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Proceedings of the Third EUROCONTROL Human Factors Workshop Integrating Human Factors into the Life Cycle of ATM Systems

HUM.ET1.ST13.000-REP-03

Edition	:	1.0
Edition Date	:	30.11.1999
Status	:	Released Issue
Class	:	EATMP

EUROPEAN AIR TRAFFIC MANAGEMENT PROGRAMME

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title
Proceedings of the Third EUROCONTROL Human Factors Workshop Integrating Human Factors into the Life Cycle of ATM Systems

EWP DELIVERABLE REFERENCE NUMBER: N/A

PROGRAMME REFERENCE INDEX	**EDITION:**	1.0
HUM.ET1.ST13.000-REP-03	**EDITION DATE:**	30.11.1999

Abstract

The Human Resources Team (HRT) of the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP), now the European Air Traffic Management Programme (EATMP), has initiated the organisation of annual workshops on topics concerning Human Resources in Air Traffic Management (ATM), namely human factors.

This report contains the proceedings of the third EUROCONTROL Human Factors Workshop held in Luxembourg in October 1998. The workshop addressed the integration of human factors into the life cycle of ATM systems

Keywords

Human Factors Integration	Design	Managerial Issues
Human-Machine Interface/Integration (HMI)	Operation	ATM Life Cycle
Concept Development	Methods and Tools	

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DOCUMENT STATUS AND TYPE

STATUS		CATEGORY		CLASSIFICATION	
Working Draft	☐	Executive Task	☐	General Public	☐
Draft	☐	Specialist Task	☐	EATMP	☑
Proposed Issue	☐	Lower Layer Task	☑	Restricted	☐
Released Issue	☑				

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME: G:\Own_use\Delvrabl\Released\HFs\Workshops\Hf_proc3.doc

HOST SYSTEM	MEDIA	SOFTWARE
Microsoft Windows	Type: Hard disk	**MicroSoft Office 97 (MS97) + Visio 4.0, Corel Draw 7, others**
	Media Identification	

DOCUMENT APPROVAL

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

AUTHORITY	NAME AND SIGNATURE	DATE
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DOCUMENT CHANGE RECORD

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

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.1	08.03.1999	Proposed Issue	All
1.0	30.11.1999	Released Issue	All (editorial and layout)

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FOREWORD

In the middle of February 1999 the re-organisation of the European Air Traffic and Harmonisation Integration Programme (EATCHIP) became effective. The former EATCHIP structure was now called EATMP (European Air Traffic Management Programme). The directorates were renamed, and the divisions and bureaux within them were re-organised into units. The sections in the former divisions were abolished. The EATCHIP terminology, including the abbreviations and acronyms as well as the staff's titles and units, was then adapted to the new organisation framework:

- The former 'Senior Director(ate) Operations and EATCHIP (SDOE)' was now named the 'Senior Director, Principal EATMP Directorate' or, in short, the 'Senior Director EATMP (SDE)'.

- The former Directorates of EATCHIP Development (DED) and EATCHIP Implementation (DEI) ceased to exist.

- The divisions and bureaux existing within the former SDOE, DED and DEI were re-organised into units within two new EATMP Directorates called the 'Directorate Infrastructure, ATC Systems and Support (DIS)' and the 'Directorate Safety, Airspace, Airports and Information Services (DSA)'.

- The former 'Human Resource Bureau DED5' was renamed as the 'ATM Human Resources Unit (in short known as DIS/HUM or HUM Unit), and put into the DIS Directorate. The work produced by the Unit will basically continue along the same lines as before.

Since these proceedings are about events that took place well before the re-organisation into EATMP, the EACHIP terminology (including titles and units) still applied and was therefore deliberatly kept in this report, even if generally followed by the equivalent EATMP terminology which is today used. However, the participant address list at the end of the document, as it is aimed to be used as a contact tool, only includes the current EATMP units and titles.

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EXECUTIVE SUMMARY

The Human Resources Team (HRT) of the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP), now the European Air Traffic Management Programme (EATMP), has initiated and organised the holding of annual workshops on different topics, namely concerning the human factors in Air Traffic Management (ATM). This report contains the Proceedings of the Third EUROCONTROL Human Factors Workshop which was held in Luxembourg in October 1998 and addressed the Integration of Human Factors into the Life Cycle of ATM Systems.

Chapter 1 gives the scope and purpose of the human factors workshops and their relevance for the work within the Human Resources Domain (HUM) in EATCHIP\EATMP.

Chapter 2 includes the text of the following presentations given during the Plenary Session on the first day of the workshop:

- ‘Managing Human Factors in Aviation’ by A. Axelsson;
- ‘A User Viewpoint on Current Human Factors Considerations in Air Traffic Control Systems’ by Ph. Domogala;
- ‘The Experience of Human Factors Integration on the Flight-Deck’ by R. Amalberti;
- ‘Automation Strategies: Evaluation of Some Concepts’ by H. Nijhuis;
- ‘Human Factors Integration within Concept Development, Design and Pre-operational Evaluation Phases: a Pragmatic Approach’ by A. Jackson;
- ‘Human Factors Integration in Aeronautical Research: Experiences, State of Progress and the Future’ by P. Jorna;
- ‘Human Factors Integration at ALENIA’ by G. Casale;
- ‘Introducing an Activity Analysis Centred Approach into the Air Traffic Management Systems Design Process’ by V. Laval;
- ‘Human Factors Techniques in the NATS Air Traffic Management System Development Process’ by B. Kirwan.

Chapter 3 provides the summaries of the Working Groups (WGs) held on the second day and presented by the rapporteurs on the third day. The themes of the WGs were:

- Integrating Human Factors into the Concept Development phase of Air Traffic Management Systems;
- Integrating Human Factors into the Design phase of Air Traffic Management Systems;

- Integrating Human Factors into the Operation phase of Air Traffic Management Systems;

- Integrating Human Factors into the Life Cycle of Air Traffic Management Systems: Managerial Issues;

- Human Factors Methods and Tools.

Chapter 4 provides the text of the following six posters, which were displayed during a Poster Session on the first day of the workshop and show methods and tools facilitating the integration of Human Factors into the life cycle of ATM systems:

- ‘Consequences of Adopting Human Factors Guidelines in Air Traffic Management Systems Design’ by B. Josefsson;

- ‘Human Factors Methods Coping with Strategies of Automated Multi-Sector Planning’ by K. Eyferth, M. Fricke, Y. Hauss, S. Leuchter, C. Niessen, O. Späth and N. Stark;

- ‘Evaluation of the Psychophysiological State and Learning Process of Air Traffic Control: From the Laboratory to Real-Time Situation’ by R. Mollard, P. Cabon, H. David and F. Caloo;

- ‘Human Factors Methods and Tools - Studies of Pilots’ Performance in Experimental Cockpit Environments’ by G. Hauland and T. Bove;

- ‘Dynamic Transparency with Multi-density Bit Planes’ by D. M. Spragg and J. Wade;

- ‘Validating Complex Human-Machine Systems: From a “User-centred” to a Systemic Approach’ by P. Amaldi and S. Pilverdier.

Participants' names and contact details, most of the Abbreviations and Acronyms used in this document and their definitions, as well as a list of the Contributors to this document are provided as annexes.

1. INTRODUCTION

Within EATCHIP\EATMP the Human Resources Domain (HUM) deals with the integration of human aspects related knowledge and methods into the current and future ATM system to ensure the overall compatibility with the human operator. The domain main activity covers human factors studies, manpower planning, selection, training and licensing.

1.1 Scope

The EATCHIP\EATMP Human Resources Team (HRT) has initiated the organisation of annual workshops on topics concerning human factors in ATM. The goal is to create a European focal point of human factors expertise in ATM. This should encourage human factors practitioners and researchers to share their experiences, to exchange the results of current research development trends and practice, and to consider the evolution of new concepts for the changing ATM environment.

The First EUROCONTROL Human Factors Workshop, held in 1996, addressed cognitive aspects in ATC (see EATCHIP, 1996), and the second workshop, held in 1997, was about teamwork in Air Traffic Services' (see EATCHIP, 1998).

1.2 Purpose

This report consists of the 'Proceedings of the Third EUROCONTROL Human Factors Workshop on the Integration of Human Factors into the Life Cycle of ATM Systems', which was held at the EUROCONTROL Institute of Air Navigation Services (IANS), Luxembourg, in October 1998, and was attended by approximately 120 participants coming from twenty States. It includes the text of all the presentations given, the conclusions of the Working Groups (WGs), the text of the posters shown during the workshop, the participants list as well as the usual standard annexes (Abbreviations & Acronyms and Contributors).

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2. TECHNICAL NOTES

After a short introduction to the workshop, nine speakers introduced a different point of view on 'Integrating Human Factors into the Life Cycle of ATM Systems'. These presentations attempted to give a wide overview of the various issues and served as an input for the Working Groups (WGs).

The workshop was opened by Mr. Wolfgang Philipp, then Senior Director Operations and EATCHIP (SDOE), now the Senior Director, Principal EATMP Directorate (SDE), and chaired by Mr. Manfred Barbarino, then Head of Human Factors Section, Human Resources Bureau DED5, now Manager of Human Resources Management Programme (HRS), ATM Human Resources Unit (DIS/HUM), Directorate Infrastructure, ATC Systems & Support (DIS) of EUROCONTROL.

2.1 Managing Human Factors in Aviation

by Arne AXELSSON, Aviation Safety Director, Luftfartsverket (Swedish Civil Aviation Administration), Chairman EUROCONTROL Safety Regulation Commission

Aviation safety regulation has been developed over the years and defines in detail the requirements of aircraft design, build, maintenance and operation, as well as personnel requirements and training. There is also a requirement for manufacturers to maintain the ongoing continued airworthiness based on service experience fed back to the safety authorities and the manufacturers from the operators. The manufacturer analyses all data, and issues service bulletins and information in order to correct problems and improve aircraft safety and reliability. The safety regulation is continually updated. The regulation and the advisory material thereby provide a detailed compilation of what is known, giving the travelling public a safe product. With this systematic way of developing and maintaining aircraft, aviation has become a very safe way to travel.

Unfortunately, there are still accidents, and, as we all know, they are dramatic and generate a lot of grief and concern. When between two and three hundred people die in one accident it is a major media event around the world. The accident investigations give technical functions as the probable cause in about 10% of the accidents of heavy aircraft. Human factors in a broad sense represent about 70%, and ATM and airports about 5%.

The pilots are at the end of the line and sometimes have to act under real-time pressure, which is also the situation for the Air Traffic Controllers (ATCOs). The human factors aspects of aircraft design and operation are in focus in research and with a high degree of international standardisation allowing a very positive flow of usable information across the aviation world.

In the ATM area we also have a good foundation in the Annexes of the International Civil Aviation Organization (ICAO) but mostly in how to organize the ATS work and separate aircraft. There is no worldwide available compilation of detailed design and operation requirements which can contribute to safety improvements in the same way as with aircraft. One reason for that is that there is not the same industrial base for design and build of ATM systems as there is for aircraft. Another reason is that the ATM infrastructure historically is a protected government responsibility.

The work created in the EATCHIP is a good start for a change of all that and the new EUROCONTROL Convention has created an environment where the present twenty-seven Member States can cooperate both in generating and implementing harmonized safety regulation, and in helping each other to provide the safe and efficient ATM services needed by the ever increasing number of aircraft using the European airways.

I mentioned earlier that ATM and airports are attributed to be the probable cause in about 5% of the accidents. Factors behind this very good result is that we have good equipment, skilful controllers and a conservative use of airspace allowing for mistakes being made without resulting in accidents. However, I am afraid that we have quite a few occasions when we from an ATM systems standpoint have had close encounters that could be described as accidents without a smoking wreck.

When we look into the near future we see increased capacity demand with among others ‘Reduced Vertical Separation Minimum (RVSM)’ and ‘area Navigation (RNAV)’ coming into use to accommodate that. We see satellite-based navigation systems providing a fantastic accuracy but also a potential serious vulnerability if intentionally or unintentionally disturbed. We have ‘Airborne Collision Avoidance System (ACAS)’ and ‘Short-Term Conflict Alert (STCA)’ as a compensating safety net for avoidance of a mid-air collision if other systems or involved controllers or pilots have not been able to cope. The free flight concept is coming along to better use the airspace but we still have to start and land at a limited number of airports. And if the world economy continues to expand we may have twice the number of large aircraft movements within ten-fifteen years.

All the sophisticated systems being developed with millions of high level software lines of code represent a great challenge, in particular regarding the controllers who operate the system in real time and also for the engineers maintaining the system and improving it during the many years of operation when the clever guys who designed the system are doing something completely different.

The human factors aspects are more difficult to define and make cost estimates of as compared with a piece of hardware. We see time and again that the software development is very difficult to estimate. The controllers’ daily environment is affected by the safety culture of their organisations and money is always involved. Also the government-operated organisations have budget pressure and there is a trend towards privatisation also of ATM services. Automation is looked upon as providing higher capacity to less cost. However, systems have to be sufficiently safe. If controllers suddenly have to take over **when** a system goes down, **not if** a system goes down, they must be sufficiently in the loop during normal operation to be able to handle the situation.

I firmly believe that the overall economic pressure makes it necessary to have a balanced structure i.e. a safety regulator setting requirements for the service provider and assuring itself that systems are safe to operate. We have a lot of work in front of us to provide harmonized safety regulation but we have among others the result from the EATCHIP activities as a good baseline.

We must have a total aviation system safety regulation i.e. including airports, ATM and all the aircraft regulation, the last currently being coordinated in the Joint Aviation Authorities (JAA). The faster that can be implemented the better safety we will be able to provide the travelling public. And the most important area is human factors. European Aviation Safety Authority (EASA) is now being negotiated between the European Union (EU) Member States and the remaining JAA full Member States (Norway, Switzerland, Iceland and Monaco). The other European Civil Aviation Conference (ECAC) Member States are invited as observers and the hope is that all ECAC States and future EU States will become members. EASA will initially cover the area now covered by JAA. ATM and airport safety regulation shall be included when the governments decide to do so. However, for the moment some States are not prepared to include these areas.

One challenge is the communication between the theoretical human factors language and engineers, pilots and controllers. There have to be enough specifics to be able to implement in design and operation. Research is needed in the human factors area, and it has to be in general understanding of humans as operators of complex systems as well as specifics in operational procedures of different implementations. To me, when considering how much money is spent on systems development, it is necessary to invest more in the human factors aspects than what is done presently.

I hope this workshop can extend the understanding of sound principles and specific problems as well as their possible solutions. I wish that we in Europe can consolidate our knowledge and views to allow for a high degree of standardisation and that this workshop will contribute to that.

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2.2 A User Viewpoint on Current Human Factors Considerations in Air Traffic Control Systems

by Philippe DOMOGALA, Centre Supervisor, EUROCONTROL Maastricht Upper Area Control Centre (MUAC)

When Dr. M. Barbarino from EUROCONTROL Headquarters asked me to make a speech to you this morning, he said: ‘You can be a bit provocative’ and ‘Do not be afraid to put some questions that can be debated in the workshop tomorrow’. It gives me great pleasure to oblige on both requests.

I am not a specialist in human factors, so please excuse my ignorance in some specific fields. What I know well is ATC and ATM, and it is from this perspective that I will look into human factors. Therefore, what follows are my personal views. I do not claim to represent the official views of EUROCONTROL nor the International Federation of Air Traffic Controllers' Associations (IFATCA) in this matter.

2.2.1 Human Factors Background

In the earlier ATM concepts which I was involved in with IFATCA, such as the Advanced Concept Group (ACG), the (ICAO Concept Group for the) Future European Air Traffic Management System (FEATS) and even the Future Air Navigation Systems (FANS II), there were very few debates on human factors issues. It was in fact IFATCA and the International Federation of Airlines Pilots’ Associations (IFALPA) Representatives who insisted on their inclusion in the draft texts. However, after political correctness had struck, what remained was often a few lines of empty text referring vaguely to things like training issues, Human-Machine Interface (HMI) or controller’s involvement. All these points were valid even if what we wanted to talk about was the limits of automation, responsibilities human-machine, abilities of humans to cope with new systems, etc. As this approach was judged too ‘provocative’, even ‘subversive’ and certainly too ‘restrictive’ for the time, it was not retained.

The other thing I would like to mention that struck me at the time was to see all those brilliant engineers coming from the best research establishments such as MITRE in the United States, CENA (*Centre d’études de la navigation aérienne)* in France, DLR (*‘Deutsche Forschungsanstalt für Luft- und Raumfahrt’*, the ‘German Aerospace Research Institute’*, now 'Deutsches Zentrum für Luft- und Raumfahrt e.V*, the German Aerospace Centre*)* in Germany and NLR (*National Lucht- en Ruimtevaartlaboratorium*, the National Aerospace Laboratory) in Holland, still considering aircraft as mathematical vectors, moving through space with identical values and, even more worrying, considering controllers and pilots as operators of their skilfully designed machines and concepts.

Unfortunately for us, those people were among the ones that designed, drafted and voted on the FANS-II concepts from which CNS/ATM (Communications, Navigation and Surveillance / Air Traffic Management) has derived. This is also why the technical side (the CNS) is put before the human side (the ATM).

The CNS/ATM concept will be applied worldwide. Now, they call on you the human factors specialist to try to fill the gaps and make the system workable and acceptable to the humans around it.

2.2.2 Human-centred Automation

Now back to today with the basic question: **Who is in charge**?

ICAO has recently produced a digest on human factors for CNS/ATM systems. The principle inside the digest is called '**human-centred automation**'.

I am sure that all of you have seen the concept, the principles of which have been developed by Dr. C. Billings. Mr. B. Ruitenberg was the controller who represented IFATCA at the ICAO panel and contributed extensively to the drafting.

Nevertheless, I am not sure that everybody involved in decision-making in ATC has seen the concept or retained its fundamental principles, which are as follows: If pilots still have to bear responsibility for their flights, and controllers for traffic separation and for maintaining a safe and efficient traffic flow, **pilots must remain in command of their flight, and controllers of their traffic**. **This implies that any automation used must assist this process**.

The concept was accepted and will be put in place together with CNS/ATM.

Just to set the record straight, this is what we are working on. It will be the ATM for the next fifteen to twenty years. What happens after that, free flight, control by exception or fully automated ATC, is not covered in this presentation.

That aside, back to our fundamentals in **human-centred automation** as defined by **ICAO**.

Now engineers and manufacturers all around the world should devise ATM systems and sub-systems that follow those principles. Automation becomes a set of tools aimed at helping humans to make better decisions. We should not, like in the past, devise ATM systems just because the technology became available, and later ask human factors to help the controllers cope with this situation. In my view, the human factors specialists should also at this stage be involved by giving guidelines on the following three points:

1. Is this new tool operable within the physical and psychological limitations of the controllers?

2. How will the controllers integrate this new tool into the system, and how will this affect their total performance (workload)?

3. How can they best be trained to get the most of this new tool?

In a moment I will come back into the process as I personally see it.

As you have probably guessed by now, my experience in human factors is not very good. Nevertheless, I firmly believe that human factors have a fundamental role to play in the future, in a far greater scope than in the past.

2.2.3 USA Human Factors Panel

Our friends in the USA have also realised this and have ordered a large national study on human factors in future ATC systems. The report of the panel is just out. I am sure many of you have seen it if not read it. It is extremely interesting and I am going to comment on some of their recommendations.

The report basically says that, due to the increasing traffic complexity and density, the controller situation awareness will be reduced, which will force the controller to rely more and more on automation.

The report also says that recovering from automation failures will be the most critical thing.

The panel recommended that extreme care should be exercised in choosing **median** response times (i.e. average times) when modelling automation, as these have implications that are very different from those based on **longest** response times.

The panel also asked for the vigorous pursuit of projections on how various automated tools will work in concert.

2.2.4 Memory

Because of our cultural background and specialist education we often fail to see the ‘big’ picture. There are many groups, panels, research institutes and manufacturers that work on different systems for ATM. However, no one is actually looking at the interaction of all these tools as they come on line.

Even if each sub-system is certified and validated, it is mostly done in isolation, and how this fits when all the systems come together is in fact left to the controller to cope with, and to invent procedures and working habits **afterwards**, in order to handle the situation.

The question coming to mind immediately after this is: What is the maximum number of sub-systems a human being can integrate?

Every sub-system has its own procedure manual, training and input sequences, all to be memorised. Also, this new tool has to work in addition to others. So unwritten procedures and working habits are defined, which are generally non-documented but still have to be memorised as well. All this will take away some RAM (Random-Access Memory).

By the way, what is the maximum RAM of an average brain? Do all brains have similar memory sizes? If the parallel brain/computer is correct, can we expect a brain saturated with information to work slower or will it refuse any new information? Something else for you to debate tomorrow in the workshops ...

This memory discussion will be fascinating because recent studies tell us that saturation of information and memory losses will be the major challenge in developing future complex ATM systems.

One of these studies is about the cognitive and psychosensorial process of controllers and has been recently presented by Mr. J. Villiers of the French 'Académie de l'air et de l'espace'. It indicates that the most vulnerable point in drafting future concepts concerns the memorisation capabilities of the human being or, in other words, the risk of memory loss in the short-term. They argue that, in a highly automated ATM environment, it will be at times impossible for controllers to act or take over a new sudden situation put to them, because they will not have had the possibility to memorise the various elements needed to make the proper decisions. This is particularly true in case of sudden failure of sub-systems.

Another study, presented by Mr. Weitzmann (1997), at the USA ATCA Convention, tells us that, although the technology may decrease the physical work, it may also increase the mental work, especially at critical times when the workload is already high.

Now, during the same ATCA Convention a computer scientist said that, in view of the extremely large quantities of information available (which will be necessary to make free flight work), the main challenge for computers will be to integrate this information broadcasted to them and to display it (it seems that today's machines do not have enough computing power to do so). In any case we do not have to wait for free flight. It is a fact today that advanced automated systems provide more and more information (previously not available) to the controller.

If we combine the results of the three statements above, there is a real case for both saturation in information (affecting the memory) and excessive workload (affecting the functional brain). However, as I am not a specialist in this I cannot judge or assess the consequences.

If the controller is to be the deciding element and remain responsible, the computerised assistance he will receive should not overload him. This is where we would need your expertise in human factors in order to ensure this.

2.2.5 Commitment and Acceptability

The last point I would like to cover in my presentation to you this morning is that of commitment and acceptability:

As we live in democracies we apply what we call consensus in our daily working practices. Consensus per se generally means compromise. Compromises never give everybody 100% satisfaction, especially if the parties involved are in conflict.

It is however paramount that once a decision has been taken, it should not only be accepted by all but also defended by all. This is even more true when considering human factors. For engineers and management, human factors are still too often seen as ‘bothering’ or ‘hindering’ progress or implementation. Too often, due to time pressure, the training times agreed are shortened, the demonstrations and validations reduced or even skipped (especially if one expects problems there), the introduction is ‘delayed’, etc.

In general, controllers are ready for changes, provided others do their job correctly. Again, my experience in the past twenty-five years has shown weaknesses in this pattern ... It is mainly due to the failures in providing what the glossy brochure said the new system will do. Too many times we have been burnt by over-enthusiastic engineers’ and manufacturers’ promises, only to pick up the pieces of their faulty software and unreliable computers. This is why we are cautious.

That aside, I am afraid that most controllers will at first treat human factors specialists and their work with suspicion. Yet we would love you to be involved in the whole phase of the ATM life cycle, not only at the Concept Definition and Design phase but also at the installation and Verification/Validation phases. You should be able to check then if all the human factors recommendations and general principles are still in place.

I would also like you to be involved in the training syllabus, and into looking at how this new system fits in the whole picture. Even later, after the introduction, you should be naturally involved in order to assess the weaknesses and the strengths of the human performance side of the whole system. We would like you to advise on future possibilities of development, even, and especially, if these involve restrictions. I am not sure that this ideal world will materialise one day although it should. Are you yourselves prepared for this challenge? Remember, I was asked to be provocative!

2.2.6 Conclusions

Now let me briefly give you my conclusions, which are as follows:

- We need you. We need human factors but you should be more proactive and come up with a more practical approach.

- We urgently need guidelines on the limits of capabilities of humans to cope with the proposed automation, with an emphasis on **memory** capabilities.

- We need you to work in cooperation with various system engineers on the self-integration of the various sub-systems, and advise them and us of the definition of the systems speeds/capacities based on possibly longer response times, in order to cater for all staff using the system.

- We also wish you to be involved during the complete life cycle of the ATM system, not only at the beginning of it or, worse, afterwards when fixing up the wounds.

- We would like some human factors specialists to go out of their offices and get involved in the real decision-making process.

- Finally, I am afraid I have to say there are too many professors and priests in your profession; the professors who identify the problems and tell us: 'You should watch this in the future', and the priests who tell us once the system has been set up: 'You have done this wrong my son'.

Let me tell you again that the above views are mine and do not necessarily reflect my employer's point of view.

I hope I have been provocative enough!

Thank you for your attention.

2.2.7 References

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2.3 The Experience of Human Factors Integration on the Flight-Deck

by René AMALBERTI, DGAC, IMASSA, France, Joint Aviation Authorities (JAA) Human Factors Focal Point for harmonization with the Federal Aviation Administration (FAA)

2.3.1 Summary

Although the integration of human factors in the flight deck design and certification is as old as cockpits, it still generates hot discussions between the authorities and the aviation industry about the writing of regulations and accompanying material. To say things simply, even though the industry has been incorporating human factors in design and certification for years, they are quite different from the ones expected by theorists. After a decade of mutual criticism the situation is slowly being released. This paper tries to capture the big picture to determine the actual reality and practice of human factors integration in the flight deck, as well as the changes which are to be expected soon.

Mr. René Amalberti is the former Chairman of the JAA Human Factors Steering Group (he left the lead in June 1998 and was replaced by Mr. Ron Pearson from the CAA UK), and still is the JAA Human Factors Focal Point for harmonization with the FAA.

2.3.2 Introduction

Flight deck human factors integration is a land of controversies. The following items attempt to capture some dimensions of the problem:

1. The last glass-cockpit generation of advanced automated aircraft (Airbus family, Boeing 73'300-600, 74'-400, 777, 717) dates back to the end of the eighties. The glass-cockpit design has incorporated, or created, most of the recent advances in Human-Machine Interface (HMI), and, as such, is a fantastic room for experiencing modern human factors.

2. However, these new interfaces have not been designed by human factors specialists, but merely by non human factors educated engineers. Whereas basic human factors (e.g. anthropometrics and psychophysics) have sometimes been considered, most of the glass-cockpit design refers to innovative ideas and intuitive human factors. These factors were guided by the following basic principles:

   - First, system performance enhancement, including safety, has been the triggering goal of the new design. The design has been engineering-driven rather than human factors driven. As long as the performance and safety of the overall system were considered to be enhanced by engineering solutions, the crew concerns (including authority and social comfort) were not first the priority.

- Negative human considerations have dominated the intuitive human factors policies used in the design of the glass cockpit. For intuitive human factors the first goal of a human factors oriented design is to reduce the potential for crew errors, while conserving the human intelligence for planning and system backup. In-service experience was the tool to capture the most unreliable human sequences.

Two guiding principles were then used to reduce the identified potential of errors:

⇒ One was to simplify crew understanding by means of new analogous presentation of the outside world (map display is the best example, but so are Primary Flight Display (PFD), status and circuits displays).

⇒ Another was to increase automation and protection. Automation of manual control is the solution to release crews from these repetitive tasks, and to enhance performance within the authorized flight envelope. Inside the authorized envelope the crew is still in charge and responsible for flying manually or for selecting automation. Outside this envelope, automatic overriding protection takes the lead on crew authority.

These design principles apply to the glass cockpit.

3. The world of design and certification has long been totally separated from the world of operations and training. The input of the human factors academy in Cockpit Resource Management (CRM) at the end of the eighties (leader style, communication, conflict resolution), despite the fact it was very important for crew training improvement, has had strictly no impact on the incorporation of human factors in design and certification.

4. Following a series of human error induced accidents that have marked the introduction of the glass-cockpit generation, a growing and significant support to research in advanced (cognitive and social) human factors was sustained worldwide by authorities. The accident analysis prioritized research on cognitive ergonomics, human-error, automation, human-centred design, socio-cognitive ergonomics and system safety. As a consequence aviation human factors research has progressively taken the lead in human error and in cognitive and socio-cognitive research, to the detriment of the nuclear industry which had the lead in the eighties.

5. Despite this tremendous growth of research and papers in aviation cognitive ergonomics, or maybe because of it, the aviation industry has long considered, and still does sometimes, that most human factors theorists criticize without understanding the domain, and are unable to propose any viable solution. Even during the worst period, when there were many accidents (1992-1994), the manufacturers have never considered their design as wrong. The results accumulated since this period tend to acknowledge this view. Moreover, industry tends to consider that the solution for a better accident prevention is to go for more automation and

safety nets rather than to return to the previous situation where crews had to recover more manual controls. The development of the Traffic Alert and Collision-Avoidance System (TCAS), the Ground-Proximity Warning System (GPWS) and the enhanced GPWS, as well as the design of future datalink, are some examples of this trend.

6. The divorce between academic human factors research and industry has been so extreme that only two persons with a degree in academic human factors were employed in design and certification offices by the whole French aviation industry in 1992 (compared to over ten thousand employees in this area!). The situation was just a bit better in the USA and in the rest of Europe, where more human factors specialists were employed even though they did not necessarily influence the design much.

7. The situation is evolving with the establishment of a positive dialogue and a search for integration of academic human factors methods in design and certification. The dialogue is developed at the highest level between the industry and the authorities. Do not forget the third player in this game, whose name is ‘Certification team’. The Certification team is the authority body that stamps the final product delivered by the manufacturer. As such, it controls all aspects of the product, including human factors, independently and without human factors assistance. It has been doing so for years. Nowadays the certification of large aircraft is unified for Europe and soon will be unified with the FAA team (first case with the new Boeing 716 certification). The certification teams are as ambiguous as the aviation industry is for the incorporation of academic human factors methods and concepts in the process of certification. They acknowledge the need for a more structured approach of the human factors certification, but still fear from outside ‘magic’ judgements, turf protection and the liability of a new approach.

8. The release of the jamming situation asks first for acknowledgement that all parties have done a much better job than the others parties said. The aviation industry and the certification teams have contributed to reaching the best safety standards of all industries in the world, thanks to the technology and intuitive human factors. The human factors community has developed a series of concepts that are mature enough to serve design, and seem to be inescapable in an attempt to meet the future safety challenges.

9. The parties now admit that they can benefit from a mutual assistance. We have entered into the time of re-focusing the needs of industry and the research in human factors. Guideline material and regulations are expected to come soon with the forming of an FAA/JAA Harmonisation Working Group (HWG) on flight crew error and performance in design and certification of large aeroplanes.

Chapters 2.3.3 and 2.3.4 cite and debate the five top successes and five top problems in today’s incorporation of human factors in design and certification of flight deck. In Chapter 2.3.5 solutions are proposed.

2.3.3 The Top Five Successes

1. Good overall results: better safety, better cost/effective performance
2. Validation of human factors concepts
3. Lessons learnt from incidents/accidents: identification of new problems in human factors, special attention paid to the first transition course
4. Back to reproductive design in the future, rediscovery of the numerous advantage of reproductive design for human factors
5. Next challenge is not cockpit design but overall aviation system design (ATM)

To a large extent the five top successes cited above reflect the value of the intuitive human factors that prevailed in the design of the glass cockpit.

1. The first result is the acknowledgement that the new glass-cockpit generation is a success. Despite the fourteen glass-cockpit crashes that occurred in the last eight years, the accident rate of that generation of aircraft appears to be twice lower than for the previous generation. Automation has proved to be cost effective with a significant performance improvement. The navigation capabilities have been increased to be compatible with future ATM. Fuel saving is more than significant. The crew training time and the maintenance time have been significantly reduced.

2. Focusing on the interface most crews admit that the map display and associated analogous presentations are among the most significant advances in HMI which they have seen for years. After a burst of criticism automation is also viewed by a majority of pilots as a comfortable means for managing the flight path. Briefly, nobody should be pleased to go back to the previous generation. All the manufacturers, even those who were more opposed at the beginning, have adopted the new standards.

3. The few glass-cockpit accidents/incidents have taught the industry the following three important lessons:

   - There is a fundamental shift in the nature of human factors problems due to the evolution of technique. Workload is no longer a big problem (thanks to automation), nor are basic ergonomics (thanks to electronic display technology). However, the system and situation comprehension, the autopilot mode management, as well as the adaptation of HMI to the worldwide varieties of pilots (cultural dimension of design), are growing problems here and now.

   - The first glass-cockpit transition course occurring in the life of a pilot is now considered as a very sensitive course. Manufacturers pay special attention to these courses - they have extended the training time and introduced a specific syllabus.

   - The systemic design logic prevails the cockpit design logic. It is increasingly admitted that the aircraft and its crew form only one piece of a large system. Many safety-related problems come from the heterogeneity of the overall aviation system (ATC, Operations, etc.), not from the cockpit design itself. The lesson in turn is that cockpit design cannot be considered in isolation. Maybe, the more effective human factors consideration for a successful cockpit design is to design first the relevant operational scenarios that reflect the real future environment.

4. After a decade of innovative design manufacturers are back to reproductive design. The success of the family concept illustrates this reproductive trend.

5. The next challenge for design is not cockpit design but ATM design, and it could be a much greater challenge. The aviation industry has learnt lessons from the recent glass-cockpit innovation and seems to be much more open-minded to academic human factors considerations in order to minimize as much as possible the negative consequences of the Transition phase.

2.3.4 The Top Five Problems

1. The safety wall compared to the growing commercial incentive to increase performance.
2. The trap of system complexity, human error and accident prevention. The solutions that have conducted to the present success could be the cause of future difficulties.
3. The almost impossible adaptation of design to the wide variety of end-users ‘cultures.
4. The industry constraints and the related reluctance to some good human factors solutions or principles, e.g., time-consuming methods, traceability of decision and results.
5. The inadequate orientation of too much research in aviation human factors and the difficulty of hiring human factors specialists.

1. Despite the intrinsic value of the glass-cockpit generation, the global safety figures are installed on a plateau (ten-six) for over two decades and nobody can see how to improve this figure.

   On the one hand the global aviation system cannot capitalize on the potential safety benefits of glass-cockpit design because of the competitive market (deregulation), the heterogeneity of the global system (ground assistance and fleet market) and the growing number of non-occidental end-users (which increases the potential for cultural problems). Paradoxically, most of these negative factors are also the key factors of a successful aviation business; therefore, the risk of safety degradation is becoming higher in the near future.

On the other hand the technical advantage of the present glass-cockpit design cannot be pushed much farther, if one wants the crews to remain responsible for the flight management. A new increase in automation should probably ask for a significant step towards full automation, a step that, technically and socially, is considered premature. Conversely, a general feeling in the aviation community is that the technique, fleet and parties involved will not significantly change before 2020. The industry has been fearing this for the past two decades. This is the chance of human factors to prove that they can propose a viable industrial solution for enhancing safety while continuing to improve performance and profits. The window of opportunity for innovative human factors in flight deck design is only open for a limited duration.

2. One of the top-ranked reasons for incorporating human factors in design has always been to reduce human error. To do so simple-minded solutions can be considered, which consist of reducing human interactions with the system (more automation), directing humans in the interaction with the system (procedure-driven), and preventing system damage and crashes (by means of passive or active safety nets). However, the concept of human error and the associated simple-minded solutions just cited are more than ambiguous and chronically lead industry to misunderstandings and contra-productive strategies.

   - Human error is ambiguous, both in definition and prevention strategies. For most involved parties, including front-line operators, human error is a concept which connotes unacceptable or unwanted behaviour. Because of this connotation the field definition of error is different from the scientifically-based psychological standards. It refers to a pragmatic approach: error is only acknowledged and reported when there are negative consequences for safety. The problem with such a pragmatic definition of error is that it is not stable: a deviation from procedure will be considered as an error by an instructor for training purposes, even though it had no direct consequences on safety, while the same deviation during normal operation would not be reported, hence it will not appear in reporting systems and databases and therefore will not be considered for design. The 'error' rate can consequently vary by several orders of magnitude between psychology-based definitions of error and industry's pragmatic approaches. For example, within the airline industry only one cockpit crew error among ten is debriefed by the instructor, only one among one hundred is reported by the crew and only one among one thousand is subject to an official file for safety investigation purpose. What becomes visible in databases, and de facto referred to in design and safety policies, is in fact the tip of the iceberg.

   - Safety strategies are not suspended in a vacuum, nor are they universal. Their degree of relevance and efficiency depends, among other factors, on the safety level reached by the system. A taxonomy of errors which proved efficient in a 10^{-5} safety level context will not necessarily be efficient when the system has reached 10^{-7}. When margins of progress are large, simple common-sense solutions may be efficient. In ultra-safe systems accidents have become remote events, which means that only a handful of such events will happen every year (or even ten years) in the global system. They are so rare that they can no longer feed individual risk perception. Their random, compound causality component, is such that they can no longer help us predicting the next scenario for disaster. Even serious incidents have become too rare. Risk must be assessed and managed with reference to minor events, which are more and more distant from real physical danger. This implies that front-line operators should report their errors even when they have no consequences. However, as mentioned earlier, front-line operators are reluctant to report error, either due to peer pressure, a fear of losing face or a lack of mutual trust between the staff in the field and their hierarchy.

However, as soon as reporting reluctance has been solved (for example through confidential reporting channels), a second and more fundamental difficulty is encountered. Current safety tools and taxonomies are inadequate to deal with this mountainous quantity of (minor) errors - they would be unable to extract safety predictions.

Virtually, all human actions can result in errors, which can, under certain combinations of circumstances, result in an accident chain. The number of existing errors then far exceeds current data processing capacities. Also, the frequency of each error is no longer a good indication for its potential of danger: frequent errors are often better defended in terms of cognition than rare ones. Moreover, designing a systematic error avoidance strategy for the whole ‘iceberg of errors’ would be unrealistic and naïve, since error is now recognised as an integral feature of cognition and learning.

In ultra-safe systems not only are common-sense safety methods no longer efficient, but even sophisticated techniques can have boomeranging negative effects. Defences can be dangerous and trying to prevent the last accident can well cause the next one. For example, automation has been seen as a drastic tool to eradicate some repetitive errors and in that sense it was successful. However, there is growing evidence that automation has also triggered the emergence of new kinds of errors (poor situation awareness, complacency) which caused some of the recent accidents in commercial aviation. Similarly, procedure-driven approaches to safety (increasing the number of procedures, checklists and call-outs) has also proved to induce a lack of adaptive intelligent behaviour. Consequently, unsafe events and safety failures can no longer be tackled by describing and detecting ‘deviations’ from a linear course of nominal events (unintentional ‘errors’ or intentional ‘violations’). Monstrous disasters in complex systems do not result from monstrous individual behaviour. They rather involve commonplace practices. Operators continuously compromise between conflicting goals: sticking to instructions, getting the job done regardless of adverse conditions, minimising fatigue and workload, preserving some parallel non-professional activities. At some level of granularity they permanently ‘deviate’ as they try, adapt, correct and adjust. After an accident, with the benefit of insight, we can name this deviation a ‘cause’ or a ‘contributing factor’ to the accident. We can inventory all these deviations, categorise them according to their psychological, physiological or sociological production mechanisms and we can feed statistical databases. However, before the accident, without the benefit of hindsight, we need something different.

3. Culture-oriented design is a nice idea, but with no significant content at the time, nor pragmatic solution to cope with. Human factors are still debating on the concept. This is one of the greatest problems to be solved in the near future, especially when considering the growing weight of Asian end-users that are also the most distant operators as compared to the culture of occidental manufacturers. Just consider that one of the most significant contributions to accidents is the poor English of many operators, but even this point, which would seem simple to solve by means of electronic translation, is dramatically complex to implement for legal reasons.

- Some solutions proposed by human factors to improve design and certification could satisfy the industry, but they are nevertheless rejected due to legal constraints. For example, written traceability of decision and experimental testing are considered as unacceptable risks if they are accessible to law, and indeed they are. Another example is the additional time asked for certain human factors procedures. Design and certification cannot be extended. Human factors methods must be suited to calendar constraints.

- The human factors academy and the research management are often naïve and outside the real needs of industry. Too much research is simply criticism of present solutions, without any other solution proposed. In other cases the human factors community assumes that solutions are known, but they only exhibit irrelevant documents on naïve ergonomics. Too many researchers also consider the industry players as being totally ignorant of everything and want to teach these professionals how to design a cockpit, although it is a job they have been doing quite well for decades. All of these reasons contribute to the divorce between aviation industry and theorists, and to the difficulty of finding human factors specialists. Education must be considered as a first priority both for aviation players (in the human factors domain) and for human factors players (in the aviation domain).

2.3.5 Towards Solutions

- New directions for new human factors guidance material and regulations. The JAA and the FAA are debating with industry on a new set of guidance materials and regulations. Up to now the existing human factors regulations are either too general (for example, it is said that ‘the procedure should be consistently executed in service by crews of average skills’ and ‘Dutch roll be controllable with normal use of the primary controls without requiring exceptional pilot skills’) or presupposing that crews are the backup of system failures. There is almost no means for compliance in the regulations, nor definition of the key terms. Also, all the regulations are component related (Flight-Management System (FMS), autopilot or brakes) and do not ask for any global integrated evaluation of the flight deck.

The new Human Factors Harmonisation Group, formed at the end of 1998, should first provide the industry with acceptable means for compliance, including a set of methods to measure crew performance related to system design (crew errors, situation awareness), a set of processes (scenario design, human factors plan in design), and a set of solutions to deal with human factors issues. Regulations will be developed as a continuation of these guidelines, if needed.

In parallel to this harmonization effort another Harmonisation Working Group (JAA/FAA HWG 1329) is dealing with automation and autopilots, with specific concern for the proliferation of autopilot modes and crew alerting in case of automatic mode reversion.

Last, a reconsideration of safety analysis revisiting human error analysis is also expected with some changes in Joint Airworthiness Requirements (JAR) 25-1309.

- New directions for human factors research. The industry is facing the challenge of system complexity. Human factors are expected to give solutions that could maintain the present fragile equilibrium for the next two decades with crews in command, while continuing at a global level to improve safety and performance at a reasonable pace. The situation is not trivial because of the already remarkable optimization of the whole system. Careful attention must be paid to the non-predicted negative interactions of any new solution or to the excessive optimization of all old solutions.

Another point is that most solutions are probably not in the human factors basket nowadays. The human factors community needs to invent or at least to revisit the measurement methods, cognitive modelling, accident modelling and operational understanding. The design of the future datalink and related ATM is the next challenge. Human factors are officially invited to participate, for the first time in the best position. The FAA initiative to dedicate a human factors group in the Radio Technical Commission for Aeronautics (RTCA) initiative is a good example of this new consideration. We cannot miss the opportunity.

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2.4 Automation Strategies: Evaluation of Some Concepts

by Herman B. NIJHUIS, Chairman of the RHEA project, Coordinator Research into Human Factors in Air Traffic Management, *National Lucht- en Ruimtevaartlaboratorium (NLR*), the National Aerospace Laboratory, Amsterdam , The Netherlands

There is a real risk that unsuitable automation concepts and systems could be implemented in the future, if automation and/or change of the ATCO's tasks were allowed to proceed without a detailed understanding of the optimum Allocation Of Functions (AOFs) and tasks to the human and the automated system. Inappropriate automation systems may be unused or under-used by the controller (which is a waste of resources) or, more seriously, the safe and efficient performance of ATM could be impaired.

This risk is addressed by the RHEA (Role of the Human in the Evolution of ATM) project. The project was partly funded by the European Commission (DG VII) and by the RHEA partners (NLR, the Defence Evaluation and Research Agency (DERA), Sofréavia, Airsys-ATM, CAA/NATS).

The RHEA project aims at providing automation strategies which systematically guide the decision process for automating functions in an ATM system to accommodate the growth in air traffic. At the same time safety and efficiency levels should be maintained, or even enhanced, and ATCOs should have satisfying jobs.

2.4.1 Classification of Automation Strategies

In the RHEA project a common **classification scheme of automation concepts** was built, suitable for ATM. It can be used for a coherent and consistent description of any automation concept and the evaluation of specific selection of automation concepts.

Based on an extensive bibliographic review, a list of automation concepts was composed. The different automation concepts identified and their main characteristics are listed in Table 1.

The first concept, autonomous computer or full automation, would by definition not involve any human controller participation. It was therefore concluded that from the viewpoint of RHEA it could not be usefully considered. The last automation concept, Human-Machine Interface (HMI) enhancement, can be considered as intrinsic to all other automation concepts. No further specific attention was therefore paid to this concept. The remaining seven concepts were evaluated with different evaluation techniques in a series of carefully drafted ATM scenarios.

Table 1: Automation Concepts

1. Autonomous computer/ full automation	*Machine acts without informing or interacting with the operator.*
2. Controller as supervisor	*The ATCO monitors the system and intervenes in system dynamics only in exceptional circumstances.*
3. Machine proposals strategy	*The system offers options so as to meet high-level system goals (i.e. solutions), which human is free to evaluate. Riley uses the term 'advisor' to describe the role of a machine providing recommendations (e.g. advising) or suggesting a selection.*
4. Machine aided evaluation	*Solutions are suggested by the ATCO and assessed using computer aids, usually graphical aids (e.g. 'What-if' tools).*
(Dynamic allocation)	*Tasks may be done, at different times, either by human or by machine.*
5. Dynamic allocation with human delegation	*Controller decides when and what task will be done by one or another.*
6. Dynamic allocation with machine delegation	*Machine decides when and what task will be done by one or another. The decision could be based on measurements of human workload or stress, traffic loading, or time.*
7. Dynamic aircraft delegation	*Tactical conflict resolution, for example, is delegated from the ground side to the airborne side.*
8. Cognitive tools	*The system allows the controller to carry out the high-level system functions, such as conflict detection and resolution, but the tasks are helped by the system through the design of cognitive tools.*
9. HMI enhancement	*Improvement of the Controller Working Position (CWP) mainly consists of enhancing HMI without adding intelligent functions.*

2.4.2 Evaluation Results for Each Automation Concept

2.4.2.1 Full Automation

There is no role for the human in a fully automated system, so it was not studied in detail in the RHEA project. ATM studies which attempted to build a fully automated ATC system were all abandoned (e.g. ARC2000). Whether the reason for lack of success is the unfeasibility of the concept or the unavailability of the technique to build such a system remains unclear to date.

- Benefit: complete predictability of airspace capacity and safety;
- Drawback: if system fails there are no fall-back options.

2.4.2.2 Controller as Supervisor of the System

Within this concept, automation is in charge of control. There are still controllers involved but only to interfere during abnormal cases (the machine does not perform its work correctly or there is a total automation failure). Although this concept might be beneficial to the overall traffic in terms of traffic throughput under ideal circumstances, the evaluation was negative from a human factors point of view. Generally speaking, a human is a poor monitor because of the tediousness of this activity. With this concept any system failure can have serious consequences for safety.

- Benefit: keeps indifferent to traffic load and allows productivity and reliability;

- Drawbacks: the concept is deemed not suitable because of de-skilling of ATCOs (no practice of skills necessary for operation if system fails), adverse impact on motivation, poor situation awareness and their related negative impact on safety.

2.4.2.3 Machine-Proposal Strategy

In this concept the machine proposes a solution which the controller evaluates and subsequently accepts or rejects.

- Benefit: decrease in controller workload;

- Potential drawbacks: superficial situation awareness, possible complacency caused by over-confidence in the output of the tools.

2.4.2.4 Machine-aided Evaluation

In this concept the machine does not propose solutions but rather helps the controller to evaluate either the current situation or a solution proposed by the controller. A positive point is that the concept can decrease workload/stress levels. The main concerns were about the controller becoming too reliant on the tool, the trustworthiness of the tool, the possible **cognitive** mismatch between the controller and the tool (it is difficult to communicate the controller's plan to the machine) and the time necessary to use the tool, which could even increase the workload in some cases.

- Benefits: saves time-consuming human resources, remains indifferent to traffic load, never fails to consider side-effects of actions, overcomes any narrowing of situation awareness or tunnel-vision;

- Drawbacks: work overload because of under-confidence in the output of the system, more superficial situation awareness, loss of core skills, loss of flexibility and possible complacency by over-confidence in the output of the system.

2.4.2.5 Cognitive Tools

This is also a machine-aided evaluation, but with tools taking into account the way controllers think, and helping them to organise their work. As this concept fits well in the structure of the current job, it was well accepted. However, there was a concern about the time necessary to use it: selective attention may develop at the expense of monitoring.

- Benefits: no fundamental change in control principles (core skills are preserved, facilitation of acceptance), decreases memory load, saves human cognitive resources;

- Drawbacks: workload overhead when using the tools if they are incompatible with high traffic load, development of selective attention at the expense of monitoring, less global situation awareness, possible complacency by over-confidence in the outputs of the tools.

2.4.2.6 Dynamic Allocation, with Machine Delegation

In this concept the machine optimises the work by deciding at each moment which tasks the controller should perform and by performing the other tasks by itself. However, this concept has some problems that might be too great to overcome, namely the possible ambiguity over what has been delegated, an unpredictable mental workload, the lack of acceptance by the controller (who is not in control).

- Benefits: capacity gain by work performed by the machine, constant controller workload, core skills are preserved;

- Drawbacks: operators are out of control (loss of job satisfaction), risk of poor acceptance, more superficial situation awareness, ambiguity over who is responsible for what at any time, mismatch between system- and controller-behaviour, poor relevance of definition and assessment of workload criteria, impairing of task performance by physiological workload measuring.

2.4.2.7 *Dynamic Allocation, with Human Delegation*

This concept is similar to the previous one, but now it is **the controller** who takes the decision to delegate tasks to the machine. The results were better in this case, but the concerns mentioned above also apply (although the controller is much more in control). Time to use the tool is also a potential problem (capacity is gained only if the tool can be trusted to function without continuous monitoring).

- Benefits: capacity gain by work performed by the machine, the controller is still much in control, core skills are preserved since the controller keeps a performing role;

- Drawbacks: ambiguity over who is responsible for what at any time, overhead of workload over manipulation and monitoring of the system, loss of job satisfaction when tasks are delegated.

2.4.2.8 *Dynamic Aircraft Delegation*

In this concept it is possible for the controller to delegate some control tasks to the airborne side (similarly to the American Free Flight concept). The conclusion was that this may reduce workload and facilitate the optimisation of the routes. But general issues about dynamic delegations also apply in this case: difficulty to build an accurate picture of the ATC situation, uncertainty about how much of the situation is known to the aircraft, possible confusion and misunderstanding on what has been delegated.

- Benefits: possible optimisation of control actions when performed airborne, reduced controller workload, core skills are preserved since the controller keeps a performing role, shared context is increased through explicit coordination;

- Drawbacks: the behaviour of the aircraft can be unpredictable (loss of anticipation and situation awareness), overhead of workload over coordination with pilots and monitoring of aircraft behaviour, loss of job satisfaction when tasks are delegated, ambiguity over who is responsible for what at any time, increased pilot workload.

2.4.2.9 *Human-Machine Interface Enhancement*

A good HMI is essential for each automation concept. An automation concept may be very well thought through on a conceptual level and even be implemented successfully from a systems’ point of view, but if the HMI has not been considered sufficiently there is a big chance of failure of the automation concept (e.g. CINCAT).

2.4.3 What is the Best Automation Concept?

'It depends' is the obvious answer, but on what? Among other things it depends whether the new system is developed from scratch or whether there is an existing system which needs adaptation. The former case is rare, certainly in the ATC field, where evolution and not revolution is the standard. For these rare cases **cognitive tools** seem to be the most promising automation concept. The RHEA analysis associated major advantages and only minor problems with cognitive tools. Although the validation of the cognitive tools concept is far from complete, this theoretical analysis seems to be confirmed in the initial concept evaluation performed in several projects, like the Programme for Harmonisation of ATM Research in EUROCONTROL (PHARE).

In the case where an adaptation of an existing concept rather than the development of a new system from scratch is proposed, the choice for a particular automation concept is less obvious. It is mainly finding the perfect match between the concept of the existing system and an automation concept which solves the drawbacks of the original. The RHEA automation concepts framework provides nine concepts with their respective benefits and drawbacks. This framework can help to perform a thorough analysis of existing operational problems. The resulting list of problems should guide the decision about the required automation concept. Drawbacks of the current implementation can be solved by choosing an automation concept that supplements these drawbacks. Even though this strategy may sound surprisingly simple it is hardly ever used when choosing an automation concept for ATM.

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2.5 Human Factors Integration within Concept Development, Design and Pre-operational Evaluation Phases: A Pragmatic Approach

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2.5.1 Introduction

For many years the human factors community has been seeking to extend its role beyond the evaluation of sub-systems, the identification and post-fixing of design faults and other remedial actions. In more recent times the contribution that human factors specialists can make to firstly, design and then to requirements capture and clarification, has come to be recognised (Kirwan et al, 1997; EATCHIP, 1998). Since the re-structuring of the EUROCONTROL Experimental Centre (EEC) in 1995 into centres of expertise we have been very fortunate in that a human factors specialist or a cognitive engineer has been involved, from the beginning, in almost every project supported by the Controller Working Position (CWP) Centre of Expertise. Since these projects are described as pre-operational we can consider that this means the human factors specialist or team participates in the:

- concept clarification,
- requirements capture,
- design,
- evaluation,

... elements of the life cycle.

This presentation focuses on our experiences and the lessons we have learnt while supporting pre-operational projects such as the PHARE Ground Human-Machine Interface (GHMI; PD1, PD2 and PD3) and the EEC part of the PHARE PD3 Simulation; the EATCHIP III Evaluation and Demonstration project; the Denmark/Sweden Interface (DSI) project, IMPACT (Information Market Policy Actions) and the Generic CWP project. It briefly describes our practice, some of the lessons we have learnt (are learning) concerning the organisation and management of our activities, and presents our current (but evolving) view of good practice in the form of a synthesis with software engineering terminology.

We should stress that most of this experience relates to work in support of research into qualitatively new ATM concepts and is not focused on the quantitative upgrade of existing facilities. The description emphasises development from the human-system interaction perspective.

2.5.2 How we Work – the Human Process (or the Shocking Truth)

Typically, our involvement begins when there is an outline 'ATM concept' or objective (and frequently an assumed technology enabler, e.g. datalink, four-dimension flight-management system (4D-FMS)) and the project is moving from the broad level, at which approval was established, to the detailed level of planning - how it will realise its objectives. The human factors representative, or team, usually participates in defining the detailed project management planning with special input on the human factors / Human-Machine Interaction (HMI[1]) aspects.

The next step involves trying to build a bridge between the general statement of the concept and the detailed level of requirements that are necessary to begin specifying the HMI and operational procedures to be followed. This activity involves operational domain experts, the engineers associated with the enabling technologies and the HMI designers. It usually takes the form of brainstorming sessions, scenario walk-throughs, provocative discussion papers, arguments, reconciliation and finally, temporary exhaustion. The HMI team often plays a supplementary role as facilitator at this stage.

The benefits are:

- a better understanding of the issues and problems which have to be resolved;
- an initial understanding of the roles of the human agents and the working methods they will follow;
- an appreciation of the innovation required. What is new *versus* what we have done before;
- some consensus of the solution strategy;
- and on another dimension, strong team-building and an understanding of the contribution each member can make.

The next step is the preparation of the HMI design and specification itself. The HMI team leads this with access to the domain and technical experts for clarification. Given our particular approach, this is based on understanding of existing working practices and roles and hypotheses about the possible new working practices. This applies to both the individuals and the interactions between team members. Effectively, we design a way of working that we believe will produce the required results. The HMI is designed to **support** this way of working but with a number of important general assumptions.

[1] HMI is normally used in the 'rich' sense to mean Human-Machine Interaction (as opposed to Interface)

- These work hypotheses are only our best guess. Therefore, the interface should not be prescriptive; it should not **dictate** those work practices although it should guide and support them.
- The implementation of the work practices should result in psychologically closed (complete and therefore satisfying) activities.
- We should adhere to known good practice in HMI design.
- There will either be an opportunity to prototype, or an extensive HMI review period following initial software implementation and prior to the main exercises.

The output of this process is the formal **HMI specification** that is used by the software team to implement the system. The HMI specification is typically structured to describe:

- the overall HMI architecture, the governing principles and global element;
- the **basic HMI functions** of most general application (often a reference system on which more advanced/experimental functions are built);
- the **advanced HMI functions** which are only used in some study organisations or controller positions.

This approach has the advantage of allowing implementation to begin earlier, without waiting for the entire specification to be delivered. However, there are disadvantages, which are discussed in Chapter 2.5.3.

Subsequently, software development is somewhat of a black box for the HMI team. During implementation their primary role is to be available to the software team for clarification of the specification. In reality, they spend a lot of time re-working aspects of the specification which are discovered to be flawed, incomplete or technically difficult to implement in the time available.

In principle, the next step involves an HMI acceptance test and audit of the system. This is followed by an 'expert' user-centred acceptance (a test pilot). Following final modifications training of the test-user population is conducted and the trials follow. Once again the HMI team is involved in the training (preparation and presentation) data collection (as observers, as interviewers and as analysts) and the interpretation phases.

2.5.3 What we have Learnt

What follows is a list of the lessons we have learnt. Some of them have already led to remedial actions in the organisation and management of our process (with varying degrees of success). Others have been recognised more recently and are the focus of discussion at the moment. Where some action has already been taken it is noted as a **Strategy**. Where some action is proposed, it is noted as a **Proposal**. In Chapter 2.5.4 we shall try to synthesize both of these into a description of how we currently imagine the development cycle should be. Many of the **Problems** described will be familiar to some of you already. The important element is to try to place these in context and develop practical solutions to them.

2.5.3.1 Requirements Synthesis Problem

Problem

Initial requirements are always incomplete. They have to be elaborated in more detail to bring them to the level necessary to make design trade-off decisions. Typically, they are clarified by examining existing systems, e.g. task analysis, observation. Where the target system or sub-system is truly original this model may not exist. How to conduct a task synthesis in a requirement-driven (as opposed to technical solution driven) manner?

Strategy

Successive iteration with experts of as many different flavours as could be involved. Supported by the development of scenario walk-throughs and the use of 'task logic diagrams' as a shared language and record.

2.5.3.2 Difficulties Associated with Reuse

Problem

Many development processes now formally seek to make systematic reuse of software elements. This has been well supported by the evolution of object-oriented design and programming methods and the use of object and function libraries. In reality, this practice is not confined just to software developments. It is also present in the reuse of procedures and in the Design process, where only 'new' elements are designed and placed in a pre-existing context. There are many arguments to support reuse. It improves efficiency, reduces development times at all phases of the activity and potentially improves consistency and compatibility with existing systems. However, there are some disadvantages that may not be immediately obvious.

The reused elements impose constraints. These constraints:

- are often hidden because the analysis which went into the design of the reused element is not available to the current team. This increases risk and their existence may not be recognised until a late stage. (Biggest problem).
- may be based on a different design philosophy from the current approach. Coherency and consistency may be threatened.

If the reused element does not fit the requirement and has to be tailored, then:

- The time to understand and re-design can be longer than the time necessary to construct from first principles (and this cannot be established until the understanding is done).

- The resulting ‘patched’ version increases the complexity of the solution, you can end up with unwanted functionality. The problem grows with repeated reuse.

Proposal

Reuse must be carefully managed. This includes:

- identification of when and where reuse is happening;

- definition and description of the re-usable components to identify both the constraints they impose and the costs of modification;

- in the longer-term, specific design of the elements for reuse;

- cleaning up and re-structuring of repeatedly reused components.

2.5.3.3 Communication Difficult between Disciplines (General)

Problem

In order to successfully implement a system a wide variety of different factors must be taken into account. This is usually achieved by introducing a range of different skills and expertise into the Design process. Different experts have different, interests, objectives, languages and experience. Communication is not always easy, particularly if the experts each operate as separate layers in the development life cycle.

Proposal

Establish a project core-team that is multi-disciplinary and can facilitate the communication process. While maintaining that different experts have specific responsibility for leading different phases of activity, ensure appropriate participation by other experts, especially those responsible for the preceding and succeeding activities.

Strategy

Employ people who have the tendency to be multi-disciplinary themselves. Seed teams with those with previous experience in multi-disciplinary teams.

Strategy

Seek to establish shared communication languages and methods.

Strategy

Emphasise team building and sharing the overall objectives.

2.5.3.4 Problems of Human-Machine Interaction Specification / Software Design Interface

Problem

An important example of the previous problem of communication between different specialists with VERY different priorities. However, in our particular case, as we improved the quality/completeness of the HMI specifications we eroded the role of the Simulation[2] Technical Coordinator (STC). The STC had formerly taken a very general HMI specification/requirement and effectively performed a compound HMI/software Design process based on maximum software reuse and under important time/effort constraints. As a result communication between HMI design and software design was implicit (within the STC). When the STC became less involved in the HMI design, it was difficult to produce a software specification of the correct type; the HMI specification was not prescriptive enough for the implementation team. It also failed to perform the trade-off between technical constraints and HMI requirements.

Proposal

Clearly establish the **Software Design Process**. Identify roles and responsibilities for HMI designers/specifiers and software designers of the interface. Establish a clear communication process and shared understanding and confidence. Probably implies ensuring that the Software Technical Designer (STD) understands and is fully implicated in the HMI Specification phase. In particular, make sure that the STD understands the priorities, the trade-offs and degree of confidence of decisions made in the HMI Design process. HMI specification should provide a means of communicating this type of information. Once again the need for shared, unambiguous communication is critical. HMI Designers must learn to trust the judgements of the STD. This is one of the most critical interfaces.

Problem

Phased production of the HMI specification, while allowing the design and implementation processes to begin earlier, means that the overall requirement may not be clear at the Design stage. It also means that the STD is potentially, less available for participation in the HMI design and specification.

Proposal

[2] Our EEC development process has inherited a number of roles and terms from the simulation development process, which has tended to dominate internally.

With a clear separation of software design and implementation, it is important that implementation begins only when it is sure that the design is stable. If the HMI design is to be delivered in a phased way then we must ensure that the STD has enough information on the entire system to ensure that the architectural design at least will require little revision. The current suggestion is for the STD to be responsible for managing the dialogue with the HMI design team to a) establish the priorities and delivery of the HMI specification and b) ensure that he has enough global information to stabilise the general design as soon as possible. This may take the form of a 'contract' between STD and HMI specifiers as to delivery time/order versus flexibility in change of direction.

Problem

The sheer size and complexity of the HMI specification. It is very difficult to find all the information necessary and, more particularly to synthesize an overview in order to perform the high-level software design.

Strategy

More involvement of software designers in the HMI Specification process. Try to more clearly understand their requirements and likely working methods.

Proposals

Review formats, examine alternative ways of structuring the specifications. Look to the use of state-transition tables and other process representations. More interactive forms of specification.

2.5.3.5 Time/Resource Estimation and False Planning (General)

Problem

One of the biggest problems in any project management activity. How long and how much effort will it all take? Current estimations tend to focus on the time taken to produce software with the consequence that this is now probably the most predictable part of the cycle. In our experience with the type of R&D activity in which we are involved, it is also one of the shortest. In particular for many R&D processes a project management approach that seeks to define the entire course of the project with equal precision at an early stage is inappropriate (and unrealistic). Some activities **cannot** be planned until the outcome of others reduces the uncertainty associated with them. Attempting to 'stick to the timescales' may lead to the elimination of phases, which can be reduced, when others overrun.

Strategy

Use experience from previous exercises to inform the project planning for new projects to be realistic. Sadly, the resulting 'true' timescales are likely to frighten sponsors. For example, it probably takes 2.5 times as long to prepare an HMI specification, and completely translate it into a software specification as to code it, and do unit testing.

Proposal

Try to change the project management process employed. Elaborate planning at a later, more appropriate stage. Employ criteria of efficiency (other than time) to control process and keep it economic.

2.5.3.6 Sacrificing the Human-Machine Interface Acceptance and Testing

Problem

An important, specific example of the consequences of the previous problem. With our current development paradigm derived from simulation the dates of the formal measured exercises are established at a very early stage in the development of the project. Subsequently, these are very difficult to change because of problems of user (controller) availability. As a consequence, when those aspects of system development which have a high uncertainty over-run, the project cannot be extended. Time has to be recovered by reducing the time allocated to some activities. In general, this is achieved at the cost of testing and, in particular, integration testing and HMI testing and acceptance. Even in cases where the HMI specification planning has identified that it will be incomplete (since the requirements are incomplete) and has consequently defined an extended period of revision and testing, this has been sacrificed to meet deadlines. The result has been that the final tested system is not in a state to achieve its objectives.

Strategy

Change of paradigm, to scaled integration. An example is the DSI project at EEC where the system has been developed on stand-alones and then on a testbed before being brought up to full simulation level.

Strategy

Acknowledge that, in the R&D context a flexible schedule which delivers late is better than a politically correct project which delivers nothing of real use.

Strategy

Improve project management planning, by having a better understanding of the processes involved and by using previous experience to improve estimation of the times and resources REALLY required for various activities. (see below)

2.5.4 How we Think it Should Work: the Formal Version

One of first things we learnt is that having the human factors input earlier is not a cure all. There is a big gap between theory and practice, and learning to apply human factors knowledge to real-world (or even research problems) while operating within the limits that that imposes, is not something that comes easily to everyone. However, when it works well it reduces risk and improves the quality of the final product. Human factors should inform the design of the application as well as the HMI (BIUSEM, 1996). Unsurprisingly, this effort has a cost both in human effort and in the amount of time that must be allocated in the earlier stages of the life cycle. This is consistent with most software development practice that emphasises the value of additional investment in the earlier stages. Further, including HMI expertise introduces additional interfaces between experts and risks to modify the roles of some of the actors in the Development process. In this last section we attempt to put the results of these experiences into a model of 'how we think things should be done'. To make this more generally comprehensible we have tried to put it into a context more familiar to the software engineering community.

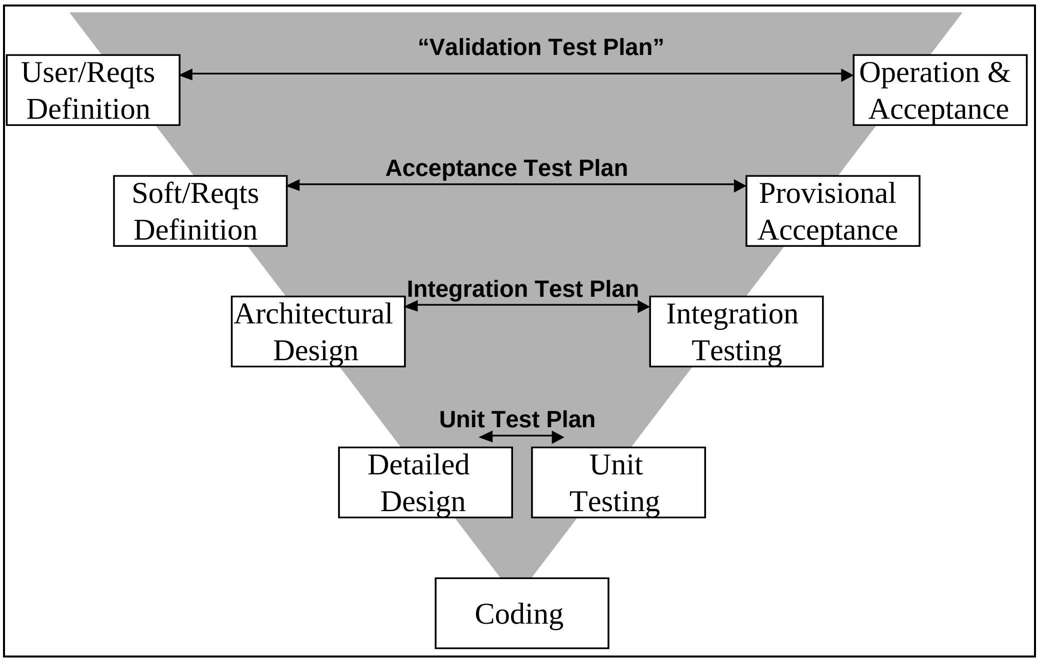

Figure 1: The 'V' Model of the Software Life Cycle (as employed at EEC)

2.5.4.1 *The Basic Software Life Cycle*

Let us consider a common view of the software life cycle, the 'V' model as shown in Figure 1. A detailed exploration and justification of this diagram can be in Elliff & Lott (1992).

There are a number of important points to note.

Firstly, the process of descending the left branch of the 'V' in Figure 1 is not necessarily a simple linear process; there may be a number of iterations at each level (e.g. feasibility studies / prototypes, especially in the earlier phases). There are also feedback loops between levels, that is constraints identified at the detailed design level may force revision at the software requirements level. These characteristics also apply to the expanded diagram in Figure 2.

Secondly, the descent is not simply a process of increasing the level of specificity of the requirements until the coding (or construction process) begins. It involves the introduction qualitatively different types of requirement at an appropriate level. It is also a process of communication and transfer of responsibility between different agents and expertise. Requirements are not only refined and clarified, they are translated (transformed) into representations suitable for the processes to be conducted in the next phase.

Finally, it is important to re-iterate the importance of the role in establishing criteria and test plans for correct performance at each level. It is the quality and rigor of these that will determine the probability of successfully ascending the second limb and arriving at an integration that achieves the overall objectives.

The principal human factors contribution is concentrated at the ‘User Requirements Definition (URD)’ – and pre-'operational and acceptance' levels of this model. It consequently feeds down into the lower layers, but through a process of transformation. The functions associated with this URD layer are typically (Kirwan et al, 1997):

a) elicitation of user requirements,
b) determination of the operational environment,
c) classification of requirements by degree of necessity,
d) identification of relevant constraints,
e) definition of acceptable performance and accuracy (capability),
f) description of the human-computer interaction,
g) feasibility studies.

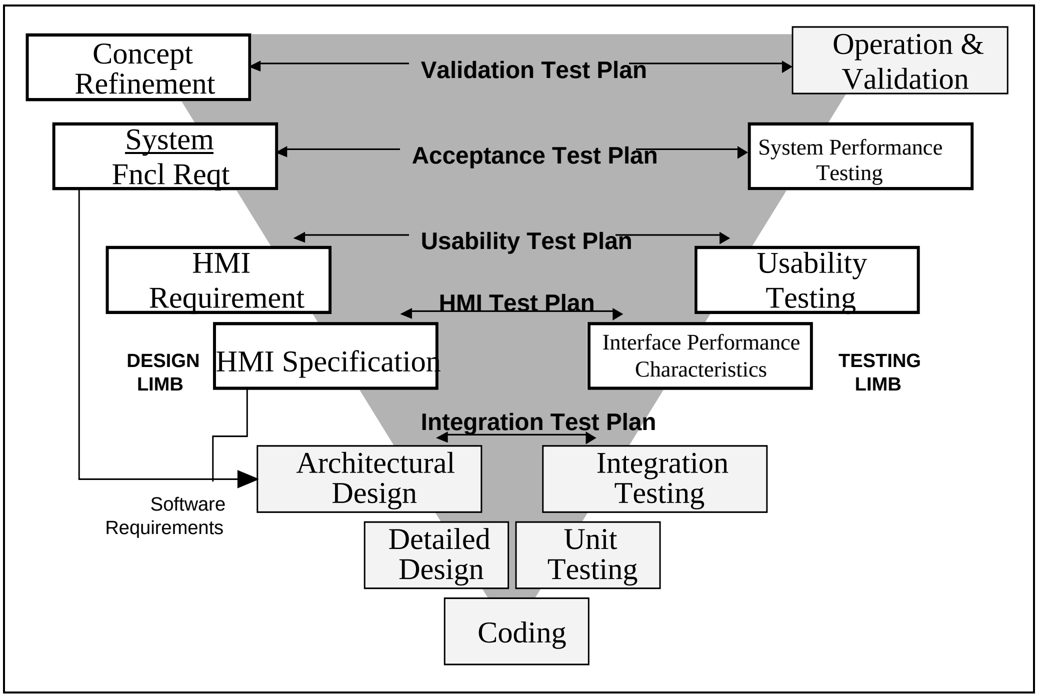

Figure 2: The Augmented 'V' Model

Traditionally, the human factors role would have been principally associated with the upper right hand sides of the 'V' model where the usability and the acceptability of the system are assessed.

2.5.4.2 The Augmented 'V' Model: Key Elements

Our view essentially represents an expansion of the URD phase into a number of layers which fulfil the functions listed above (the objectives remaining unchanged). This is shown in Figure 2. These layers also imply certain dependencies, resources, methodologies and consequences for the testing limb of the 'V' (on the right-hand side). We have attempted to summarise these in Table 1 along with actors involved and their roles.

Table 1: Dependencies, resources, methodologies and consequences for the testing limb of the 'V' Model

	Phase	Function	Products	Target Audience	Led By	Actors	Possible Methods & Tools	Test Implications
REQUIREMENTS	• Concept clarification	• Elaborate concept	• Scenarios • Task model	• All, especially sponsors, clients • Project core team, HMI analysts and designers	• Clients or project leader (or human factors as facilitators)	• Operational domain experts • Technical domain experts • HMI analysts	• Task analysis • Predictive task analysis • Task logics • Brainstorming • Supports, etc.	• Pre-operational evaluation criteria • Performance • Completeness, • Stability, concept acceptability
	• System functional requirements	• Establish consensus on system requirements • Identify objects of discourse	• System requirement document	• HMI analysts and designers • System designers • Client to check	• Project leader	• Operational, HMI analyst • Technical domain experts	• TLDs • Scenario walk-through • 'Crude' prototyping	• System performance criteria, system acceptance test plan (e.g. capacity, safety)
	• HMI requirements	• Introduce agent roles, human and system responsibilities • Define objects of interaction	• HMI requirements document • Job design/team and role design • Outline procedures	• HMI designers • Operational domain experts • Technical experts	• HMI analysts	• HMI analysts • Project leader • Operational staff • Technical domain experts, HMI designers	• TLDs • Functional matrices	• HMI test plan, HMI acceptability, usability, learnability
SPECIFICATION	• HMI specification	• Introduce HMI/HF and usability design constraints into the design	• HMI specifications (may include illustrative state-machines and prototypes) • Detailed definition of procedures	• System technical designer • Responsible for the software design	• HMI designers	• HMI designers, • System technical coordinator • HMI analysts	• HMI guidelines • Rapid prototyping and test • Human perfor. models • Experience.	• HMI response times, readability, predictability, completeness • Stability and robustness
	• Architectural design	• Integrate with other software technical reqts, architectural, resource constraints, etc.	• Software design document.	• Software implementation team • HMI	• System technical designer	• STD, HMI designers (for clarification) • STC/Software implementation team	• Appropriate O-O • Software design methodology	• Technical integration • Testing
	• Detailed system design	• Unambiguous specification	• Software specification • Detailed design	• Software implementation team • HMI for checking	• System technical coordinator	• STD, HMI designers (for clarification) • Software implementation team	• Appropriate specification support tools	• Unit testing
	• Coding	• Produce code	• Unit applications	• STD/all	• Software team leader	• Team, STD and HMI available for clarification	• Software development tools	• Sub-unit testing

Three Main Phases: Requirements, Human-Machine Interaction and Software Implementation

It should be re-emphasised that the following expansion of the model concentrates on the design of interaction intensive software systems, i.e. dominated by HMI activity. Our experience has also been mainly derived from the realisation of pre-operational concept evaluations. Issues of operational robustness and reliability do not feature except at the concept level. However, there is every reason to believe that the discussion is applicable to most system development.

The augmented model can be considered as having three main layers. Within each layer are a number of activities:

- The first layer is that of **Requirements**. Where these are identified in general terms, the criteria to be met are established and eventually, testing will decide if the resulting system is acceptable and operationally valid. The phases on the design side are identified as **concept refinement** and definition of **system functional requirements**, i.e. exactly what it is this system has to do, in what context and within what constraints. The testing will assess the final system as to how well it fulfils these requirements.
- The second layer can be thought of as **HMI Design and Assessment** (not just interface). It identifies how the system is going to work as a machine-supported human activity and defines the jobs, roles, procedures and the human-machine interface necessary to support them. There are two phases, the device independent **HMI requirements** and the **HMI specification**. It delivers the specification as a major part of the conventional software requirements process. Testing addresses **usability** issues and **interface performance** characteristics.
- The third phase is **Software Design, Implementation and Assessment**. The HMI specification is employed as requirements for the **software design** document. This is then developed in the **Software Specification** phase, prior to **implementation, unit testing** and **integration testing.**

Actors

There are a number of roles that fulfil key functions. Depending on the nature of individual skills, more than one of these roles **may** be conducted by the same person (typically, HMI analyst and designers are the same person). For the sake of simplicity these will be described as belonging to different **Actors**. Some of the actors lead activities. These are:

- project leader,
- HMI analyst,
- HMI designer (and specifier),
- STD (and software technical specifier)[3,]
- implementors.

[3] Replaces the STC described earlier with slightly different and more clearly defined responsibilities

Others are essential to the function and validity of different activities:

– domain/operational experts,
– related technical specialists.

Their roles and responsibilities are summarised in Table 1.

The two most important points to observe are the **overlap** in participants between stages and the **participation of all the skills** in the initial requirements and high-level Concept and Design stage. This allows both improvement in communication at subsequent stages and the anticipation of possible constraints at an earlier and less costly stage of Design. In general the lead actor at any stage has the additional duties of providing ‘constraint’ information to the preceding stage and ‘monitoring the validity’ of the following stage.

Key Communications Interfaces

The key communications interfaces lie at the boundaries of the three layers and are the subject of special attention. We suggest that it is the specific responsibility of the HMI Analysts and the HMI Designers to ensure that the correct aspects of the system have been captured and communicated onwards, i.e. that the interaction design will be valid. This interface has been the subject of much attention in the development of the user-centred[4] design paradigm. Similarly, the interface between the interaction and the software is the special responsibility of the HMI specifiers and the System Technical Designer. This is an area that we feel has not yet received enough attention; for instance, we are actively seeking to improve the quality and nature of our HMI specifications and dialogue with software designers.

The communications interfaces are active in both the design and the testing limbs, and in each case the ultimate responsibility lies with the receiving partner.

Methods and Tools

While it is possible to enter a long discussion to suggest specific methods and tools for each layer, it is more important to emphasize the roles which the tools and methods must help to fulfil. Amongst the most important are:

1. Support for the specific activities and objectives of the phases.
2. To be comprehensible to all the actors operating within a given phase.
3. To act as communication language between the phases.
4. To assist with tracking idea, changes and the consequences of changes.

[4] ‘Centred’, is used to describe where the users activities, representations and needs are analysed as essential elements of requirements and design. This is opposed to both technically-driven design and user-driven design, (where the client dictates the solution).

2.5.5 Summary

This brief paper tries to relate the experiences of Human Factors personnel who have been involved in the elaboration, and evaluation of experimental ATM systems to the identification and resolution of difficulties in the development life cycle of such systems. The results are presented as an augmentation of the 'V' model.

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2.6 Human Factors Integration in Aeronautical Research: Experiences, State of Progress and the Future

by Peter G. A. M. JORNA, Head of Man-Machine Integration and Human Factors, *National Lucht- en Ruimtevaartlaboratorium (NLR)* - National Aerospace Laboratory, Amsterdam, The Netherlands

2.6.1 Experiences or: The Good, The Bad and The Ugly (Clint Eastwood)

The famous title of this western film could represent the state of discussions with respect to the role and value of human factors in many ways. If we consider Human-Machine Interfaces (HMIs) there are not many around that everybody would rate as good; experience in real life has shown that some were really bad and the well-known discussions on use of colour, etc., proved that cultures still have quite different viewpoints on what is ‘ugly’ and not. Human factors has all to do with people and that is where the trouble starts. People behave differently, have opinions and do not agree with each other all the time. However, still complex creations like aircraft, ATC and ATM systems, are being designed, used and maintained all over the world. Perhaps not perfectly, but they are out there in the field. So apparently there are means to accomplish such challenges. The keywords seem to be ‘teamwork’ and ‘economics’. In that respect this movie title often refers to the ‘other players’ in the game, who do not understand anything or only think about the money. They are the bad and the ugly. You are the good.

Anyway, as people are involved in all aspects of aviation, one would expect that human factors people are more than welcome. However, as already mentioned by other speakers, nothing can be taken for granted. The science is supposedly good; methods and techniques are certainly not bad and who is ugly anyway? Perhaps the latter factor explains why an increasing number of females is entering the field of human factors. So one issue to address in this workshop is:

What are the main factors, if any, holding back human factors integration?

Is it the science, lack of theories, too much theory, the money, lack of teamwork or what? Who can and will tell?

In an attempt to follow the ‘open and provocative’ format as requested by the organiser and illustrated by a fellow speaker from a user viewpoint, I will try to inform you about the developments in human factors as experienced by myself in the recent years. Normally, we do not do that in papers, so forgive me if I step on some toes or do something else wrong. No offence, it is with the best of intentions!

In an attempt to find some answers, I entered, some nine years ago, the high-tech world of aviation at NLR, an institute with the finest of engineers and a long history of supporting the design and operation of aircraft and ATC systems. My background was psychology with an emphasis on human performance under extreme or demanding working conditions. I was going to encounter some demands myself!

I will now try to point out some of the (least embarrassing) lessons learnt from the perspective of a behavioural researcher who found himself caught in an aviation engineering environment.

2.6.2 An Englishman in New York (Sting)

This song title (I hope it is known worldwide) is compatible with the feelings I experienced. On the one hand you did belong there, on the other hand not. On my first day I was presented to a NLR team assisting the controllers that worked on the prototype of the new ATC system for Schiphol Airport. It was named ‘AAA’, meaning something like ‘Advanced ATC system Amsterdam’. As I was very much involved in military research before joining the NLR, I immediately recognised the acronym as ‘Anti-Aircraft Artillery’, a nice name for an ATC system! The joke, meant to relax the situation, did not work out that well ...

So I was introduced: ‘This is the new ergonomist and he knows everything about the use of colour.’ A very colourful display lighted up after switch-on and the next question was: ‘What do you think about the colours?’ As a trained person in handling interpersonal relations (the colours were really amazing), I gave the answer: ‘That depends on what you want to achieve with it’. Wrong answer. In an attempt to break the following silence, I tried to find out on what (theoretical) basis or concept the design was produced. The answer was: ‘None, we wanted to test the technical display capability for reproducing colours. It is your job to advise us on what to use where.’ Ah! now we are on familiar ground! ‘Oh! You want me to do the task analysis?’ Wrong answer again. They knew about that stuff; a lot of work and paper and you cannot do anything with it. The controllers know all about their jobs and these so-called human factors specialists will contradict each other anyway!

So the outside world perceived human factors specialists as contradicting each other. Is that still the case or not?

This was the first step in learning the hard way that the approaches towards ‘technical’ validation as compared with ‘behavioural’ validation can be quite different.

The next day I talked to an engineer who was designing new methods for future ATC including the now famous datalink. He was very friendly and mentioned that the datalink communication needed to be completely ‘transparent’ to the controller. That is my kind of guy! So I assumed that transparent meant inclusion of feedback to the controller concerning information on ‘Was my message sent?; ‘Is somebody doing anything with it?’; etc.’ It took some time before I found out that he actually meant that there would be nothing to see. When I protested, he felt offended! It was his personal professional pride to design a system that could be trusted, and I should not worry. ‘Furthermore, we are going for full automatic ATC anyway, so why waste time on incorporating feedback now? We need you for facilitating the transition to this future. Our sponsors want to save money and that can be accomplished by reducing the staff.' So I and others would be out of a job soon. Much to my surprise I learnt that the design goal (at that time) was to get the human out. Nobody was really interested in the controllers workload, except getting it to zero. That had to change! So we learnt that:

Design goals can vary as a function of perceived economic benefit and depend on who controls the research funds. The well-being of operators is not always a prime concern. Just pay them more when the work gets harder. How do we influence the sponsors' allocation policies?

After that I talked to a guy from the flight department in an attempt to get access to the research aircraft. I wanted to study controls inputs in-flight, so I could compare them with those found in the simulator. He responded: 'So you are really spending a lot of time on human factors?' I thought it was simply a matter of using a little bit of common sense! It is still a miracle that I did not quit.

So we tried harder to convince the community that people can perform far better when provided with the right tools, and that it takes a little bit more than common sense. We had to counter the argument that automatic systems would be superior by definition. The standard answer was that the tools designed were OK, but that some people simply used them incorrectly. So that is a matter of training and selection. That is for other people to take care of. But design and training requirements are interrelated! It is all in one ball game! The prevailing perspective at that time was that the design was done by engineers and that human factors would be involved in some usability tests and in providing the finishing touch (nice to have, no need to have). After that you get stuff like CRM training. So we quickly learnt that there was confusion about what human factors actually is and what it can do as a discipline. Furthermore, the human factors approach appeared to be 'too academic' and did not fit the project-based, time-driven approach used in the more pre-industrial environments. Depending on who controlled the funds you could have different perspectives on such projects. So there are essentially three major drivers still active or latently luring for control:

Technology-driven projects were followed by customer-driven projects. We need more user or human-centred projects. Do you agree and if so, what is needed to make it really work?

I quickly discovered that I was not the only one confronted with and confused by the discussions on the way forward with automation in aviation. Some excellent advanced-study institutes were set up by the North Atlantic Treaty Organisation (NATO) to work on the topic. Many disciplines were present there and the meetings really helped to come to terms with each other. So many friendships were founded that facilitated progress. It is up to the participants of this workshop to decide if indeed some was made. If you are interested in my earlier experiences and those of others have a look at the NATO ASI books (Jorna, 1991 & 1993).

Let us now review what happened by then, in order to understand why we are where we are. We will start by reviewing why human factors are supposed to be needed anyway. Apparently, the well-being of human operators was not always a major driver, so why bother? The next title will be the last time that I use a song title, so do not worry!

2.6.3 Status of Progress or: the Times they are Changing (Bob Dylan)

Within aviation human factors is often related to the occurrence of accidents. So-called ‘human error’ is reported as the major factor in accidents and incidents. Within the design of aircraft it was often possible to develop more or less ‘fail safe’ designs, meaning that, when a failure occurred, some structural integrity would still remain. With humans it proved more difficult to control their inherent variations in performance due to various factors like fatigue, distractions, mental overload or under-load, and the individual differences in aptitude and competence. Increased automation was a strategy to reduce dependencies on the human operator. However, limits in technologies often necessitated the use of a human as an ad-hoc backup in case the automation failed, showed bugs or received erroneous data.

Humans functioning like system monitors are not effective and, in such cases, it is difficult for them to maintain the required levels of attention and system awareness. Therefore, the strategy of designing ‘around the human’ in order to exclude human limitations is being substituted more and more by a design philosophy emphasising the strong points of human capabilities, such as flexibility and the ability to adapt to changing or unforeseen circumstances. This type of engineering aims to create working conditions and tools that are more compatible with human goals and expectations. The new strategy is known under the name of **Cognitive Engineering** (for an overview see Sarter & Amalberti, 1998).

Human errors are never made intentionally. Opponents to the idea of a ‘fallible human’ argued that in many, if not most cases, it was not the human limitations that contributed to an accident directly, but more the quality of the information available and its accessibility through the (first generation of) HMIs. Given the important and nowadays accepted role of humans even in the future system, **there is no alternative than to realise major improvements in this area.**

Next to accidents human factors problems emerging during the life cycle of a product can have other negative effects on the overall industry, as summarised in Figure 1.

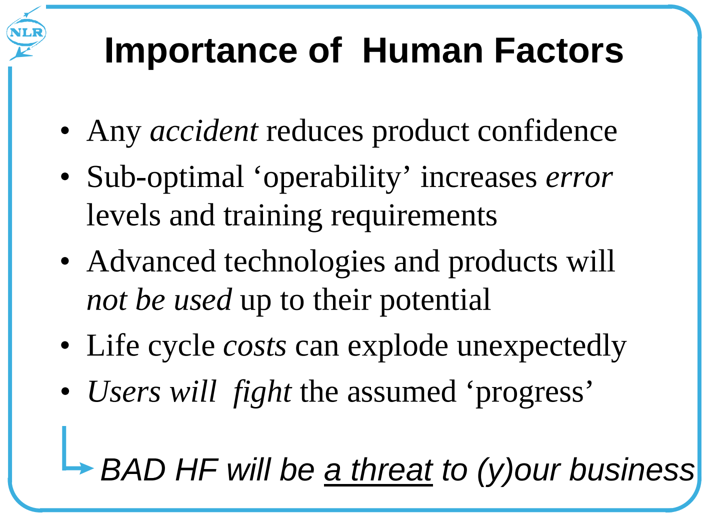

Figure 1: Summary of major problems that occurred in cases where industrial products proved to be hampered by human factors related problems

With a fully defined and manufactured product, any change to be made later on, as required to improve its 'usability' or reduce its potential for errors, will be very costly. Traditionally, training has been a (last) remedy for familiarising humans with the limits of a system, providing work-around and specific procedures. Customers like airlines or ATC providers, or even individual users, seem to have problems with such an approach. Re-training thousands of personnel is very costly, and individual consumers do not seem to be willing anymore to study thick manuals before enjoying the benefits of newly developed software. Therefore, more 'intuitive' HMIs are pursued as such types of interface would not require such extensive preparation. Note that it is a buzz word. The challenge, however, is to find and implement these solutions quickly enough to be integrated in a competitive, short 'time to market' scenario.

2.6.4 The 'New Age' Human Factors Discipline

Traditionally, human factors was a typical research topic for behavioural sciences like psychology. Within aviation, aircraft handling characteristics posed a challenge to engineers for designing control characteristics that allowed pilots to comfortably fly airplanes. The intrinsic delays in human neural information processing can, in relation to similar delayed aircraft responses, create oscillations that threaten manual control over the aircraft. The physical sciences developed manual control theories and models that influenced most aircraft designs. Behavioural sciences addressed overall workplace design and issues such as training and selection of operators. Both behavioural and technical disciplines therefore address human factors with different scopes and methodologies. The variabilities inherent to human performance and its unpredictability made it an ordeal for engineers to capture it consistently in a model, while the same variabilities were a play ground for behavioural methodologies using a more statistical approach.

Both disciplines met again with the advent of the automation revolution. Instead of resolving many of the assumed weaknesses in human behaviour, operational applications revealed **unexpected new problems with automation**, especially with human-computer interaction, sometimes at the cost of unfortunate accidents. However, automation provided many benefits, also to safety. It is the challenge of the future that requires the disciplines to work together in an attempt to both adopting the lessons learnt and preventing problems when introducing even more advanced technologies. A first step is to prevent an institution such as a 'human factors' police that controls the lawful application of its heritage; a second step is to become a better part of the teams that have created one of the safest transport systems around. Some of the main characteristics of such a 'new age' human factors discipline are summarised in Figure 2.

It has to be realised that, although the human factors discipline is ready to contribute to new designs, its knowledge is essentially based on 'human behaviour in the past'. As the more advanced transportation systems will involve many new and unfamiliar aspects, **unexpected user behaviours will occur** as was learnt in the same past. The Design and Validation process will therefore need to be adapted in order to 'learn before the accident' instead of relying on approaches learning from the accidents themselves.

Merging the disciplines is however more easily said than done due to some inherent and fundamental differences in approach, as discussed earlier. A technical design is only released after a thorough Validation process, but compared with the human factors discipline, remarkable differences exist with respect to the methods used. As an example, no behavioural scientist will accept a 'demonstration' of technology as sufficient evidence for an effective design, unless a sufficient sample of subjects (representative for the users) has been used. On the other hand industrial engineering teams fear the costs of such extensive experimentation and the impact of possible time delays. Therefore, bridges have to be built in order to meet the challenges ahead.

Figure 2. Brief description of the human factors discipline

2.6.5 Bridges and Tools under Construction

The experiences described earlier when attempting to assist the design of a new ATC system typically involved a near-operational system. Therefore, many ergonomics details prevailed, such as assisting with the finishing touch to input devices, colour schemes, console layout, seating and lighting arrangements, etc. These services were delivered on a request basis. Being practical is good, but, in certain cases, earlier design decisions put restraints on the options still open. However, the system came into operation recently and the controllers are now adapting to facilities like touch input devices, tracker balls, new automated functions and consoles. The major lesson we learnt from this period is that human factors methodologies needed to become more practical, knowledge more accessible and psychologists more operationally capable in order to sell the benefits or value for money to third parties.

Within our laboratory we took the following actions:

- **Simplify task analysis procedures**. Operational researchers use mission and task analysis, HMI designers use something similar to derive task-based requirements, and training experts use it to define skills. Their perspectives differ, but the methods are much the same. We integrated them into a single process, so that it can be reused and communicated more simply to serve as a guideline for (training) design teams.

- Create a **condensed human model** that is structured in such a way that it allows an easier transfer of complex theories to practical applications, while retaining a sound theoretical basis and a task-based approach. This S-P-R-c model supports the specification and design of information displays (Stimuli), the decisions and choices needed (Processing) and its output (Response). Keeping an overview of the process, awareness if you like, is closing the loop ('c' stands for 'controlled executive') by feedback and memory support. The model is highly compatible with in-output relations used in software design, etc.

- Include **working procedures** as an integral part of the design.

- Develop **objective human performance and workload measures** to reduce the possible fallacies of over-relying on subjective evaluations.

- Create more flexible **cost-effective facilities** for simulating and prototyping HMI and automation applications designs.

- Establish **multi-disciplinary teams** within the human factors department consisting of various kinds of psychologists, engineers, software specialists and training designers.

The PHARE program was one of the first that provided an opportunity to create a new role for human factors, namely creating an international team that had to **design and deliver** the human interface to other projects responsible for coding and simulation. In this so-called Ground Human-

Machine Interface (GHMI) project the operational concepts were not exactly clear, but the development of advanced software tools was well underway. So we were lagging behind a bit. The project proved to be successful in creating several (sometimes a bit daring) HMI specifications that were implemented and demonstrated in the PHARE Demonstrations PD1, PD2 and PD3. Many new concepts and ideas could be tried because this project addressed the development of a pre-operational system. So alternatives for electronic strips were implemented, colour schemes were standardised, what-if tools added, etc. Many lessons were learnt, the major ones being a need for a more effective translation of a specification to actual software and the other one that human factors prototyping is very difficult in such a time-driven project. The available design tools were totally insufficient (also based on designs from the past). The design team varied in composition over time, but two of my fellow presenters at this Workshop were involved all or most of the time. The design issues will be addressed by Mr. Jackson and Ms. Pichancourt, EEC, and some of the automation issues by Mr. Nijhuis, NLR.

Figure 3: Example of an operational and a prototype PHARE GHMI version

Whatever your personal opinion may be (do not take the picture above as a reference as it could reproduce poorly), it is safe to conclude that the GHMI project was successful in advancing the state of the art of ATC HMI design and implementation. Its interfaces are now fed into the EATCHIP and other programs, and also the National Aeronautics and Space Administration (NASA) and the FAA showed considerable interest in adopting some of its principles. The project will finish this year and will end the existence of one of the most hard-working teams I have ever encountered as a project leader. Their conscientious work cannot be overestimated.

2.6.6 Some Results

2.6.6.1 Integrating Human-Machine Interface Design and Human Data Measurements

The following (raw) data can be obtained nowadays to evaluate human performance, workload and effort, situation or traffic awareness, as well as systems awareness and user preferences:

- Sampling of visual data on displays by ‘Point of Gaze (POG)' head-mounted eye trackers calibrated to the particular simulator in order to depict active use of the displayed information. The system provides the following information in real time, with a sampling rate of 50 Hz:
  - ⇒ POG, expressed in X and Y coordinates relative to the viewing plane;
  - ⇒ Fixation dwell time, in msec;
  - ⇒ Millisecond-accurate time stamp (i.e. starting time of fixation) to permit referencing to simulation events;
  - ⇒ Transitions between display elements and other displays;
  - ⇒ Surface identification, for translating pre-defined planar coordinates into viewing surfaces;
- Pupil diameter, supporting mental effort evaluation.
- Analysing changes in heart rate to assure that the information ‘looked at’ is also actually processed by the crew or controller in order to make sure that information is also ‘seen’.
  - ⇒ Heart-rate changes are linked to events in the scenarios to study ‘event-related’ responses.
- Calculating Heart-Rate Variability (HRV) to monitor the mental state and effort exerted during the processing of the information.
- Analysing vocal communications within the crew or between controllers as well as communication outside. So-called voice keys (electronics that indicate both onset and duration of speech) are combined with ‘press to transmit’ switches to discriminate between types of communications like internal or external.
- Recording respiration to control for breath holds influencing heart rate and control over the occurrence of murmured speech not detected by voice keys.
- Other detailed measures on project specification, like electroence-phalogram (EEG), blood pressure, etc.

- An extensive battery of questionnaires and subjective ratings depending on the goals of the study, but standard workload ratings are always used.

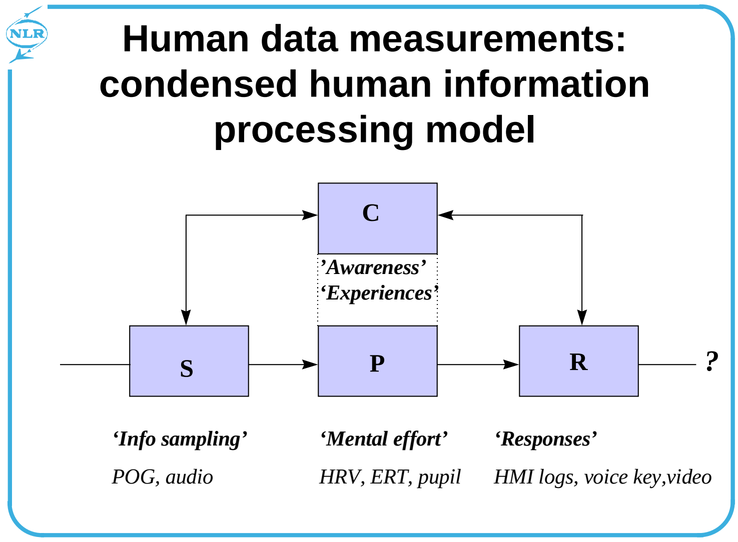

Figure 4:Condensed Human Information Processing Model

With this set of measurements it is possible to quantify the use of information displays, measure head down / head up times, sampling strategies, etc., complemented by the corresponding physiological effort and subjective feelings. All data are logged on a single time base to allow for so-called event-related measurements. More fuzzy concepts like situation awareness, etc., are quantified by multiple means involving specific measures for looking at traffic (traffic awareness) and complemented by interviewing methods, etc. The data cover all stages of human information processing from perception, processing to action and keeping a cognitive overview. These facilities can be used to support and complement the ATM Validation process. Remember Mr. Jackson's remark that specifications are not necessarily correct.

2.6.6.2 Tools for the Air Traffic Controller

Air Traffic Control Datalink

Datalink communication can involve computer-computer interfacing as well as air-ground human operator communications. Pilots can request route changes, ask for information, etc., while the controller can detect possible conflicts in the future and provide the aircraft with instructions. Finding and implementing a solution in the present day systems often requires vocal communication with the pilots as well as inputting data (the instructions) into the ATC computers in order to display the overall status to the controller.

A datalink user interface can accommodate both these functions at the same time. In an experiment different versions were developed and implemented for testing under high and low traffic loads (Hooijer & Hilburn, 1996). The datalink can be implemented as a separate communication window on the controller's display or as an integrated part of the so-called radar plot symbol that is associated with a particular aircraft. Examples of such pop-up menus are depicted in Figure 5.

Similarly, the feedback of actual status of the negotiations with the aircraft need to be provided as datalinks have a time delay in transmitting the data, depending on the particular medium used, i.e. radio frequencies, radar signals, etc. The feedback can be provided through different means, for instance, integrated with the radar plot data block or as a separate communications window. Examples are shown in Figure 6.

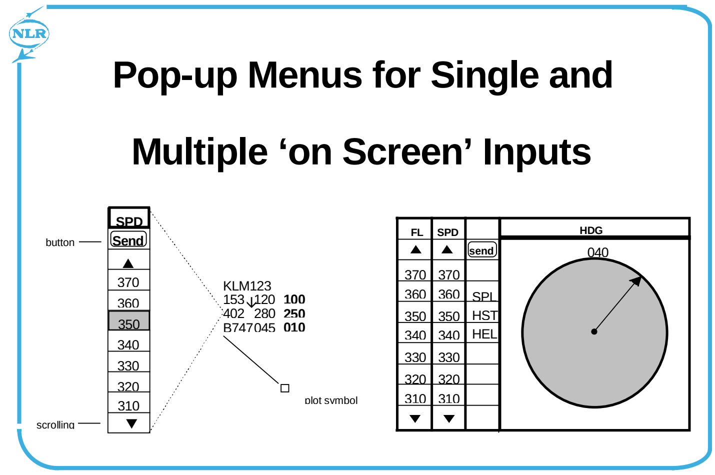

Figure 5: Examples of datalink user interfaces that allow direct selections and transmissions of solutions of problems and instructions to the aircraft

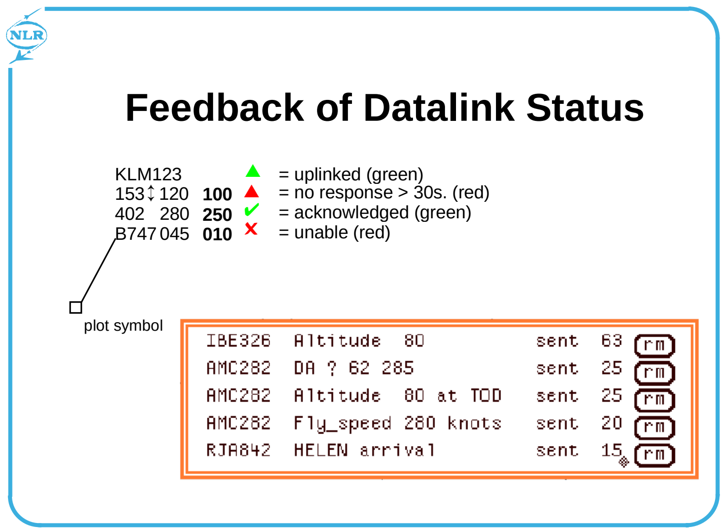

Figure 6: Examples of means for providing feedback on the datalink status for communicating and receiving confirmations from many different aircraft

From these options three combinations were designed that will be designated as user interface combinations 'A', 'B' and 'C'. The mapping of the particular features that were combined is as shown in Table 1:

Table 1: Particular Features

Condition	Input Method	Feedback
A	pop-up menus	Datalink Status Panel (DSP)
B	pop-up menus	label symbols
C	combined pop-up menu	label symbols

The conditions A, B, and C were intended to represent an increasing level of integration of task elements and feedback onto the screen of the Air Traffic Controller (ATCO). The higher the level of integration, the lower the number of on-screen search actions or required subsequent integration of data into task relevant information. However, these options have different disadvantages. As an example, the datalink status window will change in content (ir)regularly, thereby attracting the controller's attention at a time when such information would not be strictly required for mental processing. Alternatively, the pop-up or better, pop-down menus of the radar data block can obscure some of the other traffic data, although at a moment selected by the controller who decides to take an action.

The experiment used the following measurement techniques: eye POG measurements, head tracking, pupil size, heart rate and respiration, HRV, logging of system inputs and responses and extensive use of subjective ratings. The subjects in this experiment were professional controllers.

The results showed the following:

HRV normally decreases when working under conditions that are cognitively loading or stressful. So a user interface that is easier to work with should result in a relative increase as compared to more cumbersome interfaces. However, no very explicit results were expected as HRV is especially sensitive to more extreme overall working conditions resulting in particular distinctive mental states associated with levels of mental work and/or stress.

The results obtained in this experiment proved promising as indicated in Figure 7.

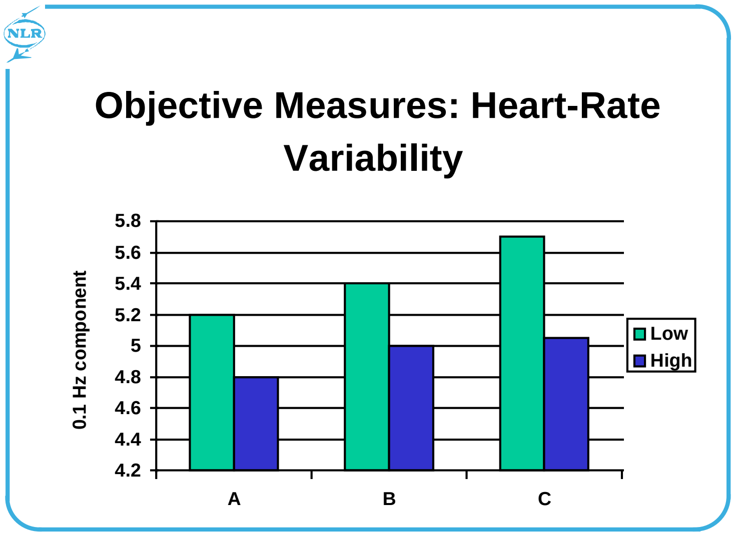

Figure 7: HRV increase, indicating lower workload, as a function of controller datalink interface and traffic density

The impact of traffic density on HRV is quite consistent, and, rather to our surprise, also quite distinct for type of user interface. Also, as an experiment the pupil size was calculated and analysed. The results of this initial analysis are depicted in Figure 8.

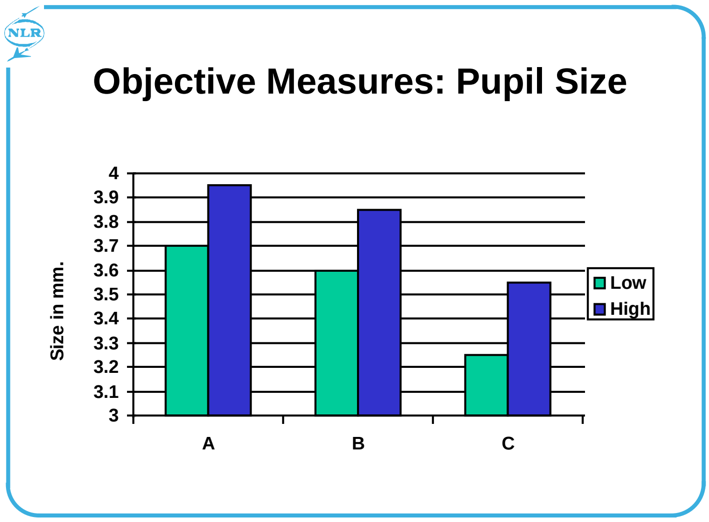

Figure 8: Pupil size decrease, indicating lower visual workload, as a function of controller datalink interface and traffic density

The size of the pupil(s) is normally modified by physical factors like the amount of light present, but it can also be influenced by the required visual information sampling and mental processing of visual data. In this case its size will 'increase' as a function of the amount of visual information processing.

The results indicated that accurate measurements of small differences in size can be realised. Similarly to the HRV data, the pupil indicated lower workload as it decreased in size as a function of level of integration in the controller datalink interface. Conversely, it increased markedly with an increase in traffic density (difference between low or high traffic samples). Note that more traffic implies more radar plots on the screen which should tempt the pupil to downsize as a function of amount of light in the display. An example of the subjective ratings provided by the controllers is summarised in Figure 9.

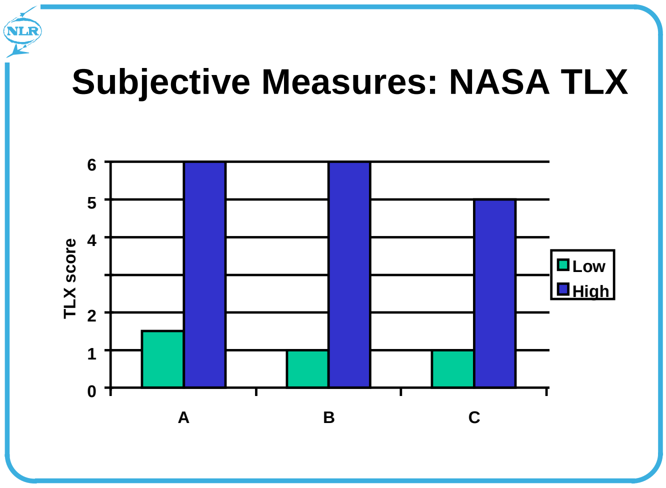

Figure 9: Ratings provided after the experimental sessions as a function of controller datalink interface and traffic density

The subjective ratings displayed a marked sensitivity to the amount of traffic present, but revealed a much less spectacular difference between user interfaces. So in this experiment the objective results all pointed to the possibilities of designing effective controller datalink interfaces, but the subjective data did not reflect this to the same extent.

2.6.6.3 Software Assistance to the Controller

The mental processing capabilities of the ATCO are generally considered to represent a major bottleneck in expanding the amount of air traffic. One reason is the communication process that is of a serial nature and has to address each plane individually. Also, the controller has to build an overview of the traffic streams in order to be able to predict and anticipate possible separation issues. In case of a possible overload, the traditional procedure is to subdivide into multiple sectors, so more controller teams can share the work. The disadvantage is, of course, that the communication requirements also increase dramatically, thereby limiting the overall effectiveness.

Software tools can provide potential 'assistance' in conflict detection and resolution of aircraft route or altitude infringements. The effectiveness of such possible assistance was investigated by means of simulations and extensive objective and subjective measurements (Hilburn et al., 1995 & 1996). The question was if these advisories would serve as ‘additional information to process', i.e. heavier workload, or would indeed help the controller. If you do not review advice, and simply accept it, you would be out of the loop …

The results of a comparison of a stepwise increase in the level of assistance as compared with a 'manual' baseline are depicted for both HRV and pupil size measurements. The data obtained seem to support extended applications of such tools.

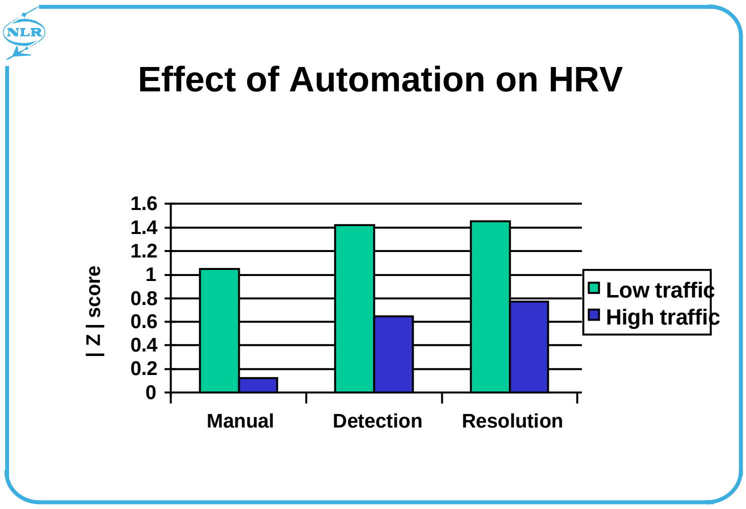

Figure 10: HRV increase as a function of automation assistance, i.e. conflict detection and resolution advisories

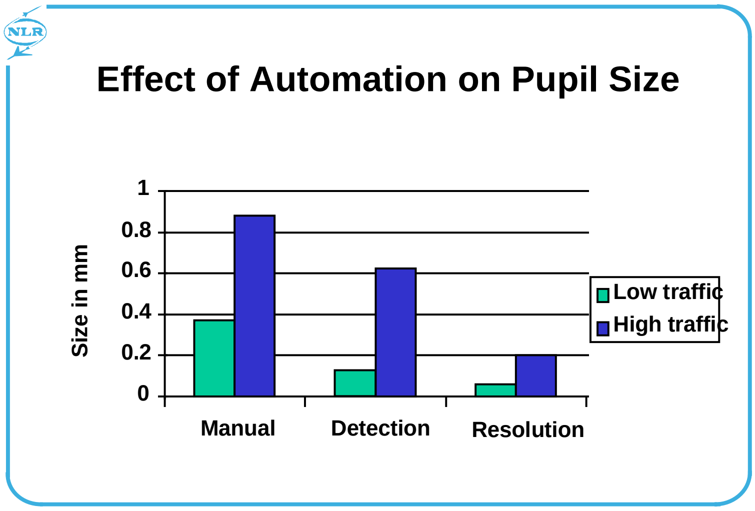

Figure 11: Pupil decrease as a function of higher levels of automation assistance

An additional technique applied was the principle of 'dual tasking' but with the purpose of acquiring an objective measure of 'situation awareness', in this case defined as awareness of communication and aircraft status. Incidentally, aircraft would fail to acknowledge their uplinks and the controller had to detect these occurrences. In case of a reduced overall task load, more options are present to perform this particular task more timely. The results are depicted in Figure 12.

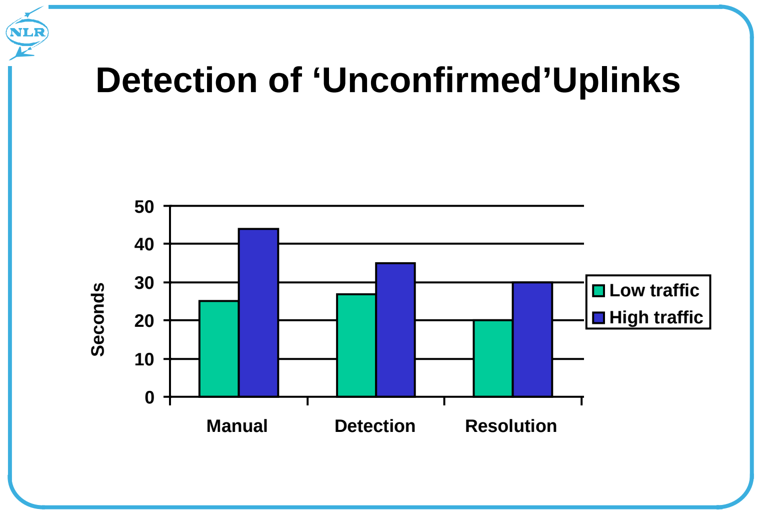

Figure 12: Controller response times to status information on communications and aircraft responses

Apparently, the tools do allow the controller to scan the display more effectively, resulting in better overall performance. So overall the objective measures clearly indicate the potential of the tools in helping the controller. But how do the controllers rate them subjectively? This datum is depicted in Figure 13.

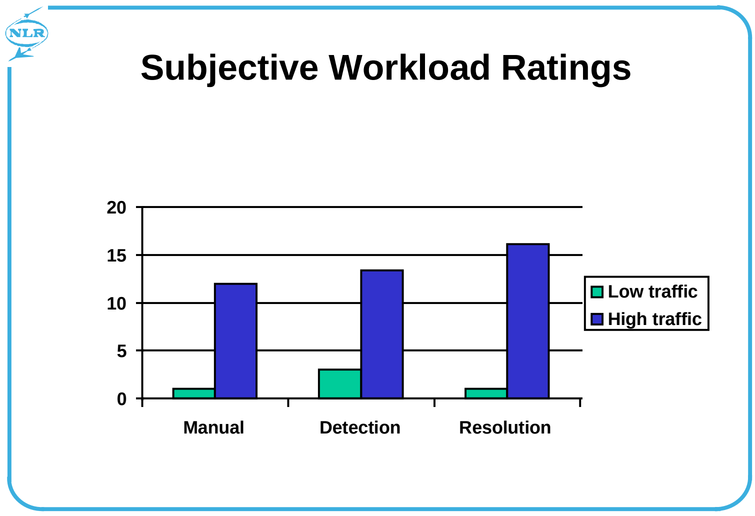

Figure 13: Controller estimates of workload effects as a function of more software tools

Surprisingly, the controllers rated the effects of the tools quite contrary to the picture provided by the objective measurements. Possibly, the addition of extra functionality is experienced as more work to be handled. The objective data showed that the assumption that advisories could increase workload was proven to be wrong, at least in this case. Also, the controllers rated the overall effects of the tools as 'neutral'. So there is a benefit for objective measurements in learning together about human-computer interactions in new situations.

A mediating factor in such results could be the particular strategy employed by the controllers in using these tools. Also, the level of practice is important. Controllers have very particular strategies in handling their traffic and these 'controller methods' could influence adaptation or transition to the new Controller Working Position (CWP). An illustration can be provided by analysing the eye scanning during high and low traffic density samples.

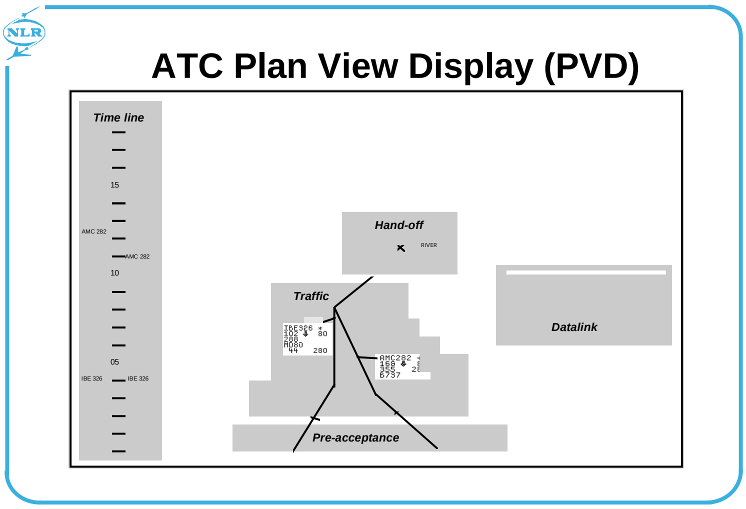

Figure 14: Display layout of a PVD with arrival scheduler at the left, aircraft hand-off area and datalink communication status panel. The areas are used by the POG equipment to provide area-related data on eye scans, durations, transitions, etc.

This study investigated the human use of possible tools in a future ATC approach scenario with present (low) and future (high) traffic loading. Arrival traffic approaching Schiphol was displayed on a PVD. It contained:

1. **Time line window** - The controller must monitor this area for scheduling information to ensure that the arrival sequence is as desired, and that ETA and STA agree.

2. **Traffic area** - The region of the screen in which controlled aircraft appear, including both the aircraft location plots, and the flight labels that display all relevant flight parameters.

3. **Datalink Status Panel (DSP)** - Displays all recently-uplinked messages, together with elapsed time since transmission, and whether the clearance has been acknowledged by the aircraft.

4. **Hand-off region** - General area in which the PVD shows the plots and flight labels of aircraft around the time that they are handed over to Amsterdam Approach control (APP);

5. **Pre-acceptance region -** The general PVD region that displays aircraft before they are accepted from the previous sector. Viewing this region provides the controller with an indication of impending traffic load changes.

Fixation frequencies across the PVD turned out to be quite sensitive to the effects of traffic load. The net change from low to high traffic conditions ranged from -6.3% (for the pre-acceptance region) to -75.7% (for the time line). The pattern of scanning can change drastically as illustrated in Figures 15 and 16.

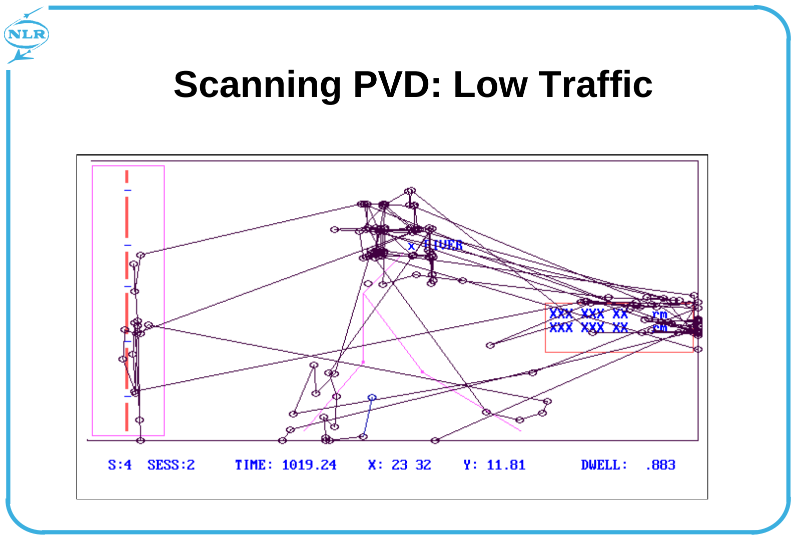

Figure 15: Sample (120 seconds) of POG transitions

The results indicate that a tool such as the scheduler for arrivals by means of a time line is used especially under low traffic conditions, but the moment traffic builds up, controllers seem to drop the tool and revert to the classic ‘on screen’ controlling methods. The paradox which occurs is that tools with technology designed to ease the job of the controller are being discarded especially in the situations where they were anticipated to benefit the most. More research seems indicated, also taking the effects of extended training into account.

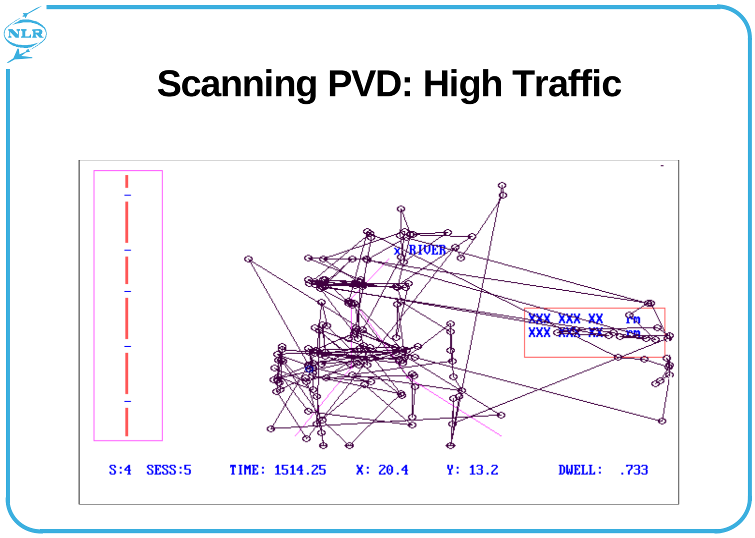

Figure 16: Sample (120 seconds) of POG transitions

Other **'unexpected' user behaviours** were noted. Within the PHARE Programme, new tools were developed to increase traffic throughput without overloading the human ATCO. Planning and looking ahead were key elements of the development. Experiments with prototyped systems revealed interesting information. Some of the tactical interventions made by controllers, probably with the intention of providing even more service to their airborne customers, interfered with the effectiveness of software tools that operated more strategically (planning up to twenty minutes ahead). Interventions caused extensive re-calculations, delaying tool response times. Normally, an aircraft request is always communicated to the controller, who can evoke a conflict detection tool when needed and act accordingly. Valuable calculation time could theoretically be obtained by adopting a different strategy. In case an aircraft wants a new trajectory, **a down-link is made directly to the conflict detection tool**. If there is no conflict, it is simply approved. Only if there is a conflict, the controller is notified. Software could probably operate more effectively in such a case, but the implications for the 'traffic awareness' or the 'mental picture' of the controller are not yet known and suspicion as to its overall effectiveness is widespread. Clearly, more experiments are in order for validating such a configuration of tools and procedures.

2.6.7 The Future Ahead: ATAFF or Air Traffic Arbitrated Free Flight?

Ergonomics thrive and the consistent growth in air traffic is appealing to many industries. The already high-density areas in the USA and Europe are expected to continue their growth. Some of the technologies involved are summarised in Figure 17, together with some keywords describing the human factors involved.

With the congested airways, one option is to reduce separations between aircraft, another is to discard the airways all together and use all available space. 'High-tech' equipment is required in both scenarios as collisions should be prevented. The type of equipment can however differ as a function of the solution pursued. One strategy is to perfectly plan all aircraft movements along routes negotiated between the aircraft and ATC, and another one is to allow 'Free Flight' in certain airspace(s) with the aircraft taking local responsibility for separation. The development of the necessary equipment is very capital intensive, and a wrong 'bet' can jeopardise the competitiveness or even the continuity of the business involved.

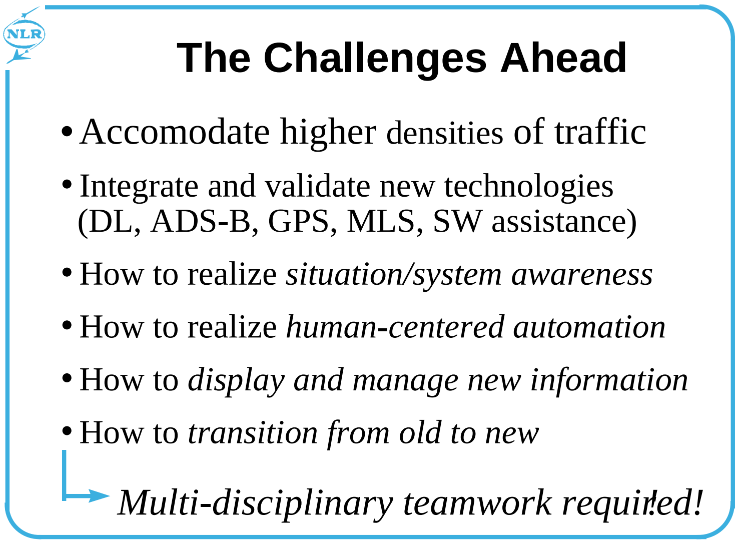

Figure 17: Some of the technologies involved in accommodating high(er) levels of traffic and a number of key or buzz words describing the human factors issues involved.

A planning application of datalink is one of contracting flight plans between crews and controllers in a non-voice format. Aircraft can be addressed separately, thereby removing the so-called party line effect. This party line allowed crews to listen in to communications from other aircraft. Such information can be of benefit for anticipating certain events like route changes or other troubles. An even more influential use of the datalink is a direct connection with the airplane Flight Management System (FMS). An 'auto-load' function allows the crew to directly load ATC clearances in the flight computers. Essentially, fully ground controlled flight would therefore be feasible even if there is the risk of 'Accept first, think later'!'

Alternatively, technologies like Aircraft Dependent Surveillance Broadcast (ADS-B) enable aircraft to broadcast flight information such as speed, heading and intent to other aircraft in their vicinity. With such information, all aircraft can create a cockpit display similar to that of the ATCO. New technologies not only support human-human communication and computer-computer communication with appealing, but also **unknown consequences** with respect to responsibilities, work procedures and the potential for human and machine errors.

The challenges ahead are therefore numerous and formidable. Next to integrating multiple technologies in a seamless global system, it is especially the human element that has to be integrated effectively and safely. Human factors play an essential role in realising a more effective and safe(r) aviation transport system.

With the progress made so far, human factors seems to be better prepared than ever before. Design and operational experience has been gained resulting in more effective support. An example of such readiness is the design, implementation and experimental investigation of a potential concept for ‘free flight’ as designed from a human-centred perspective. It took the multi-disciplinary team less than a year (!) to accomplish and present the first results (van Gent et al, 1998). The way the team worked was structured a bit like the famous Skunk works of Lockheed. So it can be done!

2.6.8 Problems to be Solved

One of the difficulties encountered with integrating human factors into more complex industrial products is the ‘product-driven’ nature of that Design process. Many features can be built into a device in order to meet different customer requirements and standardise production. Research in human factors is still much more ‘knowledge-driven’ and often uses pre-operational prototypes for studies and experiments. The outputs of such studies were often research reports, and what industry needs are improved products. This discrepancy in perspective has been ameliorated in some projects by allocating the HMI design to the human factors specialists, as in the PHARE GHMI project.

Testing of designs can also still be performed from both a technical and a human factors perspective. Many systems have to be integrated on a flight deck or PVD and, next to technical integration issues, there are issues related to integration on the task level. When performing tasks, pilots and controllers will have to use multiple systems in accomplishing their goals. Differences in individual design details, such as display layout, switchology, etc., can prove to be less compatible with other designs. Confusions and errors are more likely with a less systematic overall design. Systems or parts are often built by contractors on specification and, when finished, there is little room for modifications. For efficiency reasons human factors need to be integrated at the earliest possible level but, in that case, all companies would be required to have such expertise in-house. Especially the smaller manufacturers report that having such a team of specialists is unaffordable. So more easy access to such expertise should be provided for industry.

Alternatively, industry would like to have in-house tools that allow them to address human factors and protect their interests. The use of human modelling is still quite complex and is based on past experience, not addressing the possibilities for unexpected user behaviours in new systems. Experience has shown that specific training is mandatory to quite high levels in order to use human factors design tools or measurement procedures. Simply handing over a tool will not be effective. A colleague, no offence intended, once summarised the issue as follows: *A fool with a tool will still be a fool.*

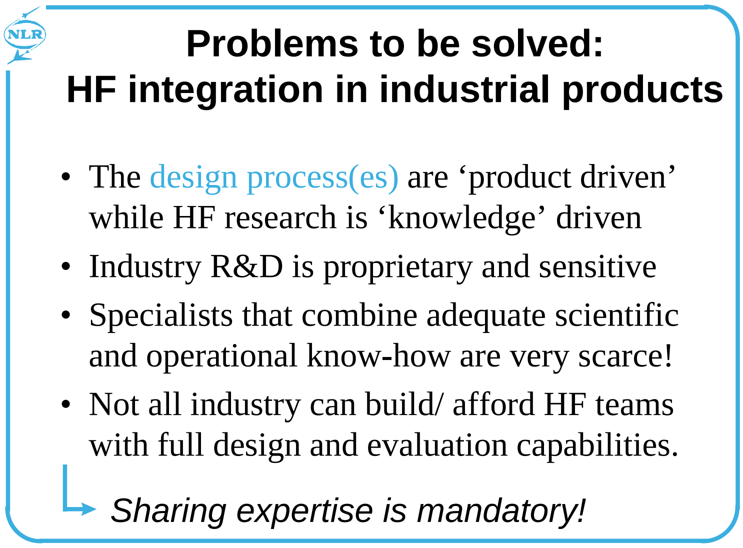

Figure 18: Some problems hampering the inclusion of human factors in product developments

A consultancy approach would seem to be a solution, even if experience has shown that to do a university degree is not enough to be a credible aviation human factors specialist. Adequate in-depth knowledge of the operational system is required to communicate effectively. Alternatively, being an experienced operator is not sufficient either as it takes years to build the required background human factors knowledge on HMI design, training, workload, selection, etc. Therefore, such combinations of expertise and experience are very rare indeed. A few aviation research establishments and ATC research centres have taken up the challenge of developing such expertise and capabilities, and this generation of specialists are now participating in industrial technologies projects. Still, direct contracts with industry lag behind expectations. One reason for that could be the sensitive and proprietary nature of product developments. The 'look and feel' of a product is strongly determined by its user interface and therefore industry tends to keep such work in-house. The other reason could be a lack of available funds. So there is work to be done on improving relationships and the protection of intellectual property rights. The problems are summarised in Figure 18.

2.6.9 Complex Facilities for User Test and Validation

The study of accident reports and efforts on setting up an incident reporting system all contribute to more knowledge and insight in the underlying mechanisms of human error. This approach of 'learning after the accident' should be complemented by an approach emphasising 'learning before the accidents occur'. Such learning could be achieved by creating simulation facilities that allow the study of future user behaviours in a full working context. Again the level of realism required would make it difficult for all industry to acquire such facilities and therefore access is required on a European scale. Existing facilities at the EEC, France, and NATS, UK, are impressive but the airborne side has a low(er) presence and the evaluations still rely heavily on subjective evaluations.

An example of a more integrated facility is the ATM human factors test bed constructed in the Netherlands. Its main features are the integration of both flight and ATC simulations, including advanced facilities for human performance and task strategy measurements. The architecture is depicted in Figure 19.

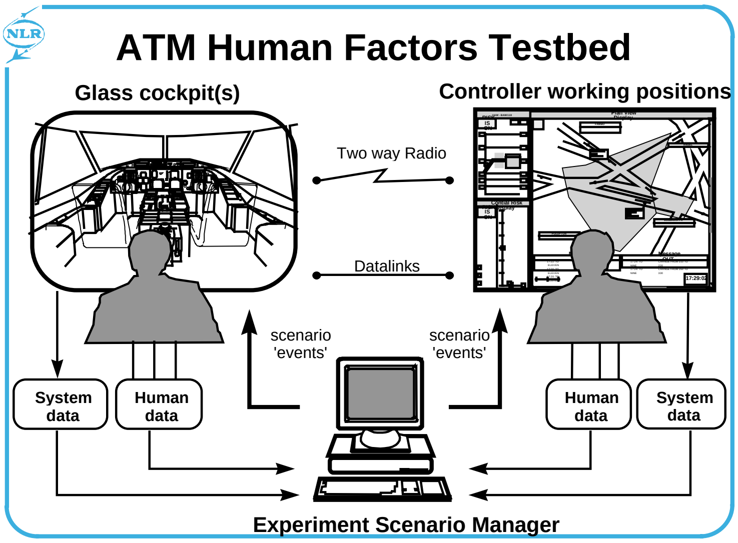

Figure 19: Example of a facility in The Netherlands that is used for assessing user behaviours according to a 'learn before the accident' perspective.

Some examples of its findings will be provided. ATM scenarios heavily rely on the use of digital datalinks. Both air and ground systems are involved, and communication should be harmonised with respect to type, content and working procedures. On the highly automated flight deck, head down times have been of some concern. The pilots are working their computers all the time and forget to orient themselves on the outside view.

Crew procedures and resource management training therefore emphasise the importance of a head up orientation and prescribe a task division between crew members.

When evaluated in a realistic working context, the following results were obtained for cockpit datalink, as depicted in Figure 20.

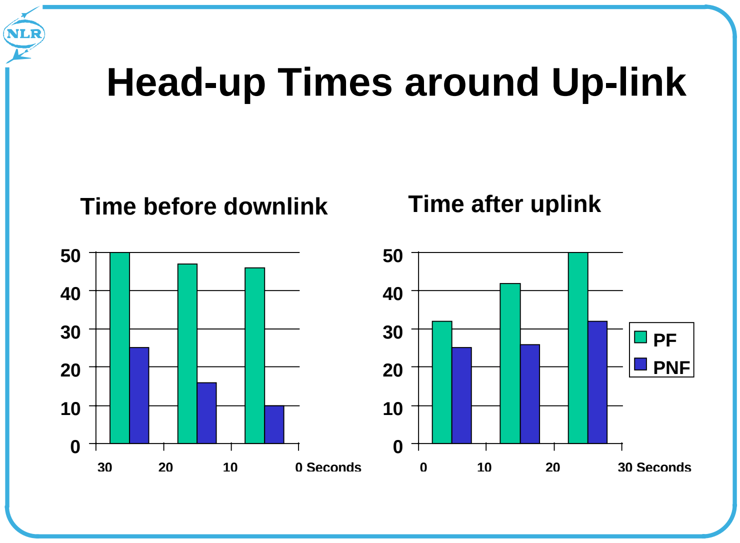

Figure 20: Measured percentage head up time for a Pilot Flying (PF) and Pilot Non-flying (PNF) when handling respectively a down link message and an up link message. Time 'zero' is the point where the message is sent or received respectively. Note the PF also going head down after receiving an up link.

The result was that the PF was also going head down immediately after receiving an up link. According to procedures, the PNF is to handle the communications in order to allow the PF to concentrate on flying. Pilots proved to be **unaware of such behaviour** although they perfectly explained why it would represent a wrong strategy!

The underlying reason seems to be obvious when considering that humans like to be informed immediately about new situations, especially if they are the captain. Therefore, attention is immediately drawn by such vital information. Some captains now realised that a high level of datalink involvement could essentially change the role of the PNF to the crew member that is actually managing the aircraft strategically. Based on such results re-thinking is possible. The application of synthetic voice for datalink could now be reconsidered as it would allow easy access to both crew members. The text message would be used for backup, verification and loading the FMS.

An example of such type of data as obtained for airline crews in an airborne assurance or free flight study are depicted in Figure 21. Note the involvement of both crew members!

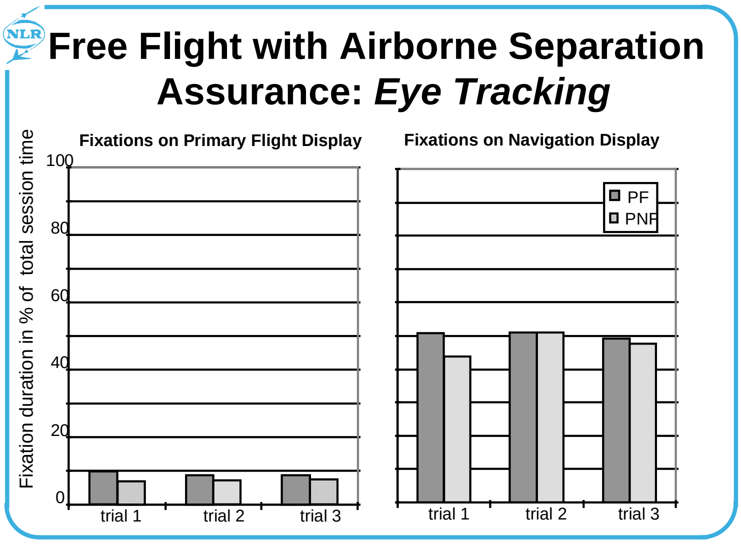

Figure 21: Eye fixations on instruments during free flight. Trials indicate repeated sessions to indicate possible learning effects (actually quite small in this cruise scenario).

An example from the ATC was provided earlier by the eye scanning results as obtained from controllers operating a PVD extended with an arrival manager and datalink facilities. The kind of traditional reaction or even reverting to old habits has been observed more often and illustrates that technologies should be fully tested on adequate human factors before implementing them in a definitive configuration. **Nobody knows all the answers beforehand!** If not, additional training will be the last resort or the tools (products) will not live up to expectations.

2.6.10 Summary

This has been an overview of some recent developments in the area of human factors. It took a little while but you reached the end of this paper. Congratulations! For me it was the first time that I revealed some personal experiences. Do not make me regret it! Writing them up reminded me that it was quite a long journey before we reached the state of affairs of today. I was lucky to meet so many pleasant and brilliant colleagues, so we could survive the battles. Many newcomers in this field perhaps cannot imagine the kind of discussions that took place in (only) the last decade!

I am confident that the workshop will be as constructive as we all expect and hope for. It is now the time to set the pace for the coming challenges as associated with going to the **real operational systems** of the next generation. I assure you that there is still a lot of work. But the uncertain part is if that is realised by everybody. We now have the software, the tools, the facilities and the people to make it work. An opportunity of a life-time! Let us collaborate and finish the job. It is up to you to use and extend them to their full potential.

So just to end with really the last song title, the following wishful thought: if we can pull this together, it represents ***a stairway to heaven*** (Led Zeppelin) **for its participants, but in this case not due to an accident!**

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2.7 Human Factors Integration at ALENIA

by Guglielmo CASALE, Project Manager, ALENIA, and Patrizia MARTI, Researcher, University of Siena, Italy

2.7.1 Background

The ICAO CNS/ATM systems concept calls for a closer integration of systems including the ground and avionics elements. This requires a new and different involvement of humans, whose operational effectiveness is at stake within a safety critical environment. Such effectiveness can only be reached if a new approach is adopted for the design of the new CNS/ATM systems. In this new approach the different factors that can influence the successful operational adoption of such new technologies should all be taken into consideration. The analysis should therefore not be exclusively limited to the performance aspects. It should also be extended to the human factors.

2.7.1.1 Why Human Factors are Becoming so Important

This 'systemic approach', as well as the technology, must include human factors considerations early in the Design stage, before the systems and their sub-systems achieve full operational status.

Most of the critical events in avionics occur even when advanced technology-based systems are deployed. The trend followed up to now to minimise such events is mainly twofold: increase the system technology, complexity and performance, and provide further training and rules for the personnel. Nowadays, this approach has guaranteed a high level of safety; nevertheless the increase of the traffic demand and the new system complexity require additional investments in order to guarantee safety.

The so-called 'technology-centred automation' approach needs to be integrated by 'human-centred automation'.

Awareness of the new situation must progress in the community of the system providers as well as in the community of the end-users. The international bodies such as ICAO and, particularly in Europe, the European Commission and EUROCONTROL are pushing the main actors, industries and end-users, in order to make such progress as effective as possible.

In the IV Framework Programme 1994-'98 of the European Commission particular attention was indeed given to the effectiveness of new technologies. It was not only necessary to propose valid technologies but also to design and validate the proposed solution with the end-users by means of real trials within the operational environment.

As a consequence of this requirement the projects funded in the Fourth Framework Programme focused on the active cooperation between system providers and end-users to define user requirements and, in particular, to prepare trials and a validation plan.

A methodology named 'Converge' was also suggested by the Commission for the preparation of the validation plan and trials.

2.7.1.2 Validation Plan and Trials

System **Validation** is the process of verifying how a system, as installed and operating in a real-life environment, performs with respect to the assessment objectives. The measures of objectives achievement are given through indicators evaluated against a reference case. This process is normally divided in two different phases: **Verification** and **Demonstration**.

The **Verification** stage concentrates on testing the physical and functional behaviour of the applications, technical performance evaluation and acceptance by users and decision-makers involved in the project. Verification is performed not only in the laboratory, but also in the 'real-life environment' without interfering with existing operational procedures. Only if the Validation process provides satisfactory results at the Verification stage, is Demonstration explored.

A milestone of the verification stage is the **System User Acceptance Test**, which aims at verifying if the users are satisfied and if applications perform as expected from a **functional viewpoint** to justify proceeding to demonstration. When the system is 'accepted', that is the system is operating according to the functional specifications, the **trials** for the Demonstration start.

During the **Demonstration** stage more emphasis is given on proving reliability and consistency of performances under operational conditions. A larger sample of end-users is involved and a comprehensive impact analysis is carried out in order to evaluate the benefits of the application. Operational performance evaluation and User Acceptance assessment are then performed more thoroughly during this stage.

2.7.2 ALENIA Approach

ALENIA as CNS/ATM system provider is aware that interest in the human factors aspects has increased in the last years mainly because:

- The **end-users** are becoming more aware of the impact that new technologies can have on their organisation and therefore they formulate specific requirements on the manufacturer;
- The **European research projects** include such aspects;
- The **maturity** reached by the human factors related technology, in terms of available methods and supporting tools allows now an effective integration of technology and human factors.

ALENIA is actively engaged in the process of updating the products and the design methods of its systems. Such a process is complex and requires large investments in terms of training, new methodology and tool adoption, product development, etc. It also requires a heavy involvement of the customer from the beginning of a project.

The solutions adopted in the different cases often depend on the specific situation, where agreement must be found case by case with the customer, even if in Europe, thanks to the action of EUROCONTROL, a standardisation process is progressing that will contribute to make the integration of the human factors easier.

Particular attention is, for instance, given to the **Human-Computer Interface (HCI) aspects**. The Operational Display and Input Development (ODID) series, followed by the EUROCONTROL Simulation Capability and Platform for Experimentation (ESCAPE), the Denmark/Sweden Interface (DSI) and the ROMATSA Interface are some of the relevant HMI standardization activities at the EUROCONTROL Experimental Centre (EEC), France, closely monitored by ALENIA.

A further good opportunity to practically experiment pre-operative systems taking into account human factors is provided by the European research projects. ALENIA has participated in several research projects within the IV Framework Programme. In particular, the integration of human factors aspects was particularly successful and valid in two recent projects. We think that the approach adopted in these two projects can be generalised and exported to other projects.

In the next sections the projects' objectives will be briefly introduced and the methodology adopted and the tools used will be described.

2.7.2.1 Example 1: The FARAWAY Project

2.7.2.1.1 Objective

The Fusion of Radar and ADS data through two-way datalink (FARAWAY) project (TR 1025) has the objective to investigate the enhancements in terms of operational performance of ground surveillance systems and in aircraft navigation which are possible through the use of Automatic Dependent Surveillance Broadcast / Two-way Datalink (ADS-B/TWDL) on self-organising time-division multiple access technique and through appropriate fusion of ground generated surveillance data (radar data) with aircraft position and status data transferred to ground by air-ground link (ADS data).

The FARAWAY project develops an appropriately equipped demonstration site to be used for pre-operational evaluation purposes (trials) to support new operational procedures based on the fusion of radar and ADS-B data through TWDL. The pre-operation implies a close scrutinising of all human factors on the ground and airborne segments.

2.7.2.1.2 ALENIA Role in the Project

ALENIA is the coordinator of the project and takes the responsibility for designing and implementing the ground system and conducting the trials.

2.7.2.1.3 Budget Share

There is a dedicated budget foreseen since the beginning of the project for validation purposes. This is about 30% of the total budget.

2.7.2.1.4 Adopted Approach

An integrated team was established. Team components were representatives from CAA, airlines, system providers and external human factors experts from the University of Siena, Italy.

A document named **Validation Plan** was produced in the early phases of the project. The plan adopted the methodology used for assessment and validation of various transport telematics applications within the transport sector of Telematics Application Programme. The Validation Plan defines the work plan for the validation of the experimental system.

The Validation Plan was afterwards refined including an implementation guide of the FARAWAY **Validation Process**, highlighting methodologies and tools employed to accomplish objective assessment.

To perform this evaluation a set of correlated **quantitative** and **qualitative** measures were gathered from human and machine components of the FARAWAY demonstrator.

As the CNS technologies under evaluation are still in the Development stage; their performances limits have not been fully established; moreover respective standards are still in the ‘draft’ stage. Consequently, the validation of FARAWAY applications was directed to:

- Assess the **technical aspects**, verifying that the system works correctly from a **functional** point of view and measuring its **performances**;

- Assess the **user acceptance**, estimating user’s **attitude** to the applications which exploits these new technologies utilised in the system.

Six months trials were performed in operational conditions, systems on board and at ground level run in a ‘shadow’ mode.

Trials are conducted with all equipment deployed at the test site and avionics integrated in the aircraft. Personnel off-duty and observers from the consortium are active during the trials, checking surveillance, communication and data processing aspects on ground against the communication and navigation aspects as lived on board by the air crew.

During the trials, all the relevant data are gathered from system(s) considered as 'reference' and from the system developed within the project, both operating in the 'real-life environment' as previously mentioned. Data collection is performed utilising revenue flights and requires recording of significant parameters on board of the aircraft and at the Ciampino Area Control Centre (ACC) site. An analysis is then performed using a number of software tools developed 'ad hoc' or acquired. The overall definition of success is measured in terms of statistically meaningful evidence that the applications perform equal or better than the reference.

As regards **technical assessment**, the methodology for such an evaluation is based on the establishment, for each application to evaluate, of a set of correlated indicators which are commonly accepted to describe the performances of the application. Meaningful statistical evaluation of the indicators is done to obtain a quantitative measurement of performances against the reference case.

As regards **user assessment**, interviews and questionnaires are used to assess if foreseen benefits such as **reduced workload, reduced communication, improved quality of information, HMI friendliness**, etc., have been achieved. Furthermore, the effects (impact) of FARAWAY applications are measured. Areas of investigation are: improvement on safety for air transport, increased capacity, increased coverage area, service and avionics cost reduction and possible reduction of separation in airspace not currently served by radar.

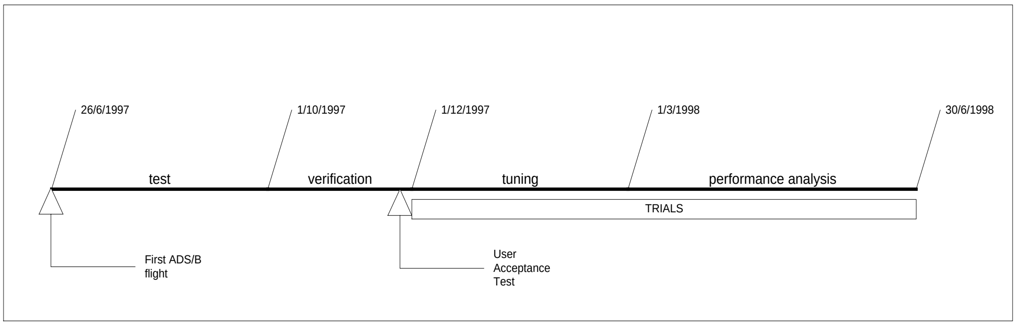

Figure 1: The FARAWAY Validation Plan

Human Factors Methods and Tools

The general theoretical framework adopted for the user acceptance evaluation was inspired by a human-centred approach focusing the activities on a strong involvement of the final users in the system Evaluation process.

Two approaches have been used:

User-centred approach, during the analysis and operational trials phases. In particular in the early phase of the process the data collection, we collected real field data and acquired a deep knowledge of the activity performed by the different actors involved in the FARAWAY applications. In the second phase of the Evaluation process, the operational trials, user-centred design methodologies were adopted to analyse the collected data in real situations (ADS equipped a/c flying from Rome to Alghero, Rome to Palermo, Palermo to Pisa, Pisa to Rome);

Participatory evaluation methodologies, during the latest phase of the process, the **synthesis and envisioning**, devoted to synthesise the results of the analysis and to envision, with the active involvement of the users, possible design solutions and potential future developments.

In Figure 2 the three phases of the user acceptance Evaluation process (analysis, operational trials and synthesis/envisioning) are described in detail.

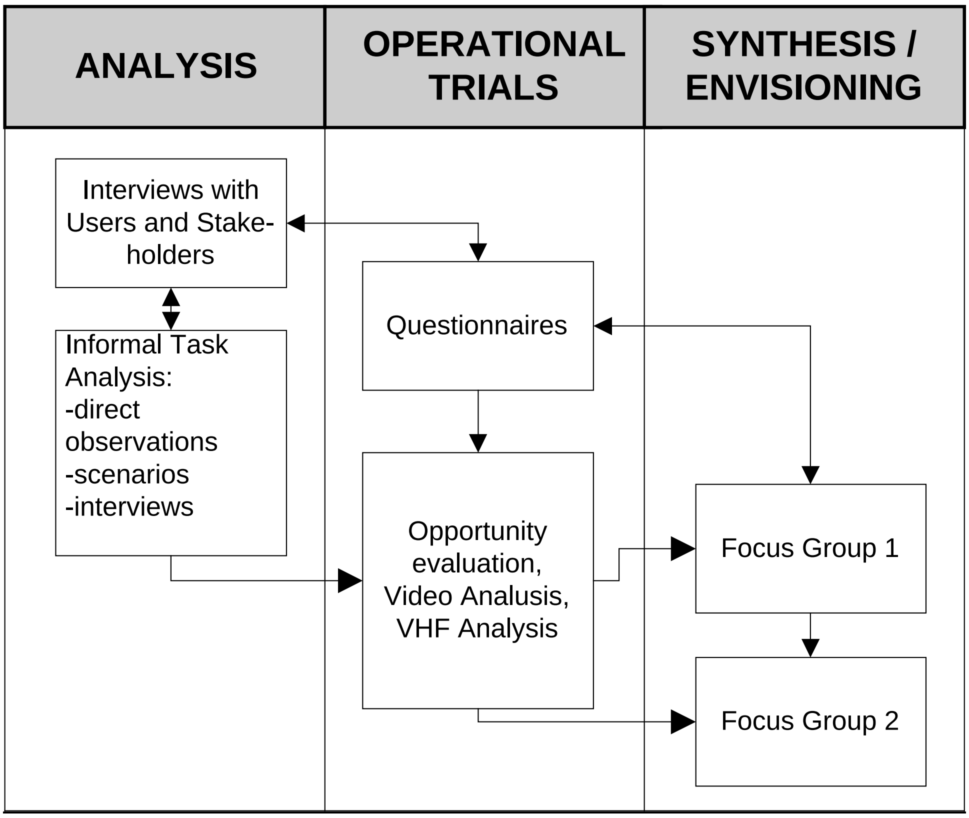

Figure 2: The FARAWAY user acceptance evaluation

Data Collection

The objective of analysis and data collection was to understand the social context of the real work settings in which the activity takes place. This analysis was mainly conducted using ethnographic methods. The key benefit that ethnography methodologies offer to design and evaluation is a rich and detailed description of the complex features of the work site. In ATM for example, what ethnography especially provides is a throughout insight into the subtleties involved in the work and in the routine interactions among members of the teamwork.

The gathered data for the user acceptance evaluation were mainly based on **direct observation**, **video analysis** and verbal **communication analysis**. Data collection was focused on the activity of controllers and pilots during trials.

User-centred Design Operational Trials

The user acceptance evaluation in FARAWAY was conducted applying user-centred design principles (Norman & Draper, 1986) and methodologies.

User-centred design processes are typically characterised by:

- an appropriate Allocation Of Function (AOF) between user and system,
- iteration of design solutions,
- the active involvement of users,
- multi-disciplinary design teams (including both technical and human factors experts).

At each stage of design user-centred activities are essential in order to understand and specify the user and organisational needs, so that potential design solutions can be evaluated against these needs. There are four essential types of activity:

- To understand and specify the context of use: the nature of the users, their goals and tasks and the environment in which a product will be used;
- To specify the user and organisational needs in terms of effectiveness, efficiency and satisfaction, and the AOF between users and the system;
- Produce designs and prototypes of plausible solutions;
- Evaluate solutions against user criteria, preferably by testing them with representative users (Nielsen, 1993).

In FARAWAY user-centred design has been achieved by a strong involvement of users in the requirement definition and the Evaluation phase. At the initial phase of Design, the requirements analysis, we analysed user characteristics and involved users in the definitions of the scenarios. During the trials the system was tested on site with the actual final users. User testing was carried out through a number of **measures** and **observations**:

- the satisfaction of the use of controllers and pilots;
- the effectiveness in accomplishing their tasks;
- the controllers' performance evaluated with respect to the number and the type of the communication between the controller and the a/c.

The objective of these tests was to obtain data about the level of support the system offers to the different actors of the process, but also to identify those aspects of the user/machine interaction that are most critical for the activity. This can provide insights also for future design in view of extending the system functionality.

During the test we used a number of well established usability techniques to collect data:

- videotape of the users activity in context,
- questionnaires of user satisfaction,
- interviews.

Furthermore, since the system could be only partially used during the trials for safety reasons, test techniques were also used closer to diagnostic evaluations (Lindgaard, 1994). These include:

- focus groups;
- opportunity evaluation, a kind of analytic evaluation to analyse and predict the performance in terms of the physical and cognitive operations that must be carried out;
- observational evaluation, providing information about what the users do when interacting with the system. Direct observation, video recording, verbal protocols are typical techniques available for this kind of evaluation.

Users and Stakeholders Analysis

We defined the target users of FARAWAY in two categories: **end-users** and **stakeholders**. Whilst the end-users are those who will use the system directly, the stakeholders are those who can influence the use of the system or those who can be affected by the system but may not be the actual users. Following these definitions, our end-users are **pilots** and **controllers**, whilst our stakeholders are mainly the representatives of Alitalia and of the *Ente Nazionale di Assistenza al Volo (ENAV)* **managing directions**.

Users and stakeholders were involved in different ways in the user acceptance Evaluation phase, mainly in interviews, questionnaires, use scenarios and focus groups.

Results

The performed work and the achieved results were reviewed according to the quality process requested by the European Commission, by the end-users involved in the Validation Plan (ENAV, controllers, Alitalia pilots and managers). The adoption of human factors methods such as those used during the participatory Design phase allowed an effective integration among users and design team. The users particularly appreciated to be part of an iterative Evaluation process, where their remarks were taken into account before the final release of the system was delivered.

The collaboration between pilots and controllers created an important knowledge common ground about the technological opportunities and the way in which they can be translated in new national procedures.

2.7.2.2 Example 2: The ATHOS/MANTEA Projects

ATHOS (TR 1005) and **MANTEA** (TR 1036) are complementary projects funded within the fourth Framework Programme in the Telematics Application Programme. ATHOS is devoted to the design of future Controller Working Postions (CWPs) integrating automated planning and monitoring supports: MANTEA develops these advanced technological tools. A more detailed description of the projects is given below.

2.7.2.2.1 ATHOS

The main goal of ATHOS is the design of the future airport tower control systems. It deals with the tower controller positions in visual control rooms in the context of future SMGCS (Surface Movement Ground Control System). ATHOS moves steps towards European ATC harmonisation and the design of the CWPs of the ‘standard European Tower Control’. Specific objectives of the project were:

1. Design of a mock-up for the future airport tower control system, in particular for the ground and tower CWPs;
2. Harmonisation in the control room of the new technologies for ATC that will be operational in the next ten-fifteen years. These include:
    - Air/ground datalink and gate-link between controller and pilot;
    - Planning tools: automatic conflict detection, departure manager, arrival manager;
    - Data fusion on mixed data sources (radar, beacons, etc.);
    - Short-term accurate meteorological and wake vortex forecasts;
    - Advanced HCI technology concerning the display functions and the HMI.
3. Assessment of their impact on the human operators.

2.7.2.2.2 MANTEA

The MANTEA project aims to provide automated support to the controllers (in particular, ground and tower controllers) with decision-making tools, seamlessly coordinated with terminal and en-route operations. Precisely, the functions automated in MANTEA are:

- surface traffic planning (integrated with approach and departure operations);
- monitoring of conformance with instructions, detection of potential conflicts and their resolution.

Surveillance is also part of MANTEA only to enhance conformance monitoring, conflict alert and surface traffic planning with accurate position and identification data

2.7.2.2.3 ALENIA Role in the Projects

The ALENIA role in these projects was mainly to perform the task analysis of the tower in the Rome Fiumicino airport, and coordinate the task analysis performed by the other partners at the Paris Charles De Gaulle, Schiphol, Fiumicino and Frankfurt-am-Main airports. ALENIA was then in charge to produce a generalised model for an European tower that was taken as the basis for the design and implementation of the system (Marti & Casale, 1997). ALENIA contributed to the system development implementing the tower CWP. Finally, ALENIA defined the Validation Plan and executed it for the Fiumicino airport.

2.7.2.2.4 Budget Share

The first year of activities of the ATHOS project were almost entirely devoted to the adoption of human factors methods (mainly task analysis) to the analysis and design of the CWPs. Furthermore, there was a dedicated budget foreseen since the beginning of the project for validation purposes.

Such budget was about 30% of the total budget.

2.7.2.2.5 Adopted Approach

The adopted approach took into consideration the following aspects:

- geographically distributed working team;
- different sites and users to survey and interview;
- need to create knowledge about the method to be used and shared by the team members.

ALENIA proposed to organise the work according to the following schema:

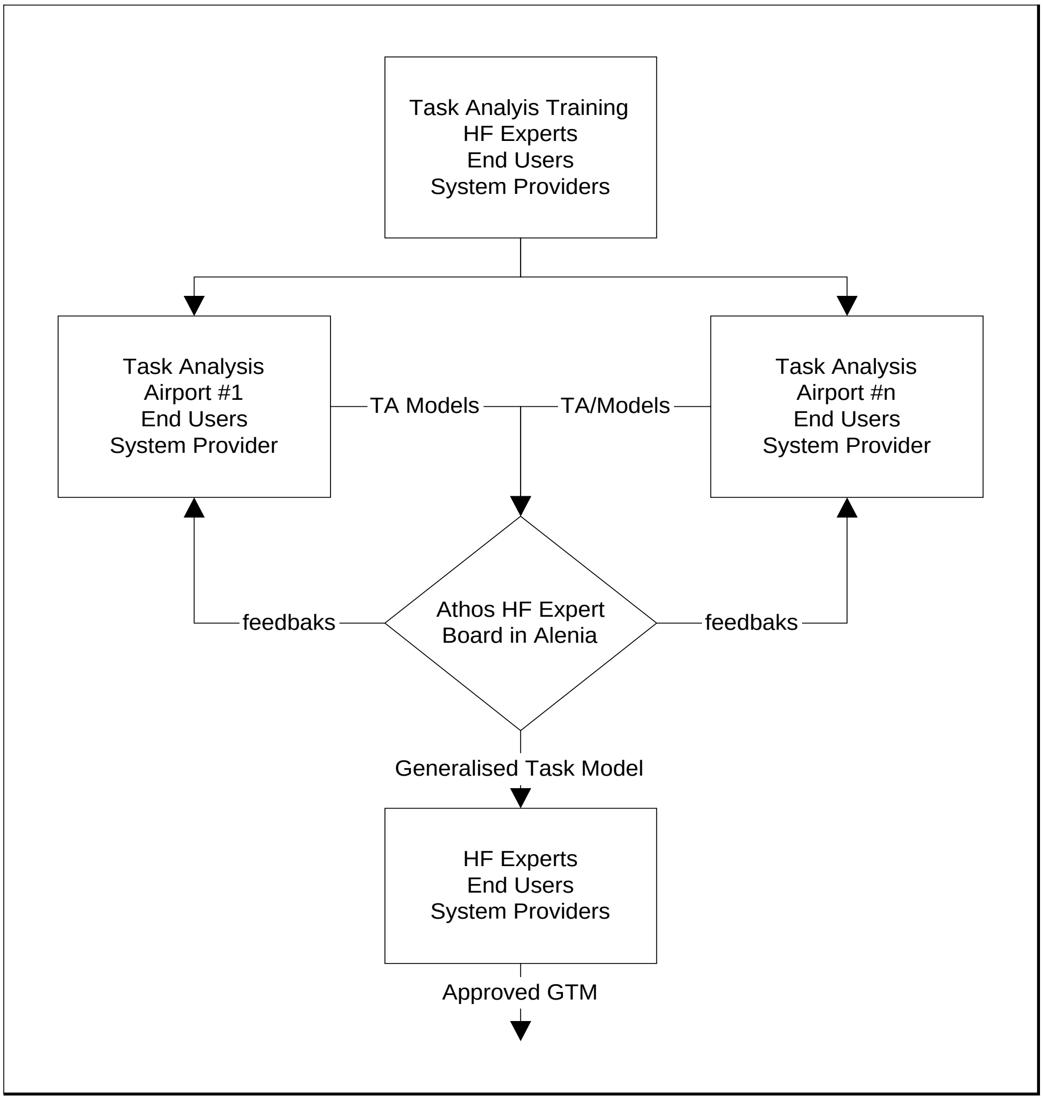

Figure 3: Human factors integration during the analysis and design in ATHOS and MANTEA

Human Factors Methods and Tools

For the integration of human factors in the ATHOS/MANTEA projects the **user-centred design** approach methodologies were used. Structured task analysis was the main design methodology adopted in the projects (Kirwan, & Ainsworth, 1992, Marti, in press). The rationale for using structured task analysis in ATHOS and MANTEA can be summarised in the following points:

- The need of a method supporting human factors throughout the whole Development process.
- The need of a method which integrates human factors and software engineering methods.

- The need of a structured Development process involving a broad view of task analysis, ensuring the effective exploitation of task analysis results throughout the process.

- The existing situations analysed: the different airports show significant similarities, but the detailed structure is very dependent on the work organisation, the topology of the airport, the traffic load, the tools used, local regulations, etc. In this respect, the abstraction from the current systems with the aim of a device independent analysis is an interesting aspect of the methodology.

- The difficulty in assessing the impact of new technological tools on the activity, starting from different practices and habits.

- The objective of the standardisation of CWP, and the assessment of controllers' acceptance of the new organisation.

- The heterogeneity of tasks, the complexity of the data involved, the high degree of parallelism and cycles during the activity.

As stated above, four important European airports were involved in the analysis activities: Amsterdam Schiphol; Paris Charles De Gaulle; Frankfurt-am-Main and Fiumicino. For each airport we modelled all the CWPs, even if we focused on ground and tower for the development of the final mock-up.

The task analysis technique that we used was inspired by MAD (Scapin & Pierret-Golbreich, 1989) and TKS (Johnson & Johnson, 1991). From TKS we took the philosophy of the approach and the graphical notation. From MAD we took the use of templates conveying information about tasks not contained in the task graphs. The basic element of the task analysis is a graphical notation to draw task graphs, i.e. a task taxonomy representing the goal structure of tasks. This structure conveys a task/sub-task decomposition, defined in terms of temporal and logical constraints among tasks; triggering conditions; loops, etc. Pre-conditions and post-conditions for task execution are specified when necessary, as well as pre-requisite and post-requisite which are tasks which need to be executed before or after a main task.

Each task in the graphs is also described in a task template collecting functional, operational, pragmatic and relational characteristics of the task. Other information about non-functional requirements of tasks like duration, interruptibility, reversibility, frequency are also specified as natural language descriptions in the task template. These aspects of our task analysis approach are inspired by MAD.

Other relevant elements of the task modelling are:

- descriptions of roles, i.e. a set of tasks that each user is responsible for performing as part of his/her duties in the context of a job;

- descriptions of objects, i.e. a set of objects or classes of objects involved in the tasks, and the semantic relationships among them.

Both roles and objects are described in role and object templates containing information about relations among roles, objects' data attributes, and actions that may be applied to the objects. This object-oriented aspect of task analysis adopted was the natural link with the object-oriented analysis method used later on in the project, therefore with the Software Engineering phase.

Task modelling was an iterative process: at each task analysis stage, the models were validated with controllers, and a final evaluation was performed on the basis of the compliance of the model with the current activities in the different airports, taking into account completeness, accuracy, expressiveness of the model, representativity of the activities, resulting scope of the task model. Furthermore, task modelling was a participatory Design process because the controllers involved in the project actively contributed in the existing systems analysis. At the beginning of the project ATCOs and designers attended a course on the task analysis process and the notation adopted, so as to be able to refine and validating the models.

Results

The performed work and the achieved results were reviewed according to the quality process requested by the European Commission, by an independent domain expert team that was not involved in the project. The assessment was generally good but in particular the project received the following evaluation with respect to the human factors adopted methodology:

> *The work achieved is a genuine contribution to the knowledge of the controller work. Generalisation of the task models gives a device-independent description of the way the job is performed. This gives a good basis to carry on the work on the next work packages*

(ATHOS/ISR-DOC-W3-033-R1 'D3.1 Peer Review Report').

2.7.3 Future Trend

The R&D activities on human factors integration described above have been fully supported by the Alenia R&D Department and Systems Development Engineering Department.

Thus the findings of FARAWAY, ATHOS and MANTEA are now a common asset of our engineers, reflected in an enhanced awareness of human factors and with an available tested methodology for human factors integration and verification.

The Alenia ATC/ATM systems have always met with the full approval of service providers, both in the civil and military operational environments.

Our expectations for the future are to provide the same level of customer satisfaction as achieved in the past in a more cost-effective manner through a structured approach to human factors integration as experienced in the R&D Domain.

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2.8 Introducing an Activity Analysis Centred Approach into the Air Traffic Management Systems Design Process

by Véronique LAVAL, Head of Ergonomics, Validation and Cognitive Activities Analysis, Centre d'études de la Navigation aérienne, France

2.8.1 Introduction

Evolution and transformation of technical systems are inherent phenomena in complex systems, which have to remain constantly in perfect harmony with their structural, economical, social and technological environment. Such is the case of Air Traffic Management (ATM). The success of these processes of change depends on the ability to develop technical systems which can both function correctly and be harmoniously integrated into the global existing system. These are the objectives and stakes of design and validation processes.

Concerning technical systems interacting with human operators, symptomatic and recurrent problems have been observed over the recent years, giving rise to difficulties or even failures when bringing them into operation and use.

The work which is presented here aims at bringing some answers to these problems by way of elaborating and proposing formalised material to assist design and validation processes actors within the field of human factors.

2.8.2 What Material is Needed for what kind of Assistance?

2.8.2.1 Level of the Assistance

A few years ago the importance of the problems described above motivated the initiation of research studies on the validation theme, within the frame of diverse projects, both European and national. Some of these projects are still in progress. Currently, their main objective is a strategic one, as it consists of defining a general validation strategy for the ATM system. This system is then considered in its whole and what is expected are the definition, organisation and planning of all validation processes and activities of the different concepts and technical systems composing the future harmonised European ATM system. This approach is essentially a top-down one.

The approach adopted in our work is more a bottom-up one. In order to bring practical assistance not to programme managers but to design and validation actors, the notion of project, related to a given concept, a given technical system, has been taken as the basis and the reference level. Consistency and coherence between projects and in a temporal perspective can be dealt with here through questions of integrability into the existing system and compatibility of projects of similar maturity levels.

2.8.2.2 *Type of Material*

The objective is to provide formal material to support the elaboration of design and validation processes to be followed by projects' actors.

For that purpose it has to be taken into consideration that each design project is specific in its contents. So are the changes it prepares, the expected level of impact, the analysis and evaluation methods to be used, which can be more or less original, the available means and the priorities, which can be instituted depending on the project stakes. Therefore, it would not be realistic to attempt to formalise adequate approaches and methods as lists of tasks and activities, which could be followed exactly and systematically whatever the project is. Expertise and creativity remain the basic requirements for the elaboration of relevant and efficient processes. However, this can be supported and facilitated through the availability of theoretical, methodological and practical guidelines.

Such guidelines are being built up on the basis of theoretical knowledge in the field of cognitive ergonomics, as well as on practical experience gained within diverse design projects over the years. They will be proposed in a 'Human Factors Design and Validation Guide'.

The whole contents of this guide will not be reproduced here; only the most determining issues will be described.

2.8.3 Determining Issues

2.8.3.1 *General Approach*

The principal aim in implementing a human factors Design and Validation process is to guarantee that the interaction or cooperation between human operators and the designed technical systems will answer the general needs for an evolution of the global system; the specific characteristics of the human operators' work and its efficiency factors will be preserved and the work conditions will be kept acceptable or will even be improved.

Being able to reach this aim requires the acquisition of elements of knowledge concerning these different aspects. On a theoretical point of view it can be observed that there is a large part of specificity in them for each work situation. Therefore, the only place where they can accurately be found is in the real operators' work activity, as composed of observable actions and underlying cognitive processes carried out by given operators in a given work situation in order to answer the given missions and objectives assigned to them.

Thus, activity analysis represents an essential part of human factors design and validation processes as proposed here. It can be completed as far as necessary by diverse qualitative measures which are useful but not explanatory enough to be sufficient.

In addition, as regards the operators' activity, the whole work situation should be considered. Indeed, it should be ensured, for example, that work organisation and procedures are compatible with the envisaged changes; their simultaneous evolution should often be prepared in order to preserve the global consistency.

2.8.3.2 Methodological Issues

2.8.3.2.1 Design, Realization and Validation: Organisation, Objectives and Stakes

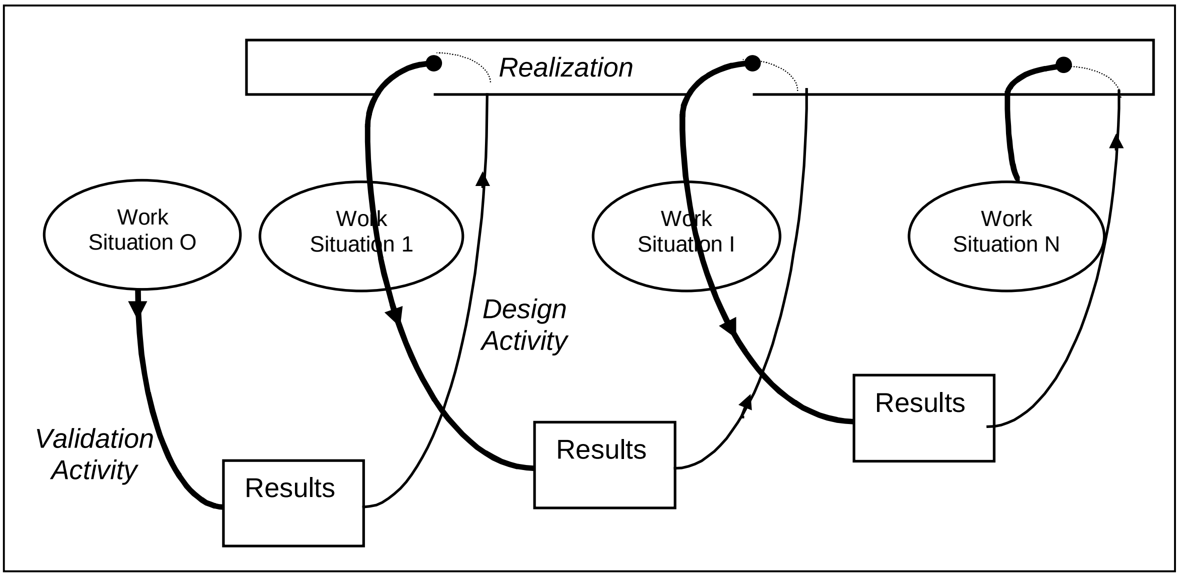
Within design projects it appears to be useful to discriminate different types of sub-processes associated with different objectives and stakes: design, realization and validation.

Design can be considered as, and limited to, the intellectual elaboration work, when realization consists of the practical development work of operational systems as well as mock-ups and prototypes.

Validation is then the process allowing passing judgement, as objectively as possible, on a design object, in order to guide choices and decisions to be taken throughout the project. In the present approach, as mentioned previously, the design object is studied as part of a whole work situation to be analysed.

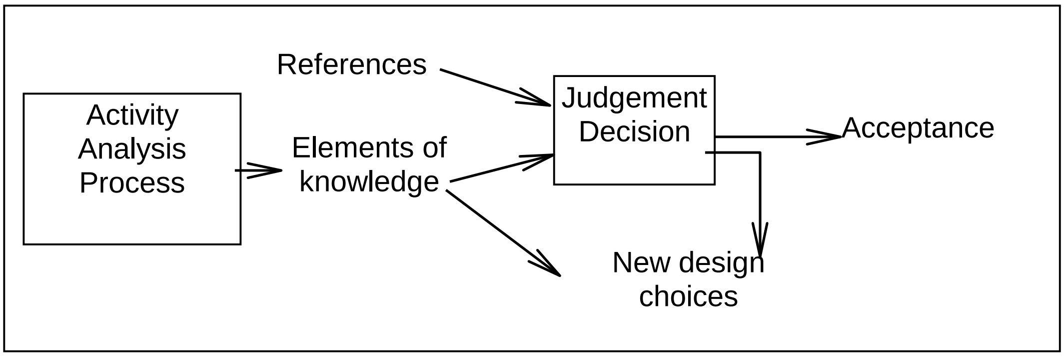
This validation approach, which is not a usual one, responds to efficiency purposes. Validation is not only anymore a way of verifying the relevance of choices after they have been made, but it also contributes to their elaboration by 'judging' them progressively and by providing useful explanation on the reasons for these judgements.

Therefore, design, realization and validation are constantly overlapped in an iterative process.



In the above scheme work situation represents the existing work situation. Work situations 1 to N-1 are simulated future situations and work situation N is the new situation resulting from the implementation of the project. Details concerning the different types of design and validation activities required at each step will be proposed later.

The realization sub-process in itself does not require the involvement of human factors specialists, whose task is design and validation. In practice, these two sub-processes can be based on common activity analysis processes, the results of which will be interpreted and utilized differently.



Within the frame of validation purposes the elements of knowledge gained through activity analysis are used to judge the design choices. Depending on the judgement a choice can be accepted or replaced by another choice, the elaboration of which is also based on the elements of knowledge resulting from activity analysis.

Making a judgement requires the use of references: the validation criteria. These criteria must be carefully chosen in relation to the specific objectives and stakes of the project. In general, they essentially concern usability, usefulness and efficiency. However, it must be added that the use of criteria is a difficult one in the field of cognitive analysis, where complexity and variability are of great importance. The Judgement/Decision process is then often an uncertainty management process. Moreover, it also involves compromise. Introducing changes in a work situation indeed consists of modifying the general harmony of the global system. This modification can have both positive and negative effects, i.e. it can generate improvements but also deterioration. So a major stake of validation is to reach an optimal compromise between improvements and deterioration, between benefits and risks.

2.8.3.2.2 Design and Validation Activities throughout the Project

Depending on the level of maturity of the project human factors design and validation activities can differ, answering diverse objectives and requiring diverse methods. The table below synthesises this diversity, proposing different possible and useful activities for each phase of the project.

The Research phase aims at elaborating new concepts, which can respond to given operational needs. During this phase an existing work situation analysis is necessary to understand current activity, in order to guarantee the transition to the future work situation, to identify the existing problems to be solved and the existing efficiency factors to be preserved or promoted. Theoretical studies are also often required for innovative concepts, and cognitive simulation as well as simple mock-ups can be used to roughly predict the impact of the envisaged concepts.

<table>
<tr><th>WHEN</th><th>RESEARCH</th><th>STUDIES</th><th>DEVELOPMENT</th><th>IMPLEMENTATION</th><th>OPERATION</th></tr>
<tr><td>WHAT</td><td>New concepts Elaboration</td><td>Definition of associated technical means</td><td>Choices finalisation</td><td>Correction Appropriation</td><td>Feedback from experience</td></tr>
<tr><td rowspan="2">HOW</td><td colspan="2">Existing work situation analysis
Real or simulated environment for diagnosis description and understanding</td><td colspan="2">New work situation analysis
in pre-operational environment with prototype</td><td rowspan="2">New operational work situation analysis</td></tr>
<tr><td>Theoretical studies
Cognitive simulation
Simple mock-ups</td><td colspan="2">Envisaged future work situation analysis
in experimental environment with mock-up</td><td>Appropriation activity follow-up</td></tr>
</table>

Once a concept appears to be promising the study project can be launched. Existing work situation analysis can still be required to detail some more specific aspects. At this phase the iterative process of design and validation really begins through the use of experimentation. Experimentation, in the form of simulation of the envisaged future work situation by the use of mock-ups, enables the evaluation and understanding of this future situation, first roughly, then more and more precisely.

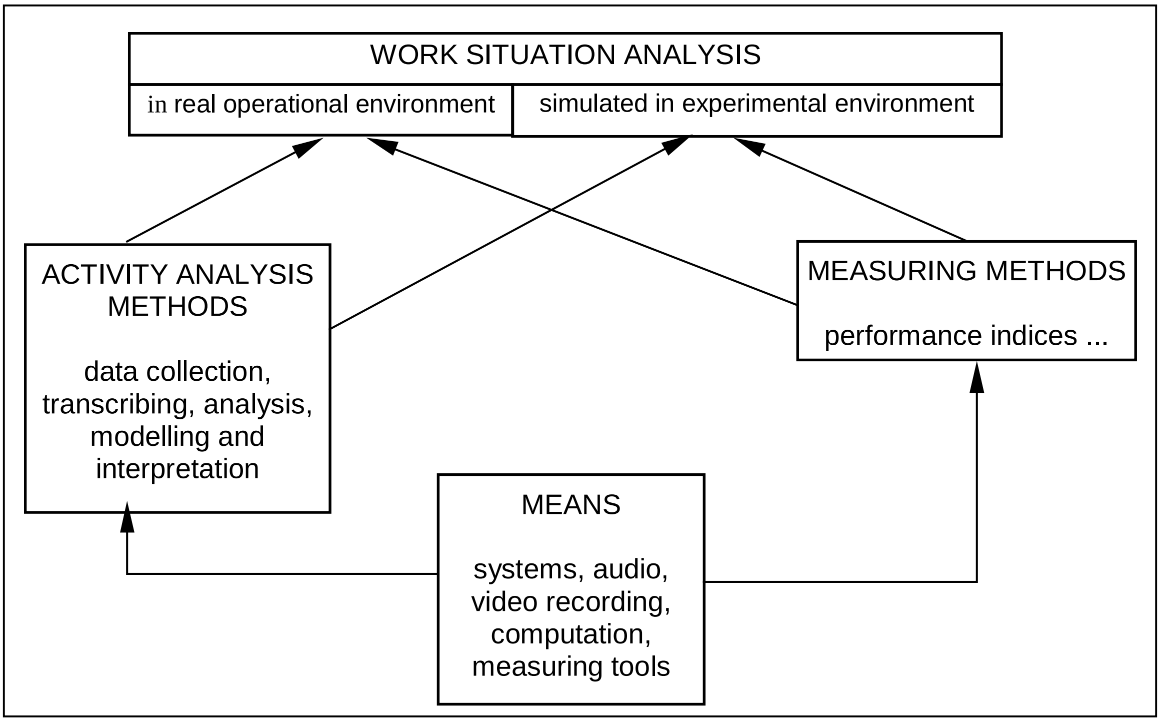
Development and implementation phases are dedicated to adjustments. Simulation is to this end followed by on-site experimentation with prototypes.

Finally, the analysis of the new operational situation brings useful feedback from experience.

2.8.3.2.3 Methods and Means

Carrying out design and validation activities requires diverse methods and means as described in the following scheme. Analysing a real or a simulated work situation is rather similar. In both cases two major types of methods can be used:

- Activity analysis, enabling the description and understanding of activity and requiring a whole process of data collection, transcribing, analysis, modelling and interpretation. These data come from activity observation and recording of communication, actions, etc., as well as explanation of what is occurring by the operators themselves in a consecutive self-confrontation context;
- Qualitative measures of indices, requiring the use of dedicated methods and tools.



It is to be noted that activity analysis as described here is very different from usual methods consisting of interrogating operators and their hierarchy, most often outside the work situation. This method provides much more precise, explanatory and reliable results.

Carrying out this analysis and these measures requires the availability of diverse and appropriate simulation, recording and computation means and tools.

2.8.4 Role of Actors in the Project

Human factors is not the only issue to be dealt with; many other categories participate in a Design and Validation process. For the project to succeed it is necessary that each party can play its own role efficiently:

- Human factors specialists bring their knowledge of the work situation and activity and introduce constraints related to work conditions.

- Operators are expected to express their difficulties and wishes; they should accept being observed at work either in real life or in experimentation; they participate in the preparation of experimentation.
- The operators' hierarchy is responsible for the operators' work, and is answerable for the results of this work; they introduce into the project their knowledge of operational constraints.
- Technical designers integrate all constraints and objectives and bring answers to needs in terms of technical solutions and feasibility.
- Decision-makers are the ones who are responsible for all decisions punctuating the project; they require validation elements provided by all other actors.

2.8.5 Conclusion

The approach of human factors design and validation which has been described rather quickly here has two major characteristics, as follows:

- It is centred on operators' activity analysis.
- It proposes a clear formal methodological framework.

On this basis it can help to organise and make efficient the participation of each domain specialist in the project. However, it mainly aims at improving the management of benefits and risk balancing by integrating knowledge and methods which are:

- adapted to the specificity of complex systems and work situations;
- dedicated to help make relevant design choices;
- suitable to evaluate, foresee and understand both the improvements and the deterioration which can be expected from the design project.

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2.9 Human Factors Techniques in the NATS Air Traffic Management System Development Process

by Barry KIRWAN, Head of Human Factors, National Air Traffic Services Ltd., ATMDC, United Kingdom (now Human Factors Specialist, EUROCONTROL Headquarters, ATM Human Resources Unit, Belgium)

Abstract

This paper considers techniques and approaches which can help achieve a better integration of human factors into the ATM Development process. Having briefly described why human factors and its integration into design is important, the key design issues or areas are defined. A model of the Design process in NATS, and the techniques for getting human factors into this Design process, are then discussed. These techniques will work in theory, but will require management support if they are actually to happen and be effective in practice. Issues related to gaining management support are therefore also briefly discussed. The paper considers where human factors are weak in supporting ATM design. This leads to the identification of fundamental research requirements, and hence where research and development in human factors technology is required to strengthen human factors support to ATM design. Finally, the need for inter-human factors unit communication and collaborative research is raised, as a major way of achieving better human factors integration into future European ATM.

2.9.1 Introduction

Human factors in ATM has probably never been as important as it is now. There are so many changes that will occur in the next decade, all of which affect the Air Traffic Controller (ATCO). The interface will change and the controller's data will be mediated by software. The roles of the controller are changing (e.g. tactical and planner). Datalink will change the major communications medium of ATM, altering a visual and auditory task to a primarily visual one. Detection of conflicts or of aircraft deviations from planned trajectories may be fulfilled by the computer rather that the controller. The pilot may gain more autonomy and self-determination over four-dimensional flight paths, changing ATM in a fundamental way.

Finally, and perhaps most importantly, there will be a tremendous period of transition from current ATM practices to those envisaged in 2015. During this period, the ATCOs must deal with aircraft of varying equipage and be ready and able to switch between future procedures and current practices, depending on such equipage. The controllers must also be able to take over in the event of system failures (and indeed detect those failures when not readily apparent), and fluently control the traffic using skills which must be expected to decay through infrequent use. All of this will occur against a background of steadily increasing traffic and procedural complexity and the threat of a real or perceived reduction in safety margins.

The above description is both sobering and challenging. This paper will argue that there is much that human factors can do to support the evolution of ATM to its next generation. However, it will also argue that human factors must be more aligned with ATM developments and must be seen to be so, both by ATCOs and management. Human factors must focus on the issues of concern and must not simply be seen as either purely ‘interesting’ or even ‘academic’ in nature. Although a good deal of human factors ‘off-the-shelf’ products and ‘best practice’ can help ATM already, there are areas where more applied R&D is required. This latter issue is dealt with at the end of this paper.

This paper does not therefore argue that R&D is not required, in fact on the contrary, it calls for an honest evaluation by human factors practitioners and leaders of where human factors are strong and where they are weak. Human factors integration will occur fastest and most effectively if human factors can focus on the key human factors issues facing ATM over the next decade. These issues are imposed by the major drivers on European ATM itself: safety; capacity; quality of service; efficiency; and harmonisation.

Responses by ATM agencies to these drivers are mediated by ATM strategists and technological capability. The strategists themselves must consult with ATCO representation at various levels to devise credible future systems that are achievable and sustainable, and which are not too big a leap from current systems, nor a step in the wrong direction. Human factors integration must therefore take account of, and ideally be involved with, these various factors, processes, and stakeholders (strategists, technology developers and ATCOs).

Chapter 2.9.2 focuses on the main areas of support which human factors can give, an idealised model of the system development life cycle, and then the techniques used within NATS to achieve integration of human factors future systems designs.

2.9.2 Areas of Human Factors Support

The following appear to be the main areas of human factors support in ATM:

1. Selection.
2. Training.
3. Job Design
4. Team Resource Management (TRM).
5. Human-Machine Interface (HMI) and Workplace Layout and Environment.
6. Incident Analysis (I/A).
7. Risk Assessment and Human Reliability Assessment (HRA).
8. Procedures design.
9. System Prototyping and Evaluation.
10. Communications.
11. Allocation Of Function (AOF) (human or machine)/
12. Workload Assessment (WLA - predictive and real time).

These areas may be grouped as in Figure 1, in terms of whether they are **primarily** concerned with the people, the equipment, the task, or a combination of these categories. Each of these issues is briefly outlined below:

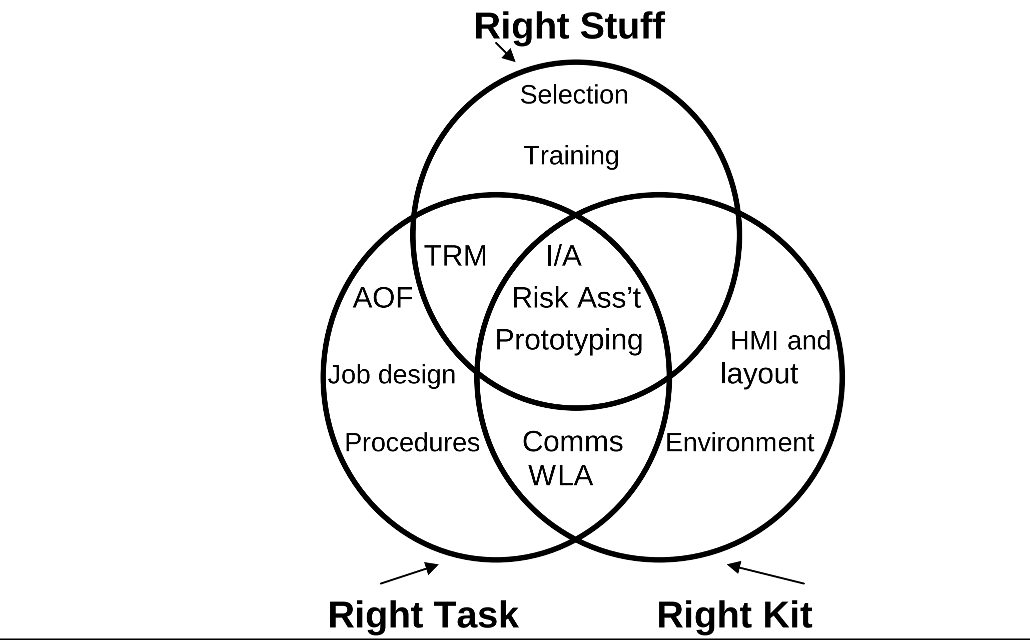

Figure 1: Main Human Factors Areas

2.9.3 System Design and Development Life Cycle

NATS' systems are developed in a number of ways, but the following is an overall and generic model of the System Design and Development Life Cycle (SDDLC) (see Figure 2).

This figure or simplified model of the SDDLC allows the human factors integration possibilities and practicalities to be explored. This can be done in the three following ways:

- **Human factors philosophy** - What does or should human factors offer each phase?
- **Human factors technology** - What techniques actually exist to support each area, and how good are they?
- **Human factors integration management** - What considerations help/hinder human factors integration?

A preliminary 'unpacking' of these aspects is given in Table 1, framed within the SDDLC. The techniques themselves are the focus of Chapter 2.9.4.

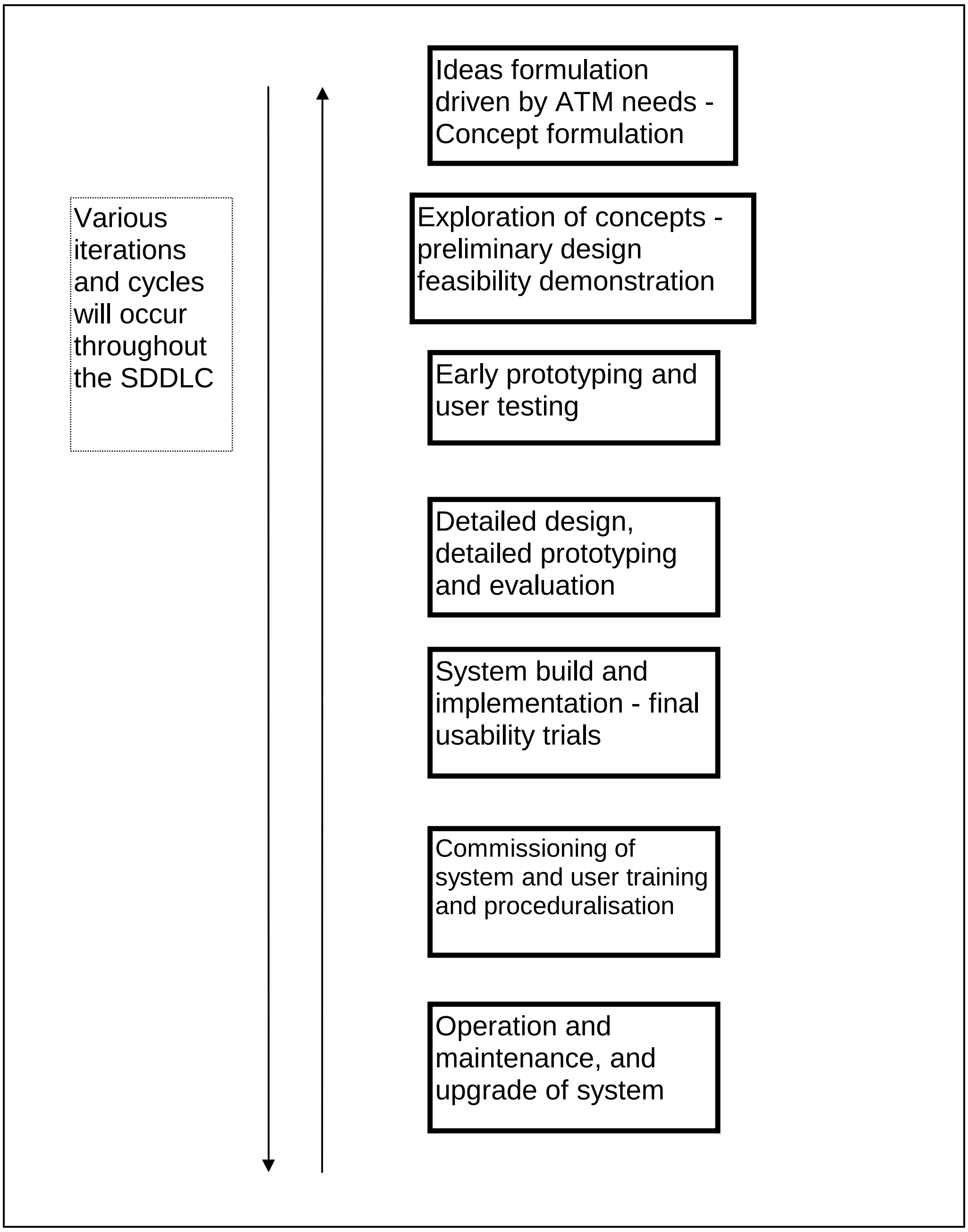

Figure 2: Idealised General Model of The Design Process

2.9.4 Human Factors Techniques Used in the System Design and Development Life Cycle

Chapters 2.9.4.1 to 2.9.4.10 outline the techniques that are relevant to Figure 1 and Table 1.

2.9.4.1 Human Factors Design Databases

There are data on AOF principles, e.g. deciding what humans are good at and what they are not good at. These simple checklists (e.g. 'Fitts' Lists') are rudimentary but do have a place in very early system conceptualisation. There are also evolving principles of human-centred automation, which are philosophically similar to more traditional AOF principles. These in particular relate to design principles that can be adopted as part of the system design philosophy.

For more detailed HMI design, there are numerous texts and company style guides that are used to decide design detail, from selection of input device to details of colour coding and VDU window border design. NATS currently has a database of some 300 basic HMI data plus an additional 1000 guidelines under consideration. All of these guidelines relate to various detailed aspects of workstation and environment design.

2.9.4.2 Target Audience Descriptions Profiles

The Target Audience Descriptions (TADs) profiles are descriptions of the aptitudes and characteristics used in the selection of ATCOs for current generations of ATM. They therefore define who the designer is designing for. Although often these are at a fairly generic and high level, they should nevertheless exist and be referred to throughout the Design process, for two main reasons. The first is that they may contain information pertinent to major changes, e.g. in interface design or level of pilot autonomy, which may influence design decisions. The second is that if the future system is not going to match the current generation of ATCOs, then the sooner this is known, the quicker new selection tests can be developed and put in place, bearing in mind the length of time it takes to select, recruit and train personnel.

An aspect that sits between selection and training, but one that is related to the TAD is that of TRM, the ATM equivalent of Crew or Cockpit Resource Management (CRM). Some of the issues raised in Table 1 (e.g. recovery from system failure) will require good teamwork to be effective. Furthermore, as computer assistance becomes more central to ATM, such assistance must inevitably become part of the ATM team (and further into the future, the pilot too), as the human and computer will have to rely (though not blindly) on each other to satisfy the goals of ATM. TRM is a developing area of human factors, but one that will be needed soon.

2.9.4.3 Task Analysis and Cognitive Task Analysis Methods

The utilisation of task analysis is growing in ATM. It ensures that things have been thought through, and then lays the foundation for the design of the interface, for job design, and for other exploratory analyses (e.g. error and workload), and can become a basis for training and procedural systems. The task analysis is the equivalent of the various system specification documentation used to develop hardware and software systems.

Table 1: Human Factors Integration Approaches

SDDLC Phase	Human Factors Philosophy	Human Factors Technology	Integration Management Considerations
1. Concept formulation	• Ensure the right options are considered. • Build on human strengths, guard against weaknesses. • Consider impacts on the whole ATM system. • Consider long-term human factors impacts (e.g. selection and training).	• Experience of HF design solutions in ATM and other industries (e.g. aviation). • Allocation of function principles. • Human-centred automation principles. • Target audience descriptive profile of current ATCO population.	• ATM tends to be technology-led. • Representative ATCO input must be sought. • Predictions of gains at Concept stage are always optimistic. • Human factors must have direct input to strategy formulation group(s).
2. Preliminary design feasibility demonstration	• Rapidly model the new tasks. • Assess new task. • Contrast with existing tasks. • Collect early ATCO opinion.	• Basic task analysis methods and talk-throughs. • Rapid prototyping methods. • Task analyses for existing tasks. • Basic error analysis predictive methods. • Data on human performance capabilities. • Interviewing and Questionnaire Design.	• Human factors may be seen as focusing on detail too soon and as impeding the creative process. • Initial system specifications will be more implicit than explicit, rendering proper analysis difficult and requiring many assumptions.
3. Early Prototyping and User Testing	• Capture the strengths inherent in the new concept. • Look for and build on additional strengths whose basis is a synergy between the computer system and the ATCO's adaptability/creativity. • Build usability, and error resistance and resilience, into the system • Ensure workload adequate.	• Prototype evaluations: **measures:** *observation, interviewing, questionnaire design*; **methods**: *experimental design; specialised techniques (Cognitive Task Analysis (CTA) techniques such as withheld information.)* • Situation awareness measurement. • Task analysis. • Predictive workload measurement. • Predictive error analysis. • HMI databases and rapid prototyping evaluations. • Walk-throughs and talk-throughs.	• There will be a tendency, particularly during early prototyping to resist formalised prototyping evaluations, preferring to have a general 'look and see'. The problem is that unstructured user evaluations and opinions based on such uncontrolled studies will then gain as much weight as if they were scientific fact. • Primacy bias - early findings, whether positive or negative, may irrevocably attach themselves to the project, whether or not supported by later findings.

Table 1: Human Factors Integration Approaches (continued)

SDDLC Phase	Human Factors Philosophy	Human Factors Technology	Integration Management Considerations
4. Detailed design, detailed **prototyping** and evaluation	• Ensure the detailed system build maintains the benefits of the original concept. • Ensure usability and error resistance, etc. • Ensure consistency/compatibility with the larger HMI environment into which the system will be placed. • Begin to determine the optimum job design to accommodate the new system. • Begin to log training requirements with the new system. • Design protocols for recovery from system failure.	• HMI development data, techniques and practices. • Specialised techniques (e.g. eye movement tracking). • Task analysis. • CTA. • Compatibility analysis with the 'mother' system. • Detailed and experimentally controlled usability trials. • More detailed workload and error prediction trials. • Prototyping and user evaluation trials and performance measures. • Risk analysis.	• The sheer amount of work on a detailed and complex HMI means that significant amounts of effort must be involved to get this phase right - human factors currently in ATM does not enjoy as much commitment to human factors resources as certain other industries (e.g. aviation, defence, etc.). • Ensuring compatibility with 'mother' systems may be difficult especially if such systems themselves are still evolving and hence are 'moving targets'. • In long timescale projects (e.g. greater than 3 years for the Concept and Design Phases) there is often some degree of corporate memory loss, relating to loss of design rationale. • User development groups involved thus far will have become significantly attached to certain design aspects and may be resistant to necessary design changes or compromise.
5. System build and implementation final usability trials	• Ensure system usable and functioning for full range of users. • Develop training and procedures for recovery from system failure.	• Real-time simulation trials using full range of measures. • Detailed analysis of system abnormalities and emergency events and recovery possibilities (task analysis, error analysis, situation awareness measurement and design, etc.).	• There will be a need to consolidate on a final design to avoid a 'creeping design' occurring. • There will be pressure for system acceptance - human factors problems at this stage will not be welcomed.

Table 1: Human Factors Integration Approaches (continued)

SDDLC Phase	Human Factors Philosophy	Human Factors Technology	Integration Management Considerations
6. Commissioning of system on site, and user training	• Prepare for transition - ensure introduction to users maximises well-calibrated trust in the system.	• Previous task analysis data and recorded job design and error recovery aspects can be utilised in the training system development. • Transition and trust considerations require development of approaches. • Training simulations can be utilised to aid transition and final capturing of practical local solutions to problems.	• Commissioning issues will arise which will inevitably require amendments to design parameters to make the system work on site - human factors rationale and user groups must be able to resolve such issues positively and within short time-frames. • Regulatory authorities will tend to start asking questions at this point - this may help or hinder human factors integration.
7. Operation, maintenance and upgrade of system	• Human performance needs to be monitored particularly during the early period of operation (e.g. the first six months) - any human factors issues that arise should be supported. • Human factors issues that were over-ridden or compromised (and hence not implemented in the design) need to be tracked to see if they require re-consideration .	• Performance monitoring - critical incident technique, best practice groups, other operations liaison groups, etc.	• The new system management may not wish the intrusion of human factors on the operation of their system.

Hierarchical Task Analysis (HTA) is often used to represent the ATCO's involvements with the system and other system users. However, other methods can be used; for example, link analysis is particularly useful for communications analysis, tabular task analysis can be used for interface design evaluation and time line analysis for basic workload prediction and communications review.

Cognitive Task Analysis (CTA) is the task analytical focus on the less observable aspects of the ATCO's tasks - the strategies being used, the decision-making criteria, etc. Since most of the ATCO's work is cognitive, and much of it involves active (but unobservable) monitoring and anticipation/prediction, CTA is very relevant to ATM. The problem is that the CTA techniques are not particularly mature, as they are basically still developing, and are more in use in training and selection areas than in supporting design of future systems. Yet it is the latter area where they will probably be most useful, determining how best to coordinate human and computer capabilities to cope with increasing capacity demands.

2.9.4.4 Rapid Prototyping Methods

This is not an exclusive human factors area, but human factors should be able (alone or in conjunction with other departments) to make various mock-ups of user display options, e.g. using visual basic or some other media. It is always useful to consider a range of options rather than focusing on one too early on, and a capability to do rapid prototyping gives human factors greater flexibility in demonstrating and exploring a variety of options with users.

2.9.4.5 Error Analysis (and Incident Analysis)

Usability trials will capture many of the errors that are likely to be seen on a system given its intended full range of users. However, usability trials are typically of short duration, are not of maximum simulation fidelity, may not always be real-time in nature, and may have only a relatively small sample of ATCOs with little training on that system and little time to get used to it. In short, some errors (or error recovery strategies) will go unseen. With later real-time simulations more such errors will be detected, but such simulations occur at a stage in the design life cycle where design changes should be minimised. It is therefore more cost effective to find these errors earlier.

Predictive error analysis is used in other industries and is now coming into ATM. Such approaches typically are based on a taxonomy of error, which operates on a task analysis to predict what could happen with a new system. Consequences and likelihoods of the errors can be considered either in terms of their relative impact and likelihood or, more precisely, by actually quantifying error probabilities and determining the system impacts each error will have. Usually, in early stages the former is done with the aim of identifying needs for changes in the design detail. If the latter occurs this amounts to risk analysis (see later).

What must underpin any error analysis method is a sound appreciation of what errors tend to happen, what factors cause them and any developing error trends in the general ATCO-error area. This means that incidents and events must be analysed, so that the results of such information feed both into predictive error analysis and risk analysis methodology, but also directly into design itself. Other industries (e.g. the nuclear power industry) have systems for monitoring errors in incidents worldwide and then channelling 'lessons learnt' to operating stations and into design projects, as well as risk assessment methods practitioners. ATM could benefit from a similar approach.

2.9.4.6 *Prototyping Evaluations*

Human factors has an important role to play in ensuring usability trials do not lead to biased results in terms of performance measured and ATCO preferences and opinions. The former relies on experimental design and control, the latter on methods of eliciting and analysing subjective data without allowing biases (whether those of ATCOs, designers, management or even human factors people) to distort the results.

2.9.4.7 *Special Measures*

Certain specialised measures exist and are developing. One such measure is Eye-Movement Tracking (EMT), which can be used to help optimise detailed HMI layout. EMT can also give information on the strategies of the ATCOs if auto-confrontation is utilised in conjunction with EMT (the subject retrospectively reviews their own eye track super-imposed on the scene, explaining what was going on, what was done, and why. Another is situation awareness measurement, which may be a way of determining what is happening to the ATCO's picture as more automation enters the workplace. The 'withheld information' technique has also been mentioned as a CTA method, which can be useful for determining what information the ATCO needs and in what sequence. These measures can be applied in prototyping or real-time simulations.

2.9.4.8 *Workload Prediction and Measurement*

As with error analysis it is undesirable to find out that workload is too high only when the system is virtually built and operational. It is far better to predict workload at an earlier Design stage and make changes if required. Furthermore, workload as a variable can be used to decide between different available options. There are several WLA techniques available and NATS uses the PUMA system based on multiple resource theory (Kilner et al, 1998).

Real-time measurement of workload, e.g. in real-time simulations, is also important, as it checks that the detailed system is not demanding too much (or too little) of the controller. Measures used in NATS are Instantaneous Self-Assessment (ISA) and the NASA Task Load Index (TLX) system. The former usefully tracks workload throughout the entire simulation, showing workload peaks and where they occur (and hence it is possible to infer why they occur). The latter measure is applied at the end of the exercise and gives an overall picture of workload, usefully broken down into six main workload parameters.

2.9.4.9 Real-Time Simulations

Human factors plays a large part in real-time simulations in NATS, assisting with the experimental design and control, setting up and analysis of various measures, and the scientific interpretation of the simulation results according to the objectives of the simulation. Although workload is a primary human factors measure (using the ISA method), others are used, such as R/T communications, erosions of separation, etc., in order to more generally see how performance was affected by the simulation independent variables.

2.9.4.10 Risk Analysis and Human Reliability Assessment

Human-Reliability Assessment (HRA) is used in a number of other industries (e.g. nuclear power, chemical, offshore, etc.), but has received little usage in ATM. This may change in the future, however, as human factors issues (in concert with new computerised support systems) are likely to dominate incident reports for some years to come, particularly through the 'transition period' (2005-2015) of mixed equipage aircraft and rapidly evolving next generation systems and procedures. This does not mean that risk will increase, but that control of risk must focus more on the human element, both as a cause and a recoverer of error and system problems. This means bringing human factors more closely into the risk equation and safety arguments that underpin the safety cases for all systems, current and future. The HRA technology is available, but will require adaptation to ATM, as it is currently based in a process control context.

The above are the main techniques either being developed or in application to a range of issues and projects. Clearly, there are some areas which require further development, as discussed below.

2.9.5 Human Factors Challenges for Future Air Traffic Management

Mr. Jorna (1998) notes that human factors is 'knowledge- driven', whereas industry is 'product-driven' (and ATM is frequently 'technology-driven'). This means that human factors research is likely to lag behind new developments in ATM, particularly when human factors is not informing future ATM concepts and strategies. However, although there are specific new tools, etc., being developed, so many in fact that it takes a lot of time just keeping up with the acronyms, there are several general trends. Fundamental human factors research may therefore be better spent on these general trends than specific software tools - not that the latter should be ignored, but they must be the subject of a more specific and focused human factors/HMI Development process (Jackson, 1998). Some of these key trends are outlined below.

2.9.5.1 *Recovery from System Failure*

This issue has been highlighted and prioritised by Wickens et al (1998) as a major source of safety concern. The essence of the concern is a familiar one to human factors people, and a hard lesson that was learnt by the aviation community with the introduction of 'glass cockpits'. Humans eventually come to rely on tools that help them, and their own manual skills degrade. These tools and their over-arching software frameworks have a finite failure likelihood. The controllers, therefore, will have a problem when these systems fail. As human factors researchers there are a number of pressing questions:

- How will failure be detected? This includes partial and total failure as well as not revealed and revealed failures.
- What special procedures will be available for such failures?
- What will be the impact on the controller of these failures (e.g. workload, stress, trust in the system)?
- What skills will the ATCOs still need to retain, with what fluency and hence what type and frequency of refresher training will they need?
- What backup displays will they need?
- What understanding of the automation will they need to diagnose failure?
- How will they re-establish a picture under such circumstances, and how long will this take?
- How will teamwork best be utilised to re-establish safe control of aircraft?
- How will pilots be made aware of such failures, and how will they operate until the system is re-established?

There are no 'off-the-shelf' answers to these questions, and opinions will help little as there has been so little experience upon which to make sound judgements - they require research. The type of research could take various forms: simulations, walk-throughs, experiments on 'trust' and 'reliance', use and application of situation awareness and workload and stress measures, etc., and finally full-loop (ATCO-pilot) testing. Such general research, which is fundamental in a real sense rather than an academic one (i.e. if we get this wrong, the first major failure [accident] could signal the end of the particular ATM agency involved [Reason, 1997]), would then impact on all the individual smaller tools, affecting some of their detail but largely influencing how they would be utilised.

2.9.5.2 *Air Traffic Controller Support During the Transition Period*

Air Traffic Controllers (ATCOs) are currently pretty busy. The focus on 2105 is to have more effective and more efficient systems. ATCOs should therefore either be as busy as they are now or even less busy. However, between 2005 and 2015 is the transition period. During this period there will be aircraft of very mixed equipage and capabilities. This raises many questions, a few of which follow:

- How will the ATCO be informed of an aircraft's equipage, non-equipage, and serviceability of existing equipage?
- How will strategies for dealing with new equipage items affect those for current equipment?
- At what a/c percentage of equipage uptake will ATM systems decide to respond to such equipment facilities (e.g. for datalink-equipped aircraft - 30%? 70%? 100%?)
- How will extra training be incorporated into current training and re-training strategies?
- How will workload be affected during this period?
- What new errors and risks will these new items impose on the ATM system?

2.9.5.3 Automation and the Picture, Situation Awareness and System Awareness

Currently there is much debate about whether the picture will be lost or simply how it will be changed, and how a picture will be retained by the system (including the ATCO). The problem is that the picture is still not fully understood. This does not matter to technologists, who believe that if the computer has the picture, then everything will be okay. However, this is an article of faith (i.e. 'trust us') rather than a proven philosophy - the lessons from aviation are salutary, though ignored by certain ATM technologists. What is clear is that the picture, whatever it is, will change. The question is simply one of whether this will be a change for the better and how to avoid the downsides of this possibility.

The problem is that human factors does not have the answer either. We need more CTA or modelling to understand the picture so that we can predict what will happen, and what aspects of the picture need to be retained by the controller. However, an important point must be raised here. The picture is more than a set of information, or a product - it is also a process. As an example, good controllers are often seen as 'proactive', i.e. they are engaging in active anticipation and search strategies, optimising service to air traffic. The picture also appears to relate to confidence and motivation aspects of the controller (MacKendrick et al, 1998), which are part of the reason that ATM is 'high reliability', with good error detection and correction properties. The technologists need to understand (i.e. we need to make it clear), that taking away the picture from the controller may have more widespread effects on ATM performance, e.g. on confidence (and hence fluidity and rapidity of performance) and motivational (and hence recovery and teamwork) aspects.

2.9.5.4 Automation and Team Resource Management

Although we are still learning about Team Resource Management (TRM) between individual team members, advancing automation means that soon automated tools will be part of the team themselves. ATCOs will need to be able to rely on such tools and interrogate them when required. Similarly, the tools will sometimes instruct (or suggest) to the ATCO what should be done. This raises all the usual questions about TRM (compliance, trust, communication, reliance, etc.) but adds the additional dimension that a tool is not a person and so is unlikely to be given any rights (although there are of course additional problematical legalistic considerations in the case of an automation-assisted accident). The controllers may have over- or under-confidence in a support system, they may simply feel threatened by it or fail to see its utility or simply not trust it.

What is needed is a way to establish usable and used tools, where the controllers have a realistic (well-calibrated) awareness of the tools' abilities, so controllers know when to trust the tools and when to ignore or over-ride them. This is no simple matter and there is little 'off-the-shelf' guidance. If human factors were to focus on this issue they would be seen as more valuable by the designers of these systems - no one wants to spend five-ten years developing a system that nobody wants to use, or that is complained of all the time, or worse yet, contributes to an accident. Human factors therefore needs to produce some solutions here, rather than simply warning of the problem.

2.9.5.5 Error Trends, Error Recovery, Error Prediction and Risk Analysis

When about to move to the next generation system, the principal problem for designers and system developers, and for human factors people, and even for regulators, is that there is no experience database from which to make detailed and sound judgements. What is wanted by all is confidence in the system, based on evidence, rather than based on belief which you may have simply because you are a stakeholder in the system itself.

In the absence of experience predictive methods at least give potential insights into what may happen. Risk analysis is used extensively in other fields, both to certify system and to detect vulnerabilities in complex systems and correct them before an accident happens. Risk analysis usually utilises HRA when dealing with systems whose performance, integrity and safety is dependent on human intervention. This approach is still largely missing from ATM. This misses an avenue to increase human factors integration because, although difficult and containing uncertainties, risk assessment will prioritise the contribution of the human to system risks and system recovery. Furthermore, it will often determine with relative precision what tasks or human involvements are most critical in the 'risk equation' and hence which tasks most need human factors support. This is therefore an avenue which should be explored for increasing human factors integration in ATM. What is needed is a tailoring of such HRA approaches from other industries to ATM.

Additionally, error analysis can be carried out on prospective new systems, early on in the design life cycle. This predicts error occurrence before usability trials and can therefore save development time. Such tools, in theory, can also predict more comprehensively those errors which are of low frequency but high importance, which might not be observed during the relatively short time-frame of a real-time simulation.

Error recovery is currently highly reliable in ATM operations, whether such detection and correction is instigated by the controller themselves, by another adjacent controller or even by the pilot. Such error recovery processes will be an intrinsic part of the controller's job. As this job changes and automation is introduced, these error recovery capabilities may diminish. This is of some concern, although the reliability of ATM operations is very high. The actual error rates during normal operations are also fairly high, even if these errors are normally trapped and corrected. The high reliability of current ATM therefore relies to a large extent on error recovery. We therefore need to establish how such processes work and what factors in the interface engender them.

Lastly, with soft measuring the general pattern of performance failures, and of seeing any big error pictures that may arise with the implementation of new systems. What is therefore needed is a systematic error analysis approach that can be applied across different ECAC States, so that European trends, as well as more local ones, can be determined. The error dimension, therefore, has much to offer human factors ATM integration.

2.9.5.6 *Interfaces vs. Modules*

For reasons better expounded upon in the papers at this conference by Messrs. Jackson (1998) and Jorna (1998), human factors work is often focused on particular products and as such is often 'compartmentalised' inside a particular 'module' of ATM human performance. This is sensible up to a point. However, many significant human factors issues (i.e. ones which make or break a system's performance) arise primarily in the interfaces between such modules. The classic example at present is ATM datalink research, which focuses significantly on controllers, but less so on ATCO-pilot interactions (the PHARE programme being a possible exception). This therefore misses out certain ATCO-pilot interface aspects such as the 'party-line' effect as a recovery mechanism, the degree to which pilots will react promptly to datalink messages, the impact of the loss of tonal quality as an indicator of pilot urgency associated with a request, etc. We therefore need more research involving the full picture of involvement, so that the understanding and intentions and interpretations of the various users can be seen when interacting with each other. This requires multi-user research and trials. Only then will the real picture of the problems and the potentials be seen in a realistic light. Unfortunately, such projects will require more resources, although different countries could share the costs and interconnect their facilities. The benefits will undoubtedly be a smoother and more rapid transition to an effective and accepted system.

2.9.6 Human Factors Unit Collaboration - A Team Resource Management Metaphor

All of the above issues rely on a closer association of human factors practitioners with other players in the ATM development and operating business. In particular, human factors must integrate more closely with the following personnel and their organisations:

- **designers**
- **controllers**
- **trainers**
- **strategists**

Finally, human factors units must collaborate more with each other. This is becoming difficult as commercial sensitivities politicise such involvements. Nevertheless, the real involvement of human factors in ATM systems developments is still a fragile phenomenon, and there is still much scepticism about the utility and practicability of human factors tools and data. Given the 'knowledge-driven' nature of human factors, the fact that we are often 'chasing' concepts and only catching up with them at the late Design stage, and given the fundamental challenges of future ATM, and above all these things, given the risks inherent in the nature of this transportation system and its continuing reliance on advanced human performance, a pooling of resources, approaches, and ideas, provides a strong counter to looking at issues in pure 'commercial' terms. Reality may prove otherwise, but philosophically at least, integration of human factors into ATM may be best served by more collaboration between different human factors units.

This idea can be taken further, and may be easier to implement by using TRM as a metaphor for such collaboration. The essence of TRM is that the whole is more than the sum of its parts, but only if those parts can work together and if there is some degree of trust and reliance. Furthermore, a team need only be so big, i.e. big enough to have the functions it needs to do the job efficiently. Each team member typically has a broad experience and can handle others' tasks, but has its own speciality. Ideally, other team members will therefore rely on each other particularly for their specialist expertise, working closely together with them if required.

Some of what each human factors in the various ECAC States is working on is primarily of national interest and may have aspects that are not of concern to other states, i.e. relating really only to their airspace. However, much of what we all work on and towards today is a European ATM framework. Nevertheless, currently much of the various human factors organisations' efforts are still nationally-bound. This is necessary since our own nation's objectives take priority, but it would make sense to share more of this work, or the techniques that have been evolved, or the lessons that have been learnt, where these results and insights relate to European objectives.

The TRM metaphor becomes more interesting if we can identify the speciality of each human factors unit. For example, without naming names, there will be some who are very experimental, with excellent research facilities and a high pedigree of experimental research; others may be focusing on particular techniques or issues and seen by the others as the leaders in the field. If information exchange could occur, it would seem that what we (and our parent companies) stand to gain in terms of new solutions, would outweigh what we might lose in terms of commercial competitiveness. The commercial balance, in fact, and certainly the risk one, would favour collaboration. This would then embody another TRM fundament, that of communication and feedback. This workshop on human factors integration could represent a significant launching pad to such an endeavour.

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3. SUMMARIES OF THE WORKING GROUPS

Five Working Groups (WGs) were held on the second day of the workshop. WGs 1 to 3 discussed the integration of human factors during/into the three main phases of ATM systems life cycle, i.e. respectively the **Concept Development** phase, the **Design** phase and the **Operation** phase. WG1 had to be split in two subgroups - WG1A and WG1B - due to the large number of participants.

WG4 covered the **managerial aspects** of the human factors integration within the whole life cycle.

Finally, WG5 evaluated the pros and cons of the existing human factors **methods and tools**.

The conclusions, presented by the rapporteur of each group on the third and last day of the workshop, are given below.

3.1 Integrating Human Factors into the Concept Development Phase of Air Traffic Management Systems (WG1A)

Facilitators:

⇨ Michiel WOLDRING, Human Factors Expert (now Manager, Human Factors Sub-Programme), EUROCONTROL Headquarters, Human Resources Bureau DED5 (now ATM Human Resources Unit), Belgium

⇨ N. DE BELER, EUROCONTROL Experimental Centre, France

Rapporteur: Ged MORRISROE, Director, Morrisroe Systems Engineering Ltd., United Kingdom

3.1.1 Introduction

The WG addressed the integration of human factors during the Concept Development phase of ATM systems.

The objectives of the group were:

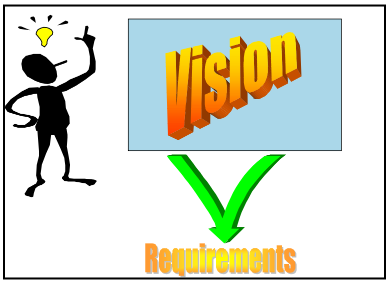
- to define WHAT human factors issues are to be considered during the Concept Development phase (the issues);
- to define HOW to deal with those issues (the methods);
- to define WHO is involved in the processes (the actors);
- to define the MEANS to be used or developed (the tools).

The WG had nine participants. Five of them had a human factors background, two were involved in organisational development and training, one came from the engineering/design domain and one had ATC operational expertise. Discussions were lively and, even though the majority of the group members were human factors specialists, all participants were actively involved.

3.1.2 Scope and Definition of the Concept Development Phase

The scope was defined by the start and the end of the phase dealing with concept development. However, these borderlines are not, in practice, always clearly defined.

We agreed on a working definition for **concept development**. Concept development starts with an idea that comes from the environment (from technology, from the identification of a need, from other domains, etc.) and clarifies the integration into its specific environment. For our discussion, concept development is the concretisation of an idea into the ATM environment.



We also agreed on a practical definition for **integration**. The proposition of concrete methods to take account of the human factors within the Design process. Much emphasis was given to the practicability (versus theoretical) of the methods.

We considered the end of the Concept Development phase as the moment where there is a clear view of the global system, the operational requirements and the design requirements.

We identified three types of expertise that should be involved from the beginning of the project:

- the human factors expertise,
- the technical expertise,
- the operational expertise.

The importance of a notion of risk and thus the need for risk analysis during the Concept Development phase were underlined but not further discussed.

3.1.3 Human Factors Issues

The following human factors issues were defined as to be considered during the Concept Development phase:

Management Issues

- Timescale and resources
- Cost-benefit analysis

Concept Development Process

- Evaluation process
- Traceability
- Stopping criteria

Man-Machine Task Sharing

- Functional description and allocation
- Task and role description
- User profile
- Usability
- Error management
- Context
- High-level design and prototyping

Scope

Transition

- All human factors issues are likely to have impact, e.g. task changes or different training needs.

- Transition may not be direct; several separate steps may be required to realise the new concept.

Principal Actors

- ATCOs, systems engineering, human factors, management, airlines, etc.

- Communication and conflict (objectives of the actors differ)

- Responsibility and accountability

3.1.4 Outstanding Issues

Several issues were identified by the group which need further exploration:

1. The notion of:

- cost benefit,
- risk taking,
- trade-off that should concern the human aspects,
- technical aspects,
- other operational aspects.

2. The question of the involvement of the end-users. Should they be involved from the beginning of the project and for which role?

3. The question of usefulness/feasibility of rapid prototyping in the Concept Development phase both for ‘selling’ purposes to stakeholders and defining at what moment the development of the new concept is ready to commit to the technical designers.

4. The common understanding between actors. Do they share the same view?

5. Traceability of the reasons of the decisions taken during the concept development.

6. The problems arising from ‘fuzzy’ requirements. Technical design needs concrete requirements.

7. Timescale difficulties.

3.2 Integrating Human Factors into the Concept Development Phase of Air Traffic Management Systems (WG1B)

Facilitators: ⇨ Lawrence BROM, EUROCONTROL Headquarters, Recruitment Section, DHR/HR1/2 (now Human Resources Management Services, DHR/HR/M1), Belgium

⇨ Dominique VAN DAMME, Human Factors Specialist, EUROCONTROL Headquarters, Human Resources Bureau DED5 (now ATM Human Resources Unit), Belgium

Rapporteur: Sylvie FIGAROL, Centre d'études de la Navigation aérienne, Human Factors Studies, France

3.2.1 Introduction

The WG has been addressing the integration of human factors during the Concept Development phase of ATM systems.

The objectives of the group were:

- To define WHAT are the human factors issues to be considered during the concept development of ATM systems (the issues);
- To define WHO should be involved in the process (the actors);
- To define HOW to deal with the issues (the methods);
- To define the MEANS to be used or developed (the tools).

The fourteen participants came from nine States. Six of them had an operational background, four were human factors specialists and four others came from the engineering/design domain.

Despite the cultural and background diversity of the participants, the group achieved its objectives.

3.2.2 Scope and Definition of the Concept Development Phase

As an introduction to the WG an attempt to define the Concept Development phase was made, as illustrated in Figure 1.

The idea to develop a new system can be triggered for different reasons. It can be the occurrence of a new problem, a change in the business situation, new needs such as an increase in the market demand (e.g., in ATC, an increase in the traffic load), the obsolescence of the existing system, or simply new opportunities such as the development of new promising technologies. One or more elements can generate a need for a new system. Most of the time, when the need appears, a feasibility study will be undertaken that will cover various aspects such as the budget, the technical or technological possibilities, the user needs, etc.

As shown in Figure 1, the various perspectives do not always fit together. Consensus can only be reached by making compromises. The Concept Development phase ends with the definition of the system characteristics. This definition could consist of more or less detailed specifications, functional descriptions or just a basic description of the concept.

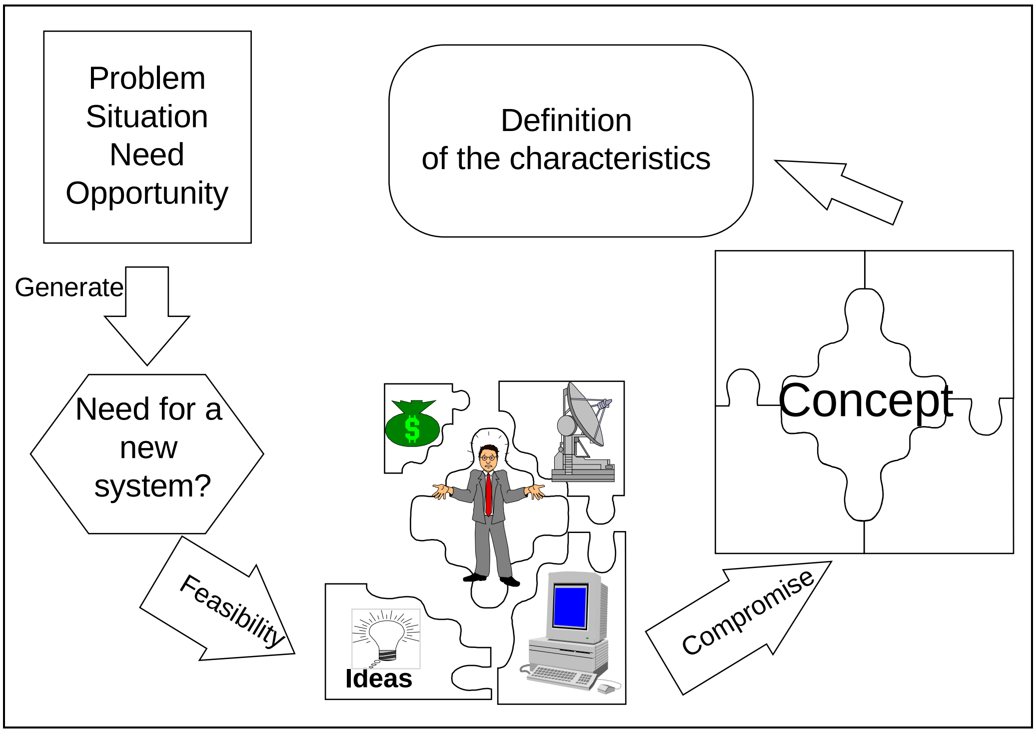


Figure 1: The Concept Development phase

On the one hand the definition of concept development was left vague enough to give the group a chance to consider various situations, on the other hand it was precise enough to give the working sessions a common framework.

The group recognised the following four points:

- It is difficult to know when the concept development starts and ends;
- There is no satisfactory answer yet;
- A new concept can either be evolutionary or revolutionary;
- The problem is not unique to ATM.

3.2.3 Overview of the Human Factors Issues in the Concept Development Phase

The group was asked to identify the human factors issues to be considered during the Concept Development phase of ATM systems.

Five major clusters were identified:

- the existing situation,
- the human potential and limits,
- the social aspects,
- the quality of the system,
- the impact of the new system.

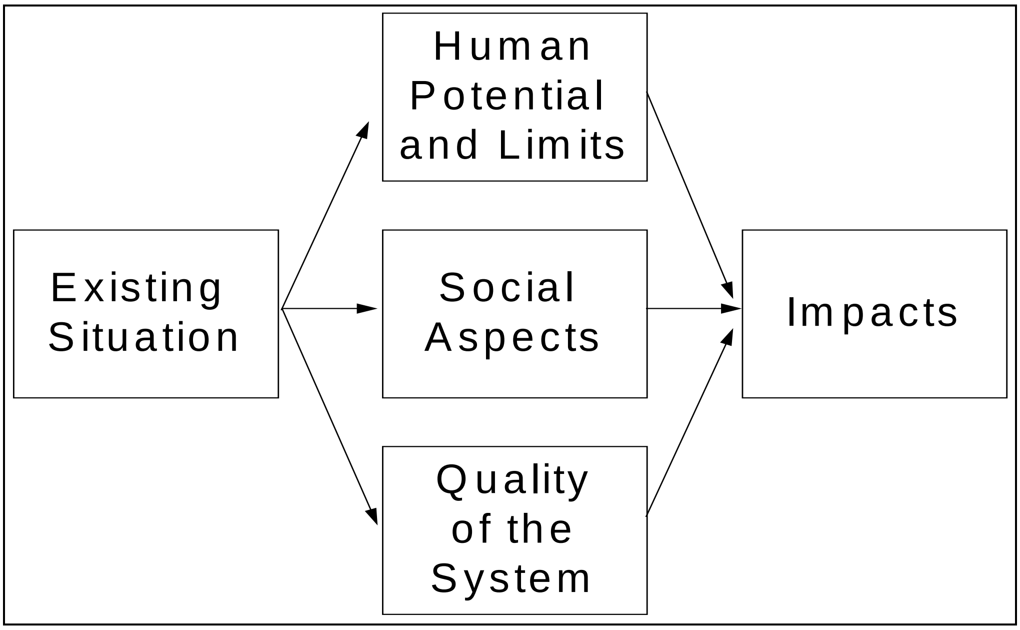


Figure 2: The Human factors issues in Concept Development

3.2.4 The Existing Situation

Bearing in mind the difference between evolutionary (new form of what is existing) and revolutionary (totally new) concepts, it is still important to look at the existing situation as this will be the baseline reference in assessing the impact of the new concept.

It is not only the formal and explicit procedures and working methods which should be considered because informal practice can also help in gaining an additional insight into the actual situation, more particularly into how people deal with the strain and constraint of the system with which they work.

3.2.5 The Human Potential and Limits

The feasibility study should include a human factors perspective. The feasibility should be studied in terms of the human performance required. It should include the understanding of the need for change and the resources management process between the system and the human being, i.e. the task sharing, the Human-Machine Interface (HMI) and the cooperation. It should also evaluate the new skills and knowledge required by the new concept, as well as its impact on the workload, the human performance and the productivity.

3.2.6 The Social Aspects

The social aspects to be considered are:

- the working organisation;
- the collective aspects such as the controllers' teamwork and the cooperation between the controller and the pilot;
- the job satisfaction;
- the security of employment.

3.2.7 The Quality of the System

Some qualities of the system should be considered from the Concept Development phase. The following are of great importance:

- human-machine compatibility,
- acceptability,
- ease of use,
- compatibility (integration) with other systems,
- evolutivity[1]/flexibility/maintainability (keep or throw tools).

Some of the above qualities can be seen as technical criteria more than human criteria. In fact, they have a human factors side. For instance, ensuring compatibility between two systems (old and new) should include human factors criteria such as the consistency of the HMI (presentation of the information, navigation and command).

The evolutivity/flexibility/maintainability trilogy is also of great importance from the human perspective, as it not only allows an iterative process during the Development phase but also easy modifications and update at any stage of the system life cycle.

3.2.8 The Impact on the Job

Some basic questions should be answered very early on, such as:

- Who will be affected by the new concept?
- What should be the consequences of the introduction of the new concept?
- What will change in the current working methods and practices?

[1] is the upgrade ability (ease of upgrading) of a system

- What kind of change is to be expected in the lines of commands/ communication?
- What will be the change of responsibility?
- What are the main potential safety-related situations?
- What sort of training will be needed?

3.2.9 Who should be involved in the Concept Development Phase?

To ensure the completeness of the process, the Concept Development phase should be a multi-disciplinary approach.

Who should be involved will depend mainly on the foreseen impact of the new concept. For example, it could be appropriate to involve workers unions if the new system happens to have a major impact on the user's qualification or on the security of employment.

Nevertheless, as the human aspects seem to be underestimated in most of the projects, a human factors coordinator should be appointed to define a human factors working plan for inclusion in the global project plan.

Figure 3 provides a non-exhaustive list of groups, individuals and/or qualifications that should be involved in the process.

◆End users ◆Controllers ◆Operational assistants
◆Pilots ◆Unions ◆Trainers ◆Customers

◆Human Factors experts
◆Ergonomists ◆Communication specialists
◆Job designers ◆Psychologists ◆Aviation doctors

◆Military

◆Initiators of the new concept development
◆Developers ◆Researchers / Industrial engineers
◆Technical support people ◆Technicians

◆Management ◆Decision makers
◆Financial specialists

◆Regulatory and legal authorities
◆Incident investigators

Figure 3: Who should be involved in the Concept Development phase?

3.2.10 How to tackle the Identified Human Factors Issues (Tools, Methods and Means)

How to tackle the human factors issues that have been identified will also mainly depend on the concept developed. Each ‘specialist’ could have his/her own valuable methods.

The methods and tools range from task and job analysis (cognitively-oriented methods), brain storming, discussion groups and interviews to fast-time modelling and use of guidelines on working conditions and human performance. Again, it is important that a human factors coordinator sets out the objectives and methods to be included in the human factors working plan. Such coordination is needed in order to avoid duplication and to allow a better synergy between the stakeholders.

It was stressed that a global and participative approach be advocated in any case, meaning that all perspectives should be considered and that the end-users should be involved in the Development process.

3.2.11 Managerial Issues

Within the scope of the integration of human factors in the development of the new system, several managerial issues were identified as follows:

- To decide what level of importance should be given to human factors within the development cycle of the system. Most of the time, the planning is so unrealistic that, when some aspects have to be removed from a project for whatever reason, human factors will often be the first to be sacrificed.

- To include human factors at an early stage. Very often, the human factors aspects are seen to be more important at the final stages of the development. This is a mistake because, most of the time, it is then too late or very costly to amend the system architecture and functionalities. Instead, including human factors at an early stage of the development can save time and money.

- Not to underestimate the scope of inclusion of human factors. They are commonly seen as the font format and colour choice of the screen! The most important issues for safety and efficiency of the human-machine performance, such as cognitive aspects, are totally neglected.

3.2.12 Concerns about Human Factors

It was also recognised that:

- human factors experts do not take the initiative in concept development;

- human factors experts are not very experienced on the conceptual level;

- human factors methods are not very compatible with engineering methods;

- human factors do not provide systematic methods to engineers to proceed to the inclusion of human factors.

- Operational people are ‘better’ human factors experts than human factors specialists.

These opinions were not all shared by all the participants. For example, it is obvious that, in a technical and financially-driven environment, a human factors specialist will only in exceptional circumstances hold a high managerial position. This could explain the lack of involvement in the conceptual work.

Most of the time human factors methods have to be adapted to each task objective. Because humans are not machines and human sciences are not exact the methods used to achieve the goals cannot be unique.

At least, Operational staff are the best experts in the field. Others should not claim that they can do the job better. However, human factors specialists have more knowledge of human beings, their skills and limitations, and they can provide proven methods.

3.2.13 Conclusions

Integrating human factors from the very beginning of the development of a new system, i.e. from the Concept Development stage, can save time and money.

The range of human factors issues is much wider than the font format or the screen colour!

In order to guarantee the system’s usability (ease of use and learning) and acceptability (suitable for the task to be done), as well as the user’s acceptance of it (positive user attitude towards the system), human factors such as cognitive aspects, human potential and limits, social aspects and the impact of the new system on the existing situation should be considered as important as the technical feasibility.

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3.3 Integrating Human Factors into the Design Phase of Air Traffic Management Systems

Facilitator: Johan KJÆR-HANSEN, Human Factors Specialist, EUROCONTROL Headquarters, Human Resources Bureau DED5 (now ATM Human Resources Unit), Belgium

Rapporteur: Bert RUITENBERG, Human Factors Specialist, International Federation of Air Traffic Controllers' Associations (IFATCA), The Netherlands

3.3.1 Introduction

The WG was addressing the integration of human factors during the ATM system Design phase.

The objectives of the group were:

- To define WHAT the human factors issues to be considered during the design of ATM systems are (the issues);
- To define HOW to deal with the issues (the methods);
- To define WHO is involved in the processes (the actors);
- To define the MEANS to be used or developed (the tools).

The WG had fifteen participants. Eight of them had an operational background, five were human factors specialists and two came from the engineering/design domain. Discussions were lively and the fact that a few of the group members were high-profiled human factors experts did not discourage contributions from the rest of the group.

3.3.2 Scope and Definition of the Design Phase

Early in the process the WG acknowledged that terms and concepts used in the discussion needed to be defined. A definition of the Design phase was sought but, due to time constraints, the WG deliberately did not try to come up with a definition of what design is; it rather concentrated on how to define its boundaries. Figure 1 illustrates the boundaries to the preceding Concept Development phase and the Operation phase.

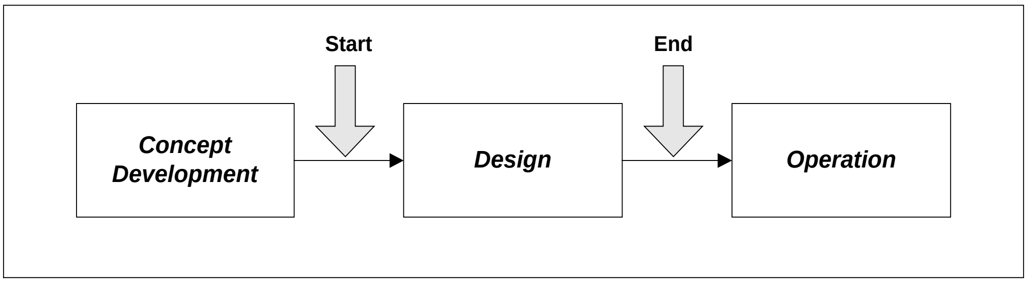


Figure 1: Interface to the Design phase

As the conceptual development often takes place in a different community than that of the actual design, the conceptual development often creates an envelope of philosophies, concepts and principles within which a particular design takes place. The design teams may adapt their work to the contemporary conceptual development, taking into account these developments. While the conceptual development may take place at research centres and other R&D establishments, the design itself will be undertaken by industry and R&D organisations. The transfer of concepts and principles from conceptual development to design was seen as a crucial issue.

While the implementation was considered as part of the Design phase, the group did not address the considerations for implementation due to time restrictions.

3.3.3 Overview of the Human Factors Issues in the Design Phase

The group identified the human factors issues listed below to be considered during the design of ATM systems. Even if they may interact with each other, they were highlighted as being individually important in the process:

- systemic view,
- approach and philosophy,
- certification/validation,
- development constraints,
- end-user involvement,
- principles,
- ergonomics,
- methods and tools,
- change management,
- training complementing design.

3.3.4 Means for Tackling the Identified Issues

The human factors issues that were identified to be of major importance in the Design process have been grouped in pairs and further elaborated in this chapter. The issues have been paired so as to maximise their synergy.

3.3.4.1 Approach/Philosophy and Systemic View

The importance of the approach and philosophy applied in the Design process was stressed. The application of a systemic view was highlighted as a major asset for the Design process. A systemic view and its use with system design are illustrated in Figure 2.

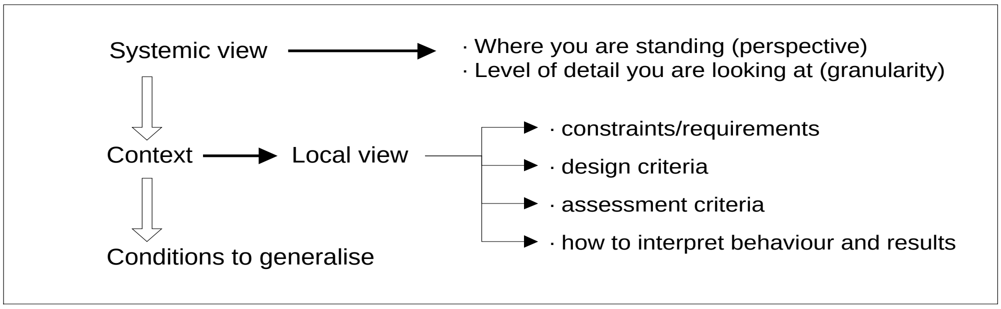


Figure 2: Application of a systemic view within design

The systemic view provides:

- a perspective from which to view things,
- the definition of the level of detail.

The systemic view gives a context for the system design, provides an orientation towards constraints/requirements, design and assessment criteria, and gives a direction for how to interpret the behaviour and results.

3.3.4.2 Certification/Validation and Development Constraints

Evaluation of present situation

The core design group and users should jointly evaluate the certification and validation.

Assumptions on future scenario

Clients and subject matter experts need to sit together and identify the assumptions upon which to design the system. Scenarios of future airspace concepts and working methods need to be addressed, and plans for integrating the human factors need to be involved. The assumptions will provide a clear transparent and traceable protocol to be used in the design.

Initial safety and risk analysis

A safety and risk analysis should form part of the system validation involving subject matter experts.

Iterative process

An iterative process should be applied in the Validation-Certification process. The process should involve human factors experts, users and externals.

Validate validation

The Validation process itself should be subject to a validation.

Prototyping/simulation

The lessons learnt from the previous prototyping as well as the simulation activities should be reviewed and applied.

3.3.4.3 End-user Involvement and Principles

User involvement in the process

This aspect could be achieved through incorporation of end-users into the design team. Active ATCOs could be involved through organisational commitment and retired ATCOs could be hired additionally for the sessions.

Testing of the equipment

The active ATCO was considered to be the most suitable person to test new equipment. He/she could be either a professional tester with a highly structured approach to testing and/or a ‘naïve’ end-user. The realism of the simulation was considered of high importance.

Monitor the end-user's experience

Constant monitoring of the end-user experience is an aspect that could be achieved through in-service systems.

Human factors goals and design philosophy

The human factors goals and design philosophy should be made explicit. The client should play a major role in setting up the goals and the design philosophy. It is important to make the goals a part of the written specification.

Design fitting the goal?

In order to address whether the design actually provides the best support towards achieving the goals; the validation team should utilise the simulations as a means for investigation. The satisfaction of end-users should be taken into account in the Certification process.

Human-centred automation

The aspect of human-centred automation should be addressed by the design team by making the design philosophy explicit not only to the end-users but to all parties involved. Documents should be prepared that would communicate the human-centred automation.

Graceful degradation

The 'graceful' degradation of the system in case of malfunction was considered an important principle in the system design. The system functions should transcend to manual human control in a controlled way. The transition should be based on a philosophy. Risk analysis should be applied to ensure contingencies involving all design team members including technical persons and utilising a software test-bed.

Is the design easy to understand and operate?

Several recommendations were considered:

- To build on existing systems;
- To think training: to incorporate (a) transition trainer(s) in the design team;
- To think architecture and system logic's: to incorporate cognitive ergonomics experts in the design team.

Easy recovery from system failure and human error

The following system requirements were suggested:

- error detection facilitation,
- error tolerance and error resistance,
- enhancement of error visibility.

There should be a cognitive ergonomic expert in the design team in order to facilitate these requirements.

3.3.4.4 Ergonomics, and Methods and Tools

Health and safety legislation

Health and safety legislation need to be applied and complied with. To ensure this aspect, human factors practitioners together with system designers need to be involved in the process.

Workplace ergonomics

Anthropometric methods should be applied in the design of the working position ergnomics. The human factors experts needs to apply empirical methods and include end-users in the design.

Designing console and working environment

The design of cnsole and working environment should be carried out by multi-disciplinary teams of end-users and human factors experts. The working methods should include prototyping and be task specific.

Human-machine interface and interaction

Experiments, prototypes, and evaluations of the human-machine interface and interaction should be performed using prototypes and simulations.

Human Reliability Analysis

Human Reliability Analysis (HRA) could be applied as part of the standard repertoire of the human factors experts to assess specific tasks.

Work situation experiments

Experiments with work situations could be used as a basis for task analysis and analysis of human resources. Techniques of observation, interviews and activity analysis could be applied.

3.3.4.5 Change Management and Training Complementing Design

The change management should be applied as an underlying principle just as end-users should participate to the design. The traceability and justification of changes should be ensured.

Principles

The principles used in the system design could be communicated on an early basis using Computer-based Training (CBT).

Working patterns

Part-task trainers should be developed in order to train particular aspects of working patterns.

Human-machine interface training

Training the end-user to use the human-machine interface needs to be considered a first priority, and should make ample use of simulators.

3.3.5 Conclusion

In summary, the WG identified the following focus points of primary importance:

- Importance of SYSTEM perspective;
- Early written expression of design philosophy;
- Process-oriented continuous validation;
- Design team: engineers, end-users, human factors and training experts;
- Qualitative and quantitative ergonomics tool-kits;
- Change management.

3.4 Integrating Human Factors into the Operation Phase of Air Traffic Management Systems

Facilitators:
⇨ Eoin MC INERNEY, Instructor, EUROCONTROL Institute of Air Navigation Services, Luxembourg

⇨ Mariann HINTZ-KELLER, Instructor, EUROCONTROL Institute of Air Navigation Services, Luxembourg

Rapporteur: Herman TRAAS, ATS Expert, EUROCONTROL Headquarters, Regional Implementation Division DEI2, now Airport Operations Unit, Belgium

3.4.1 Introduction

The WG addressed the integration of human factors during system implementation and operation.

The objectives of the group were:

- To identify the human factors issues in the implementation and maintenance of ATM systems;
- To determine the integration possibilities for human factors in the life cycle of the ATM system.

The WG had seventeen participants. Fifteen of them had a background as operational controllers, eight of them were current ATCOs. A further two participants were human factors specialists. Everyone participated in the discussions and worked well. Difficulties were experienced, occasionally, when the group tried to reach agreement on the understanding and use of technical terminology.

3.4.2 Scope and Definition of the Operation Phase

The scope was defined according to the life cycle model with the addition of operational training before implementation. The participants queried the use of the model at the beginning of the day. They agreed, however, to use the model as the basis for the analysis work, which was to follow.

The following two topics were put to the group:

- human factors considerations in system implementation and
- human factors considerations in system operation.

The issues were analysed using brainstorming and theme creation sessions for both topics.

3.4.3 Human Factors Issues

The working sessions produced elements to the following main themes:

- Implementation issues:

  ⇒ motivation,
  ⇒ training,
  ⇒ acceptance,
  ⇒ flexibility,
  ⇒ compromise,
  ⇒ modifications;

- Operation issues:

  ⇒ safety,
  ⇒ feedback,
  ⇒ situational awareness,
  ⇒ management,
  ⇒ communication,
  ⇒ guidelines.

3.4.3.1 Way Forward

When this work was complete, the group agreed that there would be insufficient time to formulate statements for all twelve themes of both topics. A Pareto vote was carried out to prioritise the importance of the themes and statements for the top three each were then composed.

3.4.3.2 Conclusion

The participants, in plenary session, formulated important statements for each of the three main issues on implementation and operation. They are as follows:

- **Implementation**

  ⇒ Motivation:

  ◊ Continue to give valid, relevant, clear information, as soon as available, to future users. Such information should explain the benefits, the changes and the system objectives.

  ◊ Give honest information; do not be afraid of weaknesses. Give the risks and a focal point for feedback.

  ◊ The information should be managed by a group composed of ATCOs, engineers, human factors specialists and managers.

⇒ Training:

◊ Have motivated skilled trainers with appropriate high-quality material and tools.

◊ Define criteria for successful training and what happens to controllers who fail.

◊ The Training Officer in charge of these training issues is ideally a member of the validation team.

⇒ Acceptance:

◊ User-friendly RAMBO (**R**eliable, **A**vailable, **M**aintainable, **B**enefits, **O**bjectives).

◊ Help Desk and clear feedback channels.

- **Operation**

⇒ Safety:

◊ Have the people involved.
◊ Continue the safety management function (monitoring, reporting).
◊ Establish a safe introductory capacity limit to traffic.
◊ RAM (Reliability, Availability, Maintainability).
◊ Operational validation of new procedures.

⇒ Feedback:

◊ Feedback is a continuous transparent loop to all concerned.

◊ Emphasis to be put on the importance of user feedback for:

- procedure improvements,
- system improvements,
- training improvements.

◊ No blame culture!

⇒ Situational awareness:

◊ Get knowledge of the system (and the constraints of the system).
◊ System needs to be 100% transparent.
◊ Identify and report any degradation of the system.

3.4.4 Conclusion

When the statements were formulated, the group was asked to summarise the discussions of the day and to formulate three statements. These should best represent the feelings of the group, as a result of the day's work. They agreed to the following:

1. Organisations are far away from fully integrating human factors knowledge in the development of ATM systems, with regard to implementation and operation.

2. There is a concern that decision-makers will not act on identified areas.

3. Language difficulties are apparent between the different professional groups (controllers, engineers, human factors specialists, etc.).

3.5 Integrating Human Factors into the Life Cycle of Air Traffic Management Systems: Managerial Issues

Facilitators: ⇨ Hermann RATHJE, Head of Selection and Manpower Planning Section (now Manager, Manpower Sub-Programme), EUROCONTROL Headquarters, Human Resources Bureau DED5 (now ATM Human Resources Unit), Belgium

⇨ Björn BACKMAN, Expert, Human Resources Management Harmonisation (now Expert, Stakeholder Relations Management), EUROCONTROL Headquarters, Human Resources Bureau DED5 (now moved to the Stakeholder Relations Management & International Coordination Unit), Belgium.

Rapporteur: Johan DELAURE, ATS Expert, Regie der Luchtwegen (now BELGOCONTROL), Belgium

3.5.1 Introduction

The WG consisted of fifteen participants, not only coming from all over Europe and ECAC States but also from North America. USA and Canada were represented by two participants. ICAO participated with one official from its headquarters. The participants were all familiar with managerial issues within ATM Organisations and life cycles of ATM systems.

The objective was set for the group as to 'mapping the managerial aspects of human factors integration within the whole life cycle of ATM systems'. After an initial discussion the objective was changed to 'mapping the managerial aspects of human factors integration within the whole life cycle of ATM systems **to include the impacts from other systems**'. The managerial aspects were related to:

- managerial responsibilities,
- managerial actions,
- appropriate managerial levels.

3.5.2 Methodology and Procedure

The method used was individual brainstorming where each participant filled in cards on what he/she regarded as managerial issues of human factors integration within the whole life cycle of ATM systems to include the impact from other systems. Each card was handed to the facilitator who pinned the card on the wall. After a sufficient amount of cards were pinned on the wall, and the participants felt that most ideas had been captured, the organisation of the cards began.

After each card was read loud by the facilitator, and the authors expanded on the meanings of the card, the cards were moved to form clusters with common boundaries. All participants were involved in these discussions, interacting with each other, exchanging and expanding on ideas.

Suitable titles and headings were discussed with the WG on what would be the appropriate descriptions of the common elements the cards shared within each cluster.

It was agreed that the number of headings should be kept to a minimum, so the number of cards under each heading would indicate the importance of each particular heading. After the headings were agreed, the Analysing phase of the WG started.

The group discussed at length the supporting and controlling elements to integrate human factors. One of the issues discussed was how managers can execute their responsibilities and take actions. Another issue was about most effective allocation of responsibilities and actions distributed between international bodies and within ATM organisations.

Basically, two different views could be depicted in the discussions and were shared by the participants. One view was to see the managerial issues as a matter of leadership and, by leadership, changes in organisational cultures towards a human factors integration are imposed. The other view advocated a systemic approach similar to what is done within safety management and quality management, i.e. controlling the process of integrating human factors within the life cycle of ATM systems.

The WG agreed that the integration of human factors within the life cycle of ATM systems and the impact from other systems can never be accomplished without a systematic top-down approach that affects leaders on all levels.

3.5.3 Results

Six different higher level issues explained the content of all single managerial issues proposed by the WG. These higher level issues also describe a top-down and systematic approach to integrate human factors within the whole life cycle of ATM systems. The agreed issues are from the perspective of a specific individual on a middle managerial level tasked to be responsible for the integration of human factors within a certain ATM organisation:

- Human Factors Philosophy;
- Human Factors Policy;
- Organisational Structure;
- Human Factors Culture and Leadership;
- Resources;
- Benefits: Why do it?

3.5.4 Human Factors Philosophy

This issue not only covers:

- the definitions of responsibilities,
- what the appropriate actions are,
- the appropriate managerial level,

but also the interactions between international bodies and single States and ATM service providers.

The first issue is to define a national human factors philosophy in line with ICAO human factors Standards and Recommendations and the EATCHIP framework for a human factors philosophy.

Before this can be done an EATCHIP framework of a human factors philosophy to be endorsed by the ECAC States must be defined. When this is done, senior managers within national administrations or ATM service providers must commit themselves to communicate this philosophy. The philosophy is the corner stone in the integration of human factors along the life cycle of ATM systems, and should include the impacts from other systems.

3.5.5 Human Factors Policy

The definition of a national human factors policy should include the scope, specific objectives and time lines. The definition of a national human factors policy must be followed up by a thorough strategy on how this policy should be implemented within the national administration or ATM service provider along the life cycle of ATM systems. The policy should address how human factors should be integrated in the Concept Development, Design and Operation phases of ATM systems.

The actions to be taken by the senior managers are to promote the policy and strategy throughout the national administration or ATM service provider, and to monitor the progress of its implementation.

3.5.6 Organisational Structure

Senior managers within national administrations or ATM service providers must ensure that a person is appointed to be responsible for carrying out the human factors philosophy, the established human factors policy and agreed strategy for integrating human factors. This appointed individual must be established at the appropriate organisational level, and given a clear responsibility for the implementation.

3.5.7 Human Factors Culture and Leadership

To foster an organisational culture in which human factors issues can be considered, and people can contribute to the achievements of organisational goals and objectives is the main responsibility at all managerial levels. This is also one of the objectives towards the integration of human factors. The integration of human factors aims to have a multi-disciplinary effort to compile and generate knowledge about people at work, and apply that knowledge to the functional relationships between people, tasks, technologies and environment, in order to produce safe and efficient human performance (see EATCHIP, 1998)[1] .

The actions necessary to create a human factors organisational culture and leadership are to define, implement and maintain the building blocks of this culture. This should be done in such a way that it becomes natural to involve social, behavioural and training specialists at early stages in the various task forces and WGs together with operational specialists and engineers. Both specialists groups should then be dedicated to diagnosing and prescribing various solutions to ATM systems problems. The objective is to be pro-active through such a multi-disciplinary approach. The integration of human factors along the life cycle of ATM systems starts with the Concept and Design phases.

Organisation climate does not change without the commitment of senior managers, who have to start the process followed by all levels to maintain it. What is important is to have the responsible human factors department or person to bring up and encourage compliance to the desired organisational culture.

3.5.8 Resources

Of course a systematic approach to integrate human factors demands resources. A major managerial responsibility in human factors integration is to plan, determine and secure the level of resources required, according to the work plan previously developed.

The actions are to determine the number of human factors specialists that are designated to work together with operational specialists and engineers on carrying out specific tasks. The budgeting of resources might also include specific staff development and training activities, such as participating in workshops, attending seminars, etc. It is absolutely essential that both the financial and human resources be available at the right time. To this end, the responsibility of the resource allocation should be in the hands of the human factors integration management. This will result in a structure that is similar to the one prevailing for the safety and quality management.

3.5.9 Benefits: Why do it?

An obvious and striking reason for integrating human factors was given by a participant when referring to lessons learnt within the FAA.

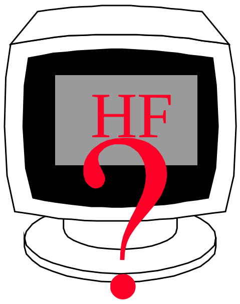
[1] EATCHIP Human Resources Team (1998) - *Human Factors Module: Human Factors in the Development of Air Traffic Management Systems.* HUM.ET1.ST13.4000-REP-01. Brussels: EUROCONTROL.

The lessons quoted from Del Balzo (1993)[2] in EATCHIP (1998)[1] were:

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

3.5.10 Conclusion

Give a sound answer to the question:
" WHY support human factors"



... to make everybody feel happy.

[2] Del Balzo, J. M. (1993) Speech to the ICAO Flight Safety/Human Factors Conference. Reprinted in D. Beringer (Ed.). The Flyer, June newsletter of the Aerospace Systems Technical Group of the Human Factors and Ergonomics Society, 2.

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3.6 Human Factors Methods and Tools

Facilitators:

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Rapporteur: Peter JORNA, Head of Man-Machine Integration and Human Factors, Nationaal Lucht- en Ruimtevaartlaboratorium, The Netherlands

3.6.1 Introduction

The WG was addressing the human factors methods and tools to be used in the ATM system.

The objectives of the group were:

- To identify human factors methods and tools that could be used for the development of ATM systems;
- To evaluate these methods and tools;
- To suggest human factors references and have critical thinking when developing new ATM systems.

The WG had fourteen participants. The majority came from research and development groups and university departments. One was from a teaching academy and one from industry. Discussions were thoughtful, and although a few of the group members were high profile human factors experts, this did not prevent the group from attempting to resolve some of the daunting issues. The mandate for the group was perhaps, in theory, a little more structured than the other groups but, in reality, this did not prove any advantage.

3.6.2 Scope of the Working Group

Early in the process the WG realised that the identification of human factors methods and tools was wide ranging, and indeed, after all members had attempted to list the possible issues, the group resolved to firstly discuss what exactly constituted the life cycle of the process. Figure 1 illustrates the issues the group identified as relevant to the discussion.

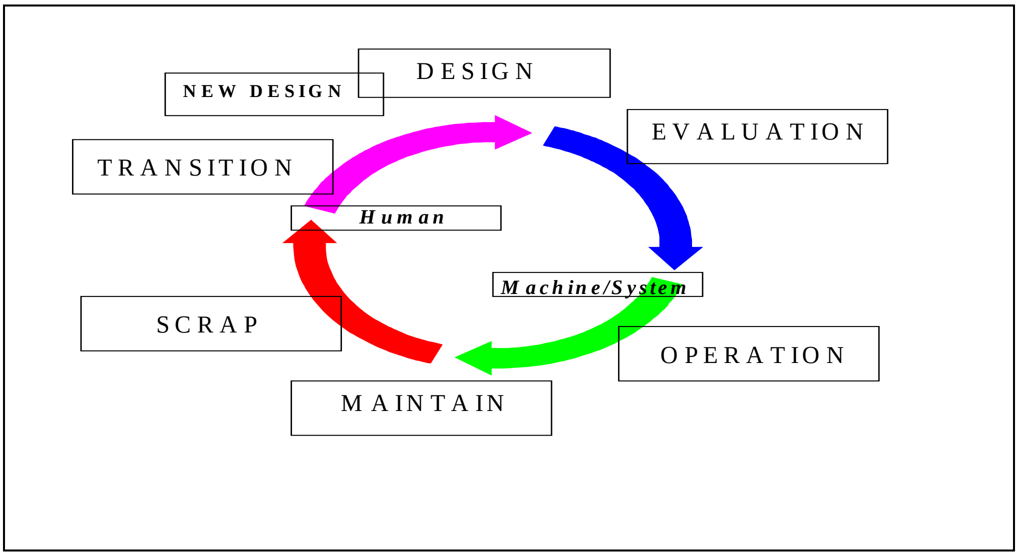

Figure 1: Stages to be considered in the identification of human factors methods and tools in the ATM life style

Figure 1 indicates that there were several stages which could be considered within the life cycle of an ATM system and therefore each stage would necessarily have a variety of different human factors methods and tools associated with them.

Typically, as was probably discussed by other workshop groups, each of these phases could be considered in terms of the developments required by the organisations; firstly, those managed and used by the controllers, secondly, their support personnel and lastly, that knowledge and experience found in the R&D establishments who may be involved in the development of methods and tools which support the ATM infrastructure.

As was reflected by the majority of those in the group, R&D establishments tend to play the most active role in the development and use of human factors methods and tools which can be used within the ATM system. However, as the advances in technology increase, so to will the design issues themselves, and these in turn will be continually influenced by the manufactures and also the users of the systems. The group recognised that the transfer of information regarding the human factors methods and tools from the Design stage through the other stages of Evaluation - Operation and Maintenance - were all very important issues.

The group also identified that the next stages in the ATM life cycle, those of 'scrapping' a clearly inadequate or unusable system, and the transition to a new system design were possibly the most difficult to discuss in terms of human factors methods and tools. Therefore, the group concentrated most of its effort on the human factors methods and tools which could be considered in the first four stages in the life cycle.

3.6.3 Objective One: Identify Human Factors Methods and Tools that could be used for the Development of Air Traffic Management Systems

3.6.3.1 Design Phase

The WG identified the issues related to the human factors methods and tools to be considered during the design of ATM systems. As shown below these issues were listed in chronological order although it was accepted that some aspects were not necessarily dependent on previous ones. For each issue appropriate methods and tools were suggested.

Table 1: Identification of human factors methods and tools in the Design phase

Issues in Design	Human Factors Methods and Tools
Customer requirements	• structured interviews with individuals or groups • questionnaires
Constraints/impact analysis	• structured interview with individuals or groups • fieldwork and observations • regulations and laws
Context analysis	• evaluation with multiple domain experts • use of books/journals/internet • discussions with experts and colleagues
Task analysis	• structured methods/ text books • analytical tools • automation concepts
Task modelling	• GOMS (Goals, Operators, Method and Selection) • GEMS (Generic Error-modelling System) • MicroSaint (networked simulation package)
Scenario, time line analysis	• PUMA (Performance Usability-modelling of ATM) • MIDAS (Man-machine Integration Design Analysis System) • IPME
Use of human factors norms	• human factors databases
Check regulations	• ICAO, JAR • FAR
Prototyping (iterative process)	• Operator Display System (ODS) • in-house simulation package • VAPS (Virtual Applications Programming Software) • mock ups

3.6.3.2 Evaluation Phase

The group discussed this phase in detail and identified the issues related to the human factors methods and tools to be considered during the evaluation of ATM systems. These issues are listed below as well as, for each of them, the methods and tools suggested.

Table 2: Identification of the human factors methods and tools in the Evaluation phase

Issues in Evaluation	Human Factors Methods and Tools
Observations	• observation criteria • video
Selection tests	• various including new types i.e. P300 (neurological functioning)
Simulation	• simulation suites
Interviews	• interview criteria
Questionnaires	• questionnaire criteria
Psychophysical measurements	• eye tracking, pupil size • heart rate • EEG

3.6.3.3 Operation Phase

The group discussed this phase and attempted to identify the issues related to the human factors methods and tools to be considered during the operation of ATM systems. Again, these issues are listed below as well as the various methods and tools suggested by the group.

Table 3: Identification of the human factors methods and tools in the Operation phase

Issues in Operation	Human Factors Methods and Tools
Working schedules	• written documents • questionnaires • sleep logs • laboratory observations
Human resource management	• appropriate criteria

Table 3: Identification of the human factors methods and tools in the Operation phase (continued)

Issues in Operation	Human Factors Methods and Tools
State and performance measures	• stress • fatigue • workload
Ergonomic/workplace evaluation	• various known criteria from reference books
Error and failure assessment	• incident reports • replay 'error' material • 'expert' observation
Quality assessment	• established criteria

3.6.3.4 Maintenance, Scrap and New Design (Transition) Phases

Unlike the previous stages and because of the time limitation the group simply identified the issues related to be considered during the maintenance of ATM systems. There was a short discussion regarding the Scrap and New Design phases, and as a result the group decided to translate these two phases into a 'Transition' phase. The issues in both the Maintenance and Transition stages are listed below.

⇨ Maintenance stage:

- re-training,
- backup procedures,
- documentation,
- checklists,
- problem-solving techniques;

⇨ Transition stage:

- re-training - refresher and conversion,
- skills analysis,
- selection implications,
- habit analysis,
- professional checks.

3.6.4 Objective Two: Evaluate the Human Factors Methods and Tools used for the Development of Air Traffic Management Systems

During this section of the workshop the group was again asked to analyse and evaluate those methods and tools suggested in the previous discussions.

This exercise was completed for the first three stages of the life cycle, that of Design, Evaluation and Operation. In order to record this discussion, the following tables summarise the contributions under either positive or negative aspects of each of the methods or tools chosen.

3.6.4.1 *Design Phase*

Table 4: Evaluation of the human factors methods and tools in the Design phase

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• structured interviews with individuals or groups	• good coverage and clarification • matching human factors knowledge with user requirements	• time consuming • no common perspective
• questionnaires		• expertise in compilation • compromise with respect to ranking priorities
• structured interviews with individuals or groups	• good review of limiting factors	• human factors 'expert' limitations • confidence in the truth and completeness of documents
• fieldwork and observations • regulations and laws	• concentrating resources on certain aspects	
• evaluation with multiple domain experts	• increased knowledge on all sides	• level of knowledge • consistency of understanding

Table 4: Evaluation of the human factors methods and tools in the Design phase (continued)

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• use of books/journals/ internet	• education of customer	• tunnel vision of expert bias
• discussions with experts and colleagues	• common perspective	• tunnel vision of expert bias • lack of common procedure
• structured methods • analytical tools	• clear strategy	• rigid methods
• automation concepts		• problems of adaptive automation • lack of work in the area of transition from total human to total automated control
• GOMS (Goals, Operators, Method and Selection)	• structured information	
• GEMS (Generic Error-modelling System) • MicroSaint (networked simulation package)		• time consuming • cumbersome • expensive • low validity
• PUMA (Performance Usability-modelling of ATM)	• reduced number of experiments required	• time consuming • insufficient consideration of operator variables
• MIDAS (Man-Machine Integration Design Analysis System) • IPME	• promising results thus far	
• ICAO, JAR • FAR	• a normative collection	• limiting progress

Table 4: Evaluation of the human factors methods and tools in the Design phase (continued)

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• ODS • in-house simulation package	• some facility to change	• based on old systems with no new systems included • not flexible enough
• VAPS (Virtual Applications Programming Software)		• expensive • awkward • slow • hard to maintain
• mock ups	• cheaper • physical validity • flexible	

3.6.4.2 *Evaluation Phase*

Table 5: Evaluation of the human factors methods and tools in the Evaluation phase

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• observation criteria	• very good and simple	• time needed • sampling errors
• video	• fast with real-time data	• some items hidden - cognitive • some rare events missed • reliability of observers • intrusive
• various selection tests, including new types i.e. P300 (neurological functioning)	• the number of abilities involved	• difficulties with simulating the job sample • complex

Table 5: Evaluation of the human factors methods and tools in the Evaluation phase (continued)

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• simulation suites	• context dependent • takes account of complexity • prepares acceptance in the field • it has multiple use	• bridge between real system and real simulation • need for training • very expensive • problems of cause and effect due to experimental control
• interview criteria	• easy • high level of control	• low ecological value • interviewer bias
• questionnaire criteria	• economic • extra value with data comparison	• acceptance problems • difficult to make an effective questionnaire • bias
• eye tracking, pupil size • heart rate • EEG	• objective • sensitive to performance • compliment other measures	• no one model explains all this data • needs specific expertise • some testing is expensive • often difficult to test in the working environment • cultural problems

3.6.4.3 Operation Phase

Table 6: Evaluation of the human factors methods and tools in the Operation phase

Human Factors Methods and Tools	Positive Aspects	Negative Aspects
• written documents		• inaccurate
• questionnaires	• lots of data	• inaccurate
• sleep logs		• time consuming
• laboratory observations	• performance decrement • prevent health problems	• time consuming • expensive • union problems • management problems
• appropriate criteria	• having a criteria	• finding a common criteria
• stress • fatigue • workload	• objective	• requires specific expertise • knowledge of scientific design • instrumentation problems • often needs more tools to compliment this approach
• various known criteria from reference books	• well documented	• knowing what is required
• incident reports • replay 'error' material • 'expert' observers	• good source of information	• human factors not always addressed • selectivity in data • legal problems • must have something to compare with
• established criteria	• having a criteria	• finding the correct criteria

3.6.5 Objective Three: Suggest Human Factors References and Develop Critical Thinking when Developing New Air Traffic Management Systems

It was anticipated that during the workshop those involved would develop their knowledge and critical thinking in terms of the subject matter discussed. However, the majority of the group had quite well advanced knowledge and experience in this area and therefore this objective was more difficult to measure and judge. The group, however, had the opportunity to use various reference materials which were available. A selection is listed below:

Cardosi, K.M. and Murphy, E.D. (1995). *Human Factors in the Design and Evaluation of Air Traffic Control Systems*. FAA: US Department of Transportation.

Garland, D.J. and Endsley, M.R. (Eds) (1995). *Experimental Analysis and Measurement of Situation Awareness*. Embry-Riddle Aeronautical University Press: Florida, USA.

Harris, D. (Ed) (1997). *Engineering Psychology and Cognitive Ergonomics*. Volumes 1 and 2. Ashgate: Aldershot.

Kirwan, B. and Ainsworth, L.K. (Eds) (1992). *A Guide to Task Analysis*. Taylor and Francis: London.

O'Brien, T.G. and Charlton, S.G. (1996) *Handbook of Human Factors Testing and Evaluation*. Lawrence Erlbaum Associates: New Jersey.

Seamster, T.L., Redding, R.E. & Kaempf, G.L. (1997). *Applied Cognitive Task Analysis in Aviation*. Avebury Aviation: Aldershot, UK.

3.6.6 Proposed Improvements

In the final discussion the WG concluded that there would be two major improvements with the use of human factors methods and tools in the life cycle of the ATM system:

1. In terms of the methods themselves it was felt that careful research and development work would ensure harmonisation and standardisation, and that the methods and tools would support the quality control and certification in this profession in such areas as task/skill analysis, situation awareness and team performance.

2. Another improvement would be seen in the careful use of facilities during data gathering. As these are such expensive tools it was anticipated that the establishment of clear goals and objectives, which met many criteria including human factors issues, would allow the successful testing of principles and the usability of a system before major developments.

3.6.7 Conclusion

In summary, the WG identified the following points of primary importance:

- risk reduction in system development,
- 'lean' systems with less complexity,
- designing what is really useful,
- user acceptance and preparation,
- less transition problems,
- reduced system 'patching' in operations,
- happy management.

4. POSTERS

This chapter provides the text of the posters displayed during the Poster Session on the first day of the workshop.

4.1 Consequences of Adopting Human Factors Guidelines in Air Traffic Management Systems Design ...

... or trade-offs between users input / human factors guidelines, or result from four years of incremental prototyping activity

by Billy JOSEFSSON, Human Factors Specialist HCI/HMI, Swedish Civil Aviation Administration

This is about modern ATM systems design, users preferences, the process, how to success and finally some examples of real usable solutions for ATM systems.

4.1.1 Modern Air traffic Management System

- Automation of routine tasks
- Stripless and label interacting
- Increased capacity
- Safe
- Cost efficient, cognitive, human factors and 'money' aspects
- Compatible with the surrounding world
- Commercial off-the-shelf hardware
- Flexible and can be updated

4.1.2 Users and their Preferences

User involvement is **critical** in order to be successful in ATM system design but the paradox is that user involvement without guiding principles may render in design solutions that hinder the users' ability to use them, or the solutions are not possible to manufacture.

When users want what's NOT best for them

(Andre, Wickens, 1995)

Sometimes, people prefer features of a human-machine interface that do not provide them with the best performance

(Bailey, 1993)

Why does this happen and can it happen in ATM system design?

Yes, because we're sometimes guided by preferences such as aesthetics, novelty, familiarity and personal experiences.

4.1.3 Typical Mistakes in the Air Traffic Management Design Process as well

- Start with details instead of adopting a concept/strategy
- Too colourful
- Too much heritage from the old environment
- Too many windows and hard buttons on the screen
- Too much information on the screen(s)
- Try to optimize small events in different ways
- Too many: 'We must have that because we have this in our present system' and 'It would be nice if I could do like this ...'

... These mistakes will probably render in a system with low usability (low task focus and consistency) and additionally (NEW!) tasks for the ATCOs to carry out!!

4.1.4 The Process with Focus on Human Factors

- Education for the staff involved, use mixed teams! (ATCOs, Software and Hardware)

  In general, people are unaware of the many information and processing mechanisms that are responsible for the speed and accuracy of human-machine interaction.

- Task Analysis

  This will help the designers to focus on the relevant parts. This will also guide the CAA Staff in order to identify the operational concept which will imply changes in rules and regulations. The result of this analysis is one of the components of the training programme for the transition to the new system.

4.1.5 Answering four Questions (Shapiro, 1993) is a Useful Approach

1. Identify tasks or events which are not valid anymore in present system (consequently, no support needs to be provided).
2. Identify relevant manual activities which will be automatized in the new system (consequently, no support needs to be provided for regular use

BUT you must address the feedback issue from the system to the operator degraded modes occur, i.e. lack of system support).

3. Identify what kind of characteristics must be supported in the new system (tracks, etc.)

4. Identify which activities will be supported in a different manner in the new system (conflict detection, etc.).

   - Identify usable human factors guidelines, and behaviour and style guide.

   - Incremental Design process with representative prototypes and agree on principles to be used. Design, test, evaluate, identify trade-offs, check consistency and task focus, modify, test.

   - Communication with the intended users:

   - First, highlight and explain the trade-offs made. Where dissociation occurs between user input and best performance, inform and explain to users the favourable aspects of performance, consistency and task focus of the selected alternative.

4.1.6 Human Factors Applied at Human-Machine Interaction Level

Agree upon some proven principles, human factors guidelines that will favour the human capabilities:

- minimum information principle (Hicks law);
- minimize mouse travel (Fitts law);
- minimize mouse clicks (prevent RSI);
- use of colour (Merwin & Wickens, 1993; Reising & Calhoun, 1982; Martin, 1984);
- avoid nugatory tasks/load (task focus);
- display design principles (Wickens, 1992).

Adopt these principles in the Design process and it will dramatically increase the possibilities to end up with a safe, usable and efficient HMI with the following characteristics:

- clean,
- put the relevant information in focus,
- minimum colours,
- direct manipulation,
- integration of actions,
- grey shades and colour coding,

- intuitive, object-oriented at user level,
- short way to reach all functions,
- context sensitive,
- flexible,
- consistent and maintained task focus,
- mental representation of task vs. current representation is considered.

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4.2 Human Factors Methods Coping with Strategies of Automated Multi-sector Planning[1]

by K. Eyferth[1], M. Fricke[2], Y. Hauß[1], S. Leuchter[1], C. Niessen[1], O. Späth[1] & N. Stark[2]

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One way of managing the growth in air traffic could be through the development of cooperative of ATM. The main objectives of the work of the interdisciplinary research group 'Human-Machine Interaction in Cooperative Systems of Air Traffic Management' at the University of Technology, Berlin, are to plan and develop a cooperative ATM from a human factors perspective. The main technical innovation of cooperative ATM is the introduction of a digital datalink, which allows a digital exchange of information in the Flight Management System (FMS) between aircraft and ground. As the main consequence, datalink will allow an optimization of ground-based ATC planning and surveillance. The datalink will provide the availability of exact airplanes' flight paths data within a single ATC sector and therefore could also be used for better planning between sectors, i.e. multi-sector planning. According to our concept, the Multi-Sector Planner (MSP) is not only an intelligent technical system but also a responsible operator who uses this tool to coordinate system's advice with flight crews and ATCOs.

The communication between air and ground will not only change with the use of the media datalink. There are two potential communication partners for one aircraft: The MSP and the executive controller. This ambiguity requires procedures that provide consistent communication and delegate responsibility to the operators. The concept distinguishes between flight plan negotiation and short-term instructions/requests. Flight plans are negotiated between the aircraft and the MSP. Short-term instructions and requests are exchanged between the aircraft and area controllers. A conflicting flight plan automatically lead to a coordination between area controllers and the MSP. A mechanism is implemented that allows this coordination to have a low false alarm rate. The responsibility for an action is delegated to the operator that is expected to have the highest situational knowledge of the relevant area at this moment.

The potential for technical improvement has long been seen in ATC. But the critical link in any new ATM scenario will be the human operator, since the responsibility for the safety of the air traffic will stay with the ATCOs. Therefore, an important part of how to design an innovative cooperative ATM system should be a prospective estimation of the probable future demands on the operators. To accomplish this aim we mainly use modelling and empirical investigations in a simulation environment. The two approaches have in

[1] This work is granted by the DFG (grant number: FR 375/48)

common the aim to find hints how the **picture** of the operators can be maintained in future automated systems.

To accomplish this goal the research group has built a highly realistic, real-time evaluation environment which simulates existing controllers' workstations, integrates new datalink functions into these workstations, and also provides a prototype of a newly designed future workstation for a MSP. An Airbus A330/A340 full flight simulator which includes a scientific research facility and the required datalink functionality is integrated in the simulation system.

At a first stage mainly cognitive experiments were performed with ATCOs in an en-route scenario, in order to analyze and model the controller's picture. The picture is essential for an ATCO in order to achieve the goal of the safe and efficient flow of traffic. We define it as an analogous, partial and transient model, which will be continuously constructed and modified by schemata in order to encounter the actual and anticipated task requirements. The picture is the basis for the inference of relation between objects against the background of conflict detection and conflict solution, as well as for the flexible sequencing of cognitive processing steps. At this stage the main focus was on the operators' skills with their present system. On the basis of results from simulator experiments, questionnaires, and memory tests with controllers at various skill levels, a computer model (MoFL) was designed and implemented. The main goal was to model the construction, the maintenance and the continuous modification of a controller's picture as a situational model that guides the action in a dynamic task environment. The modelling and the implementation of MoFL is used to examine the postulated cognitive processes in a detailed way, which cannot be achieved through verbal protocols of controllers. With the model, we hope to determine which of the controllers' skills have to be preserved and which of them can be given up in a newly designed work environment.

The investigated scenarios differ mainly in the existence of the MSP and in the media used for communication between air and ground. Each of these scenarios will be tested experimentally under the aspect of the controllers' picture modification. The results of these experiments will be fed back into the next step of technical development in such a way that, with each development cycle, the system adapts to the operators' capabilities. The main issues during this development phase concern the new task allocation for the controller team in a sector, i.e. between planning and executive controller. All experiments are planned as comparable simulator studies. The dependent variables concern situation awareness, performance and workload issues. In each scenario usability studies are performed in order to exclude the influence of an improper interface design on the simulation experiments. A method for measuring situation awareness is developed and applied. This method is based on information reproduction and anticipation tests. It takes explicitly into account that the comprehension of the significance of an element in the task environment has an influence on the information processing of the operator. In the domain of ATC it is known that number and kind of perceived parameters of an aircraft depend on its significance. In addition, it is assumed that the retrieval of already perceived parameters is also influenced by the significance of an aircraft. It is assumed that besides the parameters of the element and its relation to the other elements of the task environment the individual control strategy of the operator is the main determining factors for the significance of an element.

The first experiments are performed to evaluate the computer model of the controllers' picture. A basic version of the future en route controllers and MSP workstations are implemented. Usability studies of the ground system were started.

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4.3 Evaluation of the Psychophysiological State and Learning Process of Air Traffic Control from the Laboratory to Real-Time Situation

by R. MOLLARD and P. CABON, Université René Descartes, Laboratoire d'anthropologie appliquée, Paris, France, and by H. DAVID and F. CALOO, EUROCONTROL Experimental Centre (EEC), France

4.3.1 Introduction

The current growth in air traffic will increasingly require the development of safe and efficient ATC system, which will have to be able to manage such a growth. Future developments will necessitate the implementation of new airspace organisation, new technologies and new interfaces. Moreover, the adaptation to this growing traffic will require some evolution in the role of the ATCO. However, these future developments need to be properly assessed as regards their potential impact in terms of workload, stress and fatigue. In particular, the introduction of new facilities requires an objective evaluation of the training procedure and time needed to be able to use them before their implementation in the real world. In the last few decades simulation in the field of ATC has been a useful tool in assessing various aspects of the facilities such as Human-Machine Interfaces (HMIs).

The EUROCONTROL Experimental Centre (EEC), France, has recently initiated some research with the aim of developing a set of objective measurements that could be used in simulation. This research was conducted in three steps:

1. A feasibility study for the evaluation of several physiological measures to assess the psychophysiological state of ATCOs in a simple simulation.

2. A study on the evaluation of the learning process of ATCOs.

3. A first application of the measures into a real-time simulation.

As a result of these different steps a method is now available at the EEC to perform objective assessment of operator behaviour in human factors studies focused on ATC activities.

4.3.2 Feasibility Study

The feasibility study was conducted in the laboratory with eight experienced ATCOs using the Terminal Radar Approach Control (TRACON II) which stimulates the ATCO activity in a simple but realistic way (Cabon et al, 1997). This study focused primarily on critical issues regarding the ATCO performance through a set of objective and subjective data. The EEG was continuously recorded during the simulation as a measure of the alertness level. Workload was assessed by the amplitude of the Event-related Potentials (ERPs) and a subjective scale, the NASA Task Load index (TLX). Fatigue and sleepiness were evaluated through visual analogue scales.

Stress related to the task demand was determined by salivary cortisol. The results obtained in this study have shown the value of most of data collected for the evaluation of the psychophysiological states of an ATCO. Moreover, the spectral analysis of the EEG showed some variations of the theta rhythm in relation to the learning of the device. This result is supported by recent data from the literature. Therefore, this study has confirmed the value of the data collected for various evaluations in the area of simulation.

4.3.3 Learning Process

One of the most critical issues concerning the introduction of new technologies, interfaces or procedures deals with the amount of training which is required to help an operator to adapt to these evolutions. Therefore, the aim of this study is to determine the relevance of some of the data collected in the previous study in order to evaluate the type and the time of training required for a specific interface. The experiment was also conducted with TRACON II. The sample included eight ATCOs (four experienced ATCOs and four ATCO students) with a view to comparing the changes in the data as a function of the experience in the job. Each ATCO was successively presented with four sessions creating a growing traffic volume and complexity. The data were analysed in relation to the changes in performance and software manipulations. The results have demonstrated some significant differences between the experienced controllers and the student controllers in performance, learning and stress. EEG recording shows that learning the manipulation of the TRACON is faster and more efficient among the experienced group than among the student group. Therefore, the results showed the value of the data collected for further evaluations in the Simulation process.

4.3.4 Transfer to Real-Time Simulation

The method developed in the two previous studies was recently applied at the EEC for the Sweden-Denmark real-time simulation (July, 1998), testing a stripless interface as well as a new airspace organisation. The aim was to establish the impact of these developments in terms of workload as well as the time of training required to learn the new interface. As sleep quantity and quality can greatly affect the diurnal performance; the forty ATCOs involved in the simulation were asked to fill a daily sleep log. EEG, salivary cortisol and subjective assessment were continuously collected during the three weeks of the real-time simulation for sub-samples. The data are in the course of being processed, and will be compared to the simulator data and instantaneous workload evaluation collected by the EEC. From the results obtained in this study it should be possible to provide an objective evaluation of the learning process of controllers during the different steps of the real-time simulation, as well as objective and subjective assessments of fatigue, sleepiness, workload and stress. Furthermore, based on this objective method, recommendations will be proposed concerning the learning procedure to be applied in future real-time simulations.

4.3.5 Conclusion

The developments of the tools which will be implemented in the future ATM need to be assessed from an ergonomical point of view, including their impact on ATCOs in terms of workload, stress and fatigue. These evaluations are covered by the method we propose. Furthermore, the training of ATCOs on these new systems is one of the most important issues for the success of these evolutions. The study, conducted in close cooperation with the EEC, aims to address these topics in order to provide objective information as well as recommendations to improve the adaptation of these systems to ATCOs in a way that ensures efficient and safe ATC.

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4.4 Human Factors Methods and Tools - Studies of Pilots' Performance in Experimental Cockpit Environments

by G. HAULAND and T. BOVE, RIS∅ National Laboratory, Denmark

Human Factors Methods and Tools

Studies of Pilots' Performance in Experimental Cockpit Environments

Gunnar Hauland and Thomas Bove

Calibration of two eye-trackers in an Airbus A340 Simulator at Aerospatiale, Toulouse.

Analyses of Visual and Verbal Behaviour

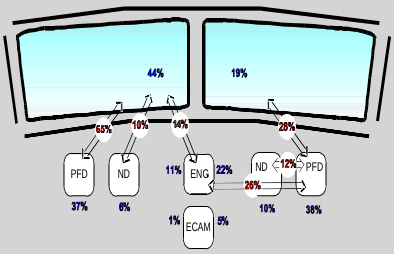
System information is often visually represented and, therefore, operators' line of gaze towards areas of interest in the interface may be used to make inferences about their ways of gathering information from the interface. Whenever it is necessary to analyse higher cognitive processes, e.g. problem solving, analyses of visual information gathering can be combined with analyses of verbal data to form a more complete basis for inferences about which system components operators think about.

Interface Design and Visual Attention

Analyses of eye movements were used as part of the development of a new take-off monitoring system. It turned out that the scan paths of pilots were influenced by the appearance of the symbology representing the new system: pilots' visual attention towards other critical instruments decreased. This was also confirmed in interviews with the pilots. These findings indicated that the system design should be changed.

The pictures illustrate the recorded video eye tracking data: a cross hair superimposed on the video image of the scene. When calibrated, the cross hair marks the line of gaze of each subject. These marks can be scored as measures of visual information gathering.

Visual attention during take-off



The figure illustrates the distribution of visual attention for two pilots (left side: Pilot Flying, right side: Pilot Not Flying). Numbers on arrows indicate the percentage of transitions between areas of interest. Numbers at areas of interest indicate the total percentage of visual attention towards these areas.

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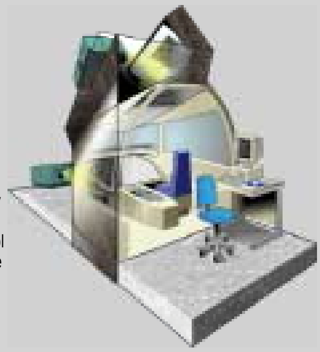
Human Factors Methods and Tools

Studies of Pilots' Performance in Experimental Cockpit Environments

Gunnar Hauland and Thomas Bove

Low Cost Simulator

The Multi Aircraft Training Environment (MATE) is a simulator developed for training aircraft procedures. The switches and instruments in the MATE are computer-generated graphics. The graphics are back-projected onto semi transparent touch screen panels in a hybrid cockpit mock-up. The technology is not specific to aviation, but can be used to simulate various types of control panels. This type of simulator is suitable for low cost realistic testing of new interfaces.



The Multi Aircraft Training Environment, MATE.

Testing Training Effectiveness

Training in MATE must meet the same standards as in conventional training. Conventional training includes the use of real environments, i.e. aircraft and full flight simulator. Two groups of pilots were compared on their checklist performance. Both non-verbal and verbal behaviour was observed from video recordings and specific acts were categorised as correct or incorrect in relation to the airline checklist and the system status.

It turned out that MATE trainees did not differ from conventional trainees with respect to errors, but they were a bit slower on some procedures directly after the transfer from MATE to a real cockpit.

The MATE cockpit during testing at SAS Flight Academy, Stockholm.

Operating touch screen switches

Risø National Laboratory - Systems Analysis Department, Roskilde, Denmark

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4.5 Dynamic Transparency with Multi-density Bit Planes

by Douglas M. SPRAGG, EUROCONTROL Headquarters, Advisory Services DEI1/2 (now DIS/ATD) and John WADE, EUROCONTROL Headquarters, Advisory Services DEI1/2 (now DIS/STS)

The introduction of powerful graphics generators, together with display screens having a pixel density of three per millimetre, has opened up the spectrum of choice available to the system specifier. As a result of some three years of research work carried out in the UK the concept of transparent layers received greater attention. Until 1996 only a fixed transparency was available. This was based upon the manual calculation for the overlapping layers and displayed as a number of polygons. The recent developments have provided a means to automatically calculate the transparent layers in real time where the movement of one layer over another is dynamically updated. In July 1997 a further facility was made available to provide a number of density levels on a single bit plane. By late 1997 this became a commercial off-the-shelf product for the display of weather for Terminal Control Area (TMA) and Approach. This product has now been implemented operationally in one of the EUROCONTROL Member States.

There is an increasing requirement for the display of data that defines airspace structures to be dynamically updated in support of increased operational civil/military flexibility. The expanded usage of area navigation will provide a challenge in the management and control of the airspace users if gains are to be achieved in capacity and operational efficiency.

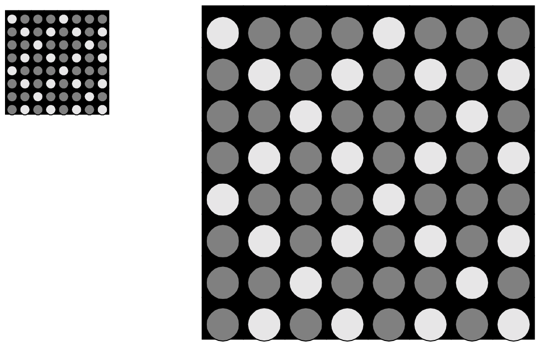
It will be essential for the efficient application of flexibility to provide the controllers with a clear and unambiguous picture of their control environment at any moment as changes occur in real time. These dynamic changes may be required in the case of the on-line definition of temporary military exercise areas or where direct routes need to be defined on a day-to-day basis or indeed on an hour-to-hour basis.

The display of weather on the traditional radar screens as an area of clutter was changed to the display of lines depicting weather clutter density according to their spacing, or to symbols whose colour described severity. In all these cases the symbology was at the same level of intensity and contrast as the radar data, thus rendering such data contained in the radar data block as difficult or impossible to read.

The result of this constraint to the display of weather data was that the display was limited to the two most dense layers of weather, even this often needing to be cancelled in order to see the data. The advent of larger, more complex and interactive radar data blocks would render the display of weather impossible. However, there is a solution that has been implemented operationally that permits the display of up to five levels of weather density without disturbing the readability of the radar data.

A typical radar display will require some six bit planes to describe the environment and the overlying data. In addition to this, it would normally require five more bit planes for the display of weather, i.e. a total of eleven bit planes. For many graphics controllers there is only capacity for eight bit planes. The need to display weather by only using a single bit plane is achieved by dithering the pixels.

For the above implementation it was decided to use the existing stipple facility on x windows for the definition of the pixel dither pattern. By varying the pattern it is possible to fill in every other pixel to represent 50% density, one out of three being 33%, etc. For a modern screen with three pixels per millimetre, and by ensuring that the dithered area overlies a low contrast background, the eye cannot see the dither pattern, only a shadow of different intensities underlying the radar data. It should be noted that the non-visibility of the dither patterns is only efficiently achieved when used in conjunction with the dynamic transparency since the pixels related to the weather pattern are Red, Green, Blue (RGB) adjusted to the underlying layers and the difference between the alternate pixels can be adjusted to a suitable contrast to minimise the patterning visible to the human eye.



Conclusions

- The increasing use of the radar label to provide one of the main sources of data for the execution of the control task requires a clear recognition of the data values displayed therein. The background is playing an increasingly important role in ensuring that the supporting environmental data relating to airspace and routes is of sufficient contrast and is not confusing.

- There will be an increasing need to provide a flexibility in airspace design and management that can be updated in real time.

- The use of dynamic transparency permits the efficient and flexible modification of airspace types and routes, whether civil or military, in real time.

- The introduction of density dithering can reduce the need for too many bit planes. However, the success of this method is dependent upon the use of dynamic transparency.

- The display of weather on the display should not intrude upon the controller's visual assessment of the traffic data. The use of dithering provides a 'shadow' of the weather and avoids the confusion of too much information at the traffic level.

- The display software providing the HMI will need to be powerful and efficient as developments evolve in the provision of elastic vectors and the avoidance of wire framing techniques when repositioning supplementary windows.

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4.6 Validating Complex Human-Machine Systems: From a 'User-centred' to a Systemic Approach

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4.6.1 Abstract

Broadly speaking, we consider that every single technological innovation should be viewed as a component of a larger developmental process whose objectives are to make the overall system safer and enhance a more proficient use of the available resources. Contrary to current tendencies we state that productivity and increased capacity should not concern the performance of single experts testing new technologies. Capacity and productivity increase has to be assessed at the level of the overall system. Testing and evaluating activities at a sub-system level should rather address issues of **tools integration**.

4.6.2 Introduction

The approach to validation outlined in this paper concerns any effort undertaken to test and evaluate portions of complex systems undergoing major technological and organizational changes. We shall however refer to major efforts in the domain of civil aviation, in particular to programmes developed to improve the actual capacity of the airspace.

The European Commission and EUROCONTROL have been sponsoring the development of a number of projects to study how progress in information technology can be proficiently implemented to improve ATM. The scenarios envisaged include the introduction of advanced automation to enhance an accurate and timely distribution of information so as to enable different agents of the ATM system to make the best use of the resources available (PHARE, 1997).

The approach outlined in this paper is consistent with statements made by some authors concerning the objectives of validating a complex human-machine system. Pejtersen and Rasmussen (1997) have identified a number of layers corresponding to different aspects of the human-machine environment under investigation. Productivity is addressed only on the outer layer when analysing performance at the level of the whole system. On the same lines the Military Programme for Human Factors Integration (MANPRINT) (Booher, 1990) explicitly considers the issue of tools integration as central to the validation of a human-machine system when tested at the individual performance level. With reference to the chosen domain we claim that any single or integrated set of devices should be evaluated as part of a wider project whose aim is to enhance a more effective use of the airspace. For the case in hand we take the Programme for Harmonized Air Traffic Management Research in EUROCONTROL (PHARE) to be the programme that defines the future ATM scenarios. Any single innovation should satisfy a subset of requirements and specifications necessary for the overall system to achieve its global objectives.

4.6.3 Purposes of Validation

Within this framework what would be the aim of evaluating a set of specific tools? It is a commonplace to state that validation has the purpose of demonstrating that the new devices do improve operators' productivity. For example, recent studies on controllers' use of datalink technology were undertaken by the FAA (1995 & 1996; Shingledecker & Darby, 1995) to prove that controllers could manage a higher number of aircraft per hour. However, the authors of the report admit that the final objectives of datalink have to be formulated in a context of advanced automation scenarios. In other words, what would be the use of controllers' increased productivity if there was no overall plan to improve the management of at least very extended areas of the airspace?

Concerning the aim of validation the European Commission has recently sponsored a project whose aim was to review current paradigms and methods of validation. According to the study the satisfaction of the 'actors' is deemed more crucial than just productivity (VAPORETO, 1995 & 1997). Below are some of the categories included in the definition of the concept of 'actors':

- airspace users (including airlines),
- regulatory authorities (in charge of applying policy, rules and standards),
- ATM service providers (including air traffic managers and air crews),
- ATM system developers (in charge of designing the ATM system).

Given the wide variety of the actors involved in the ATM Validation process, the position taken by VAPORETO is to be appreciated although somewhat naïve. No single technological innovation can satisfy simultaneously the needs and constraints of all of the actors concerned, as underlined by the Datalink Reports (FAA, 1995 & 1996). To take the example of datalink its introduction might not be fully appreciated by all the involved parties, if evaluated independently from a wider automation plan. Showing that a single component enhances productivity of a subset of ATM users does not necessarily imply that the productivity of the overall ATM system will be improved.

4.6.4 Approaches to Validation

In the next two paragraphs we illustrate two different approaches to validation. The first one is centred on the notion of user productivity in the sense that the focus is on the operator's ability to increase productivity through the use of a specific technology, independently from the efficiency of the overall system. The second one is referred to as 'systemic' approach in as much as it emphasizes that productivity as an objective, should be addressed only at the general system level. As we shall see, at the level of system components, validation should address issues of integration into the ongoing activities.

4.6.4.1 *The 'Local' Approach*

Demonstrating that a set of tools reduces controllers' workload might not be either interesting or an appropriate finding. First of all, generalizations from single testing scenarios to the overall operational environment have to be carefully weighted. Second, measurements of workload are not necessarily predictive of what will happen in a fully operational environment. Moreover, past literature about pilots' interaction with automation (Weiner, 1989) indicates that, more than taking an average value, patterns of workload should be examined, that is testing activities should identify which task conditions
co-occur with workload variations. In any case, a complex human-machine system cannot be validated by a set of measures of a single behavioural index.

The size of the validation effort should also be taken into account when weighting the appropriateness of the findings. In this respect, validation has to be intended as an iterative cyclic process that starts from the definition of the requirements and the specifications of the system under development. Within the frame time of the life cycle of any sub-system component it would be more appropriate to speak of 'Human Factors Testing and Evaluating (HFTE)' activities as part of a wider Validation process to which the component contributes. A single, or even a few testing trials, can only be said to contribute to the Validation process of the overall ATM system.

The validation of any decision-aiding systems such as the decision aiding tools proposed by PHARE poses special problems. First of all, a decision support system is supposed to improve the quality of decision-making. However, we lack general criteria to evaluate the quality of a given decision (Sheridan, 1996). Second, each HFTE cycle is far too short to definitely prove that expert performance might benefit from the introduction of new automated tools. If it does not make a lot of sense to expect that expert operators' workload will decrease or that their performance will significantly improve, what are then the questions to be addressed by a single cycle of testing activities? To what extent do they contribute to the validation of the whole system?

4.6.4.2 *The 'Systemic' Approach*

Rather than claiming to evaluate some isolated tools, a more coherent approach would be to identify two levels of validation concepts, corresponding to two orders of goals. At a global level the proposed technological innovation has to be shown to be a good candidate for fulfilling some of the requirements and the specifications (the what and the how) of the developing ATM system. At this level the new technology has to be shown to be a necessary component for the gradual development and update of the overall system. Given that we are quite far from being able to empirically validate the efficiency of the whole integrated automated ATM scenarios, validation at a global level is still a matter of rather theoretical costs/benefits analyses. Therefore, it is not up to any single HFTE cycle of activities to show the benefits in terms of **productivity** of any new information technology be it datalink, automated Controller's Working Position (CWP), Experimental Flight Management System (EFMS) (PHARE, 1997), to name just a few. However, it is widely agreed that, as part of an extensive ATM innovation programme, effective planning and management of the airspace have to be supported by the development of new automated tools which will improve the accuracy and timing dissemination of information (ASIVAL, 1997).

To understand the potential contribution made by the testing of single ATM components we need to identify a second level of objectives which can be iteratively addressed during each HFTE cycle. Broadly speaking, these objectives concern **effectiveness** of the new tools, with productivity being addressed mostly at a global level. The main question raised at this level is whether people can effectively **integrate** new tools into their current practices. ‘Integration’ is defined here as a two-way process by which the tools are assimilated into the operators' expertise and, at the same time, the operators adjust their individual and collective strategies to the properties of the new tools. As it has been widely recognized in the existing literature on the consequences of automation, the introduction of new tools implies the design of a new working environment (Woods, 1996; Woods, Johannessen, Cook & Sarter, 1994). For this we cannot simply say that automation has to fit operators' needs, since these needs will be different in a new environment. Each cycle of HFTE has to contribute to anticipate:

a) What changes will be brought about by the introduction of new technology.

b) How these changes will affect all of the parties involved in the operation and maintenance of the ATM sub-systems.

Some of these changes might imply design revisions, while others might imply the design of appropriate training emphasizing explicitly what the scope of the automated aid is. Other changes will explicitly require the operators to take the presence of new ‘agents’ into account. Each HFTE effort should address at least one of these areas and provide reliable indexes of human performance in high-tech environments. Thus, one of the primary objectives of testing and evaluation activities should be to further a better understanding of how a given set of tools enables operators to carry out their duties. To achieve inter-reliability of results (i.e. which can reliably be used by parties external to the original projects) we need a clear description of the testing conditions, the kind of data collected, the techniques used, the interpretation process and the limits and extent of the results discussed. From a research perspective all of this should contribute to the progressive construction of models of operators' activities in highly automated environments. Literature on validation and verification widely acknowledges the lack of reliable measures of relevant behaviour. Too often we just do not know how to identify and measure those activities that will be predictive of system performance in fully operational settings. Validation reports concerning Human-Machine Interaction (HMI) with complex systems, heavily rely on the operators' opinions collected during the Testing phase. Although this is valuable information, it cannot be the main source of validating data.

Note that, while effectiveness as defined here does not specifically address productivity, it is assumed that, when sub-systems are shown to have the necessary features for being effectively integrated into current practices, they are also good candidates for contributing to the overall efficiency and productivity of the global system.

4.6.5 The Design of a Testing and Evaluation Scenario

While constructing a HFTE scenario we should keep in mind that HMI within highly automated systems poses at least three challenges in the testing of the human factors involved. As the human role in such systems changes from those of operator to supervisor and diagnostician, we need to take into account a greater emphasis on tasks that are purely cognitive, a changed concept of what error is and how it is measured, and a much greater emphasis on self-report data. The latter does not only involve comments about features of the system, but also reports on ongoing activities including aspects of operator-machine interaction. Performance cannot be simply evaluated through the use of questionnaires or the measurement of superficial behavioural indexes such as ‘errors’ and reaction time. Concerning errors we lack general norms establishing whether an action or a decision taken by an expert is ‘right’ or ‘wrong’. For this reason Subject Matter Experts (SMEs) have to play a role in the interpretation of behavioural evidence by the definition of contextually-based ‘reasonable behaviour’ (Meister, 1996). Concerning the reaction time most activities in the ATM system are not characterized by a rigid sequence of steps, each taking a certain amount of time to be executed. Instead, actions might be taken in a different order, depending on the expert's time management strategies, and there is no reference time needed to make a decision or to solve a problem. A number of contextual and individual factors rather play a role in determining the frame time of decision-making activities (Zsambok & Klein, 1997).

4.6.6 Specific Issues to be raised during Human Factors Testing and Evaluating Activities

So far we have basically asserted that validating an ATM sub-system means to answer the question of how the sub-system is integrated into the operators' working environment. This question may be divided up into several issues. As we have noted, the introduction of new technologies implies the design of new practices, individual and collective. Procedures, cooperation, information-gathering strategies, cue interpretation are some of the things that might change with technological innovation. New tools are supposed to assist people to carry out old tasks in new ways. This last point raises the challenging question of how these tools support the operators' activities. For instance, are there any inferences, conclusions or decisions which people would be unable to make in the current environment with the same degree of confidence that can be achieved in the new environment through the use of automated aids?

As documented in the existing literature, a consequence of the introduction of automation is that people tend to rely on automated cues and devote less attention to monitoring the process (Mosier, 1997; Mosier & Skitka, 1996). A related issue to be addressed during HFTE activities is therefore how operators maintain their situation awareness and whether they are aware of events that are not detected by the system. In other words, to introduce a new tool implies that its limits and supporting capabilities be understood.

Whatever the specific validation scenario chosen, we should not neglect the case where a sub-system developed by a Member States of the EU has been the object of HFTE activities for a number of years. Therefore, we should construct a scenario that capitalizes as much as possible on previous findings. To this end we need to construct methodologies, the results of which contribute to a further understanding of the human-system-environment interaction.

Broadly speaking, the testing of any new ATM sub-component should address some the following issues:

- Does the introduction of the tools disrupt current practices?
- Can operators anticipate future evolution?
- Is situational awareness of the entire process kept under control?
- Can operators detect events that are not revealed by the system?
- Are there any assessment or decision that can be taken because of the presence of the automation?
- Are controllers sensitive to those cues that are not detected by the automation?

These questions aim at identifying the nature of experts-machine-environment interactions and are derived from the existing literature and our knowledge of the controller's models of activity (Amaldi, 1993; Amaldi & Cellier, 1997; Boudes, 1997; Leroux, 1994). These questions can be made operational by identifying specific behavioural cues to be observed or even prompted through the design of pertinent experimental conditions.

4.6.7 Concluding Remarks

The advantage of developing an ‘integration’ approach to validation rather than a ‘productivity’ approach is that it promises to generate data which might be shared by members not participating in a particular project. A telling example comes from cockpit literature where researchers have devoted a considerable effort to understanding how automated assistance tools have been integrated into crews' activities (Billings, 1997; Mosier, Skitka, Heers & Burdik, 1998). Many lessons might be learnt from these findings. In particular, they might suggest to us **what** the relevant issues to be addressed are and **how** we could look for the answers, neglecting to consider that the existing literature might lead us to replicate errors made in the process of cockpit automation. Nevertheless, we should keep in mind that a great deal of human factors studies on the cockpit has been carried out since the automated aids came into operation some time ago. The fact that a testing trial lasts for a few days has to be taken into account when formulating the objectives to be achieved. Software tools are now available which take into account not only quantitative but also qualitative data processing (Sanderson & Fisher, 1997).

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ABBREVIATIONS AND ACRONYMS

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

AAA	Advanced ATC system Amsterdam
ACAS	Airborne Collision Avoidance System
ACC	Approach Control Centre
ACG	Advanced Concept Group
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance Broadcast
ANS	Air Navigation Services
AOF	Allocation of Functions
ATAFF	Air Traffic Arbitrated Free Flight
ATC	Air Traffic Control
ATCA	Air Traffic Control Association
ATCO	Air Traffic Controller / Air Traffic Control Officer *(US/UK)*
ATM	Air Traffic Management
ATS	Air Traffic Services
CAA	Civil Aviation Authority/Administration
CBT	Computer-Based Training
CENA	*Centre d'Etudes de la Navigation Aérienne (DGAC/DNA, France)*
CNS	Communications, Navigation and Surveillance
CRM	Cockpit/Crew Resource Management
CRNA	*Centre Régional de la Navigation Aérienne (DGAC/DNA/ SCTA, France)*
CRT	Cathode-Ray Tube

CTA	Cognitive Task Analysis
CWP	Controller Working Position
DED	EATCHIP Development Director(ate) *(EUROCONTROL)*
DED5	Human Resources Bureau *(EUROCONTROL, EATCHIP; now HUM Unit or DIS/HUM)*
DEL	DELiverable
DERA	Defence Evaluation and Research Agency *(UK)*
DG	Director(ate) General *(EU)*
DGAC	*Direction Générale de l'Aviation Civile (France)*
DIS	Director(ate) Infrastructure, ATC Systems and Support *(EUROCONTROL, EATMP)*
DIS/HUM	ATM Human Resources Unit *(EUROCONTROL, EATMP; also known as HUM Unit; formerly DED5)*
DL	DataLink
DLR	*Deutsches Zentrum für Luft- und Raumfahrt e.V. (formerly 'Deutsche Forschungsanstalt für Luft- und Raumfahrt')* German Aerospace Centre (*formerly the 'German Aerospace Research Institute')*
DNA	*Direction de la Navigation Aérienne (DGAC, France)*
DSA	Director(ate) Safety, Airspace, Airports and Information Services *(EUROCONTROL, EATMP)*
DSI	Denmark/Sweden Interface
DSP	Datalink Status Panel
EASA	European Aviation Safety Authority
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(now EATMP)*
EATMP	European Air Traffic Management Programme *(formerly EATCHIP)*
ECAC	European Civil Aviation Conference
Ed(s)	Editor(s)

EEC	EUROCONTROL Experimental Centre *(France)*
EEG	ElectroEncephaloGram
EFMS	Experimental Flight Management System
EMT	Eye-Movement Tracking
ENAV	*Ente Nazionale di Assistenza al Volo (Italy)*
ERP	Event-Related Potential
ESCAPE	EUROCONTROL Simulation Capability and Platform for Experimentation
ET	Executive Task *(EATCHIP/EATMP)*
ETA	Estimated Time of Arrival/Estimating Arrival
EU	European Union
EWPD	EATCHIP/EATMP Work Programme Document
FAA	Federal Aviation Administration
FANS	Future Air Navigation Systems
FAR	Federal Aviation Regulations
FARAWAY	Fusion of Radar and ADS Data through two WAY datalink
FEATS	[ICAO Concept Group for the] Future European Air Traffic Management System
FL	Flight Level
FMS	Flight Management System
GEMS	Generic Error-Modelling System
GHMI	Ground Human-Machine Interface
GOMS	Goals, Operators, Method and Selection
GPS	Global Positioning System/Geographical Paging System
GPWS	Ground-Proximity Warning System
HCI	Human-Computer Interface
HF	Human Factors

HFTE	Human Factors Testing and Evaluating
HMI	Human-Machine Interface/Interaction
HRA	Human Reliability Assessment/Analysis
HRT	Human Resources Team *(EATCHIP/EATMP)*
HRV	Heart-Rate Variability
HTA	Hierarchical Task Analysis
HUM	Human Resources (Domain)
HUM Unit	ATM Human Resources Unit (*EUROCONTROL, EATMP; also known as DIS/HUM; formerly DED5)*
HWG	Harmonisation Working Group
I/A	Incident Analysis
IANS	EUROCONTROL Institute of Air Navigation Services *(Luxembourg)*
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Associations
IFATCA	International Federation of Air Traffic Controllers' Associations
IMPACT	Information Market Policy Actions
ISA	Instantaneous Self-Assessment
JAA	Joint Aviation Authorities
JAR	Joint Airworthiness Requirements
MATE	Multi-Aircraft Training Environment
MIDAS	Man-machine Integration Design Analysis System
MSP	Multi-Sector Planner
MUAC	EUROCONTROL Maastricht Upper Area Control Centre *(The Netherlands)*
NASA	National Aeronautics and Space Administration *(US)*
NATO	North Atlantic Treaty Organisation

NATS	National Air Traffic Services Ltd. *(UK)*
NAV	Navigation (systems)
NLR	National Aerospace Laboratory *(The Netherlands)* *National Lucht- en Ruimtevaartlaboratorium*
ODID	Operational Display and Input Development
ODS	Operator Input and Input Development
PD	Plan Display
PF	Pilot Flying
PFD	Primary Flight Display
PHARE	Programme for Harmonisation of ATM Research in EUROCONTROL
PNF	Pilot Non-Flying
POG	Point of Gaze
PUMA	Performance Usability-Modelling of ATM
PVD	Plan View Display
R&D	Research and Development
R/T	RadioTelephony
RAM	Random-Access Memory // Reliability, Availability, Maintainability
RAMBO	Reliable, Available, Maintainable, Benefits, Objectives
REP	REPort
RGB	Red, Green, Blue
RHEA	Role of the Human in the Evolution of ATM
RNAV	aRea NAVigation
RTCA	Radio Technical Commission for Aeronautics *(US)*
RVSM	Reduced Vertical Separation Minimum
S-P-R-c	Stimuli, Processing, Response, controlled executive

SCTA	*Service du Contrôle du Trafic Aérien (DGAC/DNA, France)*
SDDLC	System Design and Development Life Cycle
SDE	Senior Director, EATMP Principal Directorate *or, in short,* Senior Director(ate) EATMP *(EUROCONTROL; formerly SDOE)*
SDOE	Senior Director(ate) Operations and EATCHIP *(EUROCONTROL; now SDE)*
SME	Subject Matter Experts
SMGCS	Surface Movement Ground Control System
ST	Specialist Task *(EATCHIP, EATMP)*
STA	Straight in Approach
STC	Simulation Technical Coordinator
STCA	Short-Term Conflict Alert
STD	Software Technical Designer
SW	SoftWare
TAD	Target Audience Description
TCAS	Traffic alert and Collision Avoidance System
TLX	Task Load IndeX
TMA	Terminal Control Area (*formerly 'Terminal* ***M****anoeuvring Area'*)
TRACON	Terminal Radar Approach CONtrol
TRM	Team Resource Management
TWDL	Two-Way DataLink
URD	User Requirements Definition
VAPS	Virtual Applications Programming Software
WG	Working Group
WLA	WorkLoad Assessment
WP	Work Package

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The Chairman extends his thanks to all the Speakers and Authors who contributed to this Third EUROCONTROL Human Factors Workshop.

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