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Impact of Automation on Future Controller Skill Requirements and a Framework for their Prediction

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Abstract

This document provides an advanced approach of integrating human factors issues into ATM design and training by providing a predictive approach for cognitive human aspects. The approach distinguishes between defining the cognitive demands of the interface (levels of automation), the cognitive aspects of ATM and required ATM functions. The approach was validated with a datalink experiment and the predictive results are presented as well as the detailed taxonomies used for prediction.

This document was developed within the 'Solutions for Human-Automation Partnerships in European ATM (SHAPE)' Project. SHAPE has also produced a computerized toolkit, called 'SHAPE Toolkit'. The algorithm of the toolkit is based on the framework described in this report.

Keywords

Air Traffic Control (ATC)	Air Traffic Management (ATM) system	Automation
Skill requirements	Computer assistance	Impact of automation
Human Factors (HF)	Cognitive functions	ATC functions
Skill change	Taxonomy	Competencies
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DOCUMENT APPROVAL

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0.1	26.07.2002		Working Draft	All
0.2	06.03.2003		Draft 1 (change in structure of report)	Section 2 onwards
0.3	28.08.2003		Draft 2 (Internal Project Team review)	All
0.4	03.09.2003		Draft 3 (Internal Project Team review)	All
0.5	17.10.2003		Draft 4 (replacement of all bitmap figures/tables with inserted objects from the original files or sources)	All figures/ tables
0.6	20.01.2004		Proposed Issue for HRS-PSG Meeting end of January 2004 (basic document configuration and editorial changes)	All
1.0	20.08.2004	040524-01	Released Issue (agreed by HRT-PSG Members by correspondence on 15.03.2004) (final document configuration and editorial adjustments)	All

CONTENTS

EXECUTIVE SUMMARY

The role and nature of the controller tasks will almost certainly change as a result of the inclusion of increased automation within the ATM system. The ability to understand and act effectively upon these changes is the topic of a project entitled 'Solutions for Human-Automation Partnerships in European ATM (SHAPE)' being carried out by the 'Human Factors Management Business Division (DAS/HUM)' of EUROCONTROL, formerly known as the 'Human Factors and Manpower Unit (DIS/HUM)'. SHAPE investigates specific Human Factors (HF) topics or areas of potential impact and proposes various frameworks, tools or measures to tackle this issue: trust (see EATM 2003a,b,c), situation awareness (see EATM, 2003d), teamwork (see EATM, 2004a), experience and ageing (see EATM, 2003e, 2004b), future controller skill requirements (covered in this document), mental workload (see EATM, 2004c) and recovery from system failure (see EATM, 2004d).

This report on the subject of future controller skill requirements and the SHAPE Framework development describes how the development of a framework and set of en-route controller skill requirements was used to construct a new human factors technique, primarily concerned with establishing predictions about how new ATM systems may impact the controller. This technique is in the form of a software application, called the SHAPE Toolkit. The SHAPE Toolkit consolidates the different human factors topics within SHAPE and enables predictions to be made about each using a common four-step assessment process described in this report.

The development of an electronic version of the SHAPE Framework enables the necessary complexity of the data that exists within this framework to be largely made invisible to the analyst allowing them to simply input initial date and receive impact prediction reports as an output. Although the SHAPE Toolkit enables predictions in many human factors areas, this report focuses, in particular, on the toolkit's ability to predict skill change requirements as a result of new ATM systems.

The skill change predictions achieved by the toolkit are valuable in that they enable the impact of planned automation on the controller's skill and performance requirements to be better gauged earlier than is currently the case. This, in turn, enables the cost-benefits and training implications of system developments to be assessed in a timely and cost-effective manner. The skill-prediction process is intended principally for deployment early in the system development, by HF specialists or other professional involved in the design and implementation of automated systems in ATM such as: engineers; software designers and; ATCO training specialists. It enables skill predictions to be focused on practically, later in real-time simulations or trials of the ATM system.

The benefits, basic rationale and components of the automation framework are described. The reader is then taken through the steps of the framework and toolkit analysis process.

An example where skill change predictions made using the SHAPE Toolkit to assess a datalink technology is given to illustrate how the technique can be used. These predictions were validated in a real-time trial of the datalink technology and found to be fairly accurate when compared with controllers' own observations and opinions of the datalink technology. This trial, its results and implications in terms of the utility of the SHAPE Toolkit, are described and briefly discussed.

1. INTRODUCTION

1.1 Scope and Background

The work presented in this module is embedded in a larger project called 'Solutions for Human-Automation Partnerships in European ATM (SHAPE)'. The SHAPE Project started in 2000 within the Human Factors Sub-Programme (HSP) of the EATMP Human Resources Programme (HRS) (see EATMP, 2000a) conducted by the Human Factors and Manpower Unit (DIS/HUM) of EUROCONTROL, today known as 'Human Factors Management Business Division (DAS/HUM)'.

SHAPE is dealing with a range of issues raised by the increasing automation in European ATM. Automation can bring success or failure, depending on whether it suits the controller. Experience in the introduction of automation into cockpits has shown that, if human factors are not properly considered, 'automation-assisted-accidents' may be the end result. The following seven main interacting factors have been identified in SHAPE, which need to be addressed in order to ensure harmonisation between automated support and the controller:

<u>Trust</u>: The use of automated tools will depend on the controllers' trust. Trust is a result of many factors such as reliability of the system and transparency of the functions. Neither mistrust nor complacency are desirable. Within SHAPE guidelines were developed to maintain a correctly calibrated level of trust (see EATM 2003a,b,c).

<u>Situation Awareness (SA)</u>: Automation is likely to have an impact on controllers SA. SHAPE developed a method to measure SA in order to ensure that new systems do not distract controllers' situation awareness of traffic too much (see EATM, 2003d).

<u>Teams</u>: Team tasks and performance will change when automated technologies are introduced (team structure and composition change, team roles are redefined, interaction and communication patterns are altered). SHAPE developed a tool to investigate the impact of automation on the overall team performance with a new system (see EATM, 2004a).

<u>Skill set requirements</u>: Automation can lead to both skill degradation and the need for new skills. SHAPE identifies new training needs, obsolete skills, and potential for skill degradation aiming at successful transition training and design support (covered by this report).

<u>Recovery from system failure</u>: There is a need to consider how the controller will ensure safe recovery should system failures occur within an automated system (see EATM, 2004d).

Workload: With automation human performance shifts from a physical activity to a more cognitive and perceptual activity. SHAPE develops a measure for MWL, in order to define whether the induced workload exceeds the overall level of workload a controller can deal with effectively (see EATM, 2004c).

Ageing: The age of controllers is likely to be a factor affecting the successful implementation of automation. Within SHAPE this particular factor of human performance, and its influence on controllers' performance, are investigated. The purpose of such an investigation is to use the results of it as the basis for the development of tools and guidance for supporting older controllers in successfully doing their job in new automated systems (see EATM, 2003e). An additional report on a questionnaire-investigation throughout the European Civil Aviation Conference (ECAC) area has also been produced (see EATM, 2004b).

These measures and methods of SHAPE support the design of new automated systems in ATM and the definition of training needs. It also facilitates the preparation of experimental settings regarding important aspects of human performance such as potential for error recoveries or impacts of human performance on the ATM capacity.

SHAPE has also produced a computerized toolkit called 'SHAPE Toolkit', which is planned to be available in 2004. The algorithm of the toolkit is based on the framework described in this report.

1.2 Issues and Approach

The role and nature of the controller tasks will almost certainly change as a result of the inclusion of increased automation within the ATM system but the ways in which these changes occur may be quite varied and complex.

New skills may be required of controllers to work with the new systems, for example the need to navigate through menus using a keyboard or mouse to find relevant information. Other skills may become obsolete. For example, if a computer support tool for conflict detection is fully successful the controller may not need to detect conflicts but only resolve those that the system detects. There may be skills that are required to a greater or lesser extent. These skills may need to be further trained or additional refresher training may be required to keep these skills well practised. Finally, some skills may remain a requirement but change in nature due to the automation. For example, controllers may still need to remain situationally aware but the way they scan information displays and manage that information to achieve this may change considerably.

These effects need to be addressed in advance and the human-automation partnership needs to be planned so that any early training implications and design decisions can be most effectively addressed. Effective resolution of these training and other HF issues will be key to ensuring the successful design and implementation of this technology in ATM.

Hence, there is need for a unified and systematic technique to analyse automation and understand its impact on controller skills and other performance factors. The technique needs a framework which has a model of automation functions and ATCO cognitive processing, a set of ATM functions and ATCO skill requirements, and a practical process for predicting ATM and cognitive functions, and cognitive processes impacted by automation.

By constructing a technique which is task-based and includes a cognitive processing approach, it is possible to identify the underlying cognitive processes and cognitive functions, hence mental skills, as well as the ATM functions that an automated system impacts. The technique will also enable the prediction of the impact of automation on the other HF factors in the SHAPE Project.

1.3 Benefits

The ability to identify the impact of automation on these HF such as training needs, mental workload, situation awareness, etc., can aid design decisions, simulation planning, training needs assessment and successful transition training. Being able to gauge skill changes as a result of automation early (i.e. in time to influence design options and cost-benefit trade-offs) can provide the opportunity for training (and selection) to become more proactive to ATM technology change.

A unified, systematic approach to analysing automation and understanding its impact on controller mental processing, functions and skill requirements will not only enable comparisons between different design options or automation systems, but will also ensure commonality between analyses. It can also provide a traceable process which can be re-used either in iterations during the design life cycle or for different systems.

The framework and technique for predicting the impact of automation on skill change requirements and the other HF performance factors in SHAPE can be used not only by HF specialists but also by other professionals involved in the design and implementation of automated systems in ATM. These may include engineers, software designers, ATCO training specialists, etc. The benefits may be summarized as follows:

(i) Provide a common understanding of the future ATM technological developments to be considered in this study.

(ii) Be able to map generic ATM functions (and infer the mapping of skill requirements) to technological developments.

(iii) Ensure an efficient and responsive way of addressing skills changes to future technical assumptions and developments.

(iv) Represent and address the inter-dependencies between different Human Factor related issues in automation like workload, situational awareness, team interaction, trust, human error or other.

1.4 Rationale

In order to catalogue how an automated system can affect the role of the controller, it is necessary to analyse the automation system and understand the functional support that the automation aims to provide to the controller.

By establishing the links between the functional support that the automation aims to provide and the cognitive processes of the controller, it is possible to predict the impact of the functional support provided by the automated system on cognitive processing.

By mapping the cognitive processes to the cognitive and ATM functions the controller must carry out, it is possible to identify the controller functions which will be impacted by the automated system. These will be the cognitive and ATM functions that rely on those cognitive processes impacted by the automated system's functional support.

Identifying the automated system's impact on ATCO's cognitive processing will enable the prediction of the:

- impact on mental workload and situation awareness,
- impact on teamwork and trust,
- the controller's recovery from automation failure.

Identifying the automated system's impact on the ATCO functions, both ATM and cognitive will enable the prediction of the:

- change in controller skill requirements based on how the controller will function when using the automated system;
- impact on teamwork, trust and controller's behaviour during recovery from automation failure;
- HMI design problems can also be extrapolated.

1.5 Components of the SHAPE Framework

A framework for investigating the impact of automation on ATM performance requires three main components:

(i) Automation functions - A 'Level of Automation' (LOA) model, based on a basic information-processing model, and a taxonomy, which classifies the types of functions that can be carried out by automation. The development of this component and its content can be found in APPENDIX A.

(ii) Cognitive processes - A model of cognitive processing for ATM and the cognitive processes that are executed by the controller. A brief description of the model of cognitive processing and the list of cognitive processes used can be found in APPENDIX A.

(iii) ATM and cognitive functions – The functions carried out by the controller (ATM and cognitive) to achieve the ATM goals. The construction and validation of the set of ATM and cognitive functions for an en-route controller and the final set of these functions can be found in APPENDIX A.

Figure 1 shows a diagrammatic representation of the framework and the relationships between the main components.

The automation functions afforded by a new ATM system can impact upon a variety of cognitive processing. Various cognitive processes are executed in order to achieve the cognitive and ATM functions that are carried out by the controller. These cognitive processes are sequences of mental states that the controller engages in, in order to perform a series of mental actions or cognitive functions. Hence, a range of cognitive and ATM functions which require these affected cognitive processes will be impacted upon by the automation functions. For example, with a system that provides a trajectory prediction function (automation function), the controller may no longer have to search for the necessary information, make inferences and predict the trajectory (cognitive processes) to diagnose a potential conflict (cognitive function) in order to maintain separation standards (ATM function).

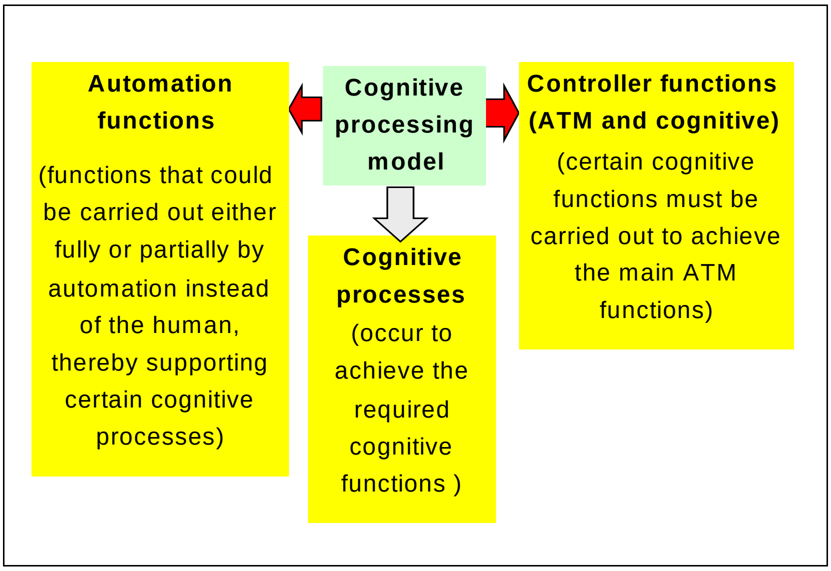

Figure 1: Diagrammatic representation of the framework and the relationships between the main components

In order to link the main components of the framework together in a meaningful way it is necessary to understand:

(i) Which specific automation functions are associated with which specific cognitive processes.

(ii) Which specific cognitive processes are associated with which specific cognitive function.

(iii) Which cognitive functions are associated with which ATM functions.

For this, the components of the framework need to be linked by matrices of data that determine these associations. Hence, within the framework, there are four matrices:

1. Automation to cognitive process matrix.
2. Cognitive process to cognitive function matrix.
3. Cognitive function to ATM function matrix.
4. Cognitive and ATM functions to ATCO skill requirements matrix.

It is these links or matrices which 'tie' the components of the framework together so that it is possible to trace an analysis path through the framework. However, it is not these links per se that are of interest to the analyst of an ATM system using the SHAPE Framework. Instead, the links are enablers that allow a structured analysis process of steps through the framework to be taken so that the ATM system to be analysed can be mapped onto each of the framework components.

Figure 2 shows a diagram of the logical explanation that illustrates how the framework components and the matrices can be used to predict the impact of an automated system on the cognitive and ATM function. In this example, an automated system T was designed to provide automation functions 1 and 2, according to the SHAPE Framework automation taxonomy.

The 'Automation to cognitive process matrix' maps each automation function onto the cognitive processes it affects. It is possible to infer that automated system T may have an impact on cognitive processes A and B because of automation function 1 and also on cognitive processes C and D because of automation function 2.

The 'Cognitive process to cognitive function matrix' maps the cognitive processes required to carry out a cognitive function. In this example, cognitive processes A and B are required by cognitive function Y and cognitive processes C and D are required for cognitive function X. Hence, it is possible to infer that automated system T may have an impact on cognitive functions X and Y.

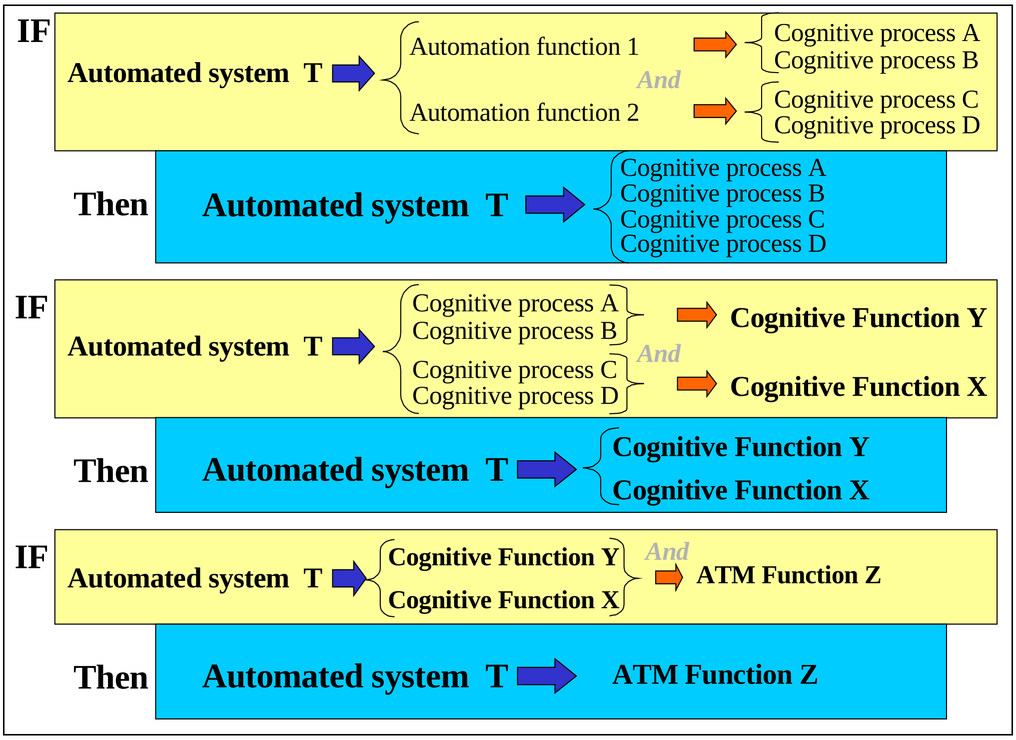

Figure 2: Illustrative example of how the framework components and roadmap can be used

The 'Cognitive function to ATC function matrix' maps the cognitive functions required to achieve an ATM function or goal. In this example cognitive functions X and Y are required to achieve ATM function Z. Therefore, it is possible to infer that automated system T may have an impact on ATM function Z.

Finally, in order to infer the controller skill requirements likely to be impacted by the system, an additional matrix specifying the skills required to carry out the cognitive and ATM functions was constructed. Thus it is possible to then infer that automated system T may impact the skills required for cognitive functions X and Y and ATM function Z. Thus these should be take into account when running simulations of system T or planning the implementation of system T.

The process for analysing an automation system using the framework, according to the roadmap is described in Section 2.

Section 3 reports on how the framework and the analysis process were applied to an illustrative example to predict impact of the automated system on controller skill change requirements. It also presents and discusses the results of the application.

Section 4 provides a summary of the framework. It also briefly describes the use of the computer-based application 'SHAPE Toolkit' not only to predict the impact of automation on controller functions and skill change requirements, but also to integrate the other SHAPE factors into the SHAPE Framework analysis process.

2. FOUR-STEP ANALYSIS PROCESS USING THE SHAPE FRAMEWORK

The analysis process using the SHAPE Framework is a four-step process. The data matrices that link the framework components together are used in each of the four steps in the analysis process to map the system of interest onto the cognitive processes, cognitive and ATM functions impacted by the system. Figure 3 illustrates the four-step process and the matrix used at each step to progress to the next step.

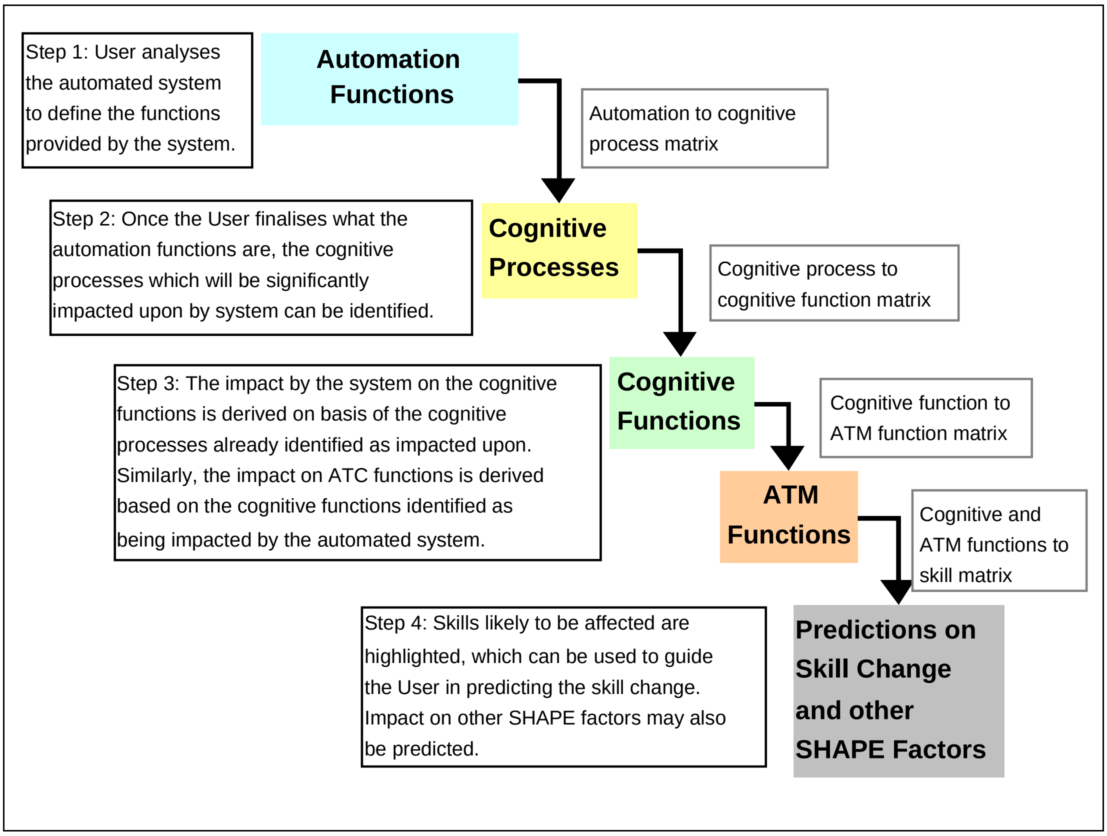

Figure 3: Illustration of the main components in the SHAPE Framework, the matrices that link these components and the steps in the process of using the framework

The analysis process was then implemented in the form of a computer application, 'SHAPE Toolkit'. The user need only complete Step 1. The computer application implements Steps 2-4 by using the user's input in Step 1 and the links from matrices at each step. The output of the analysis process from the computer application is two-fold:

- the first is an 'impact profile' consisting of the set of cognitive processes, cognitive and ATM functions predicted to be impacted by the automated system;

- the second output is ‘skill change prediction profile’, that is a matrix of skill requirements for the cognitive and ATM functions that may be impacted by automated system so that skill change predictions can then be refined.

As an illustrative example, a datalink technology was analysed in SHAPE. This system consists of various automated tools or facilities[1] that provide automated support to the controller.

2.1 STEP 1: Define the Automation Functions

The first step in the process requires an analysis of the automated system according to the SHAPE LOA taxonomy (see APPENDIX A). The aim of this step is for the analyst to construct a description of what functions the automated system will provide to the controller, using the automation functions and definitions in the SHAPE LOA taxonomy. The taxonomy of automation functions available to ATM was developed as part of the SHAPE programme. The taxonomy is based on an information-processing model and has six categories of automation functions. These are:

- information extraction,
- information integration,
- information comprehension,
- decision-making / choice,
- response execution,
- information retention.

Each category consists of several different functions that the automated system can provide to the controller. There are definitions for each of these categories and their associated functions, and these can be found in APPENDIX A.

The component in the SHAPE Toolkit that can be used for Step 1 is called the ‘automation profile’. The purpose of the automation profile component is to guide and enable the analyst to describe the automated system of interest and capture the automation functions that are provided by the system of interest. This component requires the analyst to input the relevant and necessary data into the appropriate cell on the automation-profile pro forma on the application. Instructions will be given to the analyst as he/she works through the analysis in the toolkit. In addition, definitions of the different automation functions will be provided in the toolkit.

Requirements for this step

It is essential that the analyst:

- have an understanding of the scope of the system, what the system is trying to achieve, and the goals of the tools that make up the system (it is important to have this knowledge in order analyse the automated tools and ascertain the automation function profile of each automated tool);

[1] An automated system can consist of a bundle of automated tools or may be a single system with various facilities that the human operator can use or call upon.

- have the resources to establish a detailed knowledge of the system, either via:
    - specifications, requirements, concept of operation documents;
    - Subject Matter Experts (SMEs) (e.g. ATC project managers, engineers, software designers, operational concept developers, etc.) who can contribute to the understanding and description of the automated system;
- identify all the different functionality or tools in the automated system;
- have a copy of the SHAPE Toolkit.

Tasks in the analysis process

1. Input the name of the automated system and the name of each tool/functionality into the SHAPE Toolkit. Provide a description of the automated systems and its tools.

2. Examine documentation or available knowledge on each tool or facility at a time. Define the category of support provided by that tool.

    - Does the tool provide any of these categories of automation functions?

      A. Information extraction.
      B. Information integration.
      C. Information comprehension.
      D. Decision-making / choice.
      E. Response execution.
      F. Information retention.

3. On the automation-profile pro forma on the SHAPE Toolkit, work through each category of automation function support and identify the automation function(s) that is/are provided by the tool/facility. Place a tick or a cross in the appropriate cell on the matrix (under the right tool column and the appropriate automation function row). Refer to the definitions of the automation functions given.

4. Look for clusters of ticks or crosses on the matrix and examine if the clusters form any coherent pattern. Does the level of automation support provided by the tool comply with the aims and objectives of the system? (For example, does the automation actually carry out functions that support the controller's memory if this is part of the system's objective?)

5. Once all the tools are analysed, review the automation function profile of the automated system against the technical or functional specification of the system. In addition, another analyst may also review the automation function profile. The automation profile can be completed by an individual or as part of a group process/workshop. However, it is highly recommended that the review of the automation profile be done as a group process before the profile is confirmed, for further analysis.

6. Once the automation function profile is completed, it needs to be 'confirmed' by the analyst before the application will proceed with the analysis to examine the impact the automation has.

7. Once a profile is confirmed, no further edits or amendments can be made to the profile. This is to protect the profile from accidental and unintentional changes to the profile that will affect the fidelity of the profile. The SHAPE Toolkit does, however, provide a facility to allow the analyst to make a copy or version of a confirmed profile, should they wish to amend the profile at a later date.

2.2 STEP 2: Impact on Cognitive Processes

The second step in the process uses the automation functions to cognitive processes matrix to identify the cognitive processes that will be affected by the automated system's automation profile. That is, the cognitive processes impacted by the automation functional support provided by the system.

The impact profile component in the SHAPE Toolkit implements this step. It will derive and display the impact of the system on a controller's cognitive processes for the analyst. The toolkit will automatically compute which cognitive processes are significantly affected by each tool in the automated system, based on the automation profile describe in Step 1. It is important at this stage that the analyst understands the concept of 'significant impact'.

Significant impact on cognitive processes is based on the *degree* of impact provided by the automated system and its tools to the cognitive processes. Firstly, each cognitive process is impacted by one or more of the automation functions in the SHAPE taxonomy. Hence, for each cognitive process, the degree of impact from each tool/function is computed by taking:

- the number of automation functions performed by that tool/function which impacts that particular process, and

- computing that as a percentage of the maximum number of possible automation functions that will support that process.

For example, in the SHAPE taxonomy, 'plan formulation', a cognitive process, is impacted by a total of three automation functions. Tool A, a tool in automation System X, provides all of these three automation functions. Hence, its degree of impact on plan formulation is 100%. On the other hand, Tool B only provides one of these three automation functions. Hence, Tool B's degree of impact on plan formulation is 33%. In addition Tool C provides two out of these three automation functions. Hence, Tool C's degree of impact on plan formulation is 66%.

'Significant impact' is the percentage value chosen as the cut-off, above which the degree of impact by the automated tool on the cognitive process is deemed significant.

Hence, for the example given above on automation System X. Say, the significant impact value chosen is 50%. Then only Tool A and Tool C significantly impacts the cognitive process plan formulation.

If the significant impact value chosen is 25%, then all three tools, Tool A, B and C, have a significant impact on the cognitive process plan formulation.

The component allows the analyst to choose the significant impact value. The application will use this value to compute which cognitive processes are significantly impacted upon by each tool in the automated system.

Therefore, the analyst can decide how much support from the system is required before an impact on a cognitive process is significant. The lower the value the more the system significantly impacts on cognitive processing. The toolkit will only display in the impact profile the cognitive processes that are significantly impacted.

By default, the toolkit sets a significant impact value of 0%. This allows the analyst to view all the processes that are impacted upon by the automated system, and it is up to the analyst to select the relevant value for their investigation.

2.3 STEP 3: Impact on Cognitive Functions

The third step in the process uses the cognitive processes to cognitive function matrix and the cognitive functions to ATM functions matrix to identify the cognitive and ATM functions which will be affected by the automated system described.

Similarly, the impact profile component in the SHAPE Toolkit implements this step. It will derive and display the impact of the system on a controller's cognitive and ATM functions for the analyst. Based on the impact profile on cognitive processes, the toolkit will automatically derive the impact profile of the automated system on the controller's ATM and cognitive functions.

2.4 STEP 4: Impact on Controller's Skill Requirements

The fourth step in the process uses the ATM and cognitive functions to Controller Skills requirements matrix to identify the controller skill requirements, which may be affected. The construction of a set of controller skill requirements are described in APPENDIX A.

The 'performance factor prediction' component in the SHAPE Toolkit implements this step. It will derive and display a table, listing the controller's skill requirements likely to be impacted upon, based on the impact profile on cognitive and ATM functions.

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3. APPLICATION OF THE SHAPE FRAMEWORK ANALYSIS PROCESS

3.1 Introduction

The SHAPE Automation Framework and its four-step analysis process not only allows a systematic and consistent analysis of the impact of any automated system on the controller, but also ensures that different systems can be compared with each other fairly. In addition, the cognitive processing and task-based approach allows the analyst to discern the impact on the ATM functions and be able to trace the cognitive factors behind the impact on each ATM function. Currently, the operational impact on the controller can be analysed solely by using and examining the technical and functional specification documents for the automated system. However, without such a cognitive processing and task-based approach, it would not be possible to easily pinpoint which specific ATC functions would be directly affected and by which specific tool/function. It would also be impossible to pinpoint which cognitive functions and cognitive processes, and hence the mental skills, are significantly impacted upon by the system and its individual tools/functions. By understanding these aspects of the impact of the automated system on the controller, one can better understand how skill requirements may change.

3.2 Skill Change Prediction Process (Illustration Using the Datalink Technology)

A trial of the system, the Datalink Operational Validation Experiments (DOVE), was attended at EUROCONTROL Experimental Centre (EEC), Brétigny, France, in June 2002. This trial was used as an opportunity to test the validity of the skill change prediction process using the SHAPE Toolkit with a 51% significance cut-off used. The datalink technology (DOVE) was analysed using the four-step process described in Section 2, to identify the skills likely to change as a result of this automation.

The main levels of automation that the datalink technology supported were:

- the extraction of information,
- decision choice,
- response execution and
- information retention.

The cognitive processes that the datalink technology supports were found to include:

- process control system processes (like predicting, plan formulation, decision selection and evaluating) and
- memory processes (like retrieval, short-term projections, rehearsal and actions/outputs).

The Dove Label tool, Dove FL no datalink tool and the Dove colour tool all support memory primarily, whilst the Dove request tool and the Dove message in and out tools support both memory and the process control system functions like prediction and plan formulation as well.

A table, predicting the cognitive and ATM functions affected by the datalink technology and the skills that these functions require, was produced as the main output from the SHAPE Toolkit analysis (see Table 1). This table shows the predicted impact that the datalink technology would have on the controller functions (cognitive and ATM) and the associated predicted skills that may be affected by the system as a result.

However, it is not necessarily the case that every skill required to carry out the impacted functions will actually *change*. It is not possible to predict which of the skills may change and which are not likely to change without some degree of analytical judgement being made with the system under analysis in mind. Therefore, in order to arrive at a final list of predicted skill changes it is necessary for the analyst to consider each Knowledge-Skills-Attitudes (KSA) item in this table in turn to establish whether the prediction is likely to be true and result in a change of skill or not. The analyst must consider whether the system or tool being analysed is likely to impact each KSA item ('Yes' or 'No'). See Table 1 for an excerpt of this skill change judgement table. Those items ticked as 'Yes' at the end of this process are the final skill change predictions.

Table 1: Excerpt from a skill change judgement table

Automation: DATA LINK Skill Predications Knowledge, Skills and Attitudes (KSAs) Predicted	**Cognitive Functions**	Multitasking	Manage Working memory	Build up mental picture of traffic situation	Develop a traffic plan	Active planning	Make decision for control actions	Management of A/C conflict	Manage and respond to requests	Diagnose common problem	Active problem solving	Diagnose uncommon problems	Team multi-tasking	Share mental picture of sit'n during hand-over	**ATM Functions**	Operate communication equipment	Maintain and Update flight data display	Provide a service within defined boundaries	Provide A Service In Emergency And Unusual Situations	Provide Flight Information	Provide Area Control Procedural Service	Plan And Control Aircraft Within The Area Of Responsibilit	Provide Area Radar Service	Co-Ordinate With Other Atsus/Agencies	Work As A Team Member	Monitor The Present And Forecast Weather	Monitor availability and serviceability states	Formulate and issue ATC clearances	Manage degraded systems	Operate radar equipment	Co-ordinate non-std and airspace reservation	Co-operate with MIL ATC	**Tool X could possibly impact this KSA Item (Yes or No?)**
Knowledge																																	
Data displays		x	x	x	x	x	x	x	x	x	x	x	x	x			x			x			x				x			x			
Knowledge of airspace		x	x	x	x	x	x	x	x	x	x	x	x	x						x					x			x					
Knowledge of equipment use and its limitations		x	x	x	x	x	x	x	x	x	x	x	x	x		x				x									x				
National legislation and procedures		x	x	x	x	x	x	x	x	x	x	x	x	x					x						x								
Location of information sources		x	x	x	x	x	x	x	x	x	x	x	x	x															x				
Separation standards/ procedures		x	x	x	x		x	x			x	x	x					x			x	x	x	x				x			x	x	
Influence of weather		x	x	x	x	x	x	x	x	x	x	x	x	x																			
Decoding all coded information		x	x	x	x	x	x	x	x	x	x	x	x	x																			
Basic knowledge of human performance		x	x	x	x	x	x	x	x	x	x	x	x	x																			
Clearances and instructions		x		x	x		x		x		x			x		x	x	x			x	x	x	x				x			x	x	
Approved/standard phraseology		x		x		x		x				x	x	x		x			x	x		x		x				x			x		
Flight plans		x		x	x	x	x	x	x	x	x	x	x	x																			
Aircraft performance data		x	x	x	x	x	x	x	x	x	x	x	x																				
Aviation English/working English		x		x	x	x	x	x	x	x		x	x	x																			
Aircraft types and categories					x			x	x		x	x	x				x		x									x					
Approved strip marking		x	x			x						x					x				x			x									
Strip movement procedures			x	x	x	x		x		x							x																
Radio Telephony operating procedures		x		x							x					x																	
Team roles and responsibilities												x	x	x											x								
Division of responsibility between ATC units																			x	x				x							x	x	
Standing agreements		x																x					x	x	x			x					
Physical Skills																																	
Use of all equipment		x	x	x		x		x	x	x	x	x	x			x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Speak (give info)		x	x	x		x		x	x		x		x	x		x		x	x	x			x	x	x	x			x	x	x		
Strip management		x	x	x	x	x	x	x	x	x	x	x	x	x			x	x			x	x	x		x			x	x	x	x	x	
Approved strip marking		x	x	x	x		x	x		x	x	x	x	x			x	x		x	x	x		x	x			x	x	x	x		
Ask		x	x	x		x		x	x	x	x	x	x			x	x		x	x			x	x		x						x	
Use of RT Equipment		x	x	x		x		x	x	x	x	x	x			x			x	x	x	x	x							x			
Record co ordination outcome		x		x							x						x	x	x	x		x		x	x			x	x		x	x	
Find way around workstation displays							x	x	x	x	x	x		x					x											x			
Flag appropriate strip		x	x		x		x			x								x	x	x	x							x			x		
Mental skills																																	
Prioritise tasks																	x	x	x	x		x							x		x		
Identify potenial conflicts																		x			x	x	x					x			x		
Scan information displays																			x	x						x	x			x			
Apply previous experience																			x	x				x					x	x			
Share information / Communicate with team members																x			x						x	x			x				
Information gathering and interpretation																x										x	x			x			
Scan FPS																					x		x					x			x		
Divide attention (e.g. Speaking and writing at the same time)																x			x			x											
Choose solution																			x		x											x	
Evaluate options against traffic situation / conditions																			x									x			x		
Anticipate future traffic situation																					x	x	x										
Integrate information																	x									x						x	

Once the skill changes are arrived at it is possible to use these to focus on the predicted skill changes in more detail and give these skills further. Depending on the stage of system development, these skill change predictions can be used to inform the design process or help construct observation checklists or questionnaires for system trials as was done here for the DOVE trial. Once the skill change predictions were identified for the DOVE trial, these were used to construct targeted observation checklists and controller questionnaires that could be administered in the trial. This way it was possible to test and initially validate the skill predictions made against controllers' actual experiences having used the datalink system in the trial.

3.3 Description of the Simulation

The last two days of the three-week Dove trial were attended for the SHAPE skill-prediction testing. It was not possible, within two days to conduct an experimentally controlled assessment of the skill change when using the datalink technology being trialled. Instead, the skill-prediction testing was based on simple observations from the controllers working and on controller feedback via questionnaires, self-completion pro formas and debriefs with the controllers after using the datalink technology.

Five measured exercises were run in the two days. Of these, three were high traffic load exercises and two were low/medium traffic load exercises. Two were exercises where 95% of the aircraft were datalink equipped and two were exercises where 50% of the aircraft were datalink equipped. One exercise had 75% datalink-equipped aircraft in the sample. Other factors within the exercises included whether there was turbulence in the sample or whether the 'flipcy' service (a flight plan consistency checking service) was available or not.

Two measured sectors were simulated one was an en-route sector called SW, the other SE. Each sector had two measured positions, one tactical and the other the planner position. Participant controllers rotated through these four measured positions and the 'feed' sectors that supported them.

Seven operational controllers participated in the skill-prediction testing. All seven controllers completed the self-completion pro forma, Five controllers completed the questionnaire and two controllers were debriefed to collect additional information to help clarify some of their questionnaire and skills pro forma answers. The following section describes the methodology used in the trial and its subsequent analyses. The findings from these analyses are then described in Section 3.5.

3.4 Description of the Methodology

The predictions made about the impact of the datalink technology were used to develop a simple questionnaire and pro forma that focused on the predicted skill changes so that they could be assessed in the trial. The questionnaire contained items that asked about the impact of each of the system tools and how they affected the controller in terms of the skills that were predicted to change. In addition, more general questions were asked about whether the use of the system and its constituent tools required new or additional knowledge, skills or attitudes. To try and gauge the direction and amount of skill change the questionnaire asked the controllers to estimate the percentage that the system did certain tasks for the controller (the remaining percentage out of hundred being the amount of that task that the controller still did themselves).

The pro forma was designed to cover those skills predicted to change as a result of the datalink technology as well as some skills that the datalink system were not expected to affect. The predicted skills were taken from the skill-prediction table produced from the SHAPE Toolkit analysis and the other skills were chosen at random from the KSAs and criticality rating tables for the ATM and cognitive functions. All of the skills used on the pro forma were expressed as observable behaviours that controllers could be seen to do so that the pro forma could be completed either by an observer or, retrospectively, by the controller using the system.

The pro forma was divided into four sections as follows:

- controlling, conflict detection and resolution and coordination,
- communication and task management,
- strip use and management,
- team working.

The items on the pro forma were organised under these four headings. A column was provided asking whether any of the skills were obsolete with the use of the new system and a second column was added to indicate any skills that had changed in nature as a result of using the new system. Finally, a column was added to record the relative amount of each skill used on a 1-10 scale, first when using the current system (system in current operation) and second, when using the new system compared with the current system. The purpose of this was to roughly gauge the amount and direction of change of skill use (i.e. decrease or increase) in simple relative terms compared with the current system in operation.

Data gathered using these questionnaires and pro formas were analysed to compare controller observations regarding skill changes with the SHAPE predictions made using the framework and skills data.

3.5 Summary and Discussion of Findings

Skills pro forma findings

Without exception all predictions made using the SHAPE Framework and skill-prediction process were actually observed by at least one of the seven controllers in the trial. Nearly 75% (26/35) of the predictions made were observed by four or more of the controllers (i.e. more than half) which is a very encouraging finding. These findings are illustrated in Table 2 below, showing the number of controllers (out of seven) who observed the change predicted. It suggests that the prediction process does work and is fairly accurate with few if any falsely positive predictions. There were additional observations, however, that the controllers made that were not predicted (see Table 3). This would suggest that the process is not yet fully comprehensive. However, the fact that the process seemed to work, if conservatively (i.e. under-predict rather than over-predict), is a good start for further development. The findings are discussed next comparing the different prediction types made with the controllers observations made via the pro forma and questionnaire.

Table 2: Overview of the skill changes predicted and observed in the DOVE experiment

Skill elements predicted (ATM functions; seven controllers)	**Fits**	**%**
Use standard phraseology and apply standard speech technique to provide a service and to issue relevant clearances/instructions	7	1,00
Obtain/verify readbacks and detect/correct readback errors	7	1,00
Switch attention, divide attention and/or time share between tasks	7	1,00
Incorporate new flight strips into own flight data display	7	1,00
Reflect new information and changes affecting traffic situation and/or diagnosis of problems in the strip-marking and strip arrangement correctly	7	1,00
Keep own strip display sufficiently tidy and meaningful	7	1,00
Understand the coordination requirements and coordinate with other agencies/ATS centres and respond to telephone calls with identity	6	0,86
Maintain accurate flight data display (paper and/or electronic) and update traffic information and data on all aircraft after issuing any clearances/instructions	6	0,86
Record all coordination outcomes	6	0,86
Move the flight strips and obtain an effective strip arrangement for planning	6	0,86
Support and share tasks effectively and/or offer assistance to team members	6	0,86
React to conflict information and/or conflict alert warning as soon as possible	5	0,71
Issue appropriate and safe clearances and instructions (including diversions messages) to the pilot and/or relevant ATS centres/agencies using correct communication techniques	5	0,71
Initiate and carry out coordination correctly and efficiently	5	0,71
Accept and initiate radar handovers and identification efficiently	5	0,71
Carry out efficient task management	5	0,71
Prioritise requests and only accepted requests which ensured efficient workload (his/her own and/or team's workload) was maintained	5	0,71
Prioritise own tasks effectively and efficiently and react promptly upon receiving relevant information or requests from pilots and other agencies and use the correct approved operating procedures	5	0,71
Use the R/T and telephone equipment effectively	5	0,71
Request assistance when appropriate and communicate needs clearly to other team members	5	0,71
Identify, prevent, resolve conflicts	4	0,57

Skill elements predicted (ATM functions; seven controllers)	Fits	%
Evaluate options, priority of actions and consequences of the plan against the existing and anticipated traffic situation/ conditions	4	0,57
Ensure separation standards were achieved or maintained, using separation procedures, given changes in traffic situation	4	0,57
Ask for relevant information from the appropriate persons and pass on relevant information to the pilot/other team members/other agencies as necessary	4	0,57
Monitor and actively check the relevant display/external information to gather the appropriate information for the task	4	0,57
Take action to correct mistakes or ambiguities of other team members' actions	4	0,57
Execute revised plan given significant changes (including impact of weather situation) to traffic	3	0,43
Allocate correct priority according to the category and type of the flight (including Airspace Reservations/Non standard flights)	3	0,43
Navigate around workstation displays (including communication panel) effectively and efficiently	3	0,43
Take correct action (including identifying traffic and verifying Mode C) to ensure that flight plan data is complete and valid	3	0,43
Enable aircraft to comply with the flight plan and assist efficiently in navigation of the aircraft as required (including diverting, non-standard, special flights)	2	0,29
Accept feasible and relevant requests	2	0,29
Provide an effective service (includes radar advisory, control and information)	2	0,29
Offer assistance to the aircraft when appropriate	2	0,29
Provide a service within the area of responsibilities (including elements of airspace delegated by other ATS centres) that is safe and efficient to the category of airspace	1	0,14

Table 3: Overview of the skill changes not predicted but observed in the DOVE experiment

Skill elements predicted (ATM functions)	Fits	%
Make decisions/solutions for the traffic situation/conditions	4	-0,57
Diagnosing problems and implementing solutions	3	-0,43
Performed the necessary planned actions before aircraft arrived into the sector or into area of responsibility	4	-0,57
Validate and verify Mode A & Mode C using correct R/T	4	-0,57
Disseminate weather information	5	-0,71
Use notes and physical cues to put in place effective mental reminders	7	-1,00
Raise warning or blocker strips and move strip into display	6	-0,86
Reflect the plan and status of tasks in the strip-marking and strip arrangement	6	-0,86

<u>Obsolete skills</u>

Three of the seven controllers identified the strip use and management skills as being obsolete when using the datalink technology. This finding is not surprising and was predicted using the SHAPE Framework as strips are no longer available in the datalink technology but instead aircraft data are viewed and interacted with via the Track Data Blocks (TDBs) for each aircraft. Strip use and management skills were predicted to decline or become obsolete. Of the other four, two indicated that all strip use and management skills with the exception of recording coordination outcomes and using physical cues as effective reminders were no longer used when operating datalink. The latter two skills were said to be required but had reduced and changed in nature. For example, coordination outcomes were considered easier to update with datalink by interacting with the TDB directly as opposed to updating strips. Also, the warnings provided by the datalink technology were said to be good mental reminders which saved the need to write notes or create other mental reminders. The last two controllers agreed that all of the strip use and management skills were required less than in current operations. However, they felt they were still utilising these skills in alternate ways with datalink. Overall, strip skills were observed to decline in use with datalink (see Figure 4 and the associated list of tasks). No other skill was identified as being obsolete by the controllers. This again was as predicted.

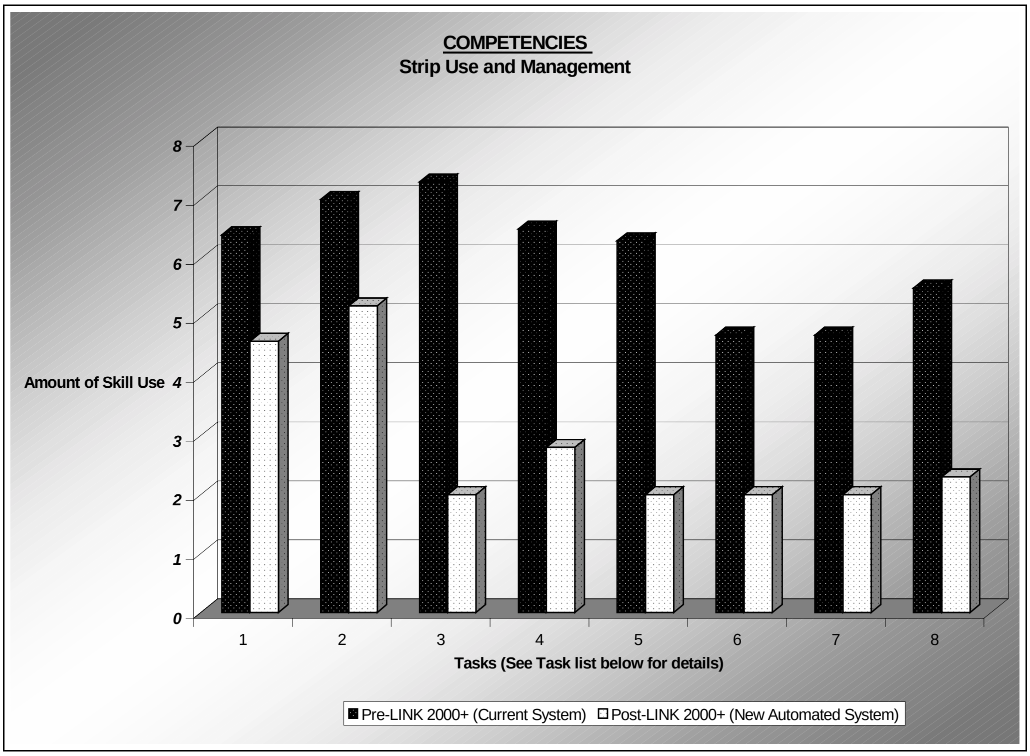

Figure 4: Change in strip use skills reported between pre- and post-datalink technology use

The tasks for Strip Use and Management are represented in conjunction with the following information.

1 Use notes and physical cues to put in place effective mental reminders.

2 Record all coordination outcomes.

3 Incorporate new flight strips into own flight data display

4 Reflect new information and changes affecting traffic situation and/or diagnosis of problems in the strip-marking and strip arrangement correctly.

5 Raise warning or blocker strips and move strips into display.

6 Move the flight strips and obtain an effective strip arrangement for planning.

7 Reflect the plan and status of tasks in the strip-marking and strip arrangement

8 Keep own strip display sufficiently tidy and meaningful.

Skills that change in nature

Six of the seven controllers felt that some skills had changed in nature due to the use of the datalink technology. That is to say that certain skills were still required but were now carried out in a different way. The areas most affected were teamwork and task management (respectively see Figure 5 and Figure 6 and the associated task lists). As was predicted the use of standard R/T phraseology to issue clearances and the verification of pilot readbacks was considered different. In addition, the verification of Mode-C using R/T and the dissemination of weather information were also changed.

Also affected was the sharing of tasks amongst the team and the offering and accepting of assistance between team members. This was not predicted and was said to be largely due to the fact that the planner had more access to tactical controller tasks, such as having direct interaction with aircraft. This could enable closer cooperation between these roles if the communication was good but it could also cause role confusion and be a potential new source of error if the communication is not clear within the team.

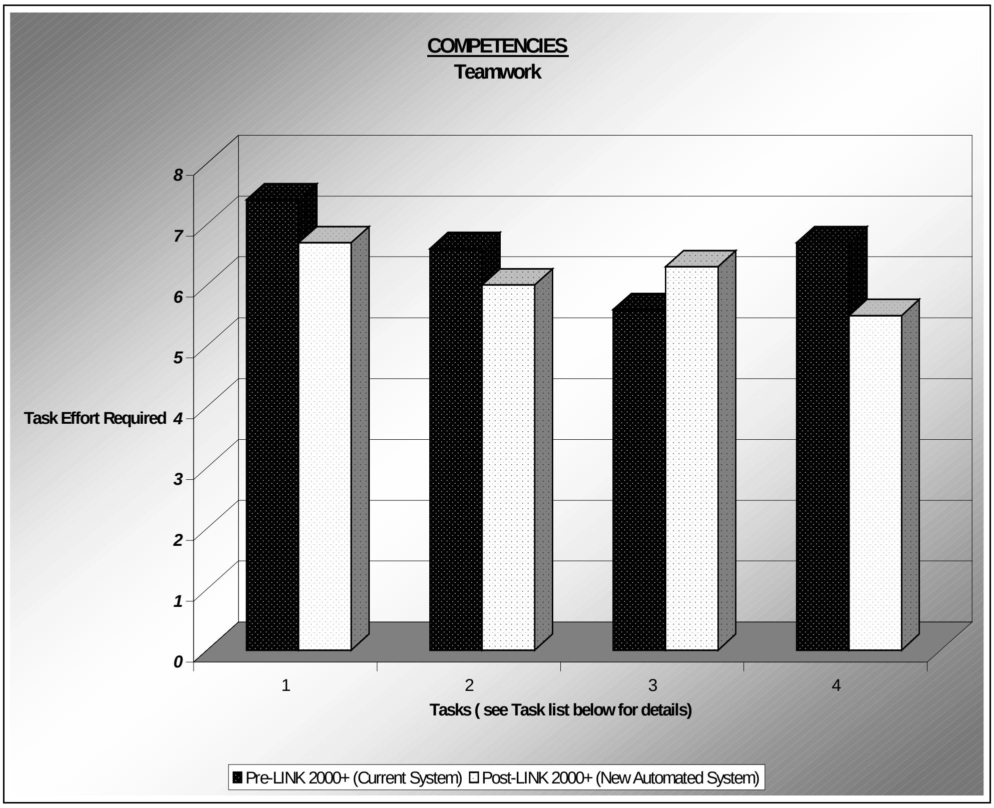

Figure 5: Change in teamwork skills reported between pre- and post-datalink technology use

The tasks for Teamwork are represented in conjunction with the following information:

1 Take action to correct mistakes or ambiguities of other team members' actions.

2 Offer assistance to the aircraft when appropriate.

3 Support and share tasks effectively and/or offer assistance to team members.

4 Request assistance when appropriate and communicate needs clearly to other team members.

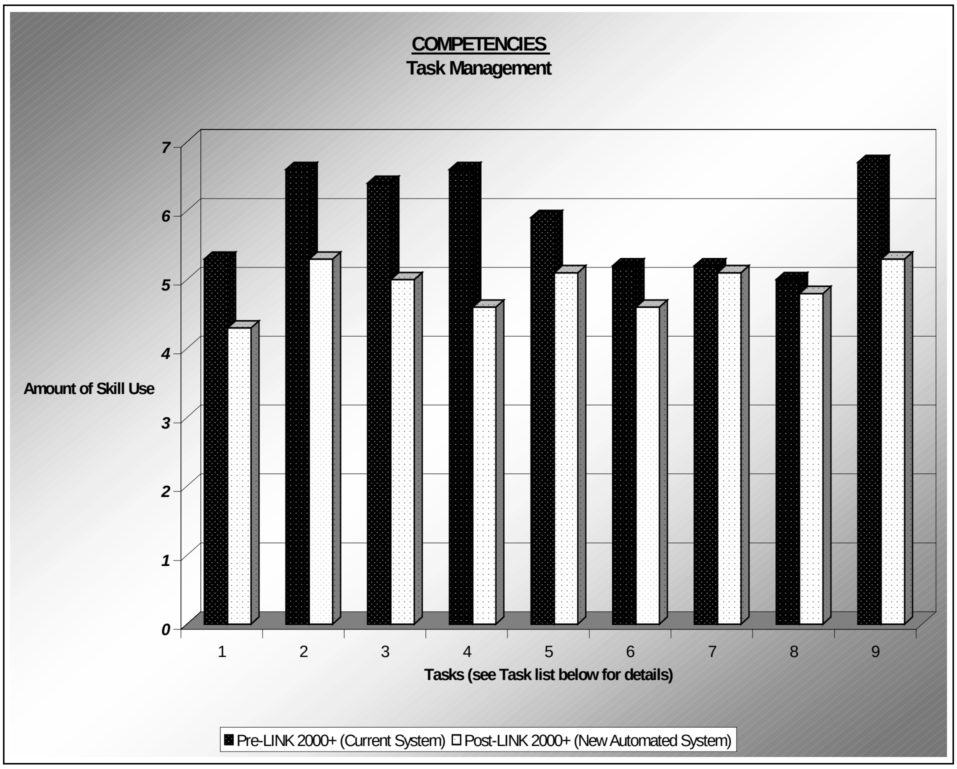

Figure 6: Change in task management skills reported between pre- and post-datalink technology use

The tasks for Task Management are represented in conjunction with the following information.

1 Validate and verify Mode A & Mode C using correct R/T.

2 Carry out efficient task management.

3 Prioritise requests and only accepted requests that ensured efficient workload (his/her own and/or team's workload) was maintained.

4 Prioritise own tasks effectively and efficiently and react promptly upon receiving relevant information or requests from pilots and other agencies and use the correct approved operating procedures.

5 Switch attention, divide attention and/or time share between tasks.

6 Navigate around workstation displays (including communication panel) effectively and efficiently.

7 Monitor and actively check the relevant display/external information to gather the appropriate information for the task.

8 Take correct action (including identifying traffic and verifying Mode C) to ensure that flight plan data is complete and valid.

9 Maintain an accurate flight data display (paper and/or electronic) and update traffic information and data on all aircraft after issuing any clearances and instructions.

Degree to which skills are required

There were some skills that were considered necessary but required to a lesser extent when using datalink. These included the use of R/T phraseology to issue instructions to pilots and the need to listen to pilot readbacks. As a result of this reduced need for verbal air ground communication there was of course also less need to use R/T equipment. Strip management and use, as discussed previously, was considered either not necessary or the need for these skills was greatly reduced. The skills required to maintain an accurate flight data display were also considered less utilised as the flight data display was considerably different in nature and required less of the controllers effort to maintain. Finally, less coordination with other agencies was required of the controllers with the datalink technology. All of these changes were predicted successfully by the SHAPE Framework and skill data.

There were some skills that were required to a greater extent with datalink. More monitoring and actively checking the displays to update awareness of the traffic information was considered necessary. Whether this was due to lack of familiarity with the system or whether it is a longer-term impact is not clear. Also more monitoring of team member's actions was considered necessary and more action was therefore necessary to correct the mistakes of team members. Whether this was partially due to the lack of clarity between planner and tactical roles in the datalink technology (as previously discussed) is, again, not clear.

There were mixed views on whether the need to switch or divide attention between tasks was required more or less. Also the sharing of tasks with team members and supporting or assisting other team members gathered mixed views. Again, this may have been due to the lack of distinction between the planner and tactical roles and who was interacting directly with the aircraft or how well the team was operating. These impacts were again not predicted.

Knowledge

Most (four of five) controllers said no new knowledge was required to operate using the datalink technology. However, one controller said additional knowledge was required about what the colour coding used on the system meant. This controller said there were also new features on the label that required new knowledge. This latter controller's comments, as well as additional knowledge required to use new electronic coordination tools, was predicted. It may be that the other controllers found this extra knowledge easy to acquire during the trial and as a result took their need to learn it for granted.

Attitude

Only one controller felt that the use of the datalink technology required a change of attitude. This controller felt that his attitude towards teamwork was improved when using this system. No attitude changes were predicted but again, this may have been due to the unexpected impact that the datalink technology had on teamwork.

New and changed mental skills

One new skill required by the datalink technology was the need for the controllers to judge the criticality of messages and, based on this judgement, decide whether to issue the instruction via datalink or R/T.

All of the five controllers questioned said that they were aware of their scanning patterns changing as a result of using the datalink technology. One controller said his scanning was improved and one said there was an increased need to scan even in low traffic for fear of missing a request. This may have been due to unfamiliarity with the new system, however, this controller felt that scanning became more demanding and tiring and could lead to a quicker loss of concentration as a result. It was predicted that there would be a change in the ability to navigate around the workstation and this may have been the indirect cause of this scanning difference. One of the five controllers felt that more concentration was required to monitor the radar (particularly the Track Data Blocks [TDBs]) when using datalink.

Four of the five controllers said additional skills were required to operate the electronic coordination tools on datalink, which was as predicted. One controller described this additional skill as the need for better anticipation of one's conflict resolution decision to meet the time restrictions placed on receiving and sending the necessary information. All of the controllers agreed that the electronic flight plan information displays were easy enough to interpret indicating that this was not an HMI issue as such but more a need to learn to coordinate in a different way.

Most controllers (four of five) said datalink assisted them in predicting the options available in a given traffic situation. This assistance from the system was estimated to be between 50-90%. This assistance was correctly predicted however the amount was not predicted. The two controllers who commented said this was due to the Potential Pilot Down-link (PPD) feature of the system.

Three of the five controllers said the system also assisted with conflict detection. This level of assistance was estimated at between 50-80 %. This was considered a result of the increased time made available as well as the ability to use speed vectors, routes or the point out feature that shows the aircraft at the same level. This was a predicted change.

As predicted, two controllers said the datalink technology assisted them in evaluating the consequences of new plans. However, no level of assistance or explanation was given for this support.

Four controllers said the system helped to predict what coordination options were available. The level of assistance was estimated to be 30-60% and said to be due to the use of the PPD feature. Only one controller felt that the datalink technology assisted them in their initiation of coordination but this controller did not expand on why this was thought to be the case. Both changes were predicted by the SHAPE Framework and skills data.

Also, as predicted, all controllers agreed the system assisted them in the formulation and execution of coordination plans. The level of assistance offered by the system was estimated to be between 20 and 80% for assisting with the formulation of coordination plans and between 50 and 90% for helping with the execution of these plans. However, no additional comments were made to expand on this issue.

Most of the controllers agreed that, of all the tasks the system assisted on, most tasks remained primarily the task of the controller with only a low level of support provided by the system. One exception to this was the task of monitoring the sector frequency. Most controllers agreed that the datalink technology provided 50% assistance on this task leaving the controller to only do half of their previous auditory monitoring task. All controllers agreed that they still needed to recognise potential conflicts themselves, diagnose problems and formulate and choose solutions.

In terms of memory management, the DOVE label, DOVE colour tools and the Message-in tool provided support to the controller in switch or dividing attention between tasks and in building the mental picture when taking over the position. Most controllers also agreed that the Dove Message-in, Dove label and Dove request tools assisted in tactical planning and to a lesser extent problem solving. The Dove message-In and message-out tools were also used to help remember clearances issued and needing to be issued. Some controllers agreed (three of five) that the Dove request tool and the Dove colours helped in the handover process. These findings were all consistent with the SHAPE predictions made in advance of the simulation.

One problem the datalink technology did cause the controllers with regard to memory management skills was the problem of remembering to change their input method between datalink equipped and non-datalink-equipped aircraft. This was not a foreseen impact.

Overall, the SHAPE skill predictions made in advance of the simulation were fairly accurate and compared favourably with controllers' own observations and opinions having used the datalink technology. There were some predictions that, although correctly made, could not be quantified. This was one of the main advantages of being able to run the simulation and obtain controller views.

The SHAPE Toolkit assisted in identifying and predicting those skills that were likely to become redundant or significantly reduced in utility and those that were likely to be newly required or significantly increased in utility. However, it was more difficult to predict the skills that would change in nature, or change with just a subtle increase or decrease in use. In addition, the direction of any change, when it was not vast, was not easy to predict (i.e. whether a skill would only slightly decrease or increase in use). Finally, the degree or amount of change was probably the most difficult factor to predict. It was often the case that a skill change was predicted in using the datalink technology but the amount of support the system provided, and thus reduced the controllers' skill requirement, was not possible to predict.

The controllers' themselves found certain skill changes difficult to articulate or consciously detect. For example, new knowledge required to operate new system functions was occasionally taken for granted as it was easily and quickly assimilated and learned and therefore did not make a great impact on the controllers' awareness. Also, the controllers' ability to judge the percentage of support (out of 100%) that the system provides for certain tasks was quite a subjective judgement to make and therefore suffered a considerable variance. As a result, these judgements are best taken purely as an indication of whether the system support was high or low.

There were a few additional skill impacts that controllers raised that were not predicted by the SHAPE Toolkit. These included the team interaction effects that datalink had and hence, the reduction in team skills exercised when using the system. Also, the need to switch and divide attention between tasks more frequently was not predicted. However, there was not agreement on this point between the controllers questioned. Finally, the controllers need to more frequently monitor displays was not predicted but this may have been due to lack of familiarity with the system or ineffective use of spare capacity that the controllers were not used to having!

In summary, it can be concluded that it was possible to predict the impact that the datalink technology would have on controller skill requirements with some accuracy using the SHAPE Toolkit. The granularity of detail that it was possible to predict in terms of degree and direction of these skill changes was less accurate and may require additional development. The fact that all predictions made were observed by the controllers in the trial is encouraging. However, there were additional observations made by these controllers that were not predicted by the analysis. Therefore, some improvements to the analysis and prediction process may still be necessary before the prediction process can be considered fully comprehensive. The SHAPE Toolkit is, however, a very useful start to identifying the key skill changes anticipated with new system designs and an improvement on the typical processes currently available and employed for this purpose.

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4. IMPLEMENTATION - THE SHAPE TOOLKIT

4.1 Summary

Within the scope of the SHAPE Project, the development of the SHAPE Framework, the skill requirements and the prediction process has proved quite a successful and useful process and tool. All of the data used for the framework and skill requirements were taken from reliable and theoretically sound sources giving confidence that the data are valid and also acceptable for use here. Each of the necessary links within the framework development and analysis process were validated to some extent and results were encouraging, again, giving confidence that the framework provides a sound basis upon which to make predictions about the impact of systems on the controller.

A set of en-route controller skill requirements were developed and prioritised to enable system impacts on the controller to be traced to likely skill changes and their importance. A process was created for analysing a system or type of automation, using the framework, to make predictions about the system's impact on controller processes, functions and skills. This process was then tested by using an example system. The datalink technology was used for this purpose and predicted impacts were identified. In addition, the impacts predicted were used to further predict skill changes and these predictions were used to design assessment questionnaires and checklists to specifically focus on the predicted changes. These predictions were then tested in an actual real-time trial of the datalink technology with controllers. The questionnaires and checklists were used to assess the datalink technology impacts on controller skills and compare these with the predictions made in SHAPE. The results were positive showing that the SHAPE skill predictions were close to the controller experiences and observations after using the system. It was, therefore, concluded that the SHAPE Framework and skill-prediction process, as it is developed so far, is already able to make useful predictions about how future systems impact controllers' skill requirements.

4.2 Implementation

The SHAPE Framework and the analysis process was developed as a systematic methodology to analyse a given automated system and make predictions on the likely impact of automation on controller's skill requirements. Another purpose of the framework and the analysis process is also to be able to make predictions on the other performance factors examined in the SHAPE programme. These include situation awareness, trust in automation, mental workload, management of system disturbance and teamwork. The SHAPE Framework was also a method of linking all the different SHAPE products (measurement tools or evaluation methodologies) to a common analysis approach. A diagrammatic representation of how the SHAPE products are integrated can be found in Figure 7.

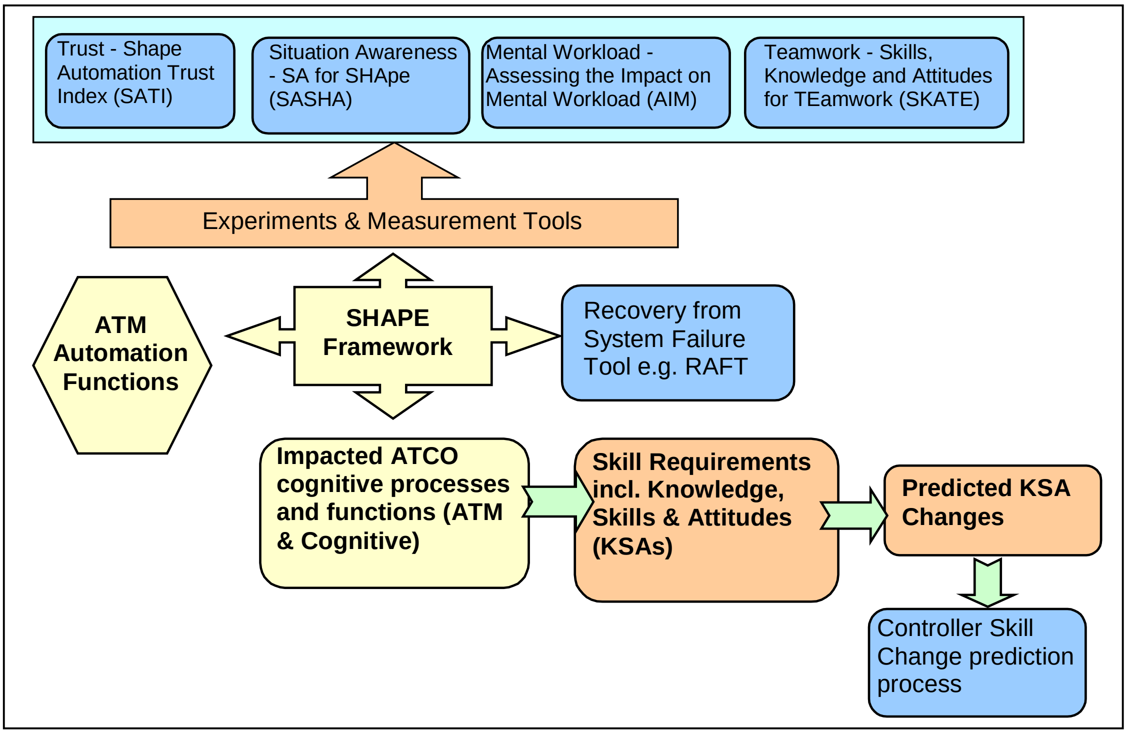

Figure 7: Diagrammatic representation of how the SHAPE products are integrated

The SHAPE Toolkit was developed to implement the SHAPE Framework and skill change prediction process in the form of a software application. By developing an electronic version of the framework the analysis process could be largely automated allowing the analyst to input the initial automation profile data only. From this they would simply receive a printed (or screen-based) report of each of the system impact tables (impact on cognitive processes, cognitive functions and ATM functions) and skills change prediction tables (including knowledge and attitudes).

The SHAPE Toolkit also includes the assessment of all the aspects of the SHAPE Project (i.e. managing system disturbances, situation awareness, trust, teamwork, mental workload). The necessary complexity of the data that exists within the framework would be largely made invisible to the analyst with the development of such an electronic tool.

The SHAPE Toolkit also includes a fifth component, called the 'tool recommendation'. Based on the impact and prediction profiles, it will recommend the relevant SHAPE measurement tool or methodology. In addition, it serves as a central depository of all the necessary materials and guidelines the analyst will require to use these measurement tools or methodologies. It allows the analyst to download these materials and resources from the Toolkit. This also includes the SHAPE reports produced in the SHAPE Project.

4.3 Conclusion

The framework enables the construction of an analysis process of an automated system that can be used in many stages of the life cycle:

- System concept development: The system designer needs a predictive tool in order to be informed about the skill changes and performance issues that may be introduced. The earlier these potential skill changes and performance impacts are considered in the design life cycle, the more economic the succeeding stages of the life cycle can be and the better succeeding tests of prototypes matches the needs of the final user.

- System validation: Experimenters need hypotheses to test a new system against. An understanding of the skill changes and performance impacts can provide guidance in the preparation of experimental studies. Herewith experiments can be cost-effectively aligned to the major changes they introduce in operation.

- System implementation, operation and maintenance: A predictive framework can support the management of the operational implementation of an automated system. Understanding the skill changes that come with a new system is essential for the set-up of training needs and design of transition training courses.

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ABBREVIATIONS AND ACRONYMS

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

a/c	Aircraft
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSU	ATS Unit
CAS	Collision Avoidance System
CTA	Cognitive Task Analysis
DAP	Director(ate) ATM Programmes *(EUROCONTROL Headquarters, SD)*
DAS	Director(ate) ATM Strategies *(EUROCONTROL Headquarters, SD)*
DAS/HUM *or just* HUM	Human Factors Management Business Division *(EUROCONTROL Headquarters, SD; formerly known as 'DIS/HUM' or just 'HUM')*
DIS	Director(ate) Infrastructure, ATC Systems and Support *(EUROCONTROL Headquarters, SDE)*
DIS/HUM *or just* HUM	Human Factors and Manpower Unit *(EUROCONTROL Headquarters, SDE; formerly stood for 'ATM Human Resources Unit'; today known as 'DAS/HUM' or just 'HUM')*
DSE	Display Screen Equipment
EAT	Expected Approach Time
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(later renamed 'EATMP' and today known as 'EATM')*
EATM(P)	European Air Traffic Management (Programme) *(formerly known as 'EATCHIP')*

EEC	EUROCONTROL Experimental Centre *(Brétigny, France)*
ET	Executive Task *(EATCHIP)*
EU	European Union
FAA	Federal Aviation Administration *(US)*
FDPS	Flight Data Processing System
FIR	Flight Information Region
FPS	Flight Progress Strip
GAT	General Air Traffic
HFFG	Human Factors Focus Group *(EATM, HRT; formerly known as 'HFSG')*
HFSG	Human Factors Sub-Group *(EATCHIP/EATMP, HRT; today known as 'HFFG')*
HMI	Human-Machine Interface
HRS	Human Resources Programme *(EATM(P))*
HRT	Human Resources Team *(EATM(P))*
HSP	Human Factors Sub-Programme *(EATM(P), HRS)*
HUM	Human Resources (Domain) *(EATCHIP, EATMP)*
ILS	Instrument Landing System
ITA	Integrated Task Analysis
KSAs	Knowledge, Skills and Attitudes
LOA	Level of Automation
MIL	Military
NATS	National Air Traffic Services *(UK)*
NAVAID	Navigational Aid
OAT	Operational Air Traffic
REP	Report *(EATCHIP/EATM(P))*
RGAT	Review Group for ATC Training

R/T or RTF	Radiotelephony
RVSM	Reduced Vertical Separation Minimum
SA	Situation Awareness
SASHA	SHAPE Situation Awareness *(EATM(P), HRS, HSP)*
SATI	SHAPE Automation Trust Index *(EATM(P), HRS, HSP)*
SHAPE (Project)	Solutions for Human-Automation Partnerships in European ATM (Project) *(EATM(P), HRS, HSP)*
SKATE (Model)	Skills, Knowledge and Attitudes in Teamwork (Model)
SME	Subject Matter Expert
ST	Specialist Task *(EATCHIP)*
TDB	Track Data Block
TCAS	Threat and Collision Avoidance System
UAS	Upper Airspace

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CONTRIBUTORS

Contribution to this document of the Members of the HRT Human Factors Sub-Group (HFSG), later renamed the Human Factors Focus Group (HFFG), during the group meetings, and their further written comments, were much appreciated.

<u>Document configuration</u>

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APPENDICES

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APPENDIX A SHAPE TAXONOMIES

I. Automation Functions

Automation in ATM to date mainly involves systems that improve the quality of the information provided to the controller and free the controller from simple but necessary routine activities. Although automation of decision-making and planning functions has been proposed as future tools, these are still in the design development life cycle. Some of these developments are likely to improve the presentation of information provided to the controller, some will increase the amount of information the controller needs to comprehend. Other developments will aim to assist the controller by carrying out parts of the tasks that were originally the controllers' and other systems will replace the need for controllers to carry out certain tasks all together.

Need for a LOA Model

The impact of automation on performance is not uniform across all types of automated systems. The effects are dependent on the degree to which the task is automated and the allocation of function between the human operator and the automated system. That is the LOA involved in implementing the system.

Wickens, Mavor, Parasuraman and McGee (1998) expanded the levels of automation concept of Sheridan (1980) and Endsley (1995) to include three scales of functionality that can be automated. These scales correspond roughly to the human information processing functions of (i) information integration through attention perception and inference, (ii) choosing or deciding upon and planning actions and (iii) executing the actions. Each scale has a continuum of the level of automation along which tasks or functions can be allocated to the computer.

Within the information integration stage, there are different features that can be automated. These are attention, integration and inference (which include diagnosis, prediction and interpolation). Each feature can be automated to different degrees. For example, for attention, important information can be filtered for the controller on one end and on the other just highlighted or cued. Computers can be used to integrate information by configuring information into different formats for display. For example, SSR code, or systems providing electronic strips. Automated systems can also make inferences from raw data. For example, interpolating or predicting data using algorithms based on known rules, procedures and heuristics for diagnosis or prediction.

Within the decision stage LOA is proposed to range from the controller having full authority to consider and select decision options, to mid-levels of automation where the system recommends options and the controller selects, to the highest level of automation where the computer fully decides, selects and implements the decision.

Within the response execution stage the automated system can replace the controller's manual or motor responses or vocal requests and communication, for example, systems using datalink communications.

ATM tasks are largely cognitive, even though actions and instructions have to be implemented. A model, shown in Figure 8, which combines the concept of levels of automation according to scales of functionality and a simple information processing approach, was considered the most appropriate to examine impact of automation in ATM and evaluate ATM future systems.

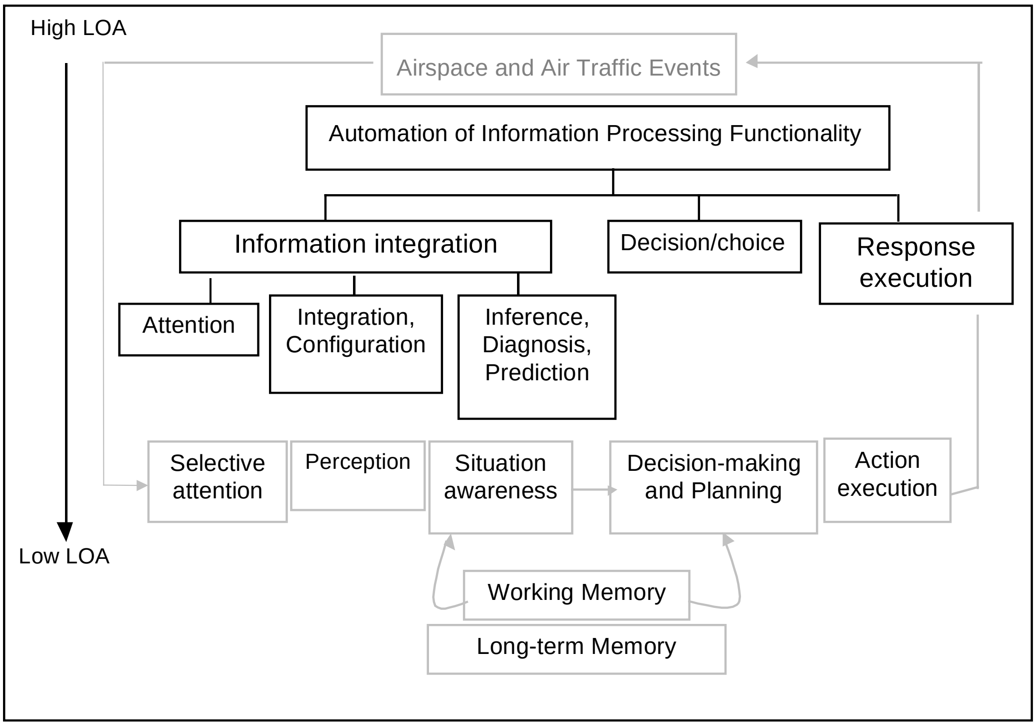

Figure 8: Levels of automation functionality, superimposed on a simple model of information processing for ATM

Automation functions

A taxonomy of automation functions was constructed using the scales of functionality suggested in Wickens *et al.* (1998). The three scales of functionality were then further expanded into six categories of possible functions that can be carried out by automation. The functions in each category are based on an extensive review of several operational strategy documents (both EUROCONTROL and NATS) as well as conceptual documents of new technological developments. The strategy documents detail numerous potential automated systems that can be implemented in ATM as well as known developing technologies which may be applied in ATM as automated tools. By understanding as much as possible the potential types of automated systems that can be applied in ATM and their actual specification or conceptual specification, the possible types of functions that future automation might be able to do to support the controller can be extrapolated.

The taxonomy provides a consistent way of examining different automation systems and enables a comparison between systems on the type of functional support provided to the controller. However, the taxonomy needs to be linked to the cognitive processes component of the framework, in order to identify the cognitive processes that are impacted upon by the functional support provided by the system, hence, what cognitive functions will benefit or be affected by the system.

Taxonomy of automation functions and definitions

<u>Automation function category: information extraction</u>

Definition: Directing attention to information sources, aiding the selection of information.	
Functions	**Definition**
Highlighting	Change in the visual, auditory, tactile properties of the display of information (single or grouped) to gain attention
Cueing	Change in the visual, auditory and tactile properties of displayed information (single or grouped) to gauge priority and/or cue an action
De-cluttering	Making information easy to access by means of re-arranging, organising information
Filtering	• To reject/prevent information from being presented • To remove information using selection process
Examples ♦ Change in colour ♦ Flashing / pulsing ♦ Stand out (raise, lower) De-cluttering and filtering are likely to be manifested within the display and/or information integration examples	

<u>Automation function category: information integration</u>

Definition • Grouping of information • Organising/configuring information into meaningful groups or subsets • Bringing together/uniting information	
Function	**Definition**
Arranging (qualitative)	Set into a specific format according to qualitative factors (colour, shapes, etc.)
Arranging (quantitative)	Set into a specific format according to quantitative factors (expressible as a quantity, weight, volume, time, etc.)
Prioritisation	To arrange in order of importance using one or more key dimensions.
Examples: ♦ Lists ♦ Tables ♦ Graphs	♦ Hierarchical diagrams ♦ Flowcharts ♦ Time lines

Automation function category: information comprehension

Definition • Transformation of information into meaning • Understanding the meaning and importance of information	
Function	**Definition**
Comparison	• To compare and match information or objects together by examining similarities or differences. • An examination of two or more objects with the view of discovering the similarities or differences.
Diagnosis	• Determine or distinguish the nature of a problem or situation. • The act or process of identifying or determining the nature and cause of a situation. • The conclusion reached by analysis.
Prediction	• Reasoning about the future. • A statement about the future. • State, tell, or make known in advance, by means of using special knowledge or inference likely future occurrences and consequences.
Testing	• Critical evaluation. • To test the soundness of a principle. • To test the validity of an argument.
Examples ♦ Graphical displays (graphs, maps, etc.) ♦ Textual (e.g. computer-generated statements)	

Automation function category: decision/choice

Definition • Passing judgement or decision on a situation; developing solutions for a situation or problem. • The act of reaching a conclusion or achieving a goal	
Function	**Definition**
Option generation	Generating options for judgement or solutions; generating a list of decision options for selection; generating strategies for achieving the goals
Option prioritisation	Guidance on selection provided by prioritising decision options; may present only a limited set of options.
Evaluation (review options)	Provides feedback or advise on option selected or decision input from controller based on system data processing
Choose option	Makes the decision or chooses the solution. Selects the best option to implement, based on a list of alternatives it generates and pre-defined rules or assumptions in the algorithm.
Examples: ♦ Textual (e.g. computer-generated advisory statements). ♦ Lists of solutions, may be prioritised. ♦ Graphical display of decision envelope or range of options.	

Automation function category: response execution

<table>
<tr><td colspan="2">Definition
• Carrying into effect
• Delivering the actions that are required to implement the decision</td></tr>
<tr><th>Function</th><th>Definition</th></tr>
<tr><td>Input</td><td>Information is passed into the technology via mediating technology, e.g. direct voice input</td></tr>
<tr><td>Output</td><td>Information is passed from the technology via mediating technology, e.g. direct voice output</td></tr>
<tr><td>Implement action</td><td>• Technology assists with the performance of selected action/response, either autonomously carrying out the action/response or some human control actions required.
• Can vary in terms of the level of human consultation the technology requires to execute the action. For example, provides advice, user approval, user can veto and autonomous behaviour with no consultation.</td></tr>
<tr><td>Emergency implementation</td><td>Only occurs in situations that the technology regards to have emergency characteristics. The system judges (according to known rules) that an action/response is required.</td></tr>
<tr><td colspan="2">Examples:
♦ Direct voice input/output
♦ Datalink
♦ System defaults
♦ Emergency defaults</td></tr>
</table>

Automation function category: information retention

<table>
<tr><td colspan="2">Definition
• Depository of information
• A device into which data can be entered, in which they can be held, and from which they can be retrieved at a later time</td></tr>
<tr><th>Function</th><th>Definition</th></tr>
<tr><td>Reminders</td><td>Holding decisions and plans</td></tr>
<tr><td>History tracking</td><td>• Recording actions that have been completed (input and output)
• Recording responses from other controllers or aircraft</td></tr>
<tr><td>Auto-deletion</td><td>Deletion of information according to known rules</td></tr>
<tr><td colspan="2">Displays including lists, tables and time lines, showing:
- decisions, plans and future actions,
- past decisions/events/actions,
- ongoing events/actions,
- input to the system,
- output and action/s taken.</td></tr>
</table>

II. Cognitive Processes

Cognitive Processing Model

The cognitive processing model for ATM described in the report on the first phase of the EUROCONTROL Integrated Task Analysis (ITA) Project (see EATCHIP, 1998) was used as a basis for the framework. The section below will describe the model and its structure very briefly. For a more detailed description and explanation of the model, please refer to the original document.

ITA Cognitive Processing Model

The model consists of four components, which are based on the core elements of an information processing system. Figure 9 displays a diagrammatic representation of the model. The components of the model are:

1. Long term memory – A structure that allows information, information processing routines, task schemas, different knowledge (about things, events, rules, etc.) to be stored.

2. Working memory – A short-term buffer with a limited capacity for new information and data, that allows processed information or the information retrieved from the long term memory to held temporarily for use.

3. Input/output system – A structure that consists of the sensory and perceptual systems as well as the motor and verbal response systems.

4. Process control system – A central control system that controls the information processing, organises the interaction between the other components and guides, and to an extent directs, the processes in the other components. It includes situation awareness as the main function or output of the process control system.

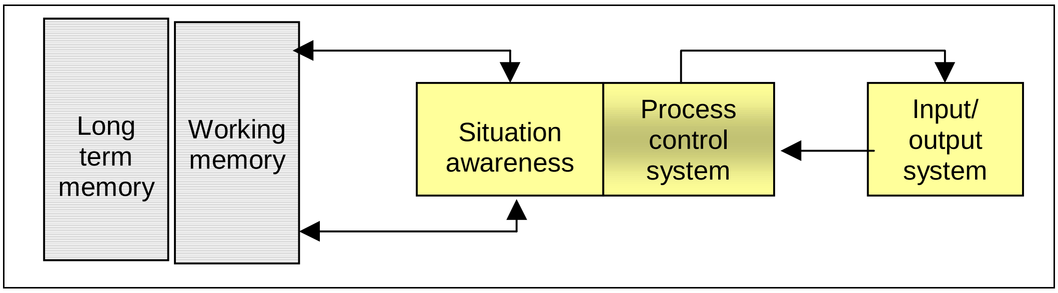

Figure 9: Model of cognitive processing in ATC

Based on the ITA Model of cognitive processing in ATC a list of cognitive processes was constructed. The cognitive processes were considered from various sources, incl. EATCHIP (1998), Bainbridge (1998), Leuchter *et al.* (1997) Reinartz and Reinartz (1989) and Miller's (1967, 1974) 25 functions.

Taxonomy of cognitive processes

Input/output system processes	
Search	Scan where information is likely to be, maybe hidden or easily discriminated
Detection	Process of noticing (something that is partly hidden or not clear) or to discover (something) esp. using a special method
Identification	Pattern/feature recognition
Comparison	Pattern/feature matching
Interpretation	Perceiving meaning/significance
Transmit	Communicate; verbal or motor
Execution	Making the planned sequence of actions/responses; verbal or motor

Process control system processes	
Selective attention	What to pay attention to
Divided attention	Organising, prioritising or sequencing things to be attended to
Switch attention	Move from one stimulus to another
Filter	Straining out what does not matter, to reduce irrelevance and disturbances
Categorise	Defining or naming groups; consists of rules and operations for classifying according to one or more shared attributes, purposes or implications
Predicting	Rules and operations for expecting what future sets of conditions or situations will occur
Testing	Gathering evidence to test or confirm expectations
Plan formulation	Responses to make and what order; responses for a set of anticipated conditions or situations towards an intended goal
Decide/select	Choosing response/plan to fit situation or condition
Control	Changing action according to plans
Evaluate	Arranging or correcting plans according to rules (determining goal achievement) or to current situation/condition
Goal image	Criteria for decision on terminating a task or segment of work or mission; mental picture of the conditions that should be obtained when task cycle is completed

Process control system processes	
Action formulation	Format or patterns for communication; put into a form that makes sense for communication
Adapt/learn response	Making new responses; consists of structural modification of previous behaviours
Reset	Getting ready for some different action; occurs when terminating a task cycle or shifting from one task to another

Working memory process	
Retain	To hold information in memory (remember)
Manipulate information	To move, arrange, manage, use, or control information
Retrieve	Accessing memorised information
Quick comparison	Examination of two or more situations with the view of discovering the similarities or differences; relative estimate
Integrate information	Unifying information sources. Organising/configuring information into meaningful groups or subsets
Output	Actions that occur as a result of working memory process
Short-term projection	A plan for an anticipated course of action A prediction or an estimate of something in the future, based on present data or trends
Encoding	The transformation of information into meaning to be stored in memory
Rehearsal	Maintenance rehearsal – an item is repeatedly said or thought about Elaborative rehearsal – item is remembered and thought about from different points of view
Purge	Rules for eliminating unwanted information

Long term memory process	
Assimilate	Encode new knowledge (facts, procedures, heuristics, strategies, etc.) and fit into existing knowledge in long term memory
Store	Put or keep knowledge (facts, procedures, heuristics, strategies, etc.) into long term memory for use in the future
Retrieve	Recall and restore existing knowledge (facts, procedures, heuristics, strategies, etc.) from long term memory into working memory for application

III. ATM Functions and Cognitive Functions

ATM functions

ATM functions are carried out by controllers in order to achieve ATM goals such as maintaining aircraft safety, managing the traffic levels with minimum delay, and providing air traffic with an expeditious route to their required destination. ATM functions can be broken down into ATM functions and cognitive functions. ATM functions are those things the controllers explicitly do to achieve their job. They are the tasks controllers would use to describe their job such as formulating and issuing ATC clearances and maintaining flight data information.

The ATM functions used in the SHAPE Framework were identified from a variety of sources. Task analyses work carried out by NATS was drawn upon and many of the ATM functions were taken from the UK En-route Review Group for ATC Training (RGAT, 1994) document, 'CAP 624 – Standards for Air Traffic Controllers, Part C Area/Area Radar Control'. This document contains the legal requirements and standards for training en-route controllers in the UK. The ATM functions contained in this document were identified as a result of a functional analysis of the en-route controller's job.

In addition to these sources, ATM functions were obtained from the EUROCONTROL European ATC Licence Harmonisation Project (see EATM, 2004e), the EUROCONTROL European Common Core Content and Training Objectives for ATC Project (see EATMP, 2000b & 2001) and the EUROCONTROL Integrated Task Analysis (ITA) Project (see EATCHIP, 1998).

Once an initial list of ATM functions and the sub-functions[2] or tasks necessary to complete those functions was compiled this list was reviewed by five UK controllers from different en-route training sections who added to and amended the list as they considered necessary in a workshop setting. During the workshop the controllers reviewed each function and its sub-functions in a structured way to determine whether there was anything on the list that was not relevant or not clear. For each function they were also asked whether there was anything missing. As a group any issues were discussed and, if agreed, amendments were made.

The list was validated by six operational UK en-route controllers using the same workshop process. Finally, the list was further validated in a workshop by three EUROCONTROL controllers to check that the list was also representative of European en-route control.

[2] Each ATM and cognitive function was broken down a level into the controller's actions required to achieve the function.

Cognitive functions

Like ATM functions cognitive functions are carried out by controllers to achieve ATM goals. However, these are not carried out in isolation from the ATM functions. Certain cognitive functions are necessary for each ATM function to be possible. The cognitive functions are the implicit activities the controller is required to do in order to achieve the ATM functions we see them do. For example, developing a plan (before issuing an ATC clearance) or building the situation awareness necessary to maintain flight data information. Without understanding the cognitive functions associated with each ATM function it is not possible to make the necessary link between cognitive processes supported by automation and ATM functions (the ones we observe controllers carrying out).

The same sources of information used for the ATM functions were reviewed and used to identify a list of cognitive functions and sub-functions or tasks, however, the cognitive functions were less explicitly stated in some of the documentation than the ATM functions. Therefore, in addition to the previously listed information sources, Cognitive Task Analysis (CTA) work previously carried out by NATS (Lamoureux *et al.*, 1999) and work published by the FAA (Wickens *et al*., 1998) was also used to construct the list of cognitive functions. In addition, work published on cognitive functions by US Navy and other occupational domains such as mathematicians and engineers were also used to supplement the identification of sub-functions.

List of ATM functions (and sub-functions) within the SHAPE Framework

E1 - OPERATE COMMUNICATION EQUIPMENT
Apply standard speech technique correctly
Obtain, listen to and verify readbacks
Monitor the serviceability of the equipment
Use telephone equipment correctly
Use standard phraseology correctly
Use RTF equipment
Respond to telephone calls with identity
Perform correct communication techniques
Test and assess standby frequencies and operational frequency
Identify equipment failure

E2 - MAINTAIN AND/OR UPDATE FLIGHT DATA INFORMATION
Ensure the data is complete
Check flight data display is up-to-date
Update the data on individual a/c
Read the flight data display and extract correct information
Receive, accept and disseminate flight plans
Arrange display suitably
Use legible standard markings (manual operations)
Disseminate information to other team members as necessary

E3 - PROVIDE A SERVICE WITHIN DEFINED BOUNDARIES
Identify the boundaries of the FIRs

E4 -PROVIDE A SERVICE IN EMERGENCY AND UNUSUAL SITUATIONS
Recognise a potential or actual emergency situation
Recognise and respond to hijacking and other acts of violence involving a/c
Initiate action on overdue a/c
Initiate and execute action in event of an emergency
React correctly to a pilot's TCAS manoeuvre
Coordinate with other agencies
Communicate with pilots
Monitor and record the emergency situation
Establish pilot requirement
Prioritise actions
Initiate action
Assist in navigation or give other assistance to a/c
Increase separation as appropriate on suspension of RVSM
Complete necessary administrative actions

E5 - PROVIDE FLIGHT INFORMATION
Monitor relevant sources of information
Disseminate relevant information
Identify and select relevant information sources
Communicate information to pilots
Recognise potential traffic conflictions and pass traffic information to pilots
Coordinate with other agencies
Obtain appropriate flight information useful to pilots

E6 - PROVIDE AREA CONTROL PROCEDURAL SERVICE
Maintain a/c separation (without use of radar)
Apply separation standards
Calculate and issue EATs
Issue procedural releases
Coordinate with other agencies and team members within sector
Handle diversions
Handle holding situations
Inform pilots as required

E7 - PLAN AND CONTROL AIRCRAFT WITHIN AREA OF RESPONSIBILITY
Enable a/c to comply with flight plans where possible
Predict detect and resolve traffic conflictions
Respond to prevailing traffic conditions
Coordinate with other agencies
Control and coordinate diverting a/c
Control and coordinate non-standard and special flights
Ensure that applied separation standards are not being eroded
Control a/c in accordance with approved procedures
Respond promptly and appropriately to requests for information
Receive meteorological information (from pilots/other agencies)
Disseminate meteorological information as soon as practical
Disseminate relevant information as appropriate
Allocate en-route levels within area of responsibility
Monitor the sector frequency

E8 - PROVIDE AREA RADAR SERVICE
Apply separation standards
Interpret and act upon radar-derived information
Identify traffic and verify Mode C
Provide navigational assistance to a/c
Issue attitude instructions
Issue vectoring instructions
Issue speed control instructions
Select and monitor radar displays
Monitor status of radar displays
React correctly to conflict alert warning
Apply radar failure procedures
Accept and initiate radar handovers and identification
Provide radar control service
Perform en-route/planning control function
Apply terrain clearance procedures
Coordinate with other ATSUs
Handle diversions
Maintain a/c separation
Handle holding situations

E9 - COORDINATE WITH OTHER ATSUS/AGENCIES
Recognise and respond to the need for coordination
Respond to requests from pilots

Respond to coordination initiated by other agencies/ATSUs
Initiate correct, timely and appropriate coordination
Respond to requests for coordination
Negotiate and agree upon appropriate course of action
Execute and maintain compliance with agreed coordination procedures
Respond appropriately when agreed coordination cannot be executed
Respond appropriately when normal methods tools and/or procedures of coordination cannot be used

E10 - WORK AS A TEAM MEMBER
Conduct all the tasks specific to the controller's role within the team
Monitor the actions of other team members and take action to correct any mistakes or ambiguities
Open, close and combine sectors
Ensure fitness for the task
Respond to the needs of team members
Work in harmony with other team members
Ensure workload is within individual capabilities
Concentrate on the current tasks
Conduct pre-shift briefing
Update shift information
Delegate tasks within the team

E11 - MONITOR THE PRESENT AND FORECAST WEATHER
Ascertain the present and forecast weather
Monitor and react to weather information
Receive and react upon pilot and controller reports
Relate impact of weather situation to traffic

E12 - PROVIDE THE PILOT WITH RELEVANT INFORMATION
Identify relevant meteorological information
Monitor essential information
Liaise with other agencies
Pass relevant information to pilot

E13 - MONITOR AVAILABILITY AND SERVICEABILITY STATES
Monitor availability of runways and aerodromes
Monitor serviceability states of NAVAIDs
Monitor serviceability states of approach aids

E14 - FORMULATE AND ISSUE ATC CLEARANCES
Interpret relevant flight plan data
Assess the request in respect of other air traffic
Apply separation standards
Coordinate with other ATSUs
Annotate flight data display to reflect clearance
Issue clearance to pilot and/or ATSUs
Respond to pilot/agency requests promptly
Check the request against the current operating procedures
Obtain, verify and if necessary correct readback

E15 - MANAGE DEGRADED SYSTEMS
Execute tasks in correct order of priority
Check traffic levels/workload is not exceeded
Check information for current status
Check information for changes in status
Inform a/c and other agencies of changes if appropriate
Assess equipment performance and react positively to degradation or failure (e.g. radar failure, FDPS, telephone, datalink)
Respond promptly and react positively to changes and agency requests
Assess the operational status within relevant ATSUs
Apply fallback procedures initial action on declaration of system failure
Apply FDPS rebuild procedures as appropriate
Apply FDPS procedures on declaration of Ops normal
Assess the operational status within relevant ATSUs
React appropriately to a change in operational status of another sector or ATSUs

E16 - OPERATE RADAR EQUIPMENT
Select and set up primary surveillance radar
Select and set up secondary surveillance radar
Verify secondary radar information
Verify Mode C
Verify a/c position

E17 - COORDINATE AIRSPACE RESERVATIONS / NON-STANDARD FLIGHTS
Monitor airspace reservations/non-standard flights
Extract and understand all relevant data (including FDPS output)
Monitor/control a/c in accordance with approved procedures
Give priority to such flights if appropriate
Coordinate with relevant agencies
Give clearances for flights in vicinity of airspace reservations and/or restricted areas in domestic airspace (e.g. danger areas)
Respond to sudden notifications and closures
Respond to airspace infringement (either civil or MIL)

E18 - COOPERATE WITH MILITARY ATC
Apply correct procedure for allocation of a cleared flight path
Ensure and maintain appropriate separation from cleared flight paths
Ascertain status of MIL training areas, corridors, danger areas and airspace blocks
Apply appropriate separation from active MIL training areas, danger areas and airspace blocks
Coordinate with MIL controllers as necessary
Raise warning strips in appropriate manner
Coordinate joining clearances including the squawk and any communication instructions
Check for requirements for a/c leaving CAS/UAS and being transferred to MIL agency
Pre-note traffic to the MIL including the squawk and an estimate for the transfer of control point

Respond to MIL's request for coordination of control of a/c operating as OAT crossing CAS/UAS
Identify 'off-route' GAT traffic that conflicts with OAT in UAS
Apply appropriate coordination requirements when off-route GAT is in conflict with OAT in UAS
Prioritise GAT holding traffic

List of cognitive functions (and sub-functions) within the SHAPE Framework

C1 - MULTITASKING
Switch attention (e.g. thinking then attending to new strip or pilot`s call)
Divide attention (e.g. speaking and writing at the same time)
Identify tasks that are highly similar (e.g. same instruction that needs issuing to several pilots)
Identify tasks that are more difficult than usual
Time share between tasks
Evaluate importance of and prioritise tasks
Find information and navigate between different information sources

C2 - DIRECT ATTENTION TO INFORMATION SOURCES
Identify need for, and source of, information
Scan radar or any ATC DSE or FDPS equipment
Attend to FPS
Attend to information displays
Attend to reminders
Ask for information
Listen to / look for relevant information
Attend to telephone/intercom

C3 - TAKE ACCOUNT OF AND PROCESS EXTERNAL INFORMATION (FROM RADAR, STRIPS, COORDINATION, PILOT REQUESTS)
Extract relevant data for traffic assessment from visual displays (level, time, route, speed)
Extract relevant data for traffic assessment from communication
Check information
Integrate information from the various sources
Update mental picture of actual traffic situation

C4 - MONITORING
Check all information sources

C5 - MANAGE AND UPDATE WORKING MEMORY
Prioritise and update currently useful and relevant knowledge in working memory
Retrieve information from LTM
Update mental model of working
Take account of relevant information updates
Update traffic plan

Check order and priority of actions in plans
Use mental or physical cues (e.g. cues, cocking strips, notes or mental tags) to remind oneself of actions required

C6 - INTEGRATE INTO LONG TERM MEMORY
Update aviation knowledge and assimilate into existing knowledge
Update ATC knowledge and assimilate into existing knowledge
Update knowledge on ATC procedures and assimilate into existing knowledge
Update other relevant knowledge and assimilate into existing knowledge
Update knowledge on a/c performance/operating procedures and assimilate into existing knowledge
Update knowledge of team behaviours/styles

C7 - BUILD UP MENTAL PICTURE OF TRAFFIC SITUATION
Gather and interpret information
Check validity of information and review plan
Integrate information
Search for conflicts
Anticipate future traffic situation
Update mental picture

C8 - DEVELOP A TRAFFIC PLAN
Evaluate mental picture
Gather and process flight plan information
Gather and process all other relevant information
Anticipate future traffic situation
Identify potential conflicts
Retrieve routine solution from memory
Revise traffic plan
Plan actions before a/c arrives in sector or into area of responsibility
Update mental picture

C9 - MAINTAINING MENTAL PICTURE OF TRAFFIC SITUATION
Compare actual situation with future situation
Detect differences between expected and actual situation

C10 - ACTIVE PLANNING
Evaluate mental picture
Evaluate anticipated traffic situation
Generate and evaluate the solutions and plans
Revise existing traffic plan, if necessary
Develop a new plan
Check viability of the plan
Evaluate the consequences of the plan
Plan ahead for consequences
Be flexible about plans and adapt plan where necessary
Update mental picture
Execution of plan

C11 - MAKE DECISION FOR CONTROL ACTIONS
Check mental picture of traffic situation
Check for cues on traffic situation
Search for conflicts
Formulate decision options
Evaluate options against traffic situation/conditions
Identify routine response
Formulate response/plan if necessary
Update mental picture

C12 - MANAGEMENT OF AIRCRAFT CONFLICT
Search for conflicts
Respond to conflict information/alert
Recognise conflict
Resolve conflict (e.g. coordination)
Update mental picture

C13 - MANAGE AND RESPOND TO REQUESTS
Switch attention
Update mental picture
Check against traffic and the feasibility and relevance of the request
Evaluate impact (e.g. workload) and prioritise request
Search for conflicts
Formulate appropriate action or response
Evaluate the context or nature of request
Take action

C14 - DIAGNOSE COMMON PROBLEM
Identify possible problem and hypothesis
Check external information and gather evidence
Integrate information
Decide whether problem exists and confirm nature of problem
Compare current mental picture with new/observed information
Update mental picture

C15 - ACTIVE PROBLEM SOLVING
Retrieve routine solutions
Review routine solution
Generate new solution if necessary
Anticipate future traffic situation
Choose solution
Evaluate solution
Update mental picture
Implement solution

C16 - DIAGNOSE UNCOMMON PROBLEMS
Identify elements of the novel situation or problem
Establish relationship between elements if possible
Identify and adapt a situation or problem analogous to novel situation if possible

Consider previous experience that could be relevant
Recall and identify existing knowledge (e.g. rules, information) for an analogous situation
Formulate possible explanations
Gather evidence to confirm or discount explanations
Generate and evaluate new solutions
Develop new plan for the novel situation/problem
Evaluate the consequences of the plan
Update mental picture
Use all resources to formulate solution

C17 - AWARENESS OF TEAM
Monitor team members' workload
Monitor own workload and performance
Monitor own capacity to cope with actual workload
Manage workload
Recognise the need to request assistance before workload exceeds capacity

C18 - TEAM MULTITASKING
Anticipate team members' needs/capability
Gather information proactively for team members
Share information / communicate with team members
Take others' workload into account
Share tasks accordingly
Take account of consequences of own actions on other team members and/or ATSUs

C19 - TEAM WORKING
Receive position control plan from previous controller
Assess previous controllers' plans before accepting handover
Concentrate on current and planned future tasks
Adapt previous controllers' plan after handover if necessary
Concentrate on current tasks

C20 - SHARE MENTAL PICTURE OF TRAFFIC SITUATION DURING HANDOVER
Tidy up strip display and put in place reminders for next controller
Share relevant information (airports, ILS, gaps, runways, coordinations, weather, non-standard events, etc.)
Explain strip display, point out traffic - significant strips, tasks/problems that need attention
Verify handover and answer any query

C21 - ESTABLISH MENTAL PICTURE OF SITUATION DURING TAKEOVER
Signal to handover controller the start of takeover (e.g. plug-in)
Evaluate the situation while the outgoing controller performs the handover
Verify handover and answer any query
Verify traffic situation with outgoing controller
Verify and accept handover only when satisfied
Update mental picture

APPENDIX B SHAPE FRAMEWORK MATRICES

I. Link between the Automation Functions and Cognitive Processes

Table 4: Level of automation function to cognitive processes matrix

Input / Output							Process Control System															Working Memory										LTM			
Search	Detection	Identification	Comparison	Interpretation	Transmit	Execution	Selective Attention	Divided attention	Switch attention	Filter	Categorise	Predicting	Testing	Plan formulation	Decide/Select	Control	Evaluate	Goal Image	Action formulation	Adapt/Learn Response	Reset	Retain information	Manipulate information	Retrieve	Quick comparison	Integrate information	Actions/output	Short term projections	Encoding	Rehearsal	Purge	Assimilate	Store	Retrieve	**Level of Automation**
																																			Information Extraction
■	■						■		■																										Highlighting
	■						■	■	■															■											Cueing
■	■									■													■												De-cluttering
	■									■																					■				Filtering
																																			Information Integration
■	■	■	■	■				■			■											■	■		■	■			■						Arranging (qualitative)
■	■	■	■	■				■			■											■	■		■	■			■						Arranging (quantitative)
							■	■			■												■												Prioritisation
																																			Information Comprehension
			■	■																					■										Comparison
				■																															Diagnosis
												■		■														■							Prediction
													■																						Testing
																																			Decision / choice
														■																					Option generation
														■																					Option prioritisation
															■		■																		Evaluation (review options)
															■																				Choose option
																																			Response execution
					■	■																					■								Input
					■	■																													Output
					■	■																													Implement response
																																			Emergency implementation
																																			Information retention
																						■		■						■				■	Reminders
																						■													History Tracking
																															■				Auto-delete

II. Link between the Cognitive Processes and Cognitive Functions

Table 5: Cognitive processes to cognitive functions matrix

Cognitive Processes: Input / Output Cognitive Functions	Search	Detection	Identification	Comparison	Interpretation	Transmit	Execution
1. Multi-tasking	x	x		x			
2. Direct attention	x	x					
3. Take acc & process ext. info			x				
4. Monitoring	x						
5. Manage working memory					x		
6. Integrate into long term memory							
7. Build up mental picture		x		x	x		
8. Develop a plan				x			
9. Maintaining SA							
10. Active planning		x				x	x
11. Make decision				x			
12. Solve a/c conflict							
13. Manage requests and assist pilots							
14. Diagnose perceived problems		x					
15. Active problem solving						x	x
16. Diagnose novel problems		x		x			
17. Awareness of team situation			x				
18. Team multitasking		x					
19. Teamworking					x		
20. Handover							
21. Takeover							

Cognitive Processes: Process Control System Cognitive Functions	Selective Attention	Divided attention	Switch attention	Filter	Categorise	Predicting	Testing	Plan formulation	Decide/Select	Control	Evaluate	Goal Image	Action formulation	Adapt/Learn Response	Reset
1. Multi-tasking		x	x												
2. Direct attention		x	x												
3. Take acc & process ext. info	x			x											
4. Monitoring		x		x											
5. Manage working memory					x										
6. Integrate into long term memory					x										
7. Build up mental picture			x		x	x									
8. Develop a plan						x		x	x		x	x	x	x	
9. Maintaining SA					x										
10. Active planning								x	x		x	x	x		
11. Make decision							x	x	x		x	x	x	x	
12. Solve a/c conflict								x			x	x	x		
13. Manage requests and assist pilots								x			x	x	x		
14. Diagnose perceived problems															
15. Active problem solving						x				x	x	x	x		
16. Diagnose novel problems							x	x			x	x	x		
17. Awareness of team situation	x			x											
18. Team multitasking			x		x		x	x				x			
19. Teamworking					x										
20. Handover				x											
21. Takeover					x										

Cognitive Processes: Working Memory Cognitive Functions	Retain information	Manipulate information	Retrieve	Quick comparison	Integrate information	Actions/output	Short term projections	Encoding	Rehearsal	Purge
1. Multi-tasking	x			x		x	x		x	
2. Direct attention	x			x						
3. Take acc & process ext. info		x						x		
4. Monitoring				x						
5. Manage working memory	x		x					x	x	
6. Integrate into long term memory					x			x		
7. Build up mental picture	x	x	x		x		x	x		
8. Develop a plan		x					x			
9. Maintaining SA					x					
10. Active planning			x		x	x				
11. Make decision							x			
12. Solve a/c conflict										
13. Manage requests and assist pilots										
14. Diagnose perceived problems			x		x					
15. Active problem solving										
16. Diagnose novel problems			x		x		x			
17. Awareness of team situation		x						x		
18. Team multitasking	x				x					
19. Teamworking					x	x				
20. Handover			x			x				
21. Takeover					x					

Cognitive Processes: LTM Cognitive Functions	Assimilate	Store	Retrieve
1. Multi-tasking			
2. Direct attention			
3. Take acc & process ext. info			
4. Monitoring			
5. Manage working memory			
6. Integrate into long term memory	x	x	
7. Build up mental picture			
8. Develop a plan			
9. Maintaining SA	x	x	
10. Active planning	x		
11. Make decision			
12. Solve a/c conflict			
13. Manage requests and assist pilots			
14. Diagnose perceived problems			
15. Active problem solving			
16. Diagnose novel problems			
17. Awareness of team situation			
18. Team multitasking	x	x	
19. Teamworking	x	x	
20. Handover			
21. Takeover	x	x	

III. Link between the Cognitive Functions and ATM Functions

Table 6: Cognitive functions to ATM functions matrix

	Cognitive Functions / Operational Functions	1 Multi-Tasking	2 Direct Attention to information sources	3 Take into account and process information	4 Monitoring	5 Manage Working Memory	6 Integrate into Long Term Memory	7 Build up mental picture of traffic situation	8 Develop a plan	9 Maintain situational awareness	10 Active planning	11 Make decision for control actions	12 Solve a/c conflict	13 Manage requests and assist pilots	14 Diagnose perceived problem	15 Active problem solving	16 Diagnose novel situations / problems	17 Awareness of team situation	18 Team multitasking	19 Teamworking	20 Share mental picture of traffic situation during handover	21 Establish mental picture of situation during takeover
1	Co-ordinate airspace reservations/non standard flights	X	X						X		X	X					X	X				
2	Co ordinate with other agencies								X					X			X					
3	Formulate and issue atc clearances		X						X		X	X	X	X			X					
4	Maintain and update flight data information	X		X		X		X							X						X	
5	Managing degraded systems	X		X		X	X	X		X		X			X	X	X	X	X	X		
6	Monitor the present and forecast weather	X	X	X		X		X							X				X		X	
7	Plan and control aircraft within the area of responsibility	X	X					X	X	X			X			X		X				
8	Provide a Service in Emergency and Unusual Situations	X	X			X						X				X	X		X		X	
9	Provide flight information	X	X			X								X			X	X				
10	Provide a service within defined boundaries	X				X	X		X				X				X					
11	Work as a team member						X											X	X		X	
12	Operate communications equipment	X	X																X		X	
13	Provide area procedural service		X					X	X	X		X				X						
14	Co-operate with mil atc		X	X		X		X	X					X	X	X						
15	Provide area radar service		X	X	X			X	X	X			X			X						
16	Provide the pilot with relevant information			X	X																	
17	Monitor availability and serviceability states	X	X					X														
18	Operate radar equipment	X	X			X		X	X							X	X					

IV. Link between the Controller Functions (both ATM and Cognitive) and Skill Requirements

Table 7: Knowledge items

Knowledge	**Cognitive Functions**	Multitasking	Direct attention to information sources	Take into account & process information	Monitoring	Manage Working memory	Integrate into Long term memory	Build up mental picture of traffic situation	Develop a traffic plan	Maintain mental picture of traffic situation	Active planning	Make decision for control actions	Management of A/C conflict	Manage and respond to requests	Diagnose common problem	Active problem solving	Diagnose uncommon problems	Awareness of team	Team multi-tasking	Share mental picture of sit'n during hand-ove	Establish mental picture of sit'n during take-o
Data displays		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Knowledge of airspace		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Knowledge of equipment use and its limitations		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
National legislation and procedures		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Location of information sources		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Separation standards/ procedures		x		x	x	x		x	x			x	x			x	x		x		x
Influence of weather		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Decoding all coded information		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Basic knowledge of human performance		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Clearances and instructions		x		x				x	x			x		x		x				x	x
Approved/standard phraseology		x	x	x				x			x		x				x	x	x	x	x
Flight plans		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aircraft performance data		x		x	x	x		x	x	x	x	x	x	x	x	x	x		x		x
Aviation English/working English		x	x	x	x			x	x		x	x	x	x	x		x	x	x	x	x
Aircraft types and categories									x	x			x	x		x	x		x		x
Approved strip marking		x	x	x		x				x	x						x				
Strip movement procedures				x		x		x	x		x		x		x						x
Radio Telephony operating procedures		x	x	x				x								x					
Team roles and responsibilities																	x	x	x	x	x
Standing agreements		x																			
Team member abilities/experience,																		x	x	x	x
Team member personalities/ attitudes/ styles																		x	x	x	x
Sectors bandboxed/split currently																		x	x	x	x
Meteorological maps and reports						x															
Uncommon problems in progress																	x			x	
Sequences and approximate duration of tasks		x																			

Knowledge	**ATM Functions**	Operate communication equipment	Maintain and Update flight data display	Provide a service within defined boundaries	Provide A Service In Emergency And Unusua	Provide Flight Information	Provide Area Control Procedural Service	Plan And Control Aircraft Within The Area Of	Provide Area Radar Service	Co-Ordinate With Other Atsus/Agencies	Work As A Team Member	Monitor The Present And Forecast Weather	Provide The Pilot With Relevant Information	Monitor availability and serviceability states	Formulate and issue ATC clearances	Manage degraded systems	Operate radar equipment
Data displays			x			x			x					x			x
Knowledge of airspace						x					x				x		
Knowledge of equipment use and its limitations		x				x										x	
National legislation and procedures					x						x						
Location of information sources																x	
Separation standards/ procedures				x			x	x	x	x					x		
Influence of weather																	
Decoding all coded information																	
Basic knowledge of human performance																	
Clearances and instructions		x	x	x			x	x	x	x					x		
Approved/standard phraseology		x			x	x		x		x					x		
Flight plans																	
Aircraft performance data																	
Aviation English/working English																	
Aircraft types and categories			x		x										x		
Approved strip marking			x				x			x							
Strip movement procedures			x														
Radio Telephony operating procedures		x															
Team roles and responsibilities											x						
Standing agreements				x					x	x	x				x		
Team member abilities/experience,																	
Team member personalities/ attitudes/ styles																	
Sectors bandboxed/split currently																	
Meteorological maps and reports												x					
Uncommon problems in progress																	
Sequences and approximate duration of tasks																	

Table 8: Mental skill items

Mental Skills	ATM Functions	Operate communication equipment	Maintain and Update flight data display	Provide a service within defined boundaries	Provide A Service In Emergency And Unusual Situations	Provide Flight Information	Provide Area Control Procedural Service	Plan And Control Aircraft Within The Area Of Responsibility	Provide Area Radar Service	Co-Ordinate With Other Atsus/Agencies	Work As A Team Member	Monitor The Present And Forecast Weather	Provide The Pilot With Relevant Information	Monitor availability and serviceability states	Formulate and issue ATC clearances	Manage degraded systems	Operate radar equipment	Co-ordinate non-std and airspace reservation	Co-operate with MIL ATC
Prioritise tasks			x	x	x	x		x								x		x	
Identify potenial conflicts				x			x	x	x						x			x	
Scan information displays					x	x						x	x	x			x		
Apply previous experience					x	x				x						x	x		
Share information / Communicate with team members		x			x						x	x				x			
Information gathering and interpretation		x										x		x			x		
Scan FPS							x		x						x			x	
Divide attention (e.g. Speaking and writing at the same time)		x			x			x											
Choose solution					x		x												x
Evaluate options against traffic situation / conditions					x										x			x	
Anticipate future traffic situation							x	x	x										
Integrate information			x									x							x
Use mental or physical cues (E.g. cues, cocking strips, notes or mental tags) to remind oneself of actions required			x	x															x
M 29-Evaluate the consequences of the plan															x			x	
M 52-Listen for relevant information		x				x													
M 53 Manage and regulate workload								x										x	
M 5-Ask for information		x										x							
M 57-Perform actions before a/c arrives in sector or into area of responsibility										x									x
M 58-Prioritise and Update currently useful and relevant knowledge in working memory			x													x			
M 33-Extract relevant data for traffic assessment visual displays (level, time, route, speed)			x													x			
M 64-Recognise conflict				x											x				
M 65-Recognise the need to request asistance before workload exceeds capacity											x					x			
M 66-Resolve conflict								x	x										
M 67-Retrieve information from Long Term Memory																x	x		
M 75-Scan Radar or any ATC DSE (Display Screen Equipment) or FDPS equipment									x										x
M 7-Check against traffic and the feasibility and relevance of the request						x				x									
M 9 Check external information and gather evidence			x									x							
M 95-Update weather information						x						x							
M 35-Formulate appropriate action or response																x			
M 36-Formulate decision options							x												
M 3-Anticipate team member`s needs / capability											x								
M 13-Check information sources													x						
M 47-Identify tasks which are highly similar (e.g. same instruction that needs issuing to several pilots)						x													
M 14-Check order and priority of actions in plans					x														
M 21-Develop new plan for the novel situation / problem					x											x			
M 25-Evaluate importance of tasks																x			
M 54-Monitor own capacity to cope with actual workload						x													
M 6 Assess impact on own and/or team`s workload and prioritise request															x				
M 60-Proactive information gathering/interpretation for team members												x							
M 62-Recall and identify existing knowledge (rules, information) for an analogous situation				x															
M 6-Assess impact on own and/or team`s workload and prioritise request																			x
M 76-Scan reminders								x											
M 84-Tidy up strip display and put in place mental reminders for next controller			x																
M 85-Time share between tasks				x															
M 86-Update ATC-knowledge and assimilate into exisiting knowledge				x															
M 94-Update team information											x								
M98 Verify Information source/trust																x			

Table 9: Physical skill items

Physical Skills	Cognitive Functions	Multitasking	Direct attention to information sources	Take into account & process information	Monitoring	Working memory	Integrate into Long term memory	Build up mental picture of traffic situation	Develop a traffic plan	Maintau mental picture of traffic situation	Active planning	Make decision for control actions	Management of A/C conflict	Manage and respond to requests	Diagnose common problem	Active problem solving	Diagnose uncommon problems	Awareness of team	Team multi-tasking	Share mental picture of sit'n during hand-over	Establish mental picture of sit'n during take-over
Use of all equipment		x	x	x	x	x		x			x		x	x	x	x	x		x		
Speak (give info)		x	x	x	x	x	x	x			x		x	x		x		x	x	x	x
Strip management		x		x		x		x	x		x	x	x	x	x	x	x		x	x	x
Approved strip marking		x		x		x	x	x	x	x		x	x		x	x	x		x	x	x
Ask		x	x	x	x	x	x	x			x		x	x	x	x	x	x	x		x
Use of RT Equipment		x	x	x	x	x		x			x		x	x	x	x	x		x		
Record co ordination outcome		x		x				x								x					x
Find way around workstation displays			x		x					x		x	x	x	x	x	x			x	x
Flag appropriate strip		x				x			x			x			x						x
Find way around comms panel layout															x		x				
Find way around information displays										x		x		x	x	x	x			x	x
Listen		x	x			x	x											x			
Incorporate strips				x					x	x	x										x
Look		x	x			x	x											x			
Tidy stripbay										x										x	
Move strips appropriately								x	x								x		x		x
Read						x	x											x			
Explain accurately and concisely																				x	

Physical Skills	ATM Functions	Operate communication equipment	Maintain and Update flight data display	Provide a service within defined boundaries	Provide A Service In Emergency And Unusual Situations	Provide Flight Information	Provide Area Control Procedural Service	Plan And Control Aircraft Within The Area Of Responsibility	Provide Area Radar Service	Co-Ordinate With Other Atsus/Agencies	Work As A Team Member	Monitor The Present And Forecast Weather	Provide The Pilot With Relevant Information	Monitor availability and serviceability states	Formulate and issue ATC clearances	Manage degraded systems	Operate radar equipment	Co-ordinate non-std and airspace reservation	Co-operate with MIL ATC
Use of all equipment		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Speak (give info)		x		x	x	x			x	x	x	x				x	x	x	
Strip management			x	x			x	x	x		x				x	x	x	x	x
Approved strip marking			x	x		x	x	x		x	x				x	x	x	x	
Ask		x	x		x	x			x	x		x	x						x
Use of RT Equipment		x			x	x	x	x	x								x		
Record co ordination outcome			x	x	x	x		x		x	x				x	x		x	x
Find way around workstation displays					x												x		
Flag appropriate strip				x	x	x	x								x			x	
Find way around comms panel layout		x		x		x				x		x		x			x		
Find way around information displays																	x		
Listen																x	x		
Incorporate strips			x																x
Look																	x		
Tidy stripbay				x			x	x			x								
Move strips appropriately																			
Read																			
Explain accurately and concisely																			

Table 10: Attitude items

Attitudes	Cognitive Functions	Multitasking	Direct attention to information sources	Take into account & process information	Monitoring	Working memory	Integrate into Long term memory	Build up mental picture of traffic situation	Develop a traffic plan	Maintau mental picture of traffic situation	Active planning	Make decision for control actions	Management of A/C conflict	Manage and respond to requests	Diagnose common problem	Active problem solving	Diagnose uncommon problems	Awareness of team	Team multi-tasking	Share mental picture of sit'n during hand-over	Establish mental picture of sit'n during take-over
Safety conscious		x	x	x		x	x	x	x	x	x	x	x	x	x	x				x	x
Attentive			x	x	x		x	x	x	x		x	x	x	x	x		x			x
Flexible		x		x	x		x	x	x	x	x	x		x	x	x			x		
Decisive		x	x		x				x	x	x	x	x		x	x	x				
Active			x	x	x		x		x	x	x	x	x			x			x		x
Assertive		x											x	x		x	x	x			x
Confident				x			x		x		x	x	x	x	x		x				
Co-operative		x												x				x	x	x	
Pro-active		x		x	x		x	x		x		x									
Team Oriented																		x	x	x	x
Responsible						x	x	x		x										x	x
Thoughtful			x	x					x		x					x	x				
Calm					x				x				x				x				
Careful											x									x	x
Professional								x		x											
Analytical									x		x	x			x		x				
Accommodating														x		x			x	x	
Supportive														x				x	x		
Open minded							x								x	x	x				
Enquiring									x						x						x
Motivated						x		x		x											
Participative																		x	x		
Understanding																	x	x	x		

Attitudes	ATM Functions	Operate communication equipment	Maintain and Update flight data display	Provide a service within defined boundaries	Provide A Service In Emergency And Unusual Situations	Provide Flight Information	Provide Area Control Procedural Service	Plan And Control Aircraft Within The Area Of Responsibility	Provide Area Radar Service	Co-Ordinate With Other Atsus/Agencies	Work As A Team Member	Monitor The Present And Forecast Weather	Provide The Pilot With Relevant Information	Monitor availability and serviceability states	Formulate and issue ATC clearances	Manage degraded systems	Operate radar equipment	Co-ordinate non-std and airspace reservation	Co-operate with MIL ATC
Safety conscious		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Attentive		x	x	x			x	x	x	x	x	x		x	x	x	x	x	x
Flexible				x	x		x	x		x	x				x		x	x	
Decisive		x		x		x		x	x						x			x	x
Active			x	x					x			x		x					
Assertive		x		x			x	x	x							x			
Confident		x					x												
Co-operative						x				x		x			x	x			x
Pro-active			x	x					x			x							
Team Oriented				x							x			x		x			
Responsible				x														x	
Thoughtful												x							
Calm					x			x								x			
Careful			x							x							x	x	
Professional			x									x	x						x
Analytical																			
Accommodating						x													
Supportive					x	x													
Open minded																			
Enquiring																x			
Motivated																			
Participative											x								
Understanding																			

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APPENDIX C VALIDATION EXERCISES AND MATERIALS USED

I. Link between the Automation Functions and Cognitive Processes

This section reports how the link between the automation functions and the cognitive processes was established and verified.

Establishing the link between the automation functions and cognitive processes

Although the categories of the taxonomy reflected the information processing model used, it was not possible to assume that specific automation functions in each category will support the different cognitive processes. A validation exercise was carried out to establish the direct link between each automation function and the cognitive processes it supported. It was assumed that the relationship is not a one-to-one function nor is it exclusive, that is a particular automation function can support more than one cognitive process. Similarly, a particular cognitive process can be supported by more than one type of automation function.

The participants of the validation exercise were eleven human factors specialists in ATM from NATS and DNV. Each participant was given a spreadsheet with the cognitive processes listed across the top (columns) and the automation functions listed along the left side (rows) (see Table 11). They were also given instructions as well as lists of the cognitive processes and automation functions with definitions and examples of each automation function or cognitive process. It was assumed that the HF specialists were familiar with the fundamental concept of human information processing.

For each automation function the participants were required to select the cognitive processes that they think were supported by the function. They recorded their selections on the ‘cognitive processes - automation functions’ spreadsheet provided.

The automation functions to cognitive processes matrix

The data returned were compiled and then analysed to obtain the relationships between automation functions and cognitive processes in terms of the cognitive processes supported by the automation function.

The final matrix of links between the automation function to cognitive processes was constructed by using function-process relationships where there was 67% (or two-thirds) agreement between participants on that relationship. No statistical analysis was conducted due to insufficient sample size.

In the analysis the relationships between cognitive processes associated with working memory and Long Term Memory (LTM) and automation functions had the lowest level of agreement. This could be due to the general level of understanding of memory issues and the fact that tools to support memory are not very common place and are relatively hard to visualise. LTM is a process that is generally supported by training and procedures. The relationships between cognitive processes associated with input/output and automation functions had the highest level of agreement.

Table 11: Automation functions to cognitive processes validation worksheet

	Attention						Perception				Working Memory										LTM			Planning/ Decision-making							Action Execution				
Cognitive Processes	Search	Detection	Selective attention	Divided attention	Switch attention	Filter	Identification	Comparison	Interpretation	Categorise	Retain information	Manipulate information	Retrieve	Quick comparison	Integrate information	Actions/output	Short term projections	Encoding	Rehearsal	Purge	Assimilate	Store	Retrieve	Predicting	Testing	Plan formulation	Decide/select	Control	Evaluate	Goal image	Action formulation	Transmit	Execution	Adapt/Learn response	Reset
Information Extraction																																			
Highlighting																																			
Cueing																																			
De-cluttering																																			
Filtering																																			
Information Integration																																			
Arranging (qualitative)																																			
Arranging (quantitative)																																			
Prioritisation																																			
Comprehension																																			
Comparison																																			
Diagnosis																																			
Prediction																																			
Testing																																			
Decision / Choice																																			
Option generation																																			
Option prioritisation																																			
Evaluation (review options)																																			
Choose option																																			
Response Execution																																			
Input																																			
Output																																			
Implement response																																			
Emergency implementation																																			
Information Retention																																			
Reminders																																			
History tracking																																			
Auto-delete																																			

Instructions to participants

Participants were given this instruction sheet and a list of definitions of the verbs used in the validation worksheet.

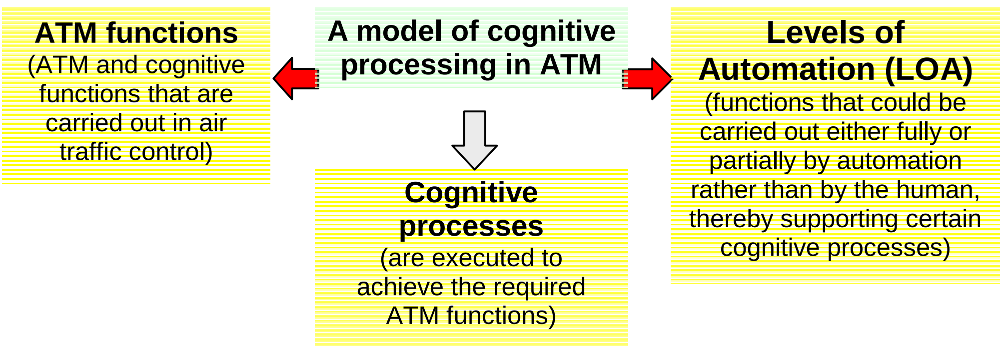
Thank you for agreeing to participate in this validation exercise!

<u>Brief introduction</u>

Initial work has began on SHAPE Phase 2 and the first part of the work involves the development of a common framework upon which the three main work packages for SHAPE Phase 2 (skills change, workload and managing system disturbances) can be built and associated with one another and with SHAPE Phase 1 work packages (trust, SA and teamwork). A cognitive processing model has been developed for use in the framework. A 'roadmap' is now being built between all of the different aspects of the framework to ensure that all of the information within the framework links together and may be used to represent the links between SHAPE Phase 2 work packages. Three aspects of the framework have already been developed in terms of their information content and how they link to one another. These are the:

- Levels of Automation (LOA),
- cognitive processes and
- cognitive functions.

(Below see a diagram illustrating the framework structure so far.)



The links between these three sets of information (red/dark arrows in the diagram) now need to be validated. It is these links that the validation exercise addresses. The validation exercise will enable us to collect data on how others view the links between these three information sets, and, as a result, it will allow us to refine our framework.

The objective of the task is to validate the mapping we have made between cognitive processes and LOA functions, that is to match the type of automation functionality onto the cognitive process(es) that it may support or assist.

The instructions for the task are described in the section below. The aim is to provide guidance that will allow you to form your own mapping between the cognitive processes and LOA functionality.

Please ensure that you have the following worksheets and appendices before starting either task:

- Automation function to cognitive process spreadsheet.
- List of cognitive processes: These cognitive processes are derived from the cognitive processing model used in SHAPE. Each process listed is defined within the context of the framework used in the project.
- Lists of LOA functions: The LOA involved in implementing the system is defined as the degree to which as a device or system accomplishes (partially or fully) a function that was previously carried out (partially or fully) by a human operator. These associated LOA functions are derived from the LOA model and taxonomy used in SHAPE. Each automation function category and function is defined. Examples are also given.

<u>Instructions (for the task)</u>

Step 1: Ensure that you have the correct material: (i) Worksheet 1 - processes vs. automation functions, (ii) list of cognitive processes and (iii) lists of LOA functions.

Read through and familiarise yourself with the sets of definitions for cognitive processes and level of automation, and with the layout of Worksheet 1. The LOA functions are displayed in the left-hand column of Worksheet 1 and the cognitive processes are displayed in the top row of Worksheet 1.

Step 2: Using Worksheet 1 and the definitions for automation function and cognitive processes, work through each cognitive process and identify the LOA functions which support or assist the cognitive process. Mark with a cross the automation functions you believe support or assist the cognitive process. Support may be full or partial to warrant a cross in the worksheet. You may wish to mark several automation functions for each cognitive process.

For example, starting with the cognitive process ‘SEARCH’, read its corresponding definition, then work down column containing the level of automation functions in order, deciding for each automation function whether it would support or assist the ‘SEARCH’ process. Mark the automation function you believe would support the selected cognitive process with a cross.

Step 3: Continue this process for all of the cognitive processes. Please use the definitions on the lists for clarification. However, should any definition be unclear to you please note down and let us know. Your feedback will help us to refine any deficient definition.

SHAPE – Verb list (with definitions)

Verb	Definition
Accept	To take or receive (something offered); to take on the responsibilities, duties, etc.
Adapt	To fit, change or modify to suit a new or different purpose or situation
Anticipate	To forecast; to form expectations of what might happen/occur in future
Ask	To put a question (to); to request an answer (from); to find out about
Assimilate	To learn and understand thoroughly, and to absorb (information, etc.)
Attend	To concentrate and direct one's mind to a problem, task or information
Assess	To estimate value or difficulty
Check	To make sure the information/data is correct or satisfactory
Choose	To select out of a number options; to decide to do one thing rather than another
Compare	To examine in order to observe similarities or differences; to regard as similar
Concentrate	To think intensely about
Confirm	To establish, to corroborate
Consider	To think carefully about it
Cope	To deal successfully with
Detect	To discover the existence of
Discuss	To investigate by reasoning or argument
Develop	To work out in detail and/or cause to grow gradually (thoughts, plot or plans) to a more advanced or expanded stage
Establish	To create or set up; to prove correct
Evaluate	To ascertain amount of
Explain	To give details about something
Extract	To find, deduce, copy out, make extracts from
Formulate	To put into or express in systematic terms
Gather	To collect or collect gradually, and to learn or conclude from information given
Handle	To control; to manage successfully; to deal with in a specified way
Identify	To establish the identity; to associate
Implement	To carry out; to put into action
Integrate	To combine into a whole; to complete by addition of parts
Interpret	To decide something’s meaning or significance when there is a choice

Verb	Definition
Listen	To concentrate on hearing something
Manage	To handle, manipulate
Monitor	To keep under observation
Navigate	To direct or plot the path or position of
Perform	To carry into effect; to go through
Plan	A proposed idea or detailed scheme or method for doing something or achieving an objective
Prioritise	To put into order of importance so that the most important ones are done first; to schedule something for immediate or earliest attention
Process	To carry out a series of actions or cause events that are part of a system or a continuing development, or a series of actions that are done to achieve a particular result
Predict	To forecast, form expectations of what might occur/happen in future
Provide	To supply, furnish
Recall	To bring back (the memory of a past event) into your mind, and often to give a description of what you remember; to call back to mind; to revive in memory; to recollect; to remember
Receive	To admit; to take in; to hold; to contain; to have capacity for; to be able to take in; to gain the knowledge of; to take into the mind by assent to
Recognise	To know again; to perceive the identity of, with a person or thing previously known; to recover or recall knowledge of; to admit with a formal acknowledgement
Regulate	To control or put in good order; to adjust or maintain with respect to a desired rate, degree or condition
Remind	To put (one) in mind of something; to bring to the remembrance of; to bring to the notice or consideration of (a person).
Request	The act of asking for anything desired; expression of desire or demand
Resolve	To solve, clear up, settle
Respond	To make answer; to perform answering or corresponding action
Retrieve	To find again; to recover; to regain; to restore from loss; to recall; to bring back; to discover
Review	To survey, to look back on
Revise	To look at again for the detection of errors; to re-examine; to review; to look over with care for correction
Scan	To look intently at all parts successively; to attend to
Search	To look (somewhere) carefully in order to find something
Share	To tell someone else about what you know or feel; to give information that one already knows

Verb	Definition
Signal	An action, movement or sound which gives information, a message, a warning or an order
Supervise	To watch over (an activity or job) to make certain that it is done correctly, or to watch over (someone) to make certain that they are behaving correctly or are safe
Solve	To find answer to
Take in account	To take into consideration before deciding
Update	To refresh, make up-to-date
Use	To employ for a purpose; to put into operation
Verify	To establish truth of
Validate	To confirm or corroborate; to make valid, ratify

II. Link between the Cognitive Processes and Cognitive Functions

Having identified and initially validated the cognitive processes to automation functions link and agreed what the cognitive functions are and validated those, it was necessary to understand the relationship between the cognitive functions and the cognitive processes. This link between the cognitive functions and processes was established in two separate exercises.

Establishing the link between the cognitive processes and cognitive functions – Exercise 1

A similar exercise to the one report in APPENDIX CI was carried out. However, in this exercise the participants were given a spreadsheet with the cognitive processes listed across the top (columns) and a list of cognitive sub-functions along the left side (rows) (see Table 12). They were given instructions as well as lists of the cognitive processes and a verb list (which can be found in APPENDIX CI). For each cognitive sub-function the participants were required to select the cognitive processes required to carry out that sub-function. They recorded their selections on the 'cognitive processes - cognitive functions' spreadsheet provided.

Results from Exercise 1 – Cognitive routes (Link 3a)

The returned data were organised in a spreadsheet and reviewed for commonality and differences. The process involved examining the cognitive function-process mapping for each cognitive sub-function and analysing the amount of agreement between subjects for each sub-functions. The agreement between subjects on what cognitive processes were required by each sub-function was insufficient. For some sub-functions agreement was as low as 29% (which is two out of seven subjects). The average agreement was approximately 53%.

Using the data, a multi-dimensional scaling analysis was conducted in order to investigate which cognitive processes were perceived to occur together for any given sub-function. Five solutions were generated by the analysis. five HF specialists then looked at one solution each and independently identified the groupings of cognitive processes that the solution had analysed as occurring together as a group. For each solution, between seven and ten groupings were identified. The groupings of cognitive processes from each solution were then pooled together and common groupings were extracted. The groups were then renamed as 'cognitive routes'. A cognitive route is defined as a sequence of cognitive processes that will be carried together (either simultaneously or sequentially) to achieve a given function. The final set contained 24 cognitive routes. A list of the cognitive routes identified can be found in Table 13. The intention for identifying the cognitive routes is establish a link between the cognitive functions and the cognitive processes via the cognitive routes. That is, establish which cognitive routes are required to achieve each cognitive function and subsequently infer the cognitive processes involved by the composition of the routes involved.

Table 12: Example of the cognitive function to cognitive process spreadsheet (this does not represent the whole spreadsheet but only an extract)

	Attention						Perception				Working Memory										LTM			Planning/ Decision Making							Action Execution				
Cognitive Processes	Search	Detection	Selective Attention	Divided attention	Switch attention	Filter	Identification	Comparison	Interpretation	Categorise	Retain information	Manipulate information	Retrieve	Quick comparison	Integrate information	Action/outputs	Short term projections	Encoding	Rehearsal	Purge	Update / Assimilate	Store	Retrieve	Predicting	Testing	Plan formulation	Decide/Select	Control	Evaluate	Goal Image	Action formulation	Transmit	Execution	Adapt/Learn Response	Reset
Adapt previous controller's plan after handover, if necessary																																			
Anticipate future traffic situation																																			
Anticipate team member's needs / capability																																			
Ask for information																																			
Assess impact on own and/or team's workload and prioritise request																																			
Assess previous controller's plans before accepting handover																																			
Attend to information displays																																			
Be flexible about plans and adapt plan, where necessary																																			
Check against traffic and the feasibility and relevance of the request																																			
Check credibility of the plan																																			
Check external information and gather evidence																																			
Check for common understanding of handover information																																			
Check for cues on traffic situation																																			
Check for expedition																																			
Check information																																			
Check order and priority of actions in plans																																			
Check task status																																			
Check validity of information and review plan																																			
Choose solution																																			
Compare actual situation with future situation																																			
Compare current Mental picture with new/observed information																																			
Concentrate on planned future tasks																																			
Concentrate on current tasks																																			
Consider previous experience that could be relevant																																			
Detect differences between expected and actual situation																																			
Develop new plan for the novel situation / problem																																			

Table 13: List of cognitive routes

Route number	Cognitive processes
1	Detection, Integrate information, Retrieve
2	Interpretation, Action/outputs, Assimilate
3	Interpretation, Categorise, Retrieve
4	Comparison, Short-term Projection, Testing
5	Detection, Retain information, Switch attention
6	Search, Quick comparison, Divide attention
7	Identification, Selective Attention, Filter, Manipulate information, Encoding
8	Comparison, Manipulate information, Short-term projections, Predicting
9	Search, Comparison, Divide attention, Action/outputs
10	Search, Divided attention, Filter, Quick comparison
11	Switch attention, Comparison, Short-term projections, Rehearsal, Retain information
12	Manipulate information, Retrieve, Encoding
13	Integrate information, Encoding
14	Retain information, Encoding, Rehearsal
15	Decide/select, Evaluate, Action/outputs, Assimilate
16	Filter, Retrieve, Action/outputs
17	Predicting, Rehearsal, Testing, Evaluate
18	Assimilate, Integrate information, Categorise, Store
19	Predicting, Control, Evaluate, Goal image, Action formulation
20	Plan formulation, Decide/select, Evaluate, Goal image, Adapt/learn response
21	Plan formulation, Evaluate, Goal image, Action formulation
22	Predicting, Control, Testing, Decide/select
23	Testing, Goal image, Plan formulation
24	Adapt/learn response, Reset, Transmit, Execution

Establishing the link between the cognitive processes and cognitive functions – Exercise 2

To establish the relationship between the cognitive processing routes and the cognitive functions, a card sorting exercise was conducted with six participants who were Human Factors (HF) staff within NATS.

Each participant was given a briefing about the purpose of the card sorting process and the following materials were provided:

(i) A taxonomy of controller cognitive functions, which can be found in APPENDIX AIII. Each function was described briefly.

(ii) A set of cognitive function cards, each with a cognitive function and its constituent sub-functions on it.

(iii) A list of cognitive processing routes (see Table 13). Each route on the list consists of a sequence of cognitive processes that will be carried together (either simultaneously or sequentially) to achieve a given function. The definition of the individual process was provided on a separate piece of paper.

(iv) A set of cards, labelled ‘Level 1’, ‘Level 2’, ‘Level 3’ and ‘Level 4’.

(v) Four paper clips and an envelope labelled ‘Results’.

Each participant was given instructions which required them to sort the cognitive functions according to their level of hierarchy then take each cognitive function in turn and decide which of the cognitive routes are necessary to achieve the cognitive function. This was repeated with each cognitive function in turn. The related cognitive routes were notes on the cards before moving on to the next function. The participants put all of their completed cards into an envelope provided and all results envelopes were collected for later analysis.

The data were organised in a spreadsheet and reviewed for commonality and differences. Analyses identified that 17 of the 21 cognitive functions had 80% agreement between the six participants’ results in terms of the cognitive processing routes that were associated with them. Of the remaining four cognitive functions two shared 60% agreement (i.e. four of the six participants agreed which cognitive processing routes related to these two cognitive functions.) and the remaining two shared 50% agreement. These results were considered very positive suggesting a considerable agreement was found between the participants regarding how the cognitive processing routes relate to the cognitive functions. The outcome of this card sorting exercise, showing the link between the cognitive processing routes and the cognitive functions can be found in Table 14.

Once the link between the cognitive functions and the cognitive processing routes was established with some confidence it was necessary to trace the link between the cognitive processing routes back to the cognitive processes to ensure that the cognitive functions had a link back to the relevant cognitive processes. The content of the cognitive routes was unpacked so that each cognitive process within each cognitive route was associated with the cognitive function that it was linked to. Hence, a matrix was developed to illustrate which cognitive processes relate to which cognitive functions.

Table 14: Associations between the cognitive functions and cognitive routes required

	Cognitive route number																						
Cognitive function	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
C1					x	x			x		x												
C2					x	x																	
C3							x																
C4										x													
C5			x											x									
C6													x					x					
C7	x		x		x			x					x										
C8								x												x	x		
C9																		x					
C10	x														x						x		
C11				x																x	x		
C12																					x		
C13																					x		
C14	x																						
C15																			x				
C16	x			x																	x		
C17							x																
C18					x													x					x
C19		x																x					
C20																x							
C21																		x					

Refer to the cognitive function taxonomy in APPENDIX AIII to find out what the cognitive function number refers to, and refer to Table 13 to find out what cognitive processes are in the cognitive route number.

Instructions to participants

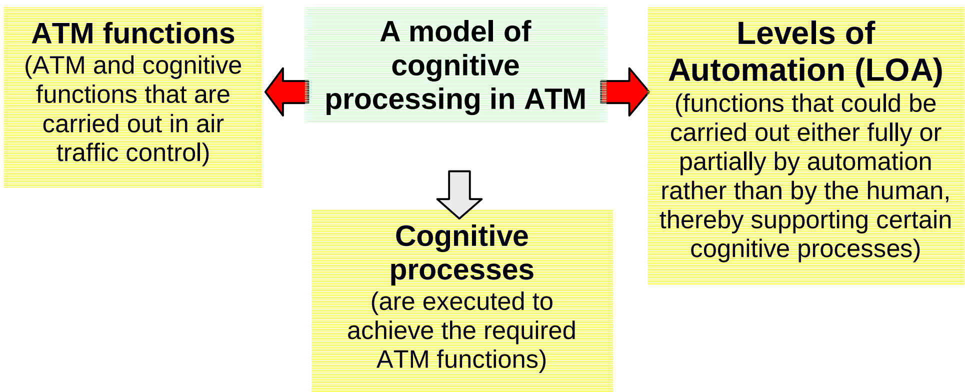
Thank you for agreeing to participate in this validation exercise!

Brief introduction

Initial work has began on SHAPE Phase 2 and the first part of the work involves the development of a common framework upon which the three main work packages for SHAPE Phase 2 (skills change, workload and managing system disturbances) can be built and associated with one another and with SHAPE Phase 1 work packages (trust, SA and teamwork). A cognitive processing model has been developed for use in the framework. A 'roadmap' is now being built between all of the different aspects of the framework to ensure that all of the information within the framework links together and may be used to represent the links between SHAPE Phase 2 work packages. Three aspects of the framework have already been developed in terms of their information content and how they link to one another. These are the:

- Levels of Automation (LOA),
- cognitive processes and
- cognitive functions.

(Below see a diagram illustrating the framework structure so far.)



The links between these three sets of information (red/dark arrows in the diagram) now need to be validated. It is these links that the validation exercise addresses. The validation exercise will enable us to collect data on how others view the links between these three information sets and, as a result, it will allow us to refine our framework.

The objective of the task is to validate the mapping we have made between cognitive processes and cognitive functions, that is which cognitive processes are required to achieve a particular cognitive function. These are cognitive functions which the air traffic controller carries out in order to achieve his/her operational goals.

The instructions for the task are described in the section below. The aim is to provide guidance that will allow you to form your own mapping between the cognitive processes and cognitive functions.

Please ensure that you have the following worksheets and appendices before starting either task:

- Cognitive function to cognitive process spreadsheet.
- List of cognitive processes: These cognitive processes are derived from the cognitive processing model that is being used in SHAPE. Each process listed is defined within the context of the framework used in the project.
- List of verbs (with definitions): Each verb listed is defined in the context of the framework being used in SHAPE. This list contains most of the verbs used to describe the cognitive tasks.

Instructions (for the task)

Step 1: Ensure that you have the correct material: (i) Worksheet 2 - processes vs. cognitive functions, (ii) list of verbs (with definitions) for cognitive functions and (iii) list of cognitive processes.

Read through and familiarise yourself with the definitions for cognitive processes and with the layout of Worksheet 2. The cognitive functions are displayed in the left-hand column of Worksheet 2 and the cognitive processes are displayed in the top row of Worksheet 2.

Step 2: Work through each of the cognitive functions one by one, identifying the verbs in each statement. Use the definitions in the verb list to obtain the meaning of the verbs in the context of ATM.

Step 3: For each cognitive function assess which cognitive process or processes you believe is or are required to carry out that function. Mark your choice with a cross. You may wish to mark several cognitive processes for each ATM function.

Step 4: Should any definition be unclear to you please note down and let us know. Your feedback will help us to refine any deficient definition.

Instructions for establishing the link between cognitive processes and cognitive functions (Exercise 2)

1. Read through the controller cognitive functions document to make yourselves familiar with the cognitive functions.

2. Read through the list of cognitive processing routes to make yourselves familiar with them.

3. The cognitive functions are of various levels of task hierarchy. The purpose of this step is to sort each of the cognitive functions according to the level of hierarchy that you feel is appropriate. There are four levels of task hierarchy heading cards (Levels 1 to 4). Only Levels 1 and 4 are pre-defined. Place the level hierarchy cards on a table from left (Level 1-basic level functions, activities that may be constituents of higher level functions) to right (Level 4 – functions that require an integration of several lower level functions). Sort the cognitive function cards according to which level you believe they represent by placing them below the relevant task hierarchy heading card.

4. Start with the pile of cognitive functions sorted under Level 1. Take the first cognitive function card in the pile and the list of cognitive processing routes. Browse through the list and select the cognitive processing route(s) that will be the most suitable for achieving the cognitive function.

5. Assign the appropriate cognitive processing route to the function by writing the index number of the route on the cognitive function card. Leave out or do NOT include cognitive processing routes that are required *as a consequence of achieving* that function.

6. Repeat Steps 4 and 5 with the rest of the cognitive requirements under Level 1. Once you have completed all the cognitive requirements in Level 1, use the paper clip to secure all the cognitive requirements to the ‘Level 1’ card. Put the card sorting results into the ‘results’ envelope.

7. Repeat Steps 4, 5 and 6 with the cognitive requirements sorted under Level 2, then Level 3 and finally Level 4.

III. Workshop with ATCOs to validate the taxonomy of ATM and cognitive functions and skill requirements

In order to ascertain what skills controllers require to carry out the ATM and cognitive functions they perform in en-route ATC it was necessary to take the list of ATM and cognitive functions and their sub-functions and determine the competence items required to carry out these functions. The competence items of interest were the knowledge, mental skills, physical skills and attitudes controllers need in order to achieve a given function. These knowledge, skills (mental and physical) and attitudes, collectively abbreviated as KSAs, are what we loosely refer to in SHAPE as ‘skills’.

To achieve this four glossaries were developed listing the potential knowledge, mental skill, physical skill and attitude items respectively that are required for en-route control. These glossaries were developed using the same information sources used to develop the ATM and cognitive functions and sub-functions. In addition, much of the knowledge and physical skills were gathered from the manuals of ATC used in the UK. Some of the attitudes were collected from internet resources and publications on organisational psychology research and competency analyses of other professions. Only the attitudes that were potentially relevant to ATC were extracted and compiled to produce the attitude glossary.

These glossaries were used as reference material in an exercise carried out by six UK controllers. The controllers were asked to look at a list of the eighteen ATM functions (with the sub-functions listed for information) and the 21 cognitive functions (again, with the sub-functions listed to help clarify what each function involved). The controllers were asked to work through each ATM function in turn and assign the items from the four glossaries that they felt were **always necessary** to achieve that function. As a guide they were instructed to keep their selection down to five-six items from each glossary per function. However, they were allowed to choose more or less items if they felt this was appropriate to capture items that were essential to achieve that function. Instructions were provided to make it clear to the controllers that KSA items should only be chosen if they were critical to achieving the function. This was done as a stopping rule to avoid the participants adding everything or considering specific scenarios or examples that might become misleading. By using only the critical KSAs the work package was also kept within a reasonable scope. Next, they were instructed to work through each cognitive function doing the same. However, for the cognitive functions the mental skills glossary was not used. This was because the mental skills in the glossary were derived from the cognitive sub-functions making it unnecessary to use the mental skills as well. Instead, the cognitive sub-functions were used to infer the mental skills required to achieve the cognitive functions.

The outcome of this activity was tables per ATM and cognitive function listing the agreed KSAs for that function and the criticality ratings for the function and its sub-functions (see Table 15 for an example).

A separate workshop was later held with a different group of six operational en-route controllers from the UK. This was to validate the KSA and criticality data collected from the first six controllers. In this workshop the controllers were given a copy of the function tables produced previously and a copy of the four glossaries and asked to review each function and the KSAs associated with it to determine whether there was anything on the list that was not relevant or clear.

Table 15: Example of a cognitive function KSA table

		Knowledge	**Physical skills**	**Attitudes**
C1	**Multitasking**	**Approved/standard phraseology** **Clearances and instructions** **Radiotelephony operating procedures** **Sequences and approximate duration of tasks** **Standing agreements** **Knowledge of airspace** **Strip marking symbols** **Separation procedures/standards** National legislation and procedures Knowledge of equipment use and its limitations	Ask (speak) Use of all equipment Record coordination outcome *Flag appropriate strip* *Strip management* *Strip marking* Speak (give info) Look Listen Read	**Flexible** **Decisive** **Proactive** **Safety conscious** Cooperative Assertive
C1.1	Switch attention (e.g. thinking then attending to new strip or pilot`s call)			
C1.2	Divide attention (e.g. speaking and writing at the same time)			
C1.3	Identify tasks which are highly similar (e.g. same instruction that needs issuing to several pilots)			
C1.4	Identify tasks which are more difficult than usual			
C1.5	Time share between tasks			
C1.6	Evaluate importance of tasks and prioritise tasks			
C1.7	Find information and navigate between different information sources			

For each function they were also asked whether there was anything else in the glossaries that was *essential to achieve the function* that should be added. As a group any issues were discussed and, if agreed, amendments were made. To ensure that the KSA data were representative of en-route control in European countries generally, an additional workshop using the same process as described above was held at EUROCONTROL with an additional three controllers with experience of en-route control in different European countries.

IV. Link between the ATM Functions and Cognitive Functions

By developing the link between the cognitive functions and ATM functions, it was possible to trace the impact of an ATM system or form of automation right through the framework to determine its impact on the controllers' ATM functions (the tasks you see a controller doing). Rather than being able to directly link the cognitive and ATM functions, it was necessary first to look at the cognitive sub-functions and compare them to a glossary of mental skills associated with the ATM functions (from the workshops described in APPENDIX CIII). By establishing this interim step between the cognitive sub-functions and mental skills related to the ATM functions, it was then possible to trace the ATM functions to the cognitive functions.

A table (see excerpt shown in Table 16) was developed to relate the cognitive sub-functions to the mental skills. This was not difficult to do as the glossary had largely been developed using the cognitive sub-functions as source of information. The glossary of mental skills was developed from the cognitive sub-functions in order to simplify the skills work by removing any duplication within the cognitive sub-functions so that one single mental skill was left to describe each similar cognitive sub-functions.

Table 16: Relationship between the mental skills and cognitive sub-functions[3]

Mental skills from glossary	Cognitive sub-functions	Cognitive sub-function number			
Respond to conflict information/ alert	Respond to conflict information/alert	C4.3	C7.5	C12.2	
Retrieve information from Long Term Memory (LTM)	Retrieve information from LTM	C5.2	C8.5	C15.1	
Review conflict solution	Review conflict solution	C15.2			
Revise existing position control plan, if necessary	Revise existing position control plan, if necessary	C10.4	C8.6		
Scan Radar or any ATC Display Screen Equipment (DSE) or Flight Data Processing System (FDPS) equipment	Attend to information displays and Scan Radar or any ATC DSE or FDPS equipment	C2.2	C2.3	C2.4	C2.5

[3] This table is only an excerpt rather than the full table of data. The cognitive sub-function numbers refer to the sub-function item under the main cognitive function for example C5.2 refers to the second item or sub-function 'retrieve information from Long Term Memory' under cognitive function n°5, 'manage and update working memory' in APPENDIX AIII.

V. Link between the Controller Functions (both ATM and Cognitive) and Skill Requirements (KSA Overlap Analysis)

An analysis was conducted of all of the KSA data gathered in the skill requirements and validation process. This analysis identified those KSA items that are common to many ATM and cognitive functions and those KSA items that are less common or specific to only a certain few controller functions (cognitive or ATM). This analysis used the data obtained from the skill requirements identification and validation workshops to list the KSA items in order of frequency with which they were required for different controller functions. For example, those required for the most cognitive and ATM functions were listed first and those that were required for the least functions (or only specific functions) appeared towards the bottom of the list. Observation of the data showed that the most commonly required KSA items were typically required for 40% or more of the controller functions. Those least commonly required were typically required for less that 25% of the controller functions.

The outcome of this analysis process was a set of KSA Item summary tables that identify which cognitive and ATM functions relate to which KSA items, with the KSA items listed in order of commonality or priority. These tables can be found in APPENDIX BIV. The dark grey shading in these tables indicates the KSA items that are most commonly required (by 40% or more of the controller functions (cognitive and ATM)). The lighter grey shading indicates the KSA items required by 25% to 39% of the controller functions and the non-shaded area represents the KSA items required by less than 25% of the controller functions. These are considered the lower priority KSA items.

By representing the KSA items in this way, it is possible to infer the potential skill changes for each controller function and their likelihood of impact in terms of skill requirement frequency.