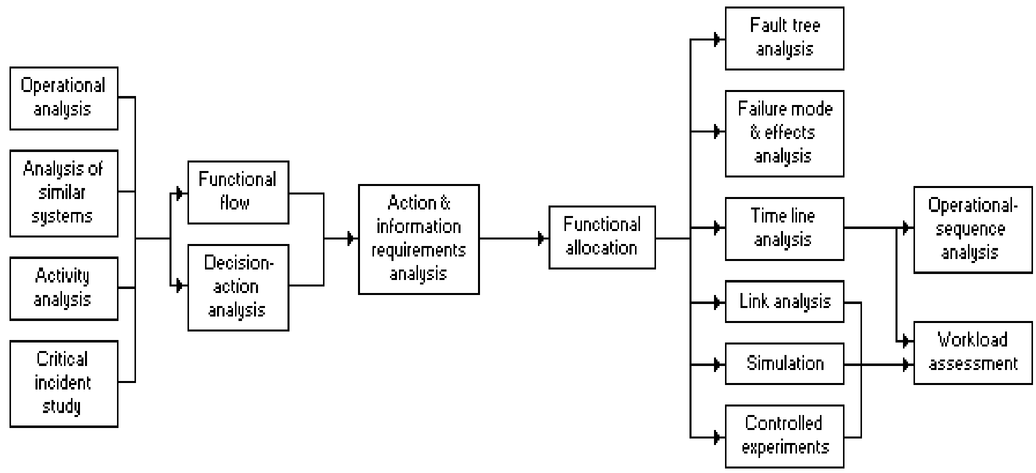

Figure 3. Sequence of human factors methods (Chapanis, 1996)

Table 2 below addresses each phase of the EATMP life cycle and indicates how the sequence of human factors activities (methods and tools) may be integrated within it.

The **Initiation phase** of a project should incorporate significant human factors effort to reduce the risk of high, long-term costs in the design. The focus at this stage will be on defining concepts, assumptions and parameters for the proposed system. This will entail using management methods (e.g. Early Human Factors Analysis and developing a human factors strategy) and descriptive methods (e.g. operational analysis and task description) to integrate human factors principles effectively into both operations and maintenance aspect of design. Some analytical methods may be useful at this stage.

The data collection methods are clearly relevant as general methods that can be applied to many of the other human factors methods throughout the design life cycle. These are activity analysis, critical incident analysis, observational techniques, questionnaires, structured interviews, and verbal protocols. Some of the methods and tools are also relevant to several areas of the design process. However, this report classifies them according to their primary applications. The methods have been divided into categories that, although they do not mirror the design life cycle, have a logical similarity to the design life cycle.

The **Planning** phase builds on the management methods to develop more detailed human factors programme plans. The use of methods such as influence diagrams and checklists might be considered.

The **Feasibility**, **Development**, **Pre-operational** and **Implementation** phases are where the iterative nature of human factors design is most evident. During the Feasibility phase the descriptive methods form the basis for the analytical and human reliability methods. Effort is likely to focus on function allocation, and the task analyses, workload analysis, performance assessments, Training Needs Analysis (TNA), and human reliability assessments. Early workload analyses are typically based on task analysis and modelling and simulation methods.

The **Development** and **Pre-operational** phases revisit these analyses periodically through the review processes determined through the management methods (e.g. design reviews). Updates are made to these analyses as the design matures, and workstation design methods are introduced at this stage (e.g. anthropometry and layout). A significant amount of modelling and simulation methodology accompanies this process as a cost-effective means of validating the design.

Later workload analyses are typically based on simulation studies using operators to evaluate the systems functionality, e.g. using a battery of objective and subjective metrics. The designer may also incorporate the evaluation methods (e.g. ergonomic checklists) to validate the design against good human factors design principles and the specification documents.

The **Implementation** phase would focus on selection and training, and the use of observation techniques, questionnaires and interviews is to be expected. It is likely to incorporate workload assessment methods, and safety analyses from the human reliability assessment methods.

The **Operational** phase incorporates the test and evaluation of the system for customer acceptance, training evaluation, and safety analysis. The management review methods continue through this phase to monitor the operational system to identify any modifications that are required for either a mid-life update or for the basis of a new system in the future. These aspects then feed into the early human factors analysis for future systems.

Table 2: Relationship between EATMP life cycle and sequence of human factors activities

Phase	Objectives	Comments	Example Methods
1. Initiation	To initiate a new programme/ project within the scope of the EATMP portfolio that contributes towards the fulfilment of the ATM 2000+ Srategy (EATCHIP, 1998a) as defined by the Provisional Council and the supporting domain strategies.	The operational and maintenance scenarios are defined, and an Early Human Factors Analysis (EHFA) is initiated. This may involve some analysis of current systems and reviewing accident and incident data. An HFI strategy should be developed, and the system concepts, requirements, constraints and assumptions should be defined.	• Operational analysis • EHFA • Questionnaires • Structured interviews
2. Planning	To gain approval for the detailed structure of the programme, i.e. its portfolio of projects, staffing and funding. It covers the transfer of tasks from the work programme to a comprehensive project plan.	The focus here is on management rather than technical input. An HFI focus and working group may be set up, as required, to prepare HFI plans.	• EHFA • Checklists • Influence diagrams • Psychometric scaling
3. Feasibility	To test the technical, operational, and financial feasibility of different development options, and to seek approval for development of the chosen option(s).	This may involve establishing function specifications to allocate functions between man and systems, and establishing initial task description and analysis, workload analysis, human reliability assessment, and manpower requirements.	• Charting and network methods • Task analysis • Functional analysis • Error analysis • Integrated Task Analysis (ITA) • Influence diagrams
4. Development	To develop proposed specifications and standards for a well-functioning solution and to produce the specifications for the equipment, functionality, functional and physical interfaces, operational procedures and automated procedures.	This can be achieved by reviewing the requirements (including assumptions and constraints), revising function allocation, increasingly detailed task and workload analyses, generating the workspace design, and incorporating a training need analysis.	• Task analysis • Timeline analysis • Functional allocation • Anthropometry • Workspace/ workplace design • Link analysis
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.	This phase incorporates the construction of the system and verification of the specification by prototyping and simulation. This involves essentially the same activities as the Development phase to achieve.	• *As above, plus*: • Real-time simulation • Performance assessment • Workload assessment • Hazard and operability studies

Table 2: Relationship between EATMP life cycle and sequence of human factors activities (continued)

Phase	Objectives	Comments	Example Methods
6. Implementation planning	To have a detailed understanding of all the practicalities of a successful implementation of the proposed solution and to produce a co-ordinated implementation plan for all ECAC States and the affected airspace users.	This may include a performance assurance programme that would incorporate many of the methods used in the Pre-operational phase. This should also be considered much earlier in the life cycle to reduce the risk of re-design. This phase should also incorporate workload analysis, training assessments, and safety analyses.	• Performance assessment • Selection • Training • Human reliability assessments
7. Local implementation	To support the local States and affected airspace users in implementation: detailed design, development, or customisation of a standard product, integration of the components, assembly and testing, publications, education, training, procedures, implementation, phase-in, phase-out.	As above	• Equipment and environment design • Observation • Structured interviews • Questionnaires • Selection • Training
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.	This phase initiates system operations and assesses performance. It also includes maintenance considerations, post product reviews to ascertain the need for modifications, and decommissioning with particular reference to recycling. The main approaches to investigate this would be through user acceptance testing and evaluation, training evaluation and system safety evaluations. The performance assurance methods would again prove useful in this phase as well as post-operational evaluations such as accidents and incident analyses. These would then link to the initiation or concept stages of successive systems, so completing the cycle.	• Observation • Questionnaires • Structured Interviews • Checklists • Critical incident analysis • Performance assessment • Verbal protocols • Event trees

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6. INFORMATION SOURCES ON THE INTERNET

INFORMATION SOURCE	INTERNET ADDRESS
Analytica	http://www.lumina.com/software/index.html
ATC electronic checklist	http://www.hf.faa.gov/products/checklst/checklst.htm
ATCS Performance Measurement Database	http://www.tc.faa.gov/hfbranch/atcpmdb
ATLAS (task analysis)	http://www.humaneng.co.uk
BMD HMS	http://www.boeing.com/assocproducts/hms
CADA (anthropometry)	http://iac.dtic.mil/hsiac/products/cada/cada.html
CASHE:PVS	http://iac.dtic.mil/hsiac/products/cashe/cashe.html
CNRS Ergonomie (*in French*)	http://www.dsi.cnrs.fr/bureau_qualite/ergonomie/ergonomie.htm
COMBIMAN	http://iac.dtic.mil/hsiac/products/combiman.html
Content analysis resources	http://www.gsu.edu/~wwwcom/content.html
CTI Psychology Centre	http://www.york.ac.uk/inst/ctipsych/dir/contents.html
Decision Explorer	http://www.banxia.com/index.html
Defence Standards (UK)	http://www.dstan.mod.uk
DRUM	http://www.usability.serco.com/msexplorer/index.html http://www.prosoma.lu
Element Toolkit	http://www.hiser.com.au/world/services/toolkits.html http://www.usability.serco.com/nonframe/products.html#hiser
Enquire Within™ (Repertory Grid)	http://www.enquirewithin.co.nz/default.htm
Ethnograph	http://www.qualisresearch.com
European Usability Support Centres	http://www.lboro.ac.uk/research/husat/eusc
FaultrEASE	http://www.process-safety.com/software/ftrease.htm
GOMS	http://www.usabilityfirst.com/goms/index.html
Health and Safety Executive (HSE)	http://www.hse.gov.uk/hsehome.htm
HFAMI	http://www.hfskyway.com
Human Factors Design Guide (FAA)	http://www.tc.faa.gov/act-500/hfl/products_index.htm http://www.hf.faa.gov/acquire/design_guide/design_guide.html

HyperSAM	http://www.dstc.edu.au/RDU/staff/ri/hyperSAM.html
IBM Web Design Guidelines	http://www-3.ibm.com/ibm/easy/eou_ext.nsf/publish/572
INCOSE Tools Database	http://www.incose.org/tools
International Standards Organisation	http://www.iso.ch
Inventory of tools and methods	http://www.megataq.mcg.gla.ac.uk/sumi.html
IPME	http://www.maad.com/MaadWeb/products/ipme/ipmema.htm
Jack	http://www.cis.upenn.edu/~hms/jack.html
KIT (Key Issues Tool)	http://www.nickleby.com/hfikit.htm
MacSHAPA	http://iac.dtic.mil/hsiac/products/macshapa.html
ManneQuinPRO	http://www.nexgenergo.com/ergonomics/mqpro.html
MANPRINT	http://www.manprint.army.mil/manprint/index.html
MATRIS Directory of Design Support Methods	http://dticam.dtic.mil/his/index.html
MEDA	http://www.boeing.com/commercial/aeromagazine/aero_03/m/m01/index.html
MEFISTO	http://giove.cnuce.cnr.it/mefisto.html
Micro Saint	http://www.maad.com/MaadWeb/microsaint/msaintma.htm
MIDAS	http://ccf.arc.nasa.gov/af/aff/midas/MIDAS_home_page.html
MUSE	http://www.ergohci.ucl.ac.uk/RESEARCH/muse.html
NASA TLX	http://iac.dtic.mil/hsiac/products/tlx/tlx.html
NASA Man-Systems Integration Standard NASA-STD-3000	http://jsc-web-pub.jsc.nasa.gov/fpd/SHFB/Msis/MSIS_home.htm
Observer	http://www.noldus.com
OIA (*in French*)	ftp://ftp.info.fundp.ac.be/pub/users/jvd/guidelin/oia.zip http://www.info.fundp.ac.be/~emb/Trident.html
PAQ	http://www.paq.com
PEAT	http://www.boeing.com/news/techissues/peat/index.htm
PeopleSize	http://www.openerg.com/psz.htm
PowerLab (formerly Maclab)	http://www.adinstruments.com/cust/products.html
PHA-Pro 5	http://www.dyadem.com/home.html
ProGAMMA SIByl	http://www.gamma.rug.nl/iecsibfr.html

PUMA	http://www.atmdc.nats.co.uk/C/PRJ/0023/0023-1.htm
QUIS	http://www.lap.umd.edu/QUIS/index.html
SAE (Society of Automotive Engineers) Human Factors Technical Committee	http://www.sae.org/technicalcommittees/ghftc.htm
SAM 2000	http://www.yse-ltd.co.uk
SAVE	http://www.value-eng.com
Scapin Guidelines (*in French*)	ftp://ftp.info.fundp.ac.be/pub/users/jvd/guidelin/scapin.zip http://www.inria.fr/RRRT/sompub-fra.html
Smith and Mosier 1986 guidelines	ftp://ftp.cis.ohio-state.edu/pub/hci/Guidelines
SUMI	http://www.ucc.ie/hfrg/questionnaires/sumi/index.html
TOPAZ	http://www.nlr.nl/public/facilities/f151-01/index.html
TRADAM	http://www.ott.navy.mil/refs/tradam.htm
U-MAN	http://www.syseca.thomson-csf.com/simulation/uman.htm
User centred design	http://inf2.pira.co.uk/use-bck.htm
VirtualMan	http://www.virtual-man.com
WAMMI	http://www.ucc.ie/hfrg/questionnaires/wammi/index.html http://www.wammi.com
W-SDA (Web Site Design Audit)	http://www.eng.buffalo.edu/~ramam_m/au_fr.html
WebGrid	http://tiger.cpsc.ucalgary.ca
WinCrew	http://www.maad.com/MaadWeb/products/wincrew/wincrwma.htm

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ABBREVIATIONS AND ACRONYMS

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

ACTA	Applied Cognitive Task Analysis
ASEP	Accident Sequence Evaluation Programme
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer / Air Traffic Controller *(UK/US)*
ATCS	Air Traffic Control Specialist
ATM	Air Traffic Management
ATM R&D CoE	ATM R&D Centre of Expertise *(EEC)*
BMD-HMS	Boeing/McDonnell Douglas Human Modeling System
CADA	CSERIAC Anthropometric Data Analysis
CASHE: PVS	Computer Aided Systems Human Engineering: Performance Visualization System
CAST	Consequences of Future ATM Systems for Air traffic controller Selection and Training
CBT	Computer-Based Training
CCAB	Complex Cognitive Assessment Battery
CCT	Concur Task Trees
CD-ROM	Compact Disc – Read-Only Memory
COMBIMAN	COMputerized Biomechanical MAN-model
CREAM	Cognitive Reliability and Error Analysis Method
CRT	Cathode Ray Tube
CSERIAC	Crew System Ergonomics Information Analysis Center
CSSM	Continuous Safety Sampling Methodology
CTI	Computers in Teaching Initiative
DAVID	Digital Anthropometric Video Imaging Device
DERA	Defence Evaluation and Research Agency *(UK)*
DIS	Directorate Infrastructure, ATC systems and Support *(EUROCONTROL, EATMP, SDE)*
DIS/HUM	See HUM Unit

DRAWS	Defence Research Agency Workload Scale
DRUM	Diagnostic Recorder for Usability Measurement
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
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre *(France*)
EHFA	Early Human Factors Analysis
ERNAP	Ergonomics Audit Program
ET	Executive Task *(EATCHIP)*
FAA	Federal Aviation Administration
FAST	Functional Analysis System Technique
F-JAS	Fleishman Job Analysis Survey
FMEA	Failure Mode and Effects Analysis
GEMS	Generic Error Modelling System
GOMS	Goals, Operators, Methods and Systems
GUI	Guidelines *(EATCHIP/EATMP)*
HAZOP	Hazard and Operability Analysis
HCI	Human Computer Interface (or Interaction)
HEART	Human Error Assessment and Reduction Technique
HFAMI	Human Factors in Aviation Maintenance and Inspection
HFDG	Human Factors Design Guide
HFI	Human Factors Integration
HIFA	Human factors Integration in Future ATM Systems
HRV	Heart Rate Variability
HSE	Health & Safety Executive
HSIAC	Human Systems Information Analysis Center (formerly CSERIAC)
HTA	Hierarchical Task Analysis
HUM (Domain)	Human Resources *Domain (EATCHIP/EATMP)*

HUM Unit	Human Factors and Manpower Unit *(EUROCONTROL, SDE, DIS; also known as DIS/HUM; formerly stood for 'ATM Human Resources Unit')*
INCOSE	International Council on Systems Engineering
ISA	Instantaneous Self Assessment
IPME	Integrated Performance Modelling Environment
ITA	Integrated Task Analysis
JSD	Jackson System Development
JHEDI	Justification of Human Error Data Information
KIT	Key Issues Tool
MACAW	MAlvern Cognitive Applied Walkthrough
MACE	Malvern Capacity Estimate
MANPRINT	MANpower, PeRsonnel and INTegration
MEDA	Maintenance Error Decision Aid
MIDAS	Man-Machine Integration Design and Analysis System
MUSE	Method for Usability Engineering
NASA	National Aeronautics & Space Administration *(US)*
NRC	Nuclear Regulation Commission
OIA	Objets Interactifs Abstraits (Abstract Interaction Objects)
OJT	On-the-Job-Training
OR	Operational Requirement
PAQ	Position Analysis Questionnaire
PEAT	Procedural Event Analysis Tool
PUMA	Performance and Usability Modelling in ATM
QUIS	Questionnaire for User Interface Satisfaction
REP	Report *(EATCHIP/EATMP)*
R&D	Research and Development
SA	Situation Awareness
SAE	Society of Automotive Engineers
SAM	Safety Argument Manager
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique

SAVE	Society of American Value Engineers
SDE	Senior Director, Principal EATMP Directorate *or, in short,* Senior Director(ate) EATMP *(EUROCONTROL)*
SPAM	Situation-Present Assessment Method
ST	Specialist Task *(EATCHIP)*
SUMI	System Usability Measurement Inventory
SWAT	Subjective Workload Assessment Technique
THERP	Technique for Human Error Rate Prediction
TLX	Task Load Index
TNA	Training Needs Analysis
TOPAZ	Traffic Organisation and Perturbation Analyzer
TRACEr	Technique for the retrospective Analysis of Cognitive Errors
TRADAM	Training Delivery Assessment Model
TRAINDEV	Training Development
VDU	Visual Display Unit
WAMMI	Web Analysis and MeasureMent Inventory
WWW	World Wide Web

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