EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

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Human Factors Module

A Business Case for Human Factors Investment

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Abstract

This document is, within the Human Resources Domain (HUM), one of the human factors modules dealing with human performance. This module suggests that human factors should be integrated throughout the Air Traffic Management (ATM) system life-cycle in order to reduce cost and make ATM systems safer and more effective.

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

Keywords

Cost Benefit Analysis	Quality Management	Human Factors Plan	Human Factors Integration
System Life-Cycle	Risk Management	Stakeholders	Cost Effectiveness Analysis
Human Factors	Change Management	Life-Cycle Cost	Human Factors Investment
Usability Engineering	Project Management	Business Case	

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EXECUTIVE SUMMARY

The module is intended to promote the integration of human factors throughout the Air Traffic Management (ATM) system life-cycle in order to reduce cost and to make ATM systems safer and more effective. It will provide the reader with an awareness of the cost and benefits of integrating human factors in the process of developing and operating ATM systems.

Chapter 1, ‘Introduction’, presents the issues addressed by the module and outlines the scope, objectives and target audience.

Chapter 2, ‘The System Life-Cycle and Human Factors Integration’, proposes some definitions and fundamentals for understanding and managing risk in the ATM system life-cycle and outlines the integration of human factors in this process.

Chapter 3, ‘The Benefits of Human Factors Integration’, analyses the benefits of integrating human factors in the system life-cycle.

Chapter 4, ‘The Cost of Human Factors Integration’, identifies some of the costs of integrating human factors in the system life-cycle.

The Annex provides a sample cost estimation of utilising some selected human factors methods.

Further annexes consist of a list of the ‘References’ made in this document, a ‘Glossary’, a list of the ‘Abbreviations and Acronyms’ used in this publication and finally a list of the Contributors.

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1. INTRODUCTION

> *"One of the lessons we learned early on in our modernisation program, was that ignoring human factors in our major acquisitions can cost us dearly, both in the expense of re-engineering and in schedule delays. We've (the FAA) made it a requirement that human factors must be systematically integrated at each critical step in the design, testing, and acquisition of any new technology introduced into the air traffic control system."*
>
> *(Del Balzo, 1993, p. 3)*

There is an increasing appreciation that taking appropriate account of human factors in the ATM system life-cycle will not only make that system safer to operate, but will in fact save a lot of money.

In traditional thinking engineers will provide the Air Traffic Control Officers / Air Traffic Controllers (ATCOs) with the latest technology, who will in turn have to perform so that the entire system will cater for the traffic flow. While this arrangement on the surface seems satisfactory it assumes a number of things.

It assumes that the system designers know what is reasonable to expect in terms of controller performance and limitations; it assumes that the system designers can anticipate how the controller and the system will actually work; it assumes that the controllers know what the system designers intended with specific system functions, etc. However, we may deceive ourselves if we rely on these assumptions - they usually do not hold.

Human factors are traditionally not considered as part of the core issues in an industrial or commercial environment. The reasons are many: ATM systems are developed by engineers, and human factors do not normally form part of an engineer's curriculum. Psychologists who make up a large proportion of human factors specialists are traditionally more interested in analysis than in design, and the two communities have different cultures; consequently, communication can be awkward. Finally, human factors may be seen as something being 'politically correct' to address but, due to their 'soft' nature, they are not conceived to produce tangible and relevant results.

To the extent that human factors are considered, it is typically too little and too late. Figure 1 illustrates a typical development scenario:

- If the requirements analysis does not address human factors, the subsequent inadequacies will leave those issues to be resolved in the Design phase.
- The problems that remain after the system has been designed will be left for the implementation phase to iron out.

- Once the system has been implemented human factors experts may occasionally be brought in to solve specific and typically grave usability problems.
- As it is very difficult to change a design due to the technical problems implied and the financial cost related herewith, issues that cannot be dealt with by the human factors experts will be addressed in the system documentation.
- Certain problems may be dealt with through training of the users of the system.
- The outstanding issues will have to be dealt with by maintenance and support personnel.
- At the end of the 'food chain' the users will have to work around the problems which hasn't been dealt with in the previous.

This scenario is not an exception; it should rather be considered as the norm.

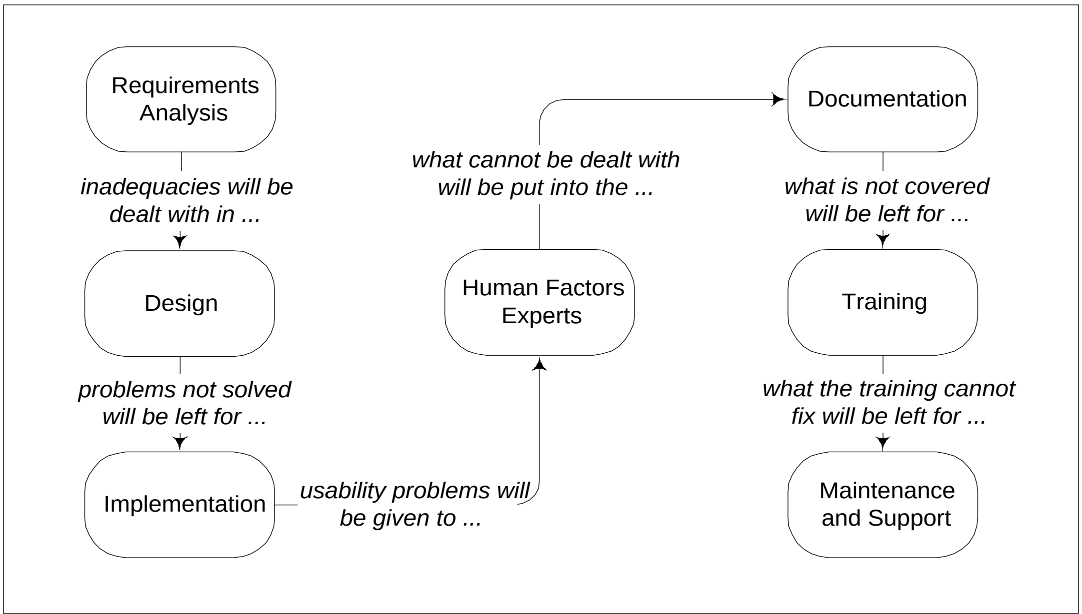

Figure 1: Passing the buck ...

However, there is an increased understanding of the importance of human factors in relation to aviation safety; statistics show that a vast majority of aircraft incidents and accidents are caused by human factors. The relation between human factors and safety has been identified, and measures such as Team Resource Management (TRM) are beginning to emerge. In addition, there is an emerging awareness that a proper integration of human factors can save vast amounts of money and risk in the system life-cycle of an ATM system.

This report argues that, in order to increase cost-effectiveness and safety, human factors should be introduced as early as possible in the ATM system life-cycle and integrated in all phases.

The return on investments of human factors is long-term and should be seen over the life span of a system rather than as 'quick-and-dirty' measures to provide corrective action and an apparent swift return.

When promoting the idea of integrating human factors into the system life-cycle many questions will be raised:

- How much will we benefit from this?
- How will we know if it helped us?
- What will be 'enough integration'?
- How much will it cost?
- How much will we gain in terms of revenue or safety?
- How to persuade my management to do it?

Although this document will not answer all of these questions it is intended to give the reader a feel for how to approach the answers and where to look.

1.1 Scope and Purpose of this Document

The objectives of this document are:

- To introduce some basic concepts in addressing the ATM system life-cycle and human factors;
- To identify the benefits and beneficiaries of integrating human factors;
- To identify relevant cost factors in integrating human factors and elaborating on cost development;
- To outline some basic strategies in approaching the system life-cycle.

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

- manager of Air Traffic Services (ATS), responsible for system development or procurement,
- human factors specialist involved in system development,
- system developer,
- operations and maintenance officer.

A previous module entitled ‘Human Factors Module - Human Factors in the Development of Air Traffic Management Systems’ (EATCHIP, 1998a) gives an introduction to the integration of human factors in the ATM system life-cycle.

1.2 Outline of the Document

This document should answer the following questions:

Question	Chapter
♦ What is included in the ATM system life-cycle, what are human factors - and how do the two things interact?	2
♦ What are the benefits of integrating human factors in the ATM system life-cycle?	3
♦ What kind of costs are associated with integrating human factors in the ATM system life-cycle?	4
♦ How much effort will it take?	Annex

2. THE ATM SYSTEM LIFE-CYCLE AND HUMAN FACTORS INTEGRATION

"That, in order to maximise safety and cost effectiveness of CNS/ATM systems, the proactive management of human factors issues be a normal component of the processes followed by designers, providers and users of the systems"

(Conclusion 6/2 from ICAO Rio Conference, 1998)

The increasing air traffic and the demand for effective air transportation have made it necessary to invest in ATM systems with larger capacity. Development and operation of ATM systems are characterised by employment of vast resources, which makes potential failures costly and the investments risky.

In this chapter a model of the system life-cycle is introduced and an outline of system development methodologies is given. Important human factors issues are related with the life cycle; a brief description of how to integrate them will be given.

2.1 System Life-Cycle Phases

In order to describe and analyse the entire life cycle of a system we may subdivide it in a number of phases, each dedicated to particular aspects in the life-cycle process and calling for different concerns.

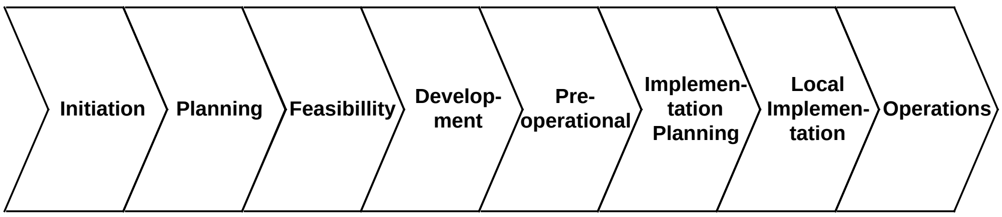

Figure 2: The EATCHIP project life-cycle (EATCHIP, 1998b)

The life-cycle phases can, in a general form, be described through the following phases (EATCHIP, 1998b):

- **Initiation:** Approval to start the project and to invest associated time, funds and effort.
- **Planning:** Obtain approval for the detailed structure of the tasks, staffing and funding.

- **Feasibility:** To test the technical, operational and financial feasibility of different development options and seeking approval for the chosen option.

- **Development:** To develop specifications for the operational performance and to produce specifications for equipment, interfaces and procedures.

- **Pre-operational:** To have an extra reality check on the proposed solution by building a pre-operational prototype and/or undertaking a real-time simulation to verify the specifications.

- **Implementation Planning:** To obtain a detailed understanding of all the practicalities of a successful implementation of the proposed solution and to co-ordinate it with affected airspace users and stakeholders.

- **Local Implementation:** To implement the system; performing detailed design, development of standard product, integrating the system components, testing, education and training, procedures, phase-in and phase-out.

- **Operations:** This phase covers several stages in the system life-cycle:

  - **Operations and Maintenance:** To start operations of the final project output as part of the ATM system. To assess and record performance.

  - **System modification:** To modify the system as necessitated by technological, economic and/or operational experience.

  - **Recycling:** To dismantle and dispose of the system, and to re-use the human resources.

2.1.1 System Development

The development phases are typically conducted using a 'waterfall' model (Royce, 1970), as shown in Figure 3. The waterfall model recognises that development has to take place in stages and feedback has to be given between the stages.

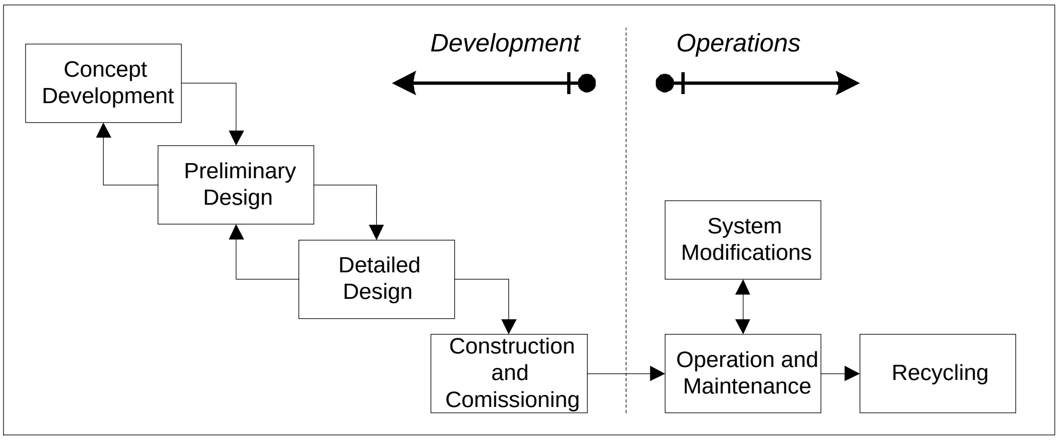

Figure 3: Waterfall model of system life-cycle

While the waterfall model gained popularity in the seventies and has been used extensively, recent developments suggest an iterative spiral approach (Boehm, 1988), as shown in Figure 4.

The spiral model suggests that system development should be carried out in an iterative succession of phases gradually expanding the scope. The model suggests the early use of prototypes and risk modelling.

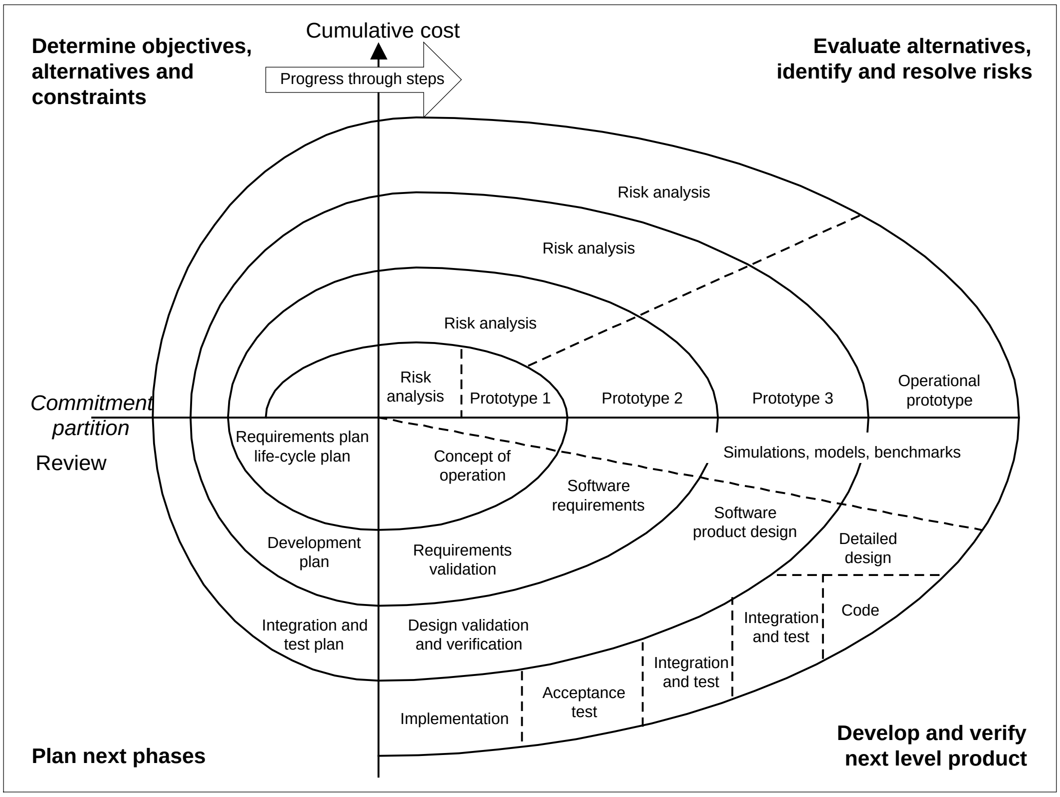

Figure 4: The iterative spiral model of system development (Boehm, 1988)

2.2 Managing Risk in the System Life-Cycle

Risk and uncertainty are at a maximum in the early stages of the ATM system life-cycle but opportunities for adding value are also greatest at this point. The risk remains relatively high during the first phases of the life cycle. It only starts to decrease once the development has turned into implementation and the system starts to prove itself. This development is shown in Figure 5.

On the other hand, the amount at stake, i.e. the money spent in the life cycle, increases moderately in the initial phases of the project, while it increases significantly once the design has to been turned into hard evidence.

These two basic risk characteristics of the life cycle, i.e. the risk/opportunity and the amount at stake, define two time intervals; while the early phases of the life cycle contain the period in which the highest risks are incurred, failures can be repaired relatively easy. In the latter phases, when the system has left the drawing board and has been implemented, the risk of failure falls. However, the impact of potential failures is rather severe as the system or parts of it will have to be reconsidered at great expense.

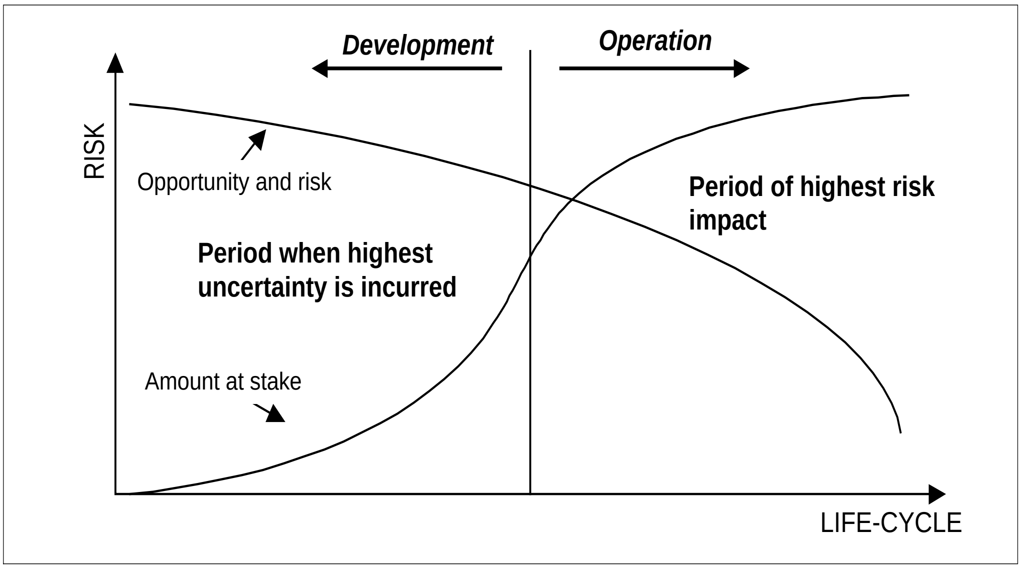

Figure 5: Risk in the system life cycle

2.2.1 System Assessment

Once the system has been developed and brought into operation, the performance of the total system will determine the level of success reached due to the efforts involved. The capacity provided by the system and its optimal use are key in determining its success.

While the system may provide an increase in its capacity for handling aircraft - whether measured by the quantity and quality of services - the ultimate factor that will determine whether the capacity provided will translate into an overall benefit - is the extent to which it is accepted by its users and the extent to which it is usable.

The acceptance of the system means whether the humans coming into contact with the system accept its existence and the way in which it operates. The usability of the system signifies whether a system is easy to use and to learn, and efficient for the human to apply in performing certain tasks. Integrating human factors in the system life-cycle will amplify the acceptability of the system and considerably improve its usability.

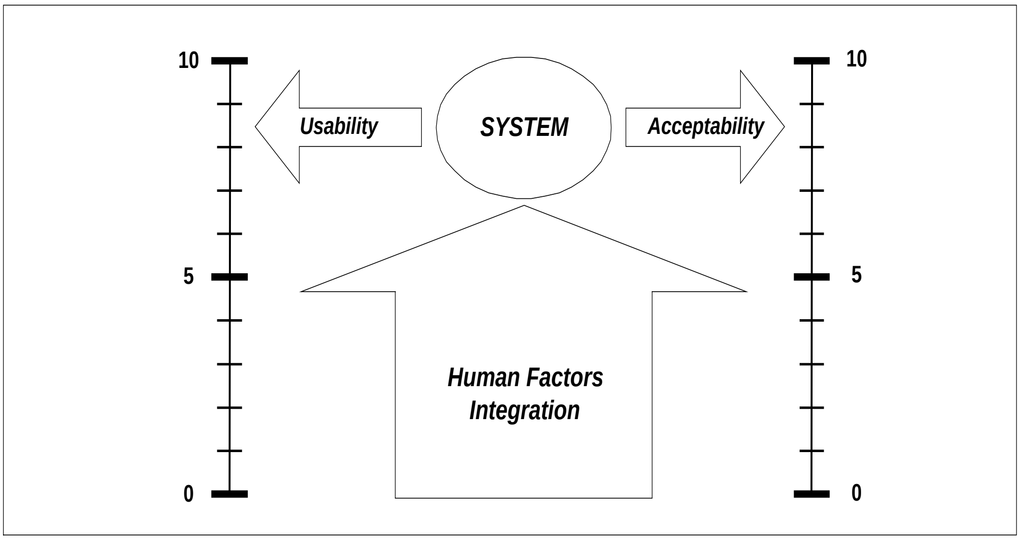

Figure 6: Designing for acceptability and usability

2.3 Human Factors

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

As a brief introduction to some of the concerns and issues within human factors, the SHEL concept (Edwards, 1972) offers some insight (ICAO, 1989). The SHEL model, as shown in Figure 7, identifies four components: Liveware (i.e. the human element), Software (procedures, symbology, etc.), Hardware (machine) and the Environment (within which the S-H-L system must function).

The model introduces a concern for the interfaces and relation between the different blocks. For example, the Liveware-Liveware relation reflects the teamwork aspects, while the Liveware-Software interface is concerned with the interaction between the human and functions provided by software in the broader sense.

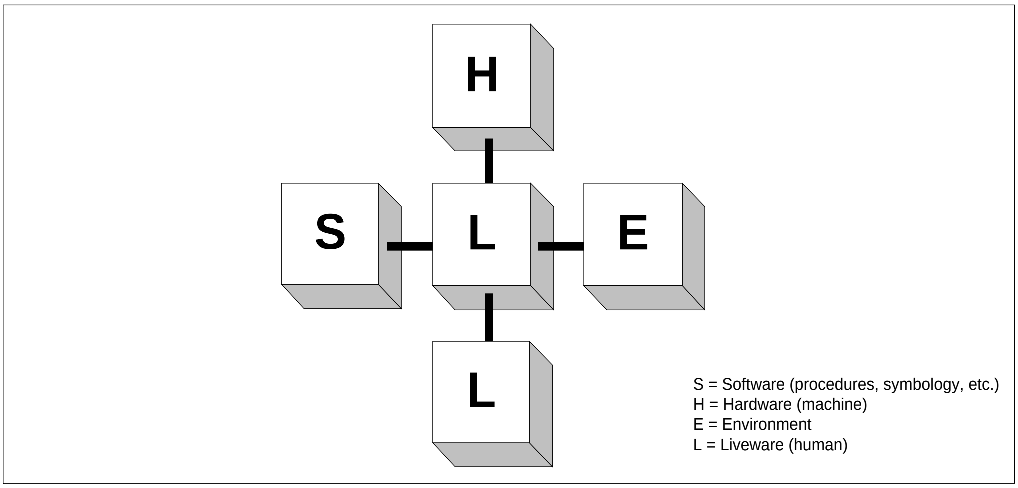

Figure 7: The SHEL model (ICAO, 1989)

2.4 Integrating Human Factors in the System Life-Cycle

Introducing and integrating human factors in the ATM system life-cycle requires some changes to the existing processes, and introduction of new elements in the concern for system effectiveness. Some of the changes will be straight forward and fall naturally in the development and operational phases, others will require changes to the philosophy upon which the ATM system is traditionally operated. Figure 8 summarises the life-cycle phases as well as some of the questions to answer in the process of integrating human factors.

A detailed description of the integration of human factors into the system life-cycle is provided in (EATCHIP, 1998a).

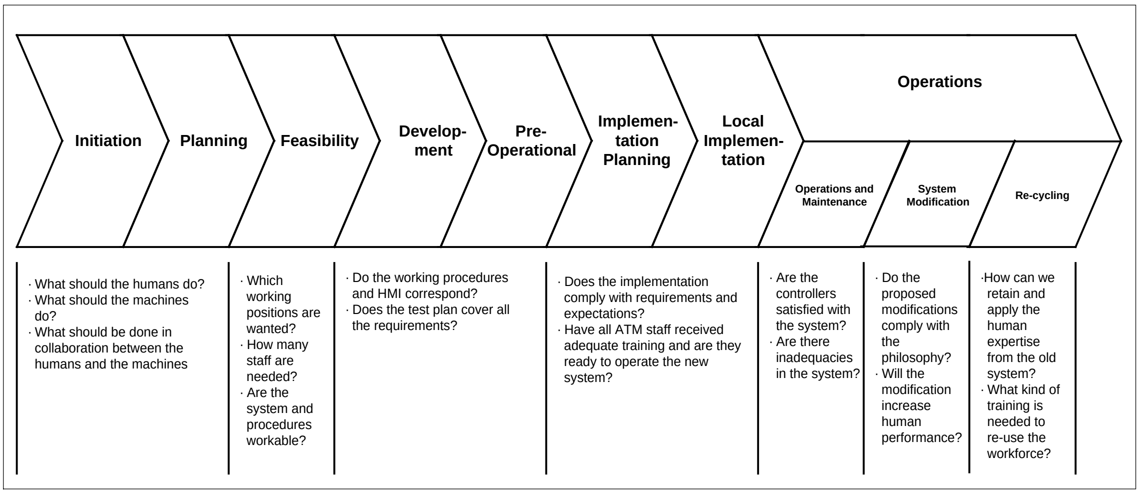

Figure 8: Human factors questions to be answered in the system life-cycle

3. THE BENEFITS OF HUMAN FACTORS INTEGRATION

"There is no free lunch - but sometimes, if you eat a good breakfast, you won't need to spend as much money on lunch."

(Hayne, 1996)

This chapter outlines some of the potential benefits induced through integrating human factors in the system life-cycle. The system will typically benefit on three levels: the working level, the development process and the overall safety level.

3.1 Benefits for Whom?

Integration of human factors in the ATM system life-cycle produces different benefits for different groups of people and stakeholders. Table 1 summarises some of the end users and stakeholders, as well as the benefits that human factors integration poses to them.

Table 1: Beneficiaries of human factors integration

BENEFICIARIES	TYPE OF BENEFIT							
	Cost savings	Increased safety	Improved working conditions	Project on time and budget	Increased system acceptance	Increased system usability	Cost/benefit evidence	Risk mitigation
Air Traffic Services Providers	✓	✓		✓	✓		✓	✓
Civil Aviation Authorities		✓						✓
Air Traffic Control Officers			✓		✓	✓	✓	
Project Managers	✓			✓	✓	✓	✓	✓
ATM System Developers	✓			✓	✓	✓	✓	✓
Airspace User	✓	✓					✓	

3.2 Investing to Gain

The existing processes and ways of doing things will have to be adapted to facilitate human factors methods and approaches. Investments in the life-cycle process have to be made as early as possible. Tasks will have to be adapted and some new ones will have to be added.

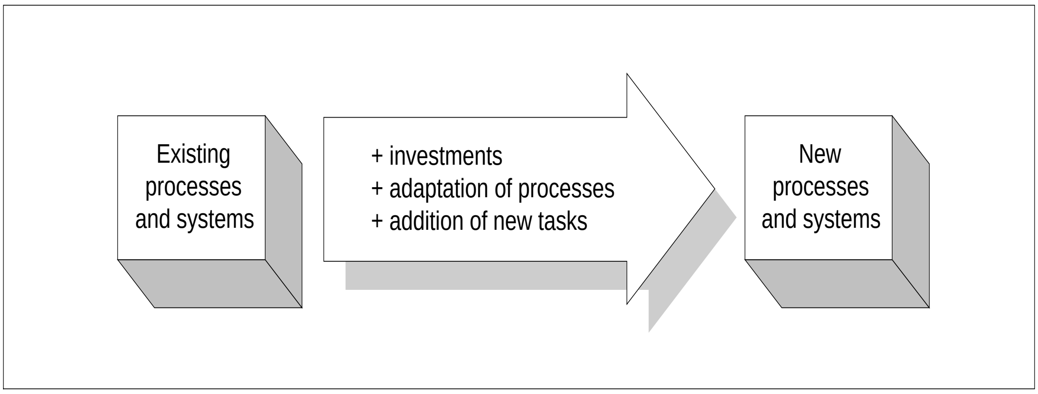

Figure 9: The change process

The system life-cycle phases will be altered through new or adapted tasks, paying primary attention to how best to take into account human strengths and limitations.

Each life-cycle phase will need particular initiatives to facilitate specific needs. Figure 10 illustrates how different initiatives will result in benefits in the system life-cycle, and their overall impact.

A more in-depth description of how to integrate human factors in the system life-cycle can be found in EATCHIP (1998a).

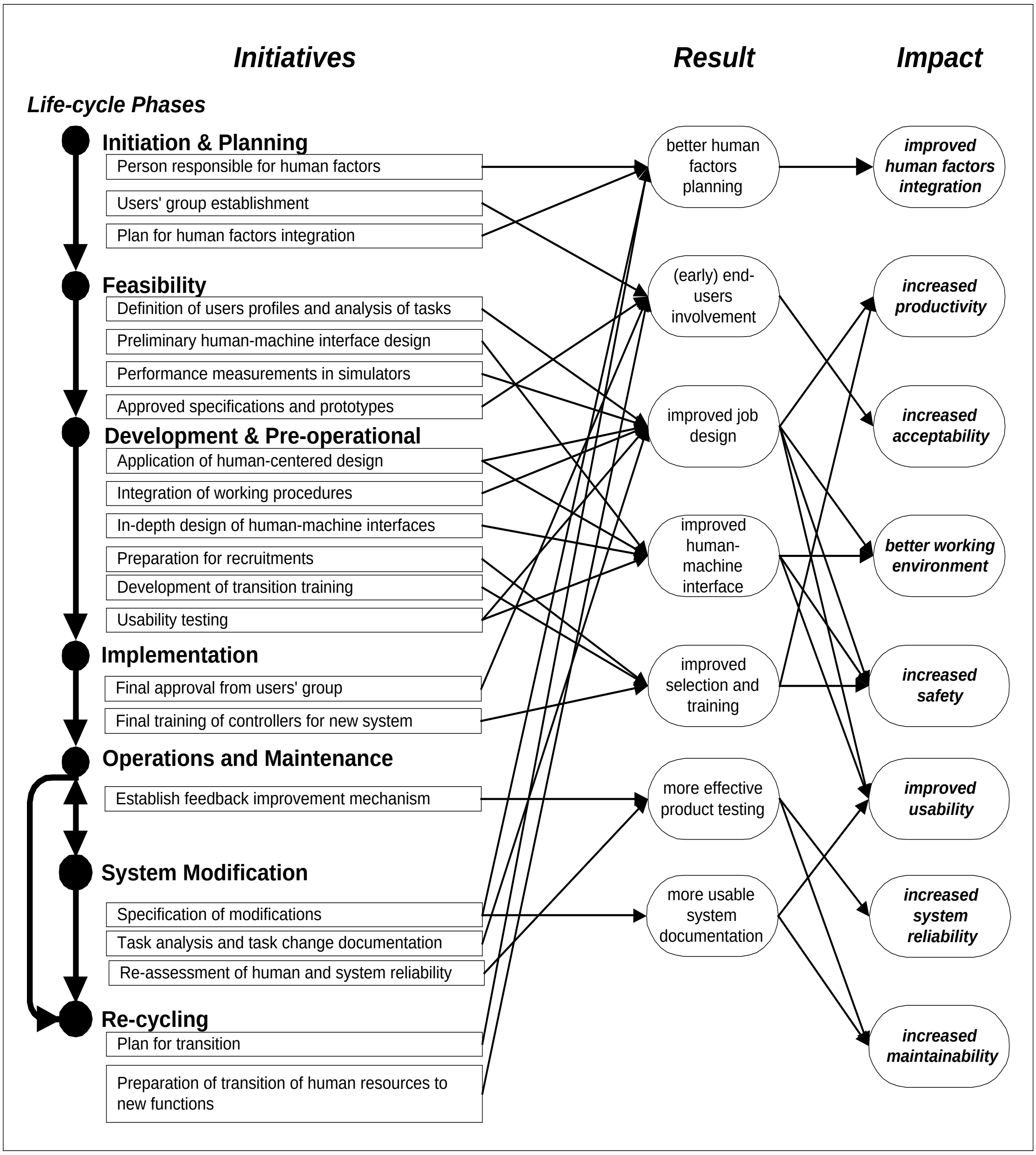

Figure 10: Human factors integration initiatives, their results and impact

3.2.1 Better Human Factors Planning

A primary prerequisite for a successful human factors integration is the nomination of a person responsible for human factors. This person should institute a human factors plan and organise end users to provide feedback in the design process. Secondly, the haphazard inclusion of human factors as described in Section 1 needs to be avoided by means of a plan of how to take into account human factors in the development and life-cycle process. A similar plan needs to be compiled when changes are to be made to the system or when a new system is to be brought into use.

Table 2: Initiatives for better human factors planning

Initiative	Rationale
Person responsible for human factors	A person should be assigned as responsible for human factors. This person should oversee the integration of human factors through participation to the system development from the earliest point possible and should participate in the planning and management throughout the life cycle of the system.
Plan for human factors integration	An early planning of the process will help the end users to understand the intentions better, just as it will allow the planning team to get a better overview.
Plan for transition	Transition to a new system or modifications to an existing system requires an early plan to accomplish communication and overview.

3.2.2 End User Involvement

Involving the people that will have to use the system in the end (the end users) and representatives from parties that have a stake in the process or the final system (the stakeholders) is mandatory in the design process. Its importance cannot be overstated. The earlier this happens, the better. A group representing the end users of the system (such as ATCOs, supervisors and maintenance engineers) needs to be set up to review and guide the development process. The approval of the preliminary design by the users' group is an important step in retrieving valuable feedback on the design and increasing the acceptability of the end users.

Table 3: Initiatives for end users involvement

Initiative	Rationale
Users' group formation	The formation of a users' group will significantly increase the acceptability of the system to the ATM staff population.
Approval of specifications and prototypes	Approval of a preliminary design from users' group and ATM staff is essential in the early phases of development.
Preparations for transition of human resources to new functions	The frustration among personnel during a transition phase can be greatly reduced through proper change management measures, notably extensive communication and frequent interaction.

3.2.3 Improved Job Design

In order to maximise the use of human strengths and to minimise the effects of human weaknesses it is vital that the job and tasks to be carried out are carefully designed. Definition and analysis of the tasks to be undertaken by the human and application of human-centered design guidelines are among the many aspects to consider. Rigorous usability testing will take out all unpleasant surprises and will cater for a system that bridges the end users capabilities and the tasks to be solved.

Table 4: Initiatives for improved job design

Initiative	Rationale
Definition of users profiles and analysis of tasks	To ensure optimum job design it is important that job and task profiles are developed for each of the positions needed and that a task analysis is performed to support the job design.
Human performance measurements	Measurements of human performance in semi-operational environments such as simulators are necessary to investigate whether the requirements imposed by the system can be adequately handled by the humans.
Application of human-centered design	Application of human-centered design principles will significantly improve the system design.
Integration of working procedures	The design of working procedures as an integral component in the human-machine design process is a requirement for an optimum design.
Usability testing	Usability testing will ensure that the system is easy to learn, pleasant to use, error-free, error-forgiving, easy to remember and efficient.
Task analysis and change documentation	It is important to analyse the effect on job design when changing the system, and to provide adequate documentation of the changes.

3.2.4 Improved Human-Machine Interface

Clarity in communication between the system and the human is imperative for the human to be effective in his or her control of the system and for the system to provide the necessary information on time and in an adequate format. It requires that both the human and software understand each other's intentions and have realistic expectations from each other. The development of Human-Machine Interfaces (HMIs) requires that end users are presented with early versions for feedback and that rigorous usability testing is applied.

Table 5: Initiatives for improved Human-Machine Interface (HMI)

Initiative	Rationale
Preliminary HMI design	The end users need to provide feedback on early HMIs to enhance design decisions and to gain their acceptance of the system
Application of human-centered design	Human-centered design principles are vital in the development of HMIs.
Usability testing	The usability testing of the HMI is an important component in the overall usability testing of the system

3.2.5 Improved Selection and Training

Assuring effective human performance is something that starts long before the controller takes the seat at the working position. The recruitment, selection and training for the job are important to bring the best human resources to the scene. With the introduction of automated functions, the role of the ATCO will change, and selection and training need to take such changes into account.

Table 6: Initiatives for improved selection and training

Initiative	Rationale
Preparation for recruitments	Early concern for recruitment of personnel for the system and concern for their profiles will improve the selection of staff for the system.
Training of controllers for new system	In the transition to a new system staff need adequate training before taking up their new responsibilities.

3.2.6 More Effective Product Testing

The involvement and increased reliance upon the humans in the system development will provide for a more effective product testing. The end users of the system will, if included in the process early enough for them to have a real saying in the development, provide invaluable feedback to the system developers.

Table 7: Initiatives for more effective product testing

Initiative	Rationale
Establish feedback improvement mechanism	While the users' group represents the end users in the life cycle, mechanisms need to be established enabling the end users themselves to provide continuous feedback on the system.
Re-assessment of humans and system reliability	The re-assessment of humans and system reliability when making changes to the system will ensure a better testing of the joint human-machine systems performance ability.

3.2.7 More Usable System Documentation

Concerns for the end users will be reflected in the system documentation, which will become more understandable and user-friendly, and hence will increase the effectiveness of the users and their acceptance of the system.

Table 8: Initiatives for more usable system documentation

Initiative	Rationale
Specification of modifications	More user-friendly documentation will increase the understanding of the system among the end users and enable good performance.

3.2.8 Types of Benefits

Some of the benefits resulting from integrating human factors in the system life-cycle are directly measurable in money terms, while others are less tangible. Some have a direct impact on the effectiveness of the system, while others merely enable the improvement of additional factors in the processes.

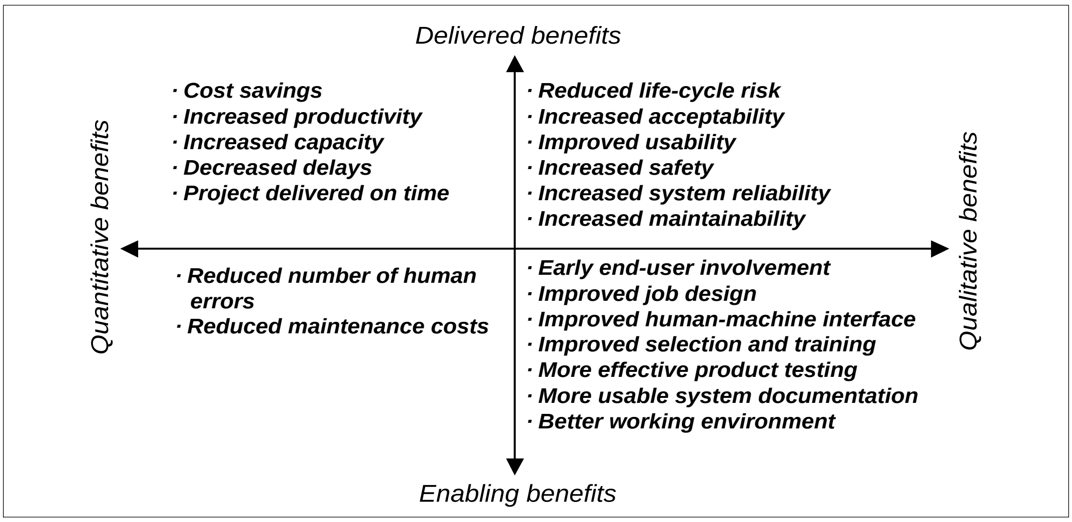

Figure 11: Types of benefits

3.3 Adding it all up

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

1. The development cycle of the system will benefit, from its initial concept to its installation, from issues such as more effective product testing, improved training and selection, better system documentation and a product which is delivered on time and within budget. The emphasis on usability and acceptability will also ensure that the system will be up and running quickly, getting it right the first time.

2. At the working position level human factors integration will contribute to reduce fatigue and stress, monotony and boredom, increase job satisfaction and motivation, improve comfort and working environment, and decrease the number of human errors.

3. The overall system will be safer through a better utilisation of the human resources and improved system reliability.

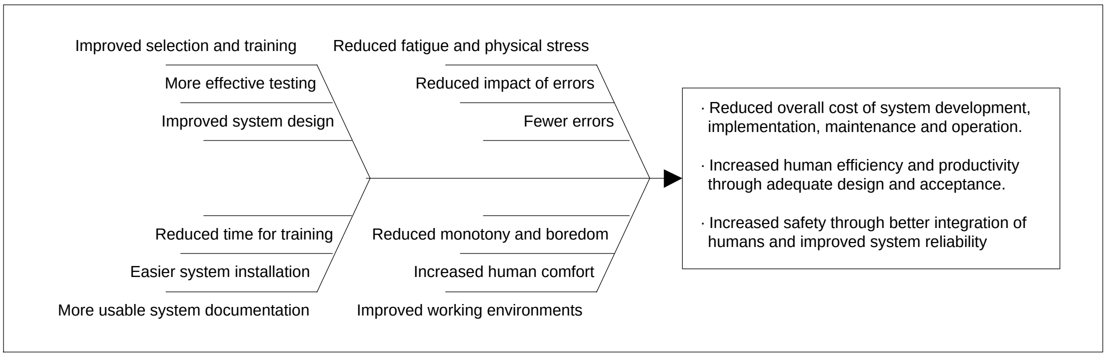

Figure 12: Some benefits of human factors integration

4. THE COST OF HUMAN FACTORS INTEGRATION

> *“There is an ‘iron’ law that should never be ignored. To consider Human Factors properly at the design and certification stage is costly, but the cost is paid only once. If the operator must compensate for incorrect design in his training program, the price must be paid every day. And what is worse, we can never be sure that when the chips are down, the correct response will be made.”*
>
> *(Wiener, 1988)*

It is generally believed that the decisions made during the first stages of a system design determine the main body (more than 70%) of a system's life-cycle cost. In an increasingly competitive world of privatised Air Traffic Services (ATS) providers and national administrations under tight budget control, it is therefore important to pay extra attention to these first steps when initiating the acquisition of a new system or when modifying an existing one.

This section will investigate some of the costs related with human factors integration. The cost items involved will not be quantified as the specific amounts depend on many factors.

4.1 Life-Cycle Investments

The integration of human factors means investments into people, processes and material. An outline of some of the investments to make is shown in Figure 13. The cost items may vary between systems.

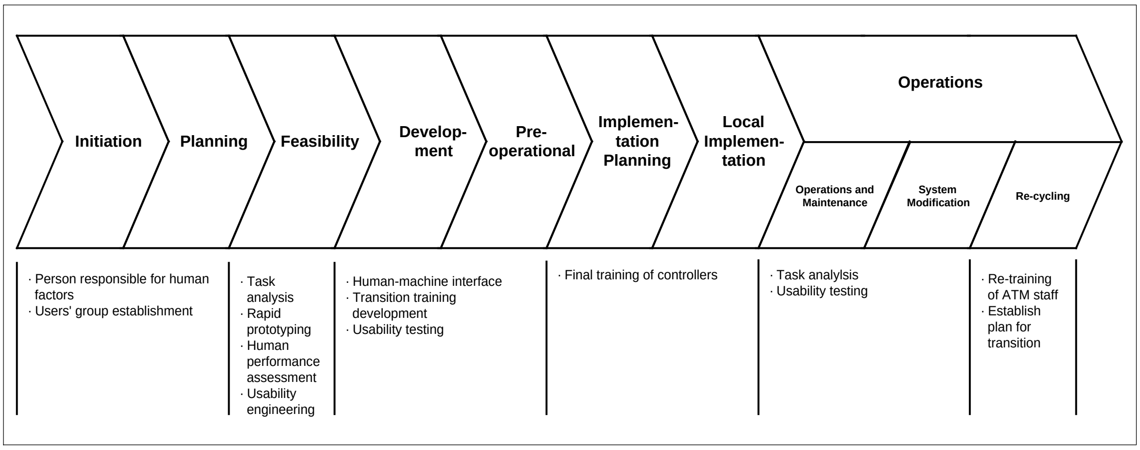

Figure 13: Life-Cycle Cost items

4.1.1 Initiation & Planning

As the infrastructure to support the integration processes needs to be set up early, two important investments need to be undertaken. The assignment of a person responsible for human factors is a significant first step in the process. This person needs to be a human factors specialist with good qualifications and experience in applying human factors principles and methods. The establishment of a users' group is another important step. Both of these constructs need to follow the system in its entire life cycle, with the development and adaptation phases being the most intense.

Table 9: Cost items in the Initiation & Planning phase

Cost Item	Detail
Person responsible for human factors	The person responsible for human factors will have to be assigned for the entirety of the system life-cycle.
Users' group	The users' group will have to exist for the entirety of the system life-cycle.

4.1.2 Feasibility

The Feasibility will see a lot of activity as it is a very crucial stage at which a solid foundation has to be laid for the integration of human factors. Some of the important cost items are shown in Table 10.

Table 10: Cost items in the Feasibility phase

Cost Item	Detail
Task analysis	To understand the tasks to perform and their specific cognitive requirements a task analysis is needed. Fast-time simulations can be used to augment steps in the task analysis with, for instance, workload indices.
Rapid prototyping	Rapid prototyping provides a flexible tool to quickly present a design and get feedback from involved ATM staff.
Human performance assessment	In order to get a first feel of the benefits of a particular design, assessment of the human performance can be obtained in small-scale real-time simulations.
Usability engineering	Early considerations need to address the usability of the system.

4.1.3 Development

The Feasibility phase and the Development phase may blend into one using an iterative system development strategy. The human factors cost items in the Development phase may therefore closely resemble the ones in the Feasibility phase, as shown in Table 11.

Table 11: Cost items in the Development phase

Cost Item	Detail
Human performance assessment	A detailed account of the human performance can be obtained using, for instance, small-scale real-time simulations.
Transition training development	The development of transition training for the ATM staff needs to be aligned with the requirements and characteristics posed by the system.
Usability testing	Thorough usability testing should iron out most of the usability problems.

4.1.4 Implementation

The Implementation phase covering the implementation of the system should ensure that the system is implemented as per the guidelines developed during the previous phases, and that the ATM staff concerned receive their final training for the system. The staff assigned to operate the system need to receive the necessary training early enough for them to be fully qualified and up to speed when they switch to the new or modified system.

Table 12: Cost items in the Implementation phase

Cost Item	Detail
Final training of ATM staff	The ATM staff should receive the necessary training enabling them to take up their duties.

4.1.5 Operations

Modifications to a running system are inevitable. The effects on tasks and working environment need to be analysed and usability aspects need testing. In the final phase of the system life-cycle two major tasks need to be undertaken; first of all, the transition of ATM staff needs to be carefully planned and the plan needs to be communicated; secondly, the ATM staff need to receive the proper re-training to take up their new functions. This phase is the major link to a new incarnation of the system life-cycle.

Table 13: Cost items in the Operations phase

Cost Item	Detail
Task analysis	The impact of changes that are made to the system on the tasks of ATM staff needs to be analysed carefully.
Usability testing	The usability of system changes needs to be tested.
Transition plan	Concern needs to be addressed to a well-planned transition to a new system. The transition plan needs to be communicated to all relevant parties to maximise the effect and acceptance.
Re-training of ATM staff	The ATM staff need proper training to take up their new duties.

4.2 Life-Cycle Cost Development

Cost within the system life-cycle is typically assessed on a short-term basis, focusing on whether specific tasks should be carried out or not. The rationale is understandably to minimise the cost and to adapt to the available resources. Focusing the attention narrowly on the cost of single tasks may however unintentionally jeopardise the overall cost of developing and operating a system.

Figure 14 illustrates this aspect. The dashed curve shows how cost is generated over the life-cycle. The curve represents an instant feedback on the 'current cost' at any given point in time within the life-cycle. From this it is quite obvious that the main bulk of the system life-cycle cost is obtained during the implementation and operation phase.

On the contrary, the curve represented by the solid curve shows how cost is being decided in preceding phases and spent on beforehand - the so-called locked-in cost. The locked-in cost represents points in time at which decisions have been made about future spending. The locked-in cost is less obvious and largely neglected in the management of system development and operation despite its obvious importance.

Looking at the locked-in cost it becomes obvious that a major part of the system life-cycle cost is determined in the very early phases. It is interesting to note that 70% of the locked-in cost is generated before the Detailed Design phase which only occupies about 10% of the total system life-cycle time. This aspect only amplifies the importance of doing it right from the beginning and of making the right decisions from the early phases.

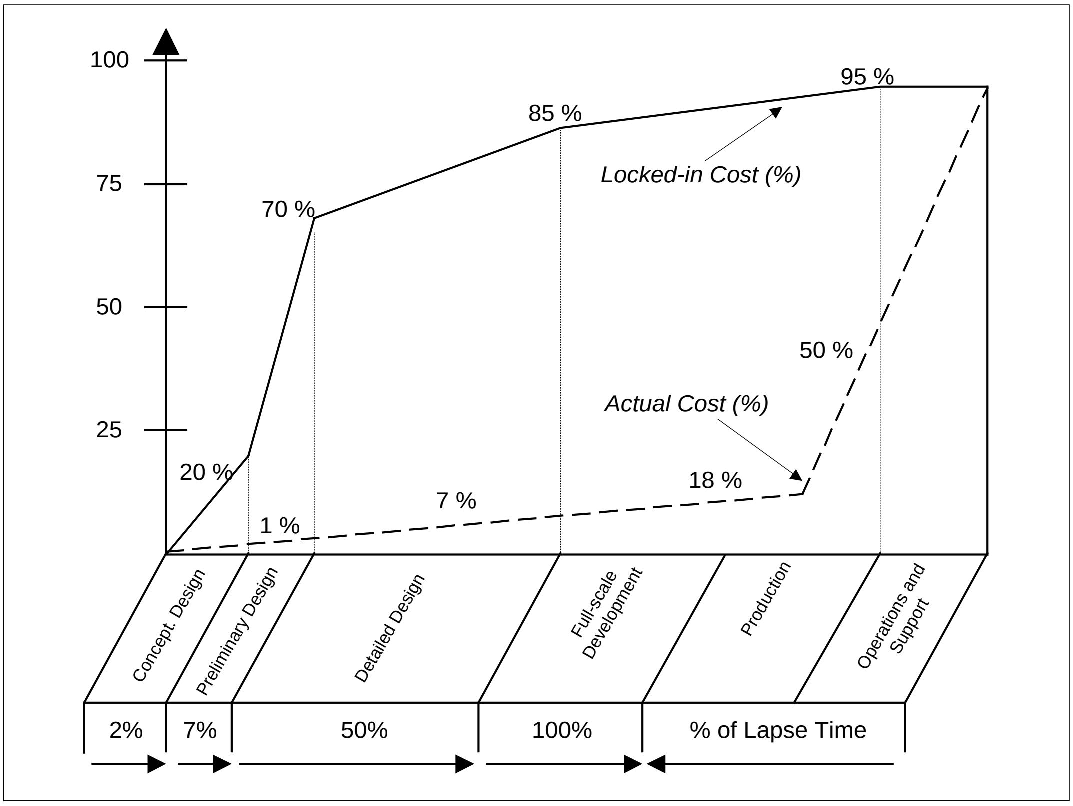

Figure 14: Life-cycle cost during the Conceptual and Preliminary Design phases (Gawron et al., 1996)

While Figure 14 illustrates the general development of cost in the life cycle, Figure 15 illustrates the effects of not getting it right the first time. The figure illustrates how the cost of changing a system design amplifies depending on the point in time when the change is introduced.

Compared to the cost of changing the design during the definition phase of the life cycle, the cost of the changes made during the development will be increased by 1,5 to 6 times. The cost of the changes made to the system, after it has been finalised and delivered to the end users, will be amplified by 60 to 100 times (Pressman, 1992).

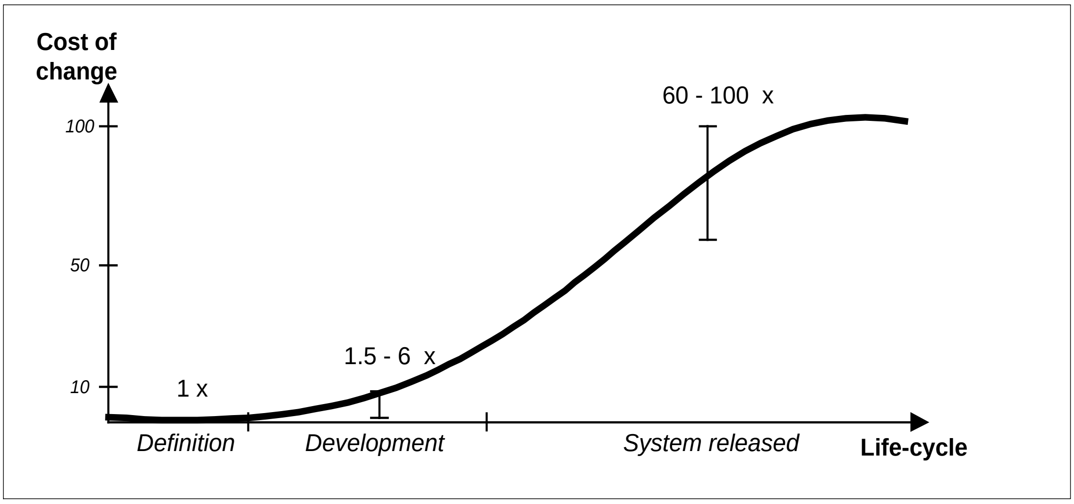

Figure 15: The amplification of design change cost

4.2.1 Three Life-Cycle Strategies

As a way of dealing with human factors in the life cycle three different strategies can be found:

a) ‘Do nothing’ approach: No initiatives are taken to counter human factors problems; only when problems arise will they be addressed.

b) ‘Reactive’ approach: Concern for human factors is left to the last stages of the development process.

c) ‘Proactive’ approach: Problems are fixed before they occur.

The cost scenarios of the three different strategies are illustrated in Figure 16. The first (‘Do nothing’) approach illustrates how cost related with human performance issues will increase rapidly over the life-cycle of the system. If some concern for human performance issues is dealt with in the final stages of the development process (as shown in Figure 16 as the ‘reactive’ approach), the cost scenario will develop in a less aggressive yet increasing manner.

However, if an early awareness to the human factors and human performance issues is introduced in a proactive manner (shown in Figure 16 as strategy c), the cost will develop in a rather different manner. The figure does not only illustrate how cost is higher compared to the other approaches due to the investments made early in the process, but it also shows how the early anticipation of problems takes the air out of later and more expensive problems.

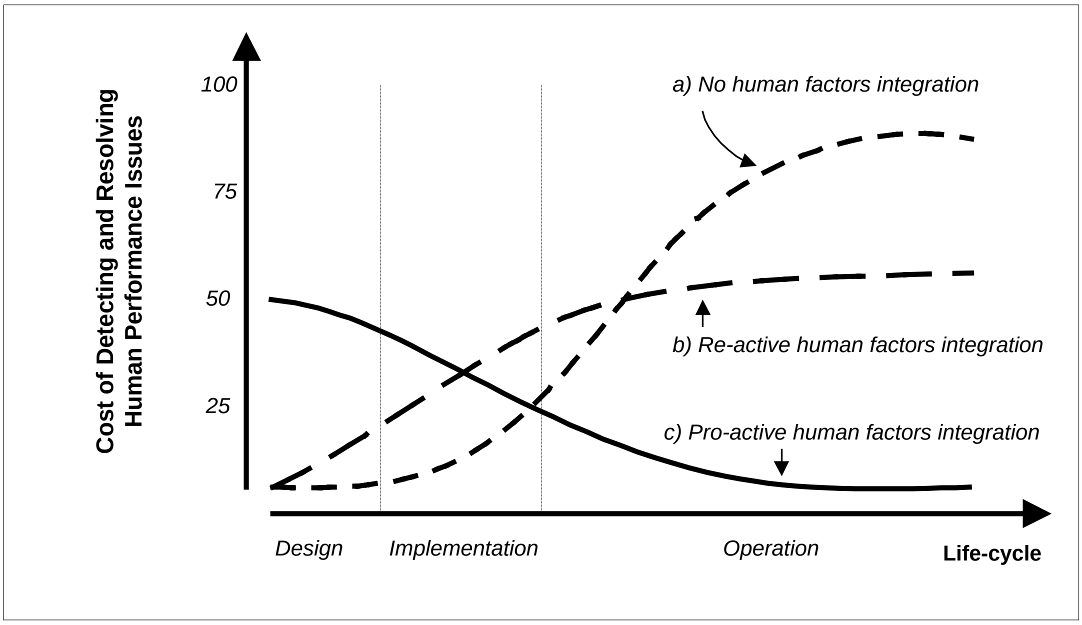

Figure 16: Cost scenarios of three different life-cycle strategies

The reluctance to provide the necessary resources to embark on a proactive approach is probably based on the notion that it is better to wait and see where the problems occur and then intervene. While this strategy may, apparently, save some money, especially when the system is being developed, experience shows that the bill will have to be paid later ... with interests.

Unless human factors are emphasised as an important part of the requirements for a new or adapted system, contractors bidding for the contract are likely to leave them out to save cost (and therefore increase the likelihood of winning the contract). Therefore, the requirements from any system development or from making changes to an existing system need to address human factors specifically.

In summary, we can make the following observations:

- 70% of cost is determined in the first 10% of the project;
- It is more cost-effective (60 to 100 times) to change the design of a system at the initial phases of development than to do it once the system has been built and is in operation.

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

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ANNEX: MANPOWER ESTIMATIONS

It is difficult to provide cost estimates as no two projects are exactly alike. Some experience has been obtained through usability engineering projects, where software products are brought through the same integration and validation process as advocated in this report. Table 14 gives an overview of cost/benefit aspects of the methods. It gives a rough estimate of the duration of the users validation process for three different users validation scenarios:

- Small users validation process: detecting deficiencies in a single design,
- Medium users validation process: comparing three designs,
- Extensive users validation process: repeated user validation at different stages in the development process.

The table describes whether additional cost is incurred by subjects or material needed for performing the users validation. Finally, the reliability of measurements is shown in the far-right columns.

The table refers to methods that are not covered in this module. Details can be found in Melchior et al. (1996).

Table 14: Estimation of the cost/benefit of applying a method for users validation (Melchior et al., 1996)

Cluster	Method	Cost of Evaluation (man-days) for Project Size			Additional Cost					Reliability of Measurements			
		Small	Medium	Extensive	Subjects required	High material cost	Low material cost	No material cost	Training (in man-days)	High reliability	Medium reliability	Low reliability	Not known
Task Analysis	TAFEI	**10**	**20**	**30**				**x**	**1**			**x**	
Checklists for users interface quality	Software checker	**1**	**2**	**3**				**x**	**1**		**x**		
	Ravden & Johnson	**2**	**4**	**6**			**x**		**2**		**x**		
	EVADIS II	**3**	**6**	**9**				**x**	**2**		**x**		
	Ergonomie-Prüfer	**1**	**2**	**3**	**x**			**x**	**1**		**x**		
Usability Inspection Methods	Heuristic evaluation	**2**	**4**	**4**				**x**	**1**		**x**		
	Pluralistic usability walkthrough	**4**	**6**	**6**				**x**	**1**				**x**
	Inspection and design review	**4**	**6**	**6**				**x**	**1**				**x**
	Cognitive walkthrough	**4**	**6**	**6**				**x**	**1**				**x**
	Formal usability inspection	**4**	**6**	**6**				**x**	**1**				**x**
Questionnaires for the evaluation of subject factors	SUMI	**1**	**3**	**3**	**x**			**x**	**2**	**x**			
	QUIS	**1**	**3**	**3**	**x**		**x**		**1**		**x**		
Cognitive Workload Questionnaires	SMEQ	**2**	**6**	**6**	**x**			**x**	**1**		**x**		
	MCH	**1**	**2**	**3**	**x**			**x**	**1**		**x**		
	SWORD	**2**	**4**	**6**	**x**			**x**	**5**		**x**		
	SWAT	**1**	**2**	**3**	**x**		**x**		**1**		**x**		
	NASA TLX	**1**	**2**	**3**	**x**			**x**	**1**		**x**		
	NASA RTLX	**1**	**2**	**3**	**x**			**x**	**1**		**x**		
Performance tests	DRUM	**20**	**60**	**50**	**x**		**x**		**5**	**x**			
	Learning time measurement	**50**	**70**	**90**	**x**	**x**			**5**		**x**		
Physiological measures of workload and stress	EMG	**30**	**60**	**90**	**x**		**x**		**20**		**x**		
	EDA	**30**	**60**	**90**	**x**		**x**		**30**		**x**		
	EOG	**30**	**60**	**90**	**x**		**x**		**10**		**x**		
	Cardiac activity	**30**	**60**	**90**	**x**		**x**		**3**		**x**		
Analytical evaluation Methods	SANe	**5**	**10**	**10**			**x**		**5**	**x**			
	ORACLE	**5**	**10**	**15**			**x**		**5**	**x**			
	Screen analyser	**2**	**4**	**6**			**x**		**1**	**x**			
	GOMS	**10**	**20**	**30**			**x**		**10**				**x**
Informal approaches	Focus Group	**5**	**5**	**8**	**x**			**x**	**2**				**x**
	Interview	**10**	**10**	**30**	**x**			**x**	**2**				**x**
	Questionnaires	**5**	**8**	**10**	**x**			**x**	**0**				**x**
	Thinking aloud	**15**	**30**	**60**	**x**			**x**	**5**		**x**		
	Co-discovery	**15**	**30**	**60**	**x**		**x**		**5**		**x**		

Note: *Small* = *Detecting deficiencies in a single design*

Medium = *Comparing three designs*

Extensive = *Repeated evaluation at different stages of the design process*

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GLOSSARY

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

Acceptability: The acceptance of the system means whether the humans coming into contact with the system accept its existence and the way in which it operates.

Cost-Benefit Analysis: An objective study in which the cost and benefits of a particular project's option are fully quantified in economic terms, taking full account of the times at which cost is paid and benefits accrue.

Human factors: Multi-disciplinary area in which knowledge about people at work is compiled and generated, and applied to the functional relationships between people, tasks, technologies and environment, in order to produce safe and efficient human performance.

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

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

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

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

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

System life-cycle: The phases a system goes through from initial concept to detailed design and implementation to installation, operation and eventually de-commissioning.

Usability: Applies to systems. Means whether a system is easy to learn, pleasant to use, error-free and error-forgiving, easy to remember and efficient.

Usability engineering: Comprises a number of methods and techniques to improve a systems usability.

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ABBREVIATIONS AND ACRONYMS

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

ATC	Air Traffic Control
ATCO	Air Traffic Control Officer/Air Traffic COntroller (UK/US)
ATM	Air Traffic Management
ATS	Air Traffic Services
CBA	Cost-Benefit Analysis
DED5	Human Resources Bureau *(now DIS/HUM or HUM Unit)*
DEL	DELiverable
DIS/HUM	ATM Human Resources Unit *(also known as HUM Unit – formerly DED5)*
DRUM	Diagnostic Recorder for Usability Measurement
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(now EATMP)*
EATMP	European Air Traffic Management Programme *(formerly EATCHIP)*
EDA	ElectroDermal Activity measurement
EEC	EUROCONTROL Experimental Centre
EMG	ElectroMyoGram
EOG	ElectroOculoGram
ET	Executive Task
EWP	EATCHIP/EATMP Work Programme
FAA	Federal Aviation Administration
GOMS	Goals, Operators, Methods, Selection rules and method
HMI	Human-Machine Interface

HUM	Human Resources (Domain)
HUM Unit	ATM Human Resources Unit *(also known as DIS/HUM – formerly DED5)*
HRT	Human Resources Team
ICAO	International Civil Aviation Organization
MCH	Modified Cooper-Harper rating scale for system workload assessment
NASA RTLX	NASA Raw Task Load indeX
NASA TLX	NASA Task Load indeX
QUIS	Questionnaire for User Interface Satisfaction
REP	Report
SANe	Skill Acquisition Network
SDOE	Senior Director(ate) Operations and EATCHIP *(now SDE)*
SDE	Senior Director(ate) EATMP *(formerly SDOE)*
SHEL	Software, Hardware, Environment, Liveware
SMEQ	Subjective Mental Effort Questionnaire
ST	Specialist Task
SUMI	Software Usability Measurement Inventory
SWAT	Subjective Workload Assessment technique
SWORD	Subjective WORrkload Dominance technique
TAFEI	Task Analysis For Error Identification
TRM	Team Resource Management

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