EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

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Integrated Task and Job Analysis of Air Traffic Controllers - Phase 3: Baseline Reference of Air Traffic Controller Tasks and Cognitive Processes in the ECAC Area

HUM.ET1.ST01.1000-REP-05

Edition	:	1.0
Edition Date	:	08.09.2000
Status	:	Released Issue
Class	:	EATMP

EUROPEAN AIR TRAFFIC MANAGEMENT PROGRAMME

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title

Integrated Task and Job Analysis of Air Traffic Controllers - Phase 3: Baseline Reference of Air Traffic Controller Tasks and Cognitive Processes in the ECAC Area

EWP DELIVERABLE REFERENCE NUMBER: HUM.ET1.ST10.1000-DEL03

PROGRAMME REFERENCE INDEX:	**EDITION:**	1.0
HUM.ET1.ST01.1000-REP-05	**EDITION DATE:**	08.09.2000

Abstract

This report presents the results from the Air Traffic Controllers' (ATCOs') task analysis conducted in fifteen different Units in European Civil Aviation Conference (ECAC) States using the Integrated Task Analysis (ITA) methods. The cognitive processes of aerodrome, arrival/departure and en-route controllers are depicted. A new concept, 'the cognitive profile', was developed in order to allow comparison from the cognitive point of view between the different types of Air Traffic Services (ATS) provision. Additional results on working style, behavioural observation, stress and strain are also provided. Finally, some ideas for potential use of the results in controllers' selection and training, and the development of new ATM system are suggested.

Keywords

Cognitive Process	Stress and Strain	ECAC Area
Cognitive Profile	Cognitive Task Analysis (CTA)	Air Traffic Controllers (ATCOs)
Bottom-Up/Top-Down Processes	Integrated Task Analysis (ITA)	Working Style

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DOCUMENT STATUS AND TYPE

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

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME: G:\Own_use\Delvrabl\Released\H_factor\ITA\ITA3.doc

HOST SYSTEM	MEDIA	SOFTWARE
Microsoft Windows	Type:	**MicroSoft Office 97 (MS97)**
	Media Identification:	

DOCUMENT APPROVAL

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

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DOCUMENT CHANGE RECORD

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

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.1	10.09.1999	Working Draft	All
0.2	15.11.1999	Draft	All
0.3	10.03.2000	Proposed Issue	All
1.0	08.09.2000	Released Issue	All - Document Configuration

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EXECUTIVE SUMMARY

This document is the final Phase Report, i.e. Phase 3 Report on Integrated Task Analysis (ITA). It was contracted out by the Human Resources Bureau DED5 of EUROCONTROL, which later was the ATM Human Resources Unit and has now become the Human Factors and Manpower Unit (DIS/HUM or HUM Unit), to the ‘Institute for Evaluation Research’ (Institut für Begleitforschung or IfB), Germany, under the auspices of the EATCHIP/EATMP[1] Human Resources Team (HRT) and within the Human Resources Domain (HUM).

It provides the reader with an overview of the results of the ITA methods in a European Civil Aviation Conference (ECAC)-wide study of the Air Traffic Controllers' (ATCOs') job and tasks in different geographical areas and in different services, i.e. en-route, arrival/departure and aerodrome. The focus of Report Phase 3 deals with the results of the ECAC-wide study, including a brief description of the ITA methods with a special focus on the data analysis of the cognitive interview and the flight progress reconstruction as well as the behavioural observations. The development of methods and recommendations for application are given in Phase 1 Report (EATCHIP, 1998a) and results on basic cognitive processes for en-route controllers are given in the Phase 2 Report (EATMP, 1999a). The process analysis turned out to be an appropriate method for depicting the cognitive aspects of the en-route controllers’ work. Results are briefly reviewed, as this serves as a reference for the analysis and the comparison of different units and different positions. Cognitive profiles are used to show similarities and differences between positions from a cognitively oriented point of view. Data is integrated by a cluster analysis. Cognitive profiles are compared to behavioural profiles based on task observations. Results are supplemented by profiles for stress and strain. Finally, implications of the results for different areas of application (selection, training, new technologies) are discussed in detail.

Chapter 1, 'Introduction', stresses the central role of cognitive processes in Air Traffic Control (ATC) and gives a brief summary of the purpose and the ideas behind the Integrated Task Analysis (ITA). ITA was applied to collect data for a baseline reference of ATCOs' cognitive processes in the different jobs and tasks of ATC, which is needed to guide decisions and activities in the scope of EATCHIP/EATMP.

Chapter 2, 'Data Collection and Analysis', describes the rationale and the design of the ECAC-wide study. The sample, methods of data acquisition and principles of data analysis are reviewed.

Chapter 3, 'Basic Cognitive Processes of Air Traffic Control', refers to the basic cognitive processes of en-route ATC from Phase 2 of the project. Similarities and differences between the basic cognitive processes of en-route, arrival/departure and aerodrome control are outlined. With a few modifications, the same basic cognitive processes can be used for en-route, arrival/departure, and aerodrome control.

[1] European Air Traffic Harmonisation and Integration Programme (EATCHIP); has now become EATMP standing for ‘European Air Traffic Management Programme’

Chapter 4, 'Cognitive Profiles of Air Traffic Control', describes the procedure for rating cognitive interview data and data of the flight progress reconstruction to obtain 'cognitive profiles'. Analyses of the reliability of the rating procedure show satisfactory results for the majority of categories. Some influence from the observers may be assumed insofar as they have no ATC background. Controllers' cognitive tasks differ clearly according to the type of service, while differences with respect to geographical area are comparably negligible. The same pattern of results emerged for both the ratings of cognitive interviews and flight progress reconstruction interviews.

Chapter 5, 'Behavioural Profiles', gives behavioural profiles based on the behavioural observations for the different positions in en-route control, arrival/departure control, and aerodrome control. Satisfactory reliability was achieved for aggregated data. Results show different behavioural patterns for different sector types. Reliability coefficients are provided in Tables 17 and 18.

Chapter 6, 'Stress and Strain Analysis' shows the results of two stress and strain questionnaires. There are differences between units as far as stress of controllers is concerned.

Chapter 7, 'Results Integration', gives additional results which help to integrate the findings from the different methods. Clustering the subjects with respect to their cognitive working style shows that the major differences and similarities between controllers can be derived from the kind of ATC service they provide.

Chapter 8, 'Comparison of Air Traffic Control Services: Summary of Results' provides an overall summary of the ITA Phase 3 results by emphasising the comparison of the different services.

Chapter 9, 'Field of Application', is a summary of ideas for using ITA results that were collected from experts in Selection, Training and System Development.

The following five technical annexes can be found at the end of the report:

A. 'Top-down/Bottom-up Rating Criteria';
B. 'Top-down/Bottom-up Ratings: Distribution of "O-Ratings" across Services';
C. 'Rating Criteria for the Evaluation of the Flight Progress Reconstruction Interview';
D. 'Flight Progress Reconstruction Ratings: Distribution of Excluded non-routine Cases';
E. 'Comparison of Services: Air Traffic Controllers' Statements'.

A Bibliography, a Glossary, the Abbreviations and Acronyms used in this report, and their definition(s), and a list of the Contributors to this document are also provided, as standard annexes.

1. INTRODUCTION

An accurate understanding of the ATCOs' cognitive processes in different services and areas in Europe opens up considerable prospects which could be used to help resolve future problems in ATC.

It is difficult to understand the way controllers work from merely observing their behaviour or their communication with pilots or adjacent controllers. The 'art of ATC' or the 'miracle of ATC' seems to be much more than the provision of safe Air Traffic Management (ATM) and appropriate behaviour in emergencies. An increasing number of publications and textbooks tackle the question of the cognitive processes and situational awareness involved in ATC (Stein, 1998; Seamster et al, 1997; Wickens, 1997 & 1999). This recent development in ATC research shows that the hidden cognitive activity of controllers has drawn the interest of many researchers.

Many different methods have been used to better understand ATCO cognitive processes. These methods range from simple inquires to complex simulations of the information processing in ATC. Most of these have been carried out in the laboratory or simulation settings (see Seamster, Redding & Kaempf, 1997). Methods to analyse the ATCOs' cognitive processes in the everyday operational ATC environment are rare.

1.1 Rationale

As a result of the rapidly increasing number of aircraft, air traffic has changed drastically during the past two decades. Travelling by aircraft has become relatively inexpensive and safe. Safety has been increased in spite of the fact that the ATC system is being stretched to its limits, which normally increases the risk of errors, failures and accidents (see Rasmussen, 1999). Improved ATC equipment and the increasing proficiency of ATCOs together with advanced equipment of airports, ATC, and aircraft enable ATCOs to manage highly complex air traffic according to separation standards which would have been thought impossible in the past. The changes in air traffic place new demands on the ATCOs' information processing. ATCOs cope with these demands routinely and professionally.

However, increasing air traffic causes a lot of delays due to overcrowded airspace. Putting aircraft on hold at large airports in high traffic periods is becoming common even for short-distance flights. Delays have many disadvantages. It is costly for the airlines (e.g. in terms of fuel, personnel overtime, passenger discomfort, missed connecting flights, luggage delays, etc). For the controllers, delays can cause additional workload as traffic peaks and traffic structure become less predictable. In this case, additional planning is necessary and can become highly complex.

With increasing traffic, pre-planning on the controllers' part becomes increasingly necessary. It is no coincidence that the Federal Aviation

Administration (FAA) is to incorporate a planner position in their ATC system. If strategic planning spans are increased, tactical time buffers must be provided to enable controllers to avoid conflicts between aircraft as and when required. It is important to know more about the cognitive processes involved if one is to provide appropriate solutions for these developments.

In Europe additional problems can arise, as there are multiple changes in language and cultural background of the controllers within very small distances. These cultural differences have a wide-ranging influence. The well-known work by Helmreich (1998) on cultural influences in controller-pilot communication is also relevant for ATC in Europe. There are some additional aspects in Europe which require ECAC-wide studies. When attempting to harmonise ATC in Europe, one must take into account local and national working practises. In Europe the ATCO job differs considerably according to the technical equipment used, be it American, French, British or Russian systems. Further differences appear with respect to the controllers themselves: age, gender, distribution, organisational variables (public-owned/ private organisation), working conditions, working schedule, retirement age, salary, social esteem and team structures. In addition, in their communication with pilots and communication with adjacent sectors, the controllers must repeatedly deal with cultural differences.

This fits well with the fact that nearly all controllers stress the major cultural differences between different units and that it is difficult for controllers to switch to another unit in Europe without extensive On-the-Job Training (OJT) before they can work at top performance levels. Some reports state that switching from (solely) military to civil control in the same area of ATC can be accompanied by comparable problems. These observations support the hypothesis that an elaborate mental model of the sector in which the controller works is necessary if he[2] is to do the job expeditiously without too much stress. An elaborate mental model allows the controller to keep his traffic picture and his ongoing anticipations up to date. He is able to do this without overload even when presented with large amounts of information or when something unexpected occurs.

1.2 Project Overview

1.2.1 Objective

The objectives of the ITA project are to create a baseline reference for the cognitive task processes of ATCOs and to outline common aspects and differences in cognitive task processes between different services and different regions within the ECAC area. The results are aimed at contributing to the knowledge of cognitive aspects that could be applied to different human resource areas specifically training and possibly selection and the development of new systems in European ATM.

[2] For convenience, when referring to the following: ATCO, pilot, ATS staff member, student, learner, instructor, etc., the pronouns used are ‘he’, ‘him’ or ‘his’. In this context, these male pronouns also refer to the female gender.

1.2.2 Scope

The project is based on a descriptive cognitive model of ATC that stresses the role of process control and puts special emphasis on anticipation and planning processes.

The project is divided into three different phases. In Phase 1, the aim was to develop a set of generic methods which could be applied within the real-time working environment of ATC. It should also account for different ATC services and for controllers from different geographical areas. In Phase 2, the methods were tested and validated using a sample of **36** en-route controllers from **5** different units in Europe. In Phase 3, the methods were applied in **13** ATC units which form a fairly representative sample of various ATC services and regional areas of the ECAC area. The sample is small and comprises a large degree of variance.

1.2.3 Project Phases

<u>Phase 1: Development of methods</u>

In accordance with existing ATC cognitive models, the objective of Phase 1 was to develop a set of ITA methods that could be adapted to the objectives of the project and the special nature of the ATCO job in a real-time operational environment. Special emphasis was given to the acceptance of the methods by ATCOs and minimal interference with normal working procedures.

The methods used in Phase 1 of the project were based on an extensive literature review. To tailor the methods to the specific demands of ATC, the results from the review were supplemented by task observations, interviews with ATCOs and group interviews at the Frankfurt ATC units at Deutsche Flugsicherung GmbH (DFS) in Germany. These observations and interviews were conducted in conjunction with the development of the cognitive ATC model (see EATCHIP, 1997a). The search for a set of methods for a task analysis of ATCOs was focused on action-oriented task analysis methods for mental work and for Cognitive Task Analysis (CTA). CTAs had been, up to that time, conducted in laboratory and simulation environments (Bierwagen, Eyferth & Niessen (1997); Seamster, Redding & Kaempf, 1997). Based on an overview of available task analysis methods for action-oriented task analysis, a method designed for task analysis of computer work stations (KABA: Dunckel, Volpert, Zölch, Kreutner, Pleiss, & Hennes, 1993) was selected as a basic framework for the organisational interview, observations and ratings used within ITA. A cognitive interview and a cognitive reconstruction method supplemented these methods. The following material resulted from the method development of the Integrated Task Analysis (ITA):

- a guideline for organisational interviews,
- a cognitive interview guide,
- grids for observations at the working position,
- guidelines for post-observational ratings,
- a guide for conducting flight-progress-strip reconstruction methods.

In addition, because stress is often referred to as a sensitive issue in ATC, complementary questionnaires to assess stress and strain were selected. Two questionnaires are used to cover the area of stress: SYNBA-GA (Wieland-Eckelmann, Sassmannshausen, Rose & Schwarz, 1997) and one other for strain: RESTQ (Kallus, 1995). The RESTQ was supplemented with a small set of questions which assess team quality (Kallus, 1996). Results from Phase 1 of the project have been documented in a report (EATCHIP, 1998a) and the material for conducting ITA has been compiled in the form of a technical supplement.

Phase 2: Task analysis of en-route controllers

The main objectives of Phase 2 were to test the usability and the acceptability of the ITA methods, and to refine and shorten the methods if necessary. It was also aimed at identifying task processes and a structural breakdown of en-route controllers' jobs and tasks. Phase 2 also included the definition and refinement of the procedures for data-collection and data-processing methods.

In Phase 2, task analyses were carried out for 36 controllers in 5 different units (Vienna, Zurich, Copenhagen, Malmö, and Stockholm). The observational data was analysed with quantitative statistical methods and the interview data with qualitative statistical methods. The results of the qualitative content analysis were summarised in flow diagrams. Results were documented in the Phase 2 Report (EATCHIP, 1999a) and the technical supplement was updated.

The main result of Phase 2 consists of an interrelated set of task processes that summarise the quantitative and qualitative data of the en-route controller study. These task processes focus on the cognitive aspects (memory, decision-making, evaluation, attention and action-control) and include behavioural aspects. They complement current hierarchical and CTAs of en-route controllers.

In general, the controllers' answers to the cognitive interviews and on the flight progress reconstruction could be summarised into ten different processes, which were depicted as flow diagrams. The flight progress reconstruction relates the cognitive processes directly to the non-routine events that occurred during the observation period of about 60 minutes.

Two basic results from the Phase 2 Report (EATMP, 1999a) are reviewed in Table 1.

Table 1: Cognitive processes: results

4 Sub-Processes (Level 1)	⇨ Updating mental picture / Maintaining situational awareness
	⇨ Checking
	⇨ Searching conflicts
	⇨ Issuing instructions
5 Task Processes (Level 2)	⇨ Taking over position / Building up mental picture
	⇨ Monitoring
	⇨ Managing routine traffic
	⇨ Managing requests / Assisting pilots
	⇨ Solving conflicts
1 Control Process (Level 3)	⇨ Switching attention

As shown in the box above, three process levels were identified. Level 1 processes (sub-processes) like 'updating mental picture' appear consistently throughout all en-route control tasks. Five task processes (level 2) were identified, of which the 'monitoring' process plays the central role. The various task processes are coordinated and organised by the control process (level 3) of 'switching attention', which spreads the attention to the appropriate task and sub-processes and keeps track of the action hierarchy. The control process is activated especially when ATCOs 'manage requests' or 'assist pilots' or when they are involved in 'solving conflicts' The task processes mainly have bi-directional interrelations as shown in Figure 1. These processes can be used as a comprehensive framework to analyse the process of ATC.

One important feature of the flow-diagrams is that the different entries and steps in the flow-diagrams can be characterised according to underlying psychological functions (memory, sensori-motor activity, evaluation / decision-making).

Some of the controllers' actions are conducted mainly using memory functions. Redding and Seamster (1992) have examined memory functions and the knowledge-base behaviour of ATC in greater detail through CTA. They used the expert / novice paradigm to highlight the different knowledge structures of controllers. Results from their work complement the memory functions of the current task analysis. For en-route controllers the results of different cognitive task analyses can be interpreted within a common framework, despite the fact that the cognitive models of Seamster et al. (1997) and ITA are slightly different and focus on different functions of the human cognitive system.

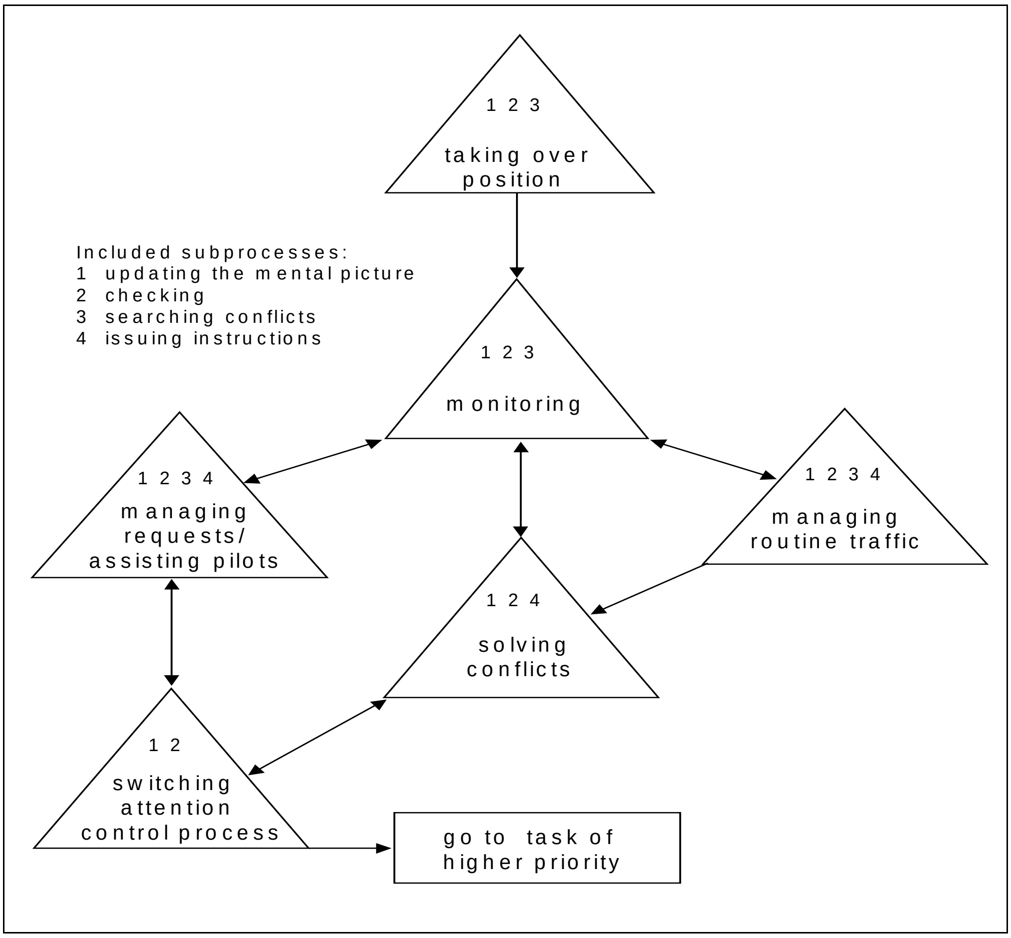

Figure 1: Basic cognitive processes of en-route control; interrelation of the processes

The second set of functions in the flow diagram can be termed sensori-motor functions. The perceptions and observable actions of the controller are included in this category. The hierarchical structure of the different types of ATCO behaviour can be found in analyses conducted for specific positions, for example the hierarchical task analysis conducted in the UK by Cox (1994).

A third set of psychological functions necessary for successful ATC includes evaluative and decision-making functions. These functions are attributed to the process control system of the underlying cognitive model. The role of decision-making has been stressed and studied in detail by the Swedish MRU working group of Brehmer (1998) in regard to selection of *ab initio* controllers.

Phase 3: Baseline Reference of Air Traffic Controller Tasks and Cognitive Processes in the ECAC Area

The set of ITA methods was applied and data was collected in an ECAC-representative sample of fifteen units. The objectives were to validate the task processes of en-route control, to expand the application of the methods to aerodrome and arrival/departure control, and to develop and define a method to compare units and services quantitatively according to the different cognitive processes. This concept is termed 'cognitive profiles' and is discussed in detail in this report. The additional objective of Phase 3 of the ECAC study was to collect more data on the reliability and validity of the ITA methods.

A better understanding based on the cognitively oriented process description of ATCOs' jobs and tasks can be used to improve knowledge.

A basic finding from Phase 2 of the project is that despite the large number of differences within Europe, it seems to be possible to describe the en-route controllers' job and tasks with a homogeneous set of basic and unique cognitive processes. At the same time it is very important to look for differences between en-route control and sectors in which the planning span is much shorter, such as arrival/departure control or aerodrome control. There is little doubt that these different services will show remarkable differences in some respects (Roske-Hofstrand & Murphy, 1998). Aerodrome control in particular needs special attention, because the technical equipment, information input and possibilities of the controllers to handle traffic are quite different from en-route control. For example, ground controllers can hold aircraft on the ground as long as it is necessary to ensure safety. Tower controllers have no means to hold inbound aircraft. Arrival/departure and en-route controllers have more possibilities in this respect. The basic differences between the various positions should be incorporated into a cognitive process description of the different ATCO jobs, which is one of the objectives of Phase 3 of the ITA project.

During Phase 3 various questions were addressed:

- How can the cognitive processes of en-route control be applied to arrival/departure and aerodrome control?
- How can these results and the process definition be used to characterise the differences in ATCO work between the various countries within the ECAC area?
- Are the cognitive processes involved in the various services qualitatively different or are there any comparable cognitive processes that are adapted to the different demands?
- Can we find differences between the geographical regions?
- Do factors such as experience and age impact on ATCO work?
- Are the cognitive processes dependent on traffic density?

The first steps (after data collection) were to check whether the cognitive processes identified for en-route controllers in Phase 2 could be applied to arrival/departure and aerodrome controllers and to identify any differences. Minor changes were made to the processes for aerodrome controllers but the cognitive process structures have basically remained the same. Differences in processes between en-route controllers and aerodrome controllers are shown in Chapter 3.

The next step was to develop a way to quantify the differences in the way controllers conducted cognitive tasks and subtasks in the various services, regions and traffic situations. These are qualitatively similar (e.g. all controllers have to update their mental traffic pictures and monitoring is a central cognitive process). To quantify these differences, rating procedures were developed to characterise the way controllers perform the cognitive processes which allow them to manage their specific sectors.

Finally, a cluster analysis of data from the ECAC-wide study provided an indication of which positions were similar from a cognitive point of view.

At the end of Phase 3 a feedback and validation meeting was organised with ten controllers who had been involved in the task analysis.

At the final stage of the project, a presentation on the results was made and group discussions were held with experts in selection, training and system development in order to obtain an accurate picture of possible applications of the ITA results. A summary of the ideas is set out in Chapter 9 of this report.

From a conceptual point of view, at least the four following approaches call for a better understanding of how ATCOs manage to guide aircraft through European airspace with a very high level of safety in spite of increasing traffic density and delays:

Situational awareness

The concept of situational awareness (SA) (Endsley 1988; Endsley & Smolensky, 1998; Dominguez, 1994, Durso & Gronlund, 1999) offers the prospect of looking at the jobs and tasks of ATCOs in a cognitive, process-oriented way. The problem of keeping the controllers actively ‘in the loop’, i.e. enabling them to maintain SA, has already been addressed by several authors (Hopkin, 1995; Roske-Hofstrand & Murphy, 1998; Wickens, 1997). While tests for situational awareness are oriented primarily towards memory functions, the concept itself is process-oriented and planning and action play an important role. A process-oriented analysis of ATC in an operational environment might well contribute to a better understanding of how controllers maintain situational awareness in different traffic situations.

Human error research

Human error research has to carefully assess the strengths and weaknesses of the human element in the system. In particular, there has to be a better understanding of the way in which latent errors or manifest problems are compensated for in routine work. A cognitively oriented analysis of the ‘normal’ way jobs are done in Europe will add to the understanding of how slips, lapses, mistakes, and system errors are compensated for or avoided. Up to now most errors have been attributed to the problem of limited resources of the human (working) memory system. Even perception errors, attention failures ('tunnel-vision') or decision errors are often attributed to the limited resources of the working memory system. It is important to note that working memory is only one of several sources of ATC error. Long-term planning, decision-making and establishing a complex goal as well as error management are other important parts of the controllers‘ jobs.

Action theory

Action theory (e.g. Frese & Zapf, 1994) describes goal-oriented behaviour. Viewing the controller’s job from this perspective shows the means by which the controllers achieve their goals and by which problems are solved while controllers do their jobs. It depicts how controllers manage to constantly maintain all separation standards and direct the traffic towards its destination as quickly and safely as possible. The relevant anticipation, planning and decision steps are taken before any action is observable, such as issuing instructions to pilots, coordinating with adjacent controllers, putting down notes on Flight Progress Strips (FPSs) or changing the presentation of the information on the radar display system. This approach also calls for a cognitive-oriented analysis.

Stress and strain analysis

It is necessary to examine how controllers manage workload. Studies on the workload and strain of en-route controllers (e.g. Hoffmann & Lenert, 1994) demonstrate that stress in ATC is quite different from traditional emotionally oriented stress concepts, such as critical incident stress. As reported earlier, controllers find the switch from ‘no traffic’ to ‘high traffic’ within very short time periods very demanding. Why is high traffic following low traffic more demanding than constant high traffic? – Probably because the mental ‘picture’ has to be (re)-established. Preliminary data from our observations and data from a study of Deutsche Flugsicherung GmbH (DFS) (Kastner et al., 1998) show that during ‘taking over the position’, workload indicators like blood pressure and heart-rate variability indicate increased workload. Therefore, a better understanding of the cognitive processes may well add to a better understanding of stress and strain of the controllers.

In summary, there are practical and theoretical grounds for calling for a cognitively oriented task analysis of ATC in Europe which can serve as a baseline reference for future developments and further analyses. A process-oriented approach is needed to give a better understanding of the cognitive processes of controllers in different services and to take account of cultural, technical and geographical differences within the ECAC area. To obtain valid results, the whole set of ITA methods was applied, which includes interview methods, behavioural observations, reconstruction techniques and traditional observation-based interview techniques.

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2. DATA COLLECTION AND ANALYSIS

Various services and regions were included in the data collection of Phase 3 in order to obtain a relatively representative data set on controllers' cognitive processes. Four geographical regions (North, Central, South-East and South-West Europe) and three types of service (en-route sectors, arrival/departure sectors, and aerodrome control) were systematically included in the sample.

Between two and six controllers volunteered in each of the units, giving in a total sample of 82 controllers. In addition, an organisational interview was conducted in order to gather initial information about the unit such as sectorisation, rostering and shift system, equipment, etc.

All ITA methods (cognitive interview, flight progress reconstruction interviews, observation at the work places, post-observational interviews, stress and strain questionnaires, organisational interview) were conducted in English. Data was collected using a standard procedure adapted to the situation of the unit at hand. Even though English proficiency was not checked, it is assumed that the controllers could cope with the interviews and questionnaires.

Two to four observers/ interviewers visited the ATC units during a period of two to four days. An introductory visit by one of the project leaders allowed proper pre-planning of the data collection. The observers were human factors specialists who had been given training consisting of:

- Training by an experienced observer on how to conduct ITA observation and interviews, including a detailed presentation of the different methods and the procedures for application.
- On-the-job observations with an experienced observer followed by debriefing.
- Familiarisation with ATC phraseology as defined in the ICAO Doc 4444.

No experienced controllers conducted the interviews, observations or data analysis.

2.1 Sampling and Description of the Units

Expert ratings moderated by EUROCONTROL were obtained to decide on a fairly representative sample for the ECAC study. The ECAC area was divided into the four regions of north, central, south-east, and south-west Europe, based on considerations such as type and frequency of traffic and probable differences in working practices. For each of the four regions, three units, one en-route, one arrival/departure and one aerodrome, were to be included. The intention was to include a total of six controllers per unit. Owing to the fact that not all units were able to provide six controllers, additional units were included. For en-route control, data obtained from Stockholm and Malmö in the project

Phase 2 was included in the analysis of Phase 3 because these units were studied with the same set of methods.

2.1.1 Service Provision

The final sample consists of seven en-route units, four aerodrome units and four arrival/departure units. For some analyses the sectors were re-classified, because some units provide different kinds of service as explained below:

En-route positions

- ACC/ACC: en-route sector with other en-route sectors as main adjacent sectors.
- ACC/APP: en-route sector with an approach sector as an important adjacent sector.

Arrival - Departure positions

- APP/FEED: approach sector (‘pick-up’) with a final approach sector (feeder) as main adjacent sector.
- FEED/TWR: approach sector with tower as main adjacent sector (usually feeder / final approach position).

Aerodrome positions

- TWR: tower position.
- GND: ground position.

This classification does not take into account further characteristics of the sectors such as their complexity (i.e. number of vertical movements, number of A/C at maximum capacity, etc.)

The number of the participating ATCOs in the different regions and their distribution across type of sector and type of service is given in Table 2.

Table 2: Number of participating ATCOs for regions, sectors and services

Region	N	Sector	N	Service	N
North	20	ACC/ACC	28	En-route	38
Central	18	ACC/APP	10		
South West	18	APP/FEED	6	Arrival/departure	19
South East	26	FEED/TWR	12		
		DEP	1		
		TWR	17	Aerodrome	25
		GND	8		
Total					82

Note: N: number of cases (ATCOs) included in the analysis

Six out of fifteen units are responsible solely for civil air traffic, and in the remaining eight units there is an overlap between military and civil ATC.

Questions and analyses were restricted to civil air traffic. Some controllers commented on the differences between civil and military traffic, which is quite different in terms of regulations, speed, and predictability.

2.1.2 Organisational Environment.

This section gives a broad overview of the information collected during the organisational interviews. Because most of the information was provided in the local language and was qualitative information, it could not be quantified.

As one can see, environment varies considerably from one unit to the others.

The majority of the units are still public-owned.

The number of fully licensed controllers in the units varies between 42 and 400.

The number of workplaces ranges from 4 to 36.

Between 1 and 3 controllers work at the same position.

For all except two units, a watch manager/supervisor is responsible for the position allocation of controllers; in nearly 50% of the cases, the working teams participate actively in the allocation. Few units used fixed schedules.

In six of the fifteen units the controllers are organised in formal teams.

Eleven of the fifteen units use a fixed schedule for shifts (with a maximum of three different patterns of working days and days off). Two units have variable starting times (more than seven starting times). The minimum number of days off between two shift cycles varies between one and three; the maximum number of days off varies between two and six. The maximum number of consecutive working days within a shift-cycle varies substantially among the units (three to twelve days). A normal working period during the daytime varies between 60 and 120 minutes in all units. Staffing is planned independently of the controllers' influence in all units. In all cases controllers have the opportunity to switch or exchange duties with each other.

The average age of ATCOs ranges between 30 and 40.

The percentage of female controllers ranges between 0% and 55%.

The official retirement age also shows a great variability, ranging from 52 to 65.

In 50% of the units, controllers receive regular feedback on their individual performance.

All units provide regular health checks, some twice a year, most of the units once a year and some once every two years. In two units additional physical checks are conducted before each shift and in another unit once a week.

Smoking at the workplace is prohibited in half of the units. In 4 out of 15 units beverages are not allowed at the working position itself.

2.2 Participating Controllers

The total sample consisted of 82 controllers (65 male, 17 female) with an average age of 38.4 years and ranged in age from 26 to 59 years. Job experience ranged from 3 to 28 years, with an average of 12.3 years.

The distribution of controllers across units, regions, and sectors is given in Table 3. To this table have been added the means and standard deviations of the ATCOs' age and the number of female controllers. Aerodrome and arrival/departure controllers were slightly older (on average about 40) than en-route controllers (average about 36).

Table 3: Distribution of the participating controllers across units, regions and sector types, including means and standard deviations in their ages and the number of female ATCOs

Unit	Region	Sector	N	N	Age	
			Total	Female	m	sd
Oslo	North	3=TWR 3=GND	6	1	37.8	8.4
Helsinki	North	2=APP/FEED 2=APP/TWR 1=TWR	5	1	31.6	4.0
Stockholm	North	4=ACC/ACC 1=ACC/APP	5	0	33.6	5.4
Malmö	North	4=ACC/ACC	4	2	34.0	3.5
Bremen	Central	5=ACC/APP 1=APP/TWR	6	1	36.5	9.0
Reims	Central	6=ACC/ACC	6	1	36.0	2.4
Brussels	Central	1=ACC/APP 1=ACC/FEED 2=ACC/TWR 1=DEP 1=Planner* (APP/TWR)	6	1	45.2	1.4
Prague	South East	1=APP/FEED 1=APP/TWR	2	0	39.5	4.9
Rome	South East	4=TWR 2=GND	6	1	44.5	13.6
Athens	South East	3=TWR 3=GND	6	2	40.0	4.2
Sofia	South East	6=ACC/ACC	6	0	32.3	2.1
Varna	South East	4=ACC/ACC 1=APP/TWR 1=Planner* (ACC/ACC)	6	0	33.5	6.7

Table 3: Distribution of the participating controllers across units, regions and sector-types, including means and standard deviations of their age and the number of female ATCOs (continued)

Unit	**Region**	**Sector**	**N**	**N**	**Age**	
			Total	**female**	**m**	**sd**
Lisbon	South West	3=ACC/ACC 3=ACC/APP	6	2	45.5	3.3
Madrid	South West	6=TWR	6	4	40.2	5.0
Barcelona	South West	2=APP/FEED 4=APP/TWR	6	1	40.8	6.1
Total			**82**	**17**	**38.4**	**7.4**

*Qualified radar controller

Note: N: Number of cases (ATCOs) included in the analysis
m: mean
sd: standard deviation

2.3 Procedure

Between two and four observers visited the ATC units for two or three days. Before the observational days started, an organisational interview with the head of the unit or a representative of the unit was conducted by one of the observers. On the day of the first interviews and observations, the participating controllers were given detailed instructions, which took about 60 minutes. Questions about the purpose and the procedure of the study were answered and the confidentiality of the study was assured. During this briefing the different parts of the Integrated Task Analysis (ITA) were incorporated into the working procedures of the unit. The behavioural observations were done in periods of moderate to high traffic density and the interviews were scheduled so as to allow the controllers sufficient break within their working cycles. Normally, one additional controller on duty was needed to fill in the time which was spend on the interviews. Usually, data was gathered in the following sequence:

- The cognitive interview, which lasted about 60-90 minutes;
- The observation at the working position, which also lasted 60-75 minutes;
- The post-observational interview and the flight progress reconstruction interview, which took 45-75 minutes;
- The stress and strain questionnaires, which took about twenty minutes.

Where necessary, the cognitive interview was re-scheduled and not necessarily conducted in this sequence.

2.4 Data Analysis

2.4.1 Interview Data

Data from the organisational interviews was categorised and summarised in a Microsoft Excel spreadsheet.

Data from the flight progress reconstruction interviews and the cognitive interviews was transcribed and underwent qualitative content analysis. Qualitative data analyses of the cognitive interviews and the flight progress reconstruction interviews are described in detail in the Chapters 3 and 4. The planned recognition exercise with controllers did not take place owing to time constrains.

The ratings that resulted from the qualitative analyses were entered into a PC system and statistically analysed using the SPSSPC statistical software. Services (en-route, arrival/departure and aerodrome and geographical regions were checked for significant differences using non-parametric statistical significance tests (Mann-Whitney U-Test; Kruskal-Wallis H-Test).

Differences were termed ‘significant’, if the statistical probability that the observed difference is ‘true’ and not due to random effects was 95% or higher. In this case the remaining risk (P) to interpret random differences as ‘true’ differences is not more than 5%. For highly significant differences, P is not more than 1%.

2.4.2 Behavioural Observation, Post-observational Interviews and Stress-Strain Questionnaires

Data from the rating scales for the post-observational interview, the frequency counts from the behavioural observations and the ratings of the stress and strain questionnaires were entered into a PC system and statistically analysed using the SPSSPC statistical software.

The independent variables sector-type or service and geographical regions were checked for significant differences, using a one-way analysis of variance.

ATCOs’ ratings of the traffic load within the observation period were included into the statistical analysis of the observation data as a co-varying variable. This was done so that significant differences between, for example, sector-types that are simply due to differences in traffic load would not be included.

Differences were termed ‘significant’ if the statistical probability that the observed difference was ‘true’ and not due to random effects, was 95% or higher. In this case the remaining risk (P) to interpret random differences as ‘true’ differences is not more than 5%. For highly significant differences P is not more than 1%.

3. BASIC COGNITIVE PROCESSES OF AIR TRAFFIC CONTROL

3.1 Introduction

Ten different basic processes could be identified in the en-route controllers' task in Phase 2 of the project; these are shown in Table 4.

Table 4: The basic cognitive processes of ATC

4 Sub-processes	⇨ Updating mental picture / maintaining situational awareness ⇨ Checking ⇨ Searching conflicts ⇨ Issuing instructions
1 Control Process	⇨ Switching attention
5 Task Processes	⇨ Taking over position / building up mental picture ⇨ Monitoring ⇨ Managing routine traffic ⇨ Managing requests / Assisting pilots ⇨ Solving conflicts

Interrelations between sub-processes and task processes are shown in Figure 1.

It should be emphasised that these basic cognitive processes represent a simplified model of the ATC task. For this reason their validity in representing the 'true' cognitive processes of ATC must be considered to be restricted:

- The aim is to provide the reader with a structured description of the cognitive processes in ATC. However, the flowcharts probably do not yet meet the logical requirements of a computer simulation program.
- The cognitive processes have been named after their contents. In some instances e.g. for the processes of 'monitoring' or 'managing routine traffic', the names might not correspond completely with the general idea of the terms in ATC. They should be regarded as labels for the respective process.

- The processes refer only to normal traffic situations. Very exceptional conditions (e.g. extremely bad weather) or emergencies have not been considered.

- They do not reflect individual working styles or sector peculiarities, but should rather be seen as a common denominator in the interview data we collected in different units.

- Since task-sharing between radar controllers and planning or coordinating controllers is handled in different ways within the various units we did not include this aspect in the processes. The cognitive processes refer only to the task of a radar or executive controller.

The intention is to be able to visualise the cognitive ATC processes we derived from our data, with the emphasis on particular aspects we considered important. The processes are therefore closely related to our sample of ATCOs, their working conditions and the methods we used. However, our sample of ATCOs and units may nevertheless be considered balanced and representative enough to provide valuable results and to throw light on current cognitive processes in ATC within the ECAC area.

In Phase 3 the ITA method was also applied to arrival/departure and aerodrome positions. Consequently, the validity of the basic cognitive processes derived from the analyses of en- route controllers' tasks had to be re-checked regarding the arrival/departure and aerodrome controllers' tasks.

In order to validate our results, a meeting was organised with a group of ten ATCOs from nine different units who had participated in the ITA. Results were presented and explained in small working groups and they were asked to give their comments and feedback. Only minor corrections had to be introduced to the cognitive processes following this feedback from experts.

The results were as follows: the basic cognitive processes also apply to arrival/departure and aerodrome positions. The structure of the processes developed for en-route control remains basically the same despite some slight adaptations.

For the four sub-processes and the control process there seem to be no major differences between the three positions. Of course some situational conditions vary, e.g. the view outside or the wind display are important information sources for aerodrome controllers.

For the five task processes no major differences emerged regarding the structure of the processes between en-route and arrival/departure control. For aerodrome control, only the task process "taking over position" had to be slightly adapted. General differences between the three positions were found to relate mainly to the **parameters of the processes** such as timing, complexity and speed of processing or frequency of certain processes.

In Chapters 3.2 to 3.4 we will explain the differences between en-route, arrival/departure and aerodrome control in detail for each process. Processes which had to be adapted as a result of structural differences are shown for both en-route and aerodrome control.

3.1.1 Basic Cognitive Processes: Data Processing and Analysis

The steps in the data analysis of the interviews in order to obtain the basic cognitive processes are briefly reviewed (see Phase 2 Report [EATMP, 1999a]):

The cognitive interviews and the flight progress reconstruction interviews were transcribed and the transcript was carefully cross-checked by an experienced interviewer/observer. In cases of doubt, the original recording and the transcript were compared and any differences were corrected. The processing of the interview data is summarised in Figure 2.

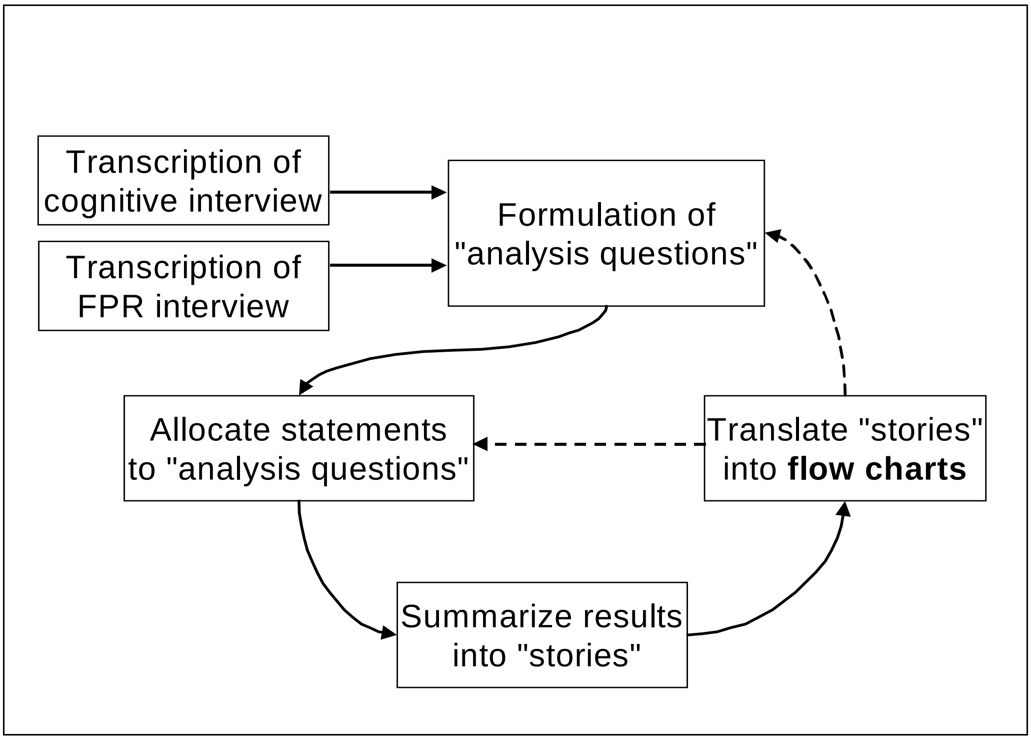


Figure 2: Steps of qualitative data processing in order to obtain the basic cognitive processes

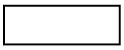
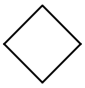
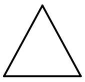
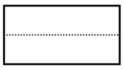
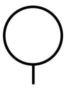
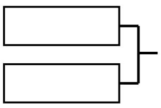
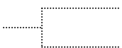
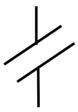
The standard procedure for qualitative data analysis includes formulation of analysis questions following the transcription and correction of the transcripts. These analysis questions were closely related to interview questions, taking into account the cognitive processes found in Phase 2 of the project. All of the controllers' answers were allocated to the analysis questions. The allocated answers were summarised into stories which describe what the controllers do, for example, when they take over the position. The stories were checked again by one of the experienced observer and complemented with the answers to the flight progress reconstruction interviews. In the next step the stories were cross-checked with the flowcharts of en-route control from

Phase 2 of the project and necessary changes were introduced for arrival/departure and aerodrome control.

3.1.2 Graphical Representation of the Processes

A classical flowchart approach is used to present the core processes of the ATC task. The symbols used for the flowcharts are depicted in Table 5.

Table 5: Symbols and notation used in the flowcharts

	Action field / activity
	Optional action field; skipped under certain conditions
	Decision field
	Named task process or sub-process
	Simultaneous action / activity
	Start: indicates start of process / subprogram Exit: return to main process
	And / or junction
	Comment
	Time buffer

Note: Different fill colours are used to indicate a separation of the memory processes (light grey), evaluative/decision processes (dark grey), and observable behaviour (no shadow/white).

3.2 Sub-processes for En-route, Arrival/Departure and Aerodrome Control

No major differences were identified between the sub-processes of en-route, arrival - departure and aerodrome control. Of course some situational conditions vary, e.g. the view outside or the wind display are important information sources for aerodrome controllers.

3.2.1 Sub-process 1: Updating Mental Picture/Maintaining Situational Awareness

En-route control

The process of maintaining situational awareness is equivalent to maintaining a valid mental traffic picture. From a cognitively oriented point of view this is the very core sub-process of ATM. It is part of all the other sub-processes and task processes. The process, which starts with the mental picture, is represented in Figure 3.

The en-route controller's anticipations are usually realised. This realisation confirms the mental picture and their SA is maintained. In cases where the mental picture and the actual situation do not correspond beyond the en-route controller's mismatch tolerance level, the en-route controller tries to find an explanation (diagnosis). The mental model of the sector and similar situations are normally used to find this explanation. Repeated mismatches between the en-route controller's expectations and the actual situation can lead to the building up of a 'mental error model', e.g. when interpreting an unidentified blip on the radar screen as a radar reflection after having experienced this several times. 'Mental error models' can be sources of error when they are not recognised as such, e.g. when the unidentified blip is not a radar reflection but an unidentified aircraft. Diagnosing a mismatch normally includes an active check of external information, which has to be integrated in the mental picture.

Arrival/departure control

There is no structural difference between the process of updating the mental picture / maintaining situational awareness in en-route and arrival/departure control. However, regarding the parameters of the process, the anticipations included in the mental picture do not reach so far into the future. The integration of new information into the mental picture is aimed more towards the updating of a short-term sector action plan.

Aerodrome control

There is no structural difference between the process of updating the mental picture / maintaining situational awareness in en-route and aerodrome control despite the fact that the information sources used (e.g. the view outside) are different. Also, compared to en-route control, the aerodrome controllers' anticipations are more short-term and the update of the mental picture serves the maintenance of a short-term action plan.

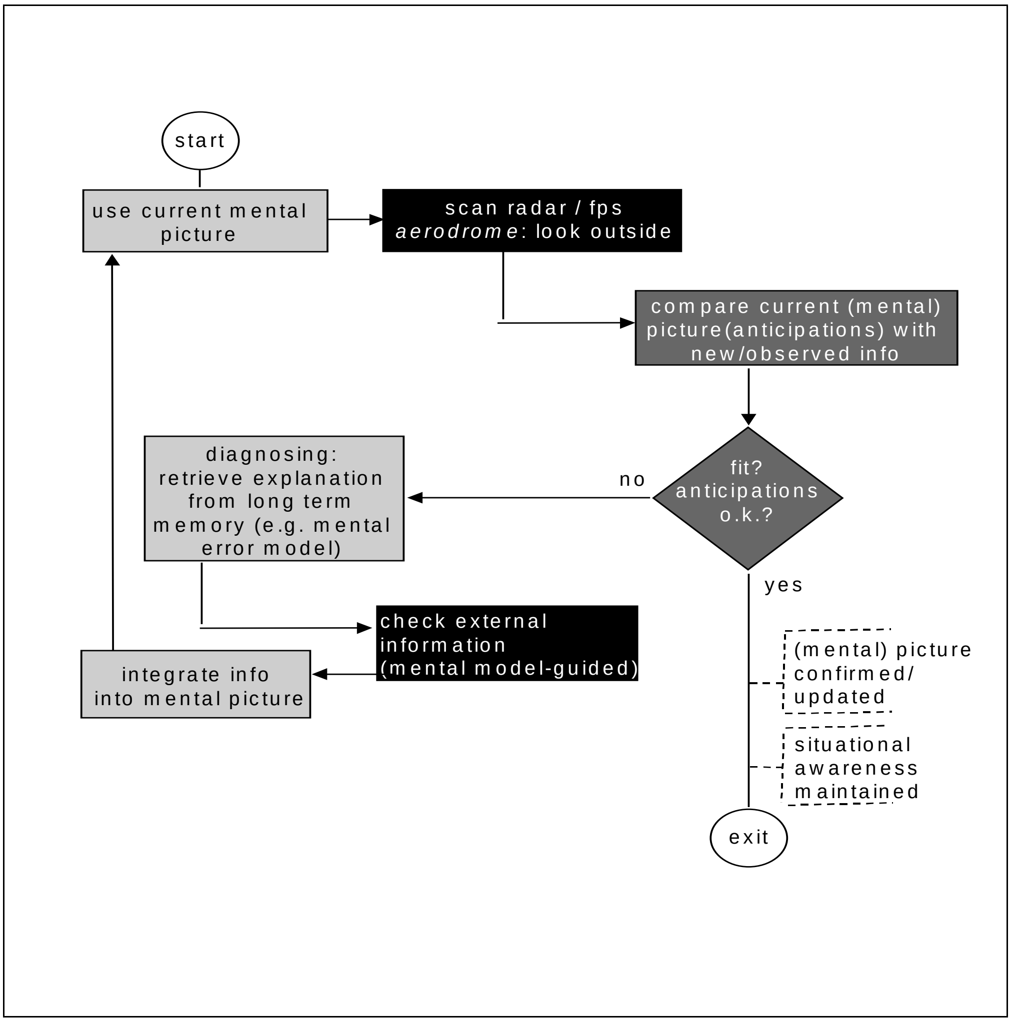


Figure 3: Sub-process 1: Updating mental picture / maintaining situational awareness

3.2.2 Sub-process 2: Checking

En-route control

Checking (see Figure 4) is the second central sub-process and is based on the cognitive process of checking as described in the 'Model of the Cognitive Aspects of Air Traffic Control' (EATCHIP, 1997a).

When the en-route controllers carry out the checking they deliberately direct their attention to external information sources such as the radar screen, Flight Progress Strips (FPSs), certain information displays, reminders they have set themselves (e.g. notes or highlighted FPSs), or they may ask for certain information. Also, particularly at the beginning of a working period, the equipment may be checked. The information check is generally triggered when the en-route controllers receive new or unexpected information or by the en-route controllers' suspicion or presumption that something might not be going as expected or planned.

After a deliberate check for information the mental picture will be confirmed or updated.

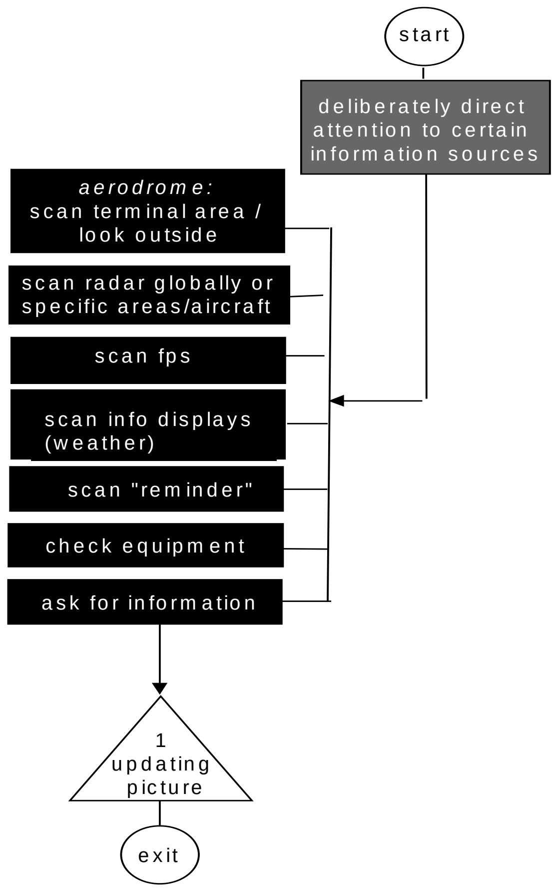


Figure 4: Sub-process 2: Checking

Arrival/departure control

Regarding the checking process no differences can be identified between en-route and arrival/departure control.

Aerodrome control

There is a slight difference between the checking process in aerodrome and en-route control. In aerodrome control the view outside is a crucial source of information. The importance of the different information sources and frequency of checking them is therefore different. As the mental picture changes more quickly, the checking process is presumably run more often.

3.2.3 Sub-process 3: Searching Conflicts/Checking Safety

En-route control

Detecting conflicts is another of the core cognitive tasks of the en-route controllers, shown in Figure 5. The conflict search starts with the en-route controllers receiving external information, e.g. by monitoring aircraft on the radar screen, by receiving new FPSs or by receiving requests. The en-route controllers extract the relevant data for the assessment of a potential conflict: level, route, time estimates, and speed of the aircraft. In doing so, the en-route controllers retrieve other, possibly conflicting aircraft including their relevant data. This is not a random process but is guided by the en-route controllers' mental model, since they usually know where in the sector conflicts are more likely to occur. This has been termed the ‘conflict possibility library’. For a more precise assessment radar tools are used.

The data of the aircraft are mentally integrated and future developments are anticipated or predicted: the en-route controllers estimate whether the aircraft are going to conflict or not. This is followed by an update of the mental picture.

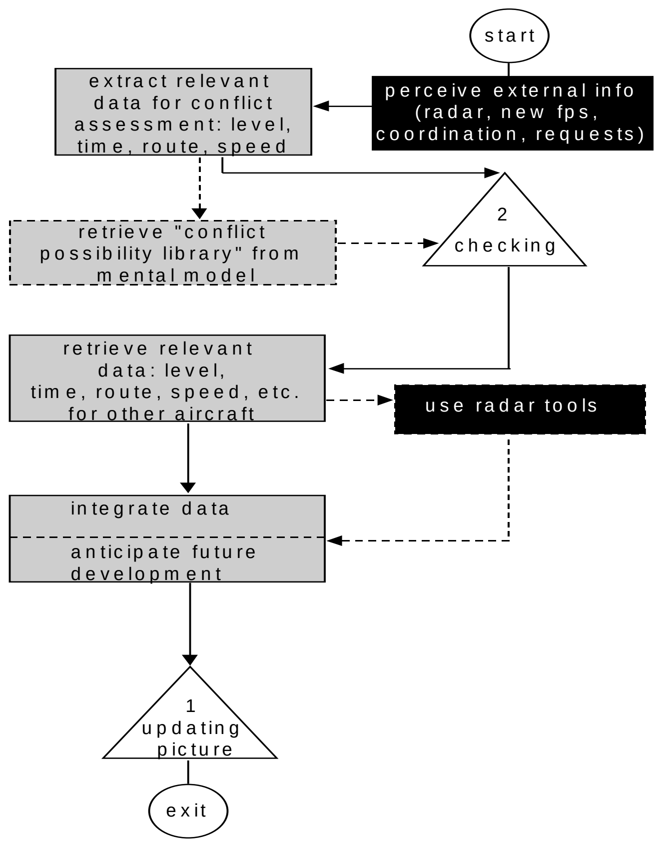


Figure 5: Sub-process 3 for en-route / arrival/departure control: searching for conflicts/checking safety

Arrival/departure control

In general the process is the same for arrival/departure control, as can be seen from Figure 5. Conflict detection of arrival/departure controllers is, however, focused more on information from the radar screen than from FPSs. As the entire traffic cannot be planned too far in advance, conflicts are not detected as early as they are in en-route control.

The speed of the aircraft is of central importance for controllers in arrival sectors in particular, since they must not allow aircraft to catch up on each other.

Aerodrome control

Generally, the process remains the same for aerodrome control (see Figure 6) as in arrival/departure control, the main source of information in detecting potential conflicts is not the FPSs but the view outside and the radar screen. The ‘conflict possibility library’ is supplemented by the finding that aerodrome controllers rely a lot on their personal experience when evaluating potential conflict situations. Experience forms their expectations about the reliability or competence of pilots from certain countries or certain companies. For example the decision whether to let an aircraft take off between two landings or not, often depends on the aerodrome controller's trust in the pilot. If he thinks that the aircraft will take off immediately, he might clear the aircraft for take-off. If he has any doubts about this, e.g. because he knows that pilots of airline XY usually take their time after getting the clearance, he might prefer to hold the aircraft. In our sample of aerodrome units, ATCOs did not use radar tools for conflict assessment. However, depending on the equipment and the sector structure, there might be exceptions to this finding. Tower controllers face a high variability of scenarios resulting from the mix of pilots' experience, type of A/C, impact of weather conditions, etc.

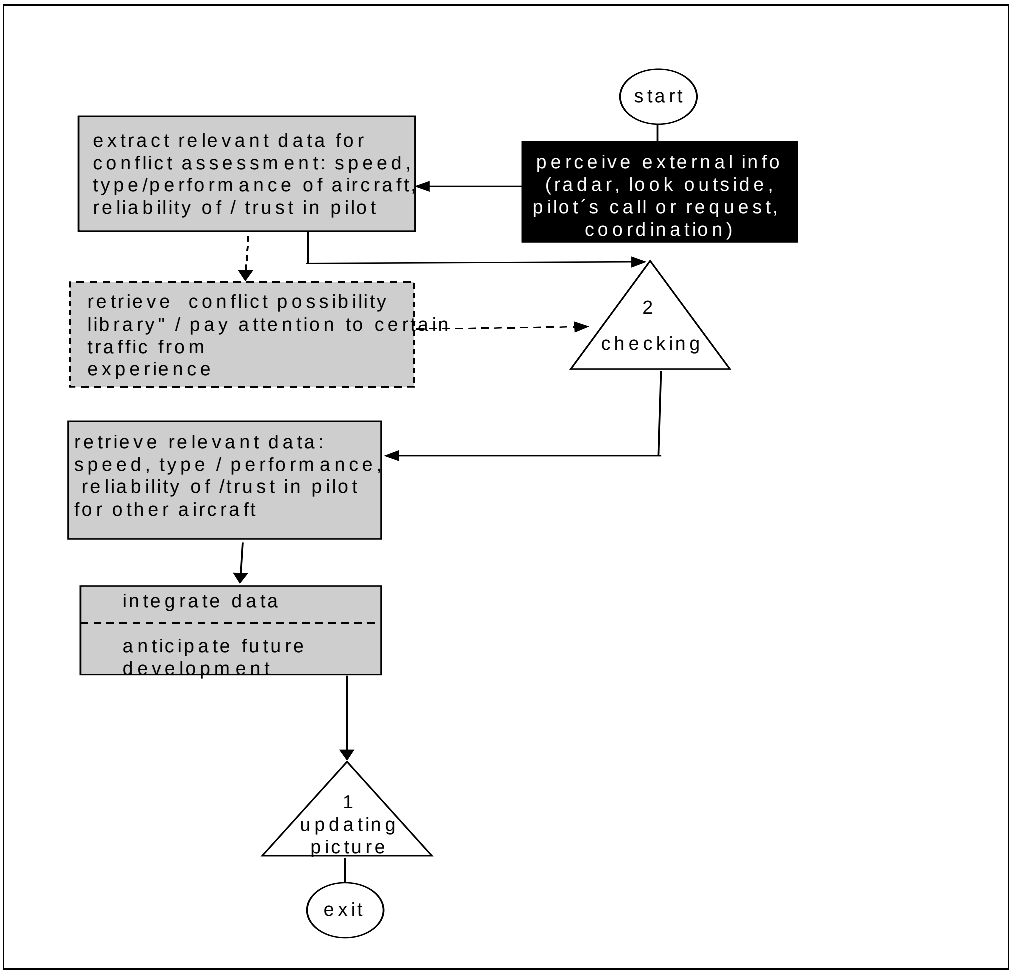


Figure 6: Sub-process 3 for aerodrome control: Searching for conflicts / checking safety

3.2.4 Sub-process 4: Issuing Instructions

En-route control

Issuing an instruction is one of the most habitual actions of the en-route controller. The ‘issuing instructions’ sub-process demonstrated in Figure 7 is always activated when it is necessary to instruct or inform pilots in a given timeframe. Accordingly, the decision as to timing is the most important function of the ‘issuing instructions’ sub-process. The mental picture, the short-term sector plan and a cognitive ‘script’ of the control action govern the issuance of instructions or information. The ‘script’ is highly automated and normally subconscious. Monitoring the readback and the expected changes are fixed elements of the issuing instructions sub-process. The en-route controller usually does a brief check after each instruction. If the pilot does not follow the instructions properly or did not receive the given information, the en-route controller evaluates the consequences of the deviation or failure for safety and for his plans. If the deviation compromises safety or is crucial for the plan, the ‘issuing instructions’ sub-process has to be run again immediately. If this is not the case there may be no need to react immediately and the en-route controller will leave the issuing instructions sub-process and returns to the higher task process. Sometimes several routine instructions, e.g. handing over aircraft to the next sector, are chained or given in sequence. In this case the en-route controller repeats the issuing instructions sub-process several times before returning to the higher task process.

Arrival/departure control

No major structural differences could be identified. Depending on the position, issuing instructions is probably done more often within a certain period of time, particularly at arrival positions (i.e. pick-up and feeder) (see Chapter 5).

Aerodrome control

No major structural differences could be found. However, issuing instructions is probably done more often within a certain period of time but is also related to the amount of traffic (see Chapter 5).

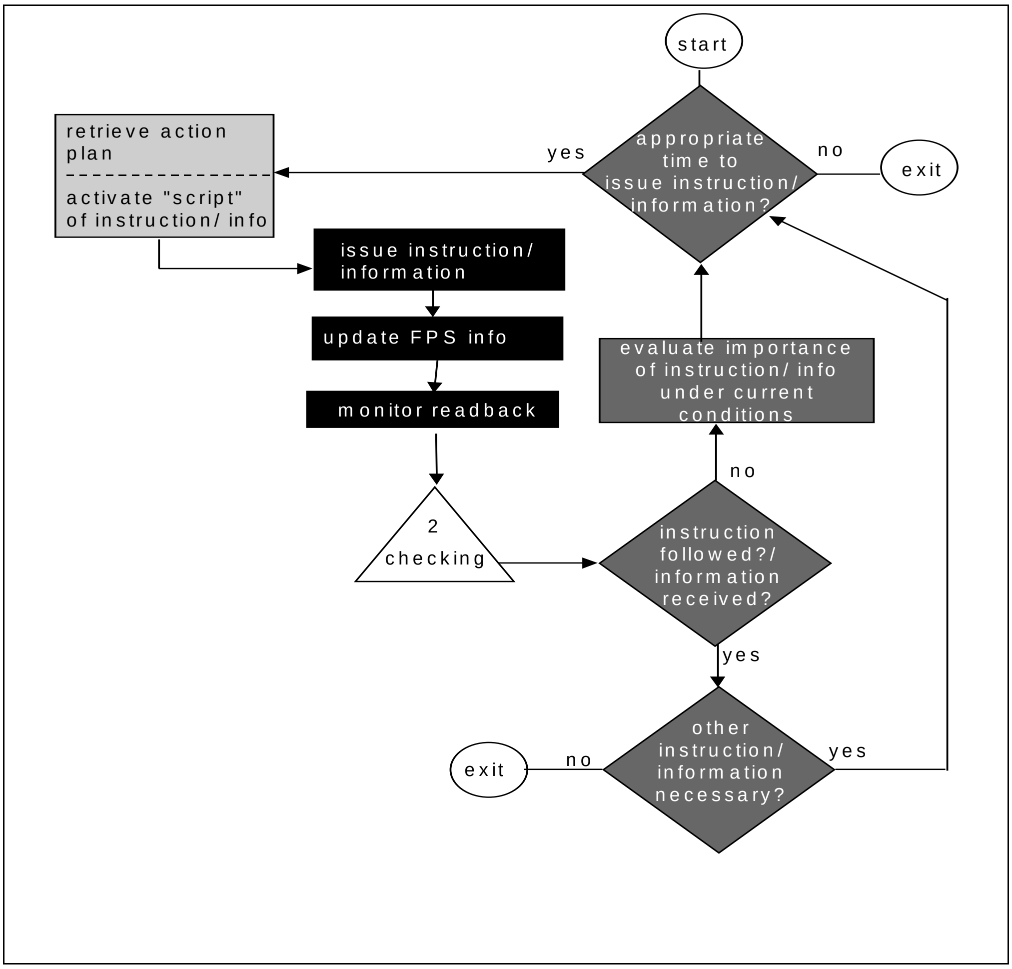


Figure 7: Sub-process 4: Issuing instructions

3.3 Control Process for En-route, Arrival/Departure and Aerodrome Control

3.3.1 Control Process: Switching Attention

En-route control

This process takes into account those aspects of multitasking in which several parallel tasks are executed consecutively by the alternate switching of attention. If a certain task requires a high level of concentration, attention must be divided between this task and other highly demanding tasks.

This is particularly the case in high traffic load conditions when the number of routine tasks (e.g. scanning the radar screen, R/T communication) increases, as does the number of potential conflicts. Resolving a conflict is a task that requires a high level of concentration and therefore, in situations where several conflicts have to be resolved, attention has to be switched almost all the time. This is also the reason why the switching of attention is a very important process in conflict resolution.

En-route controllers actively try to avoid having too many tasks pending. Many of them state that, especially in times of high workload, they follow a fixed sequence of (part-) tasks, which allows them deliberately to do one thing after another. This requires an appropriate and adaptable sector plan.

The process (see Figure 8) begins with a review of the sector plan or action hierarchy. Based on the current mental picture, the en-route controller checks and assesses whether there is a task which takes priority over the current task (e.g. monitoring a potential conflict in the conflict-resolving task process). If the result is negative the controller focuses on the current task or activity and exits the attention-switching process. In this case this process is just to check for tasks of higher priority.

If there is a higher-priority task, the en-route controller subconsciously sets a ‘time window’ and integrates it into the sector plan. In his mind he does an update of the action hierarchy and, in order to ensure that he returns to the previous unfinished task, he may set himself a reminder, e.g. flag an FPS. Then there is a switch to the higher-priority task. Within the ‘time window’ he fades out the other tasks while he focuses on the highest-priority task. As long as the ‘time window’ is not exceeded, the en-route controller will focus on this task of highest priority. At the end of the ‘time window’, a checking sub-process is undertaken. If the highest-priority task is highly automated and of predictable length (e.g. answering a pilot’s first call), there may be no need to monitor the time window. At the end of such a task, the en-route controller will switch directly to the checking sub-process.

After the highest-priority task is completed, the en-route controller will review his action hierarchy, do another check and return to the assessment of whether there is a task which takes priority over the current task. If there is, he will repeat the attention-switching process. If there is not, he will return to the task within the higher-task process.

If the highest-priority task is not completed at the end of the time window the en-route controller sets himself a mental or visible reminder and updates and reviews the action hierarchy. After having undertaken another check he comes back to the assessment of whether there is a task which takes priority over the current task process activity. This could be, depending on his action hierarchy, a new task or the previous unfinished task. If he considers the previous unfinished task to be the task of highest priority he will repeat the sub-process by setting a new time window. If a new task is considered that of highest priority, he will open up a new time window, but will also have to keep an open or unfinished task in mind.

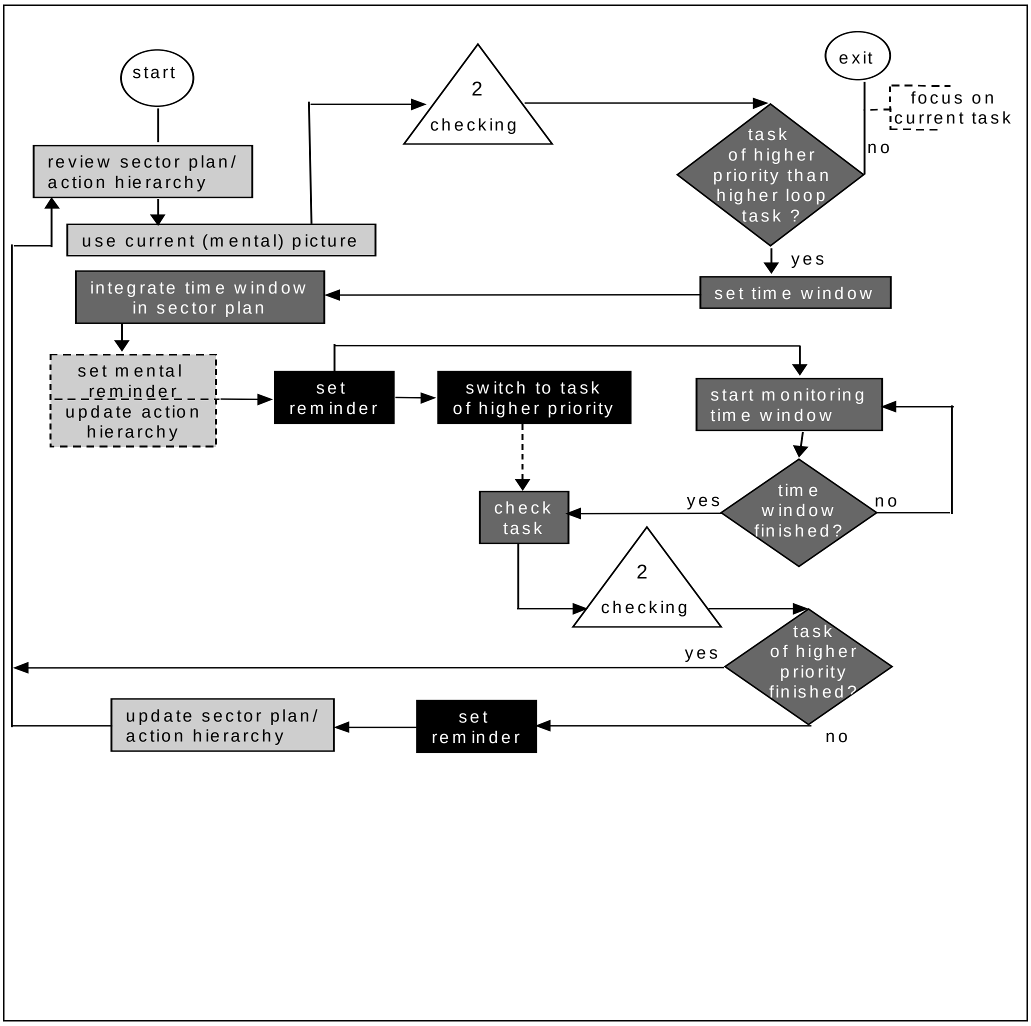


Figure 8: Control process 1: Switching attention

It is clear that, in the case of unfinished tasks of higher priority, the attention-switching process cannot be exited. This means the en-route controller is caught up in tasks of higher priority, and there is a risk that they might not come back to the unfinished previous task. In such situations there is always a risk that the en-route controller might forget something and this risk increases the more often the en-route controller puts aside an unfinished task in favour of a task which appears to be of higher priority. Particularly in the case of on-the-job-trainees or inexperienced en-route controllers, this can be a major source of error. A high risk of memory overload arises in this situation.

Arrival/departure control

The 'attention switching' control process remains unchanged for arrival/ departure control.

Aerodrome control

The 'attention switching' control process remains unchanged for aerodrome control.

3.4 Task Processes for En-route, Arrival/Departure and Aerodrome Control

3.4.1 Task Process 1: Taking over Position/Building up Mental Picture

En-route control

As can be seen from Figure 9 the taking-over position process starts with a pre-shift briefing. In most countries, in any case, the pre-shift briefing is compulsory. However, it may be a self-briefing under certain circumstances. In some units, where an en-route controller has been working on a regular basis and there have not been any major changes since his last shift, the pre-briefing was skipped.

The en-route controller walks up to the position. While he is doing this, he is already recalling the sector peculiarities regarding the actual conditions such as traffic density and weather.

Most en-route controllers first check the radar, then the FPSs. Shortly afterwards, the en-route controller is briefed by the previous en-route controller. In high traffic density situations it may be that they have to monitor the ongoing action for a while before the previous en-route controller has time to brief his successor. By first checking and integrating the actual information into their mental model, they establish the mental picture and the first inferences about the previous en-route controller’s sector plan.

The next step is to anticipate or predict future traffic developments, including a first check for conflicts. If no conflict is expected, a sector plan is formulated, the mental picture is updated again and the en-route controller evaluates the situation as safe: he feels comfortable with the situation and takes over the position.

If conflicts have to be resolved, the en-route controller normally adopts the previous controller’s plan and takes over. As soon as the active controller finds time, he develops his own sector plan and continues in his personal way of handling the traffic.

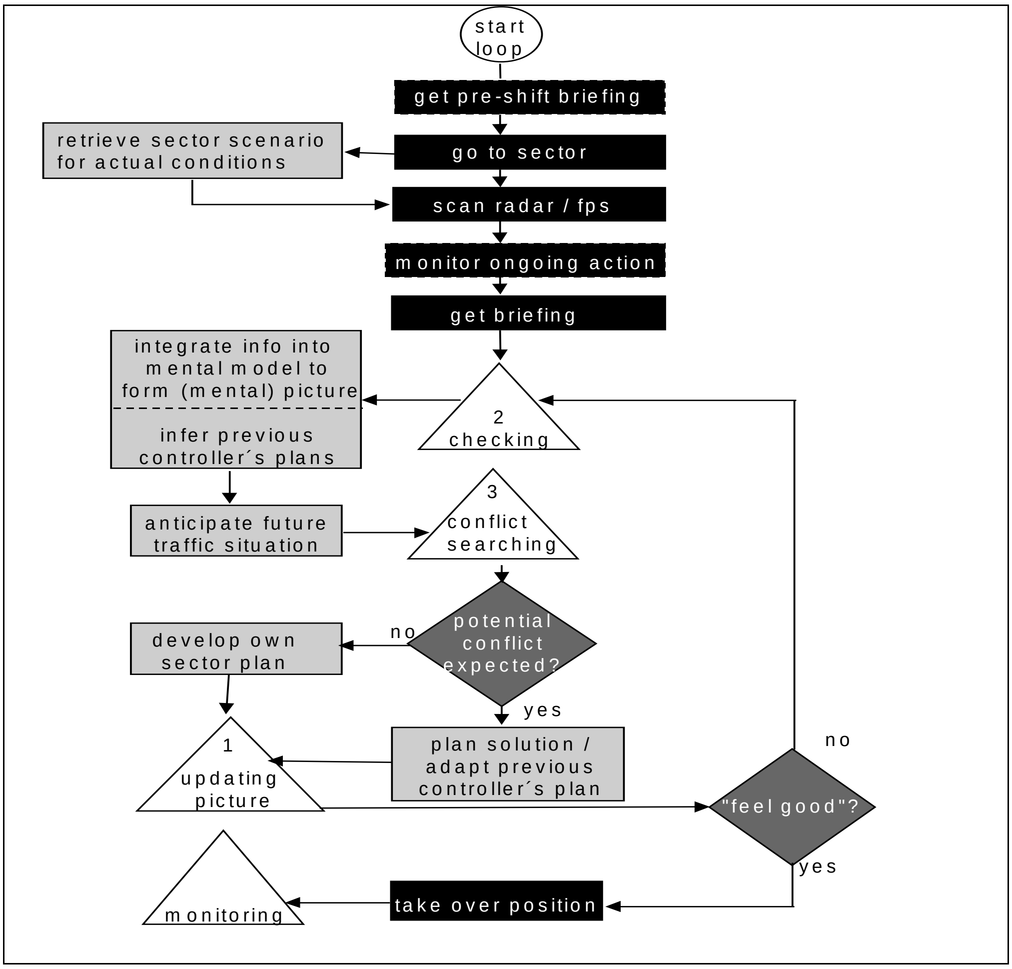


Figure 9: Task process 1 for en-route / arrival/departure control: Taking over position / building up mental picture

Arrival/departure control

For arrival/departure controllers the 'taking over the position and building up mental picture' process is almost the same as for en-route controllers, as can be seen from Figure 9. They are given a pre-shift briefing if necessary, they walk up to the position and recall the sector peculiarities.

The arrival/departure controller checks the radar screen and the FPSs, but the emphasis clearly lies on the information from the radar screen. The briefing is conducted in the same way as it is for en-route controllers.

For controlling arrival/departure traffic the anticipation of future traffic developments takes less time. The traffic is not planned or anticipated as far in advance as it is in en-route control. For this reduced pre-planning time the controller’s intentions and the next steps in handling the traffic after having taken over are clear.

A check for conflicts is carried out but conflicts are usually resolved by the controller who is still in charge before the handover of the position.

The change to an individual working style is not emphasised by arrival/departure controllers.

Aerodrome control

As can be seen from Figure 10 the process starts with a pre-shift briefing.

In most countries, in any case, the pre-shift briefing is compulsory. However it may be a self-briefing under certain circumstances. In some units, where an aerodrome controller has been working on a regular basis and there have not been any major changes since his last shift, the pre-briefing was skipped.

The aerodrome controller walks up to the position and gets a first impression of the traffic situation by having a look outside at the aerodrome environment (aircraft taxiing, aircraft in holding or waiting for departure on the runway), the radar screen and the weather display. Meanwhile he is already recalling the peculiarities of the position regarding the actual conditions such as runways in use and weather conditions. Shortly afterwards he is briefed by the previous aerodrome controller. By retrieving the standard action plan from the mental model and updating it with the actual information he establishes the mental picture.

The next step is to anticipate future traffic developments, including a first safety check. If they expect a potential safety problem, it is usually up to the previous controller to solve it. If no potential conflict is expected the aerodrome controllers evaluate the situation as safe: he feels comfortable and takes over the position.

Generally, the major difference between taking over the position in an en-route and aerodrome position is the qualitative and quantitative amount of pre-planning of the following actions that have to be done after taking over the position. In routine traffic situations the aerodrome controllers hardly need to plan their task deliberately, but simply implement a highly automated standard action plan. On the other hand potential conflicts put the aerodrome controllers under more strain since the time windows for solving the safety problems are usually extremely short and require immediate action. For this reason aerodrome controllers usually do not take over the position from the previous controller if they recognise a potential safety problem.

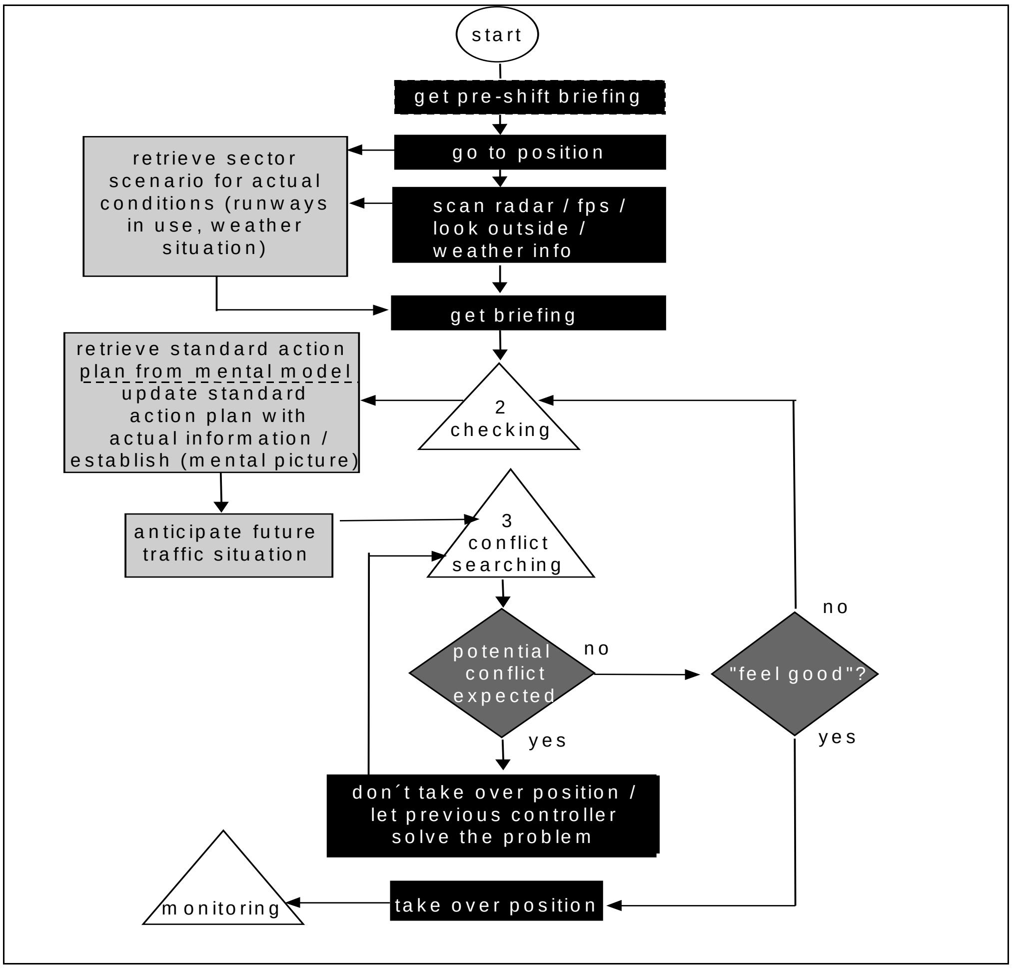


Figure 10: Task process 1 for aerodrome control: Taking over position/ building up mental picture

3.4.2 Task Process 2: Monitoring

En-route control

The monitoring process (see Figure 11) is closely related to routine traffic management and is constantly repeated while en-route controllers are in position. It starts with an update of the mental picture and a conflict search. When the mental picture is confirmed the en-route controller updates his sector plan and, at the same time, particularly under high workload conditions, checks the action hierarchy and the next and most urgent things to be done.

If it is necessary to take action, the 'monitoring' process leads to three alternative task processes:

- if a potential conflict is expected, the 'solving conflicts' process is activated;

- if the en-route controller receives a request, the 'managing requests/ assisting pilots' task process is run;
- otherwise the routine traffic-managing task process is activated.

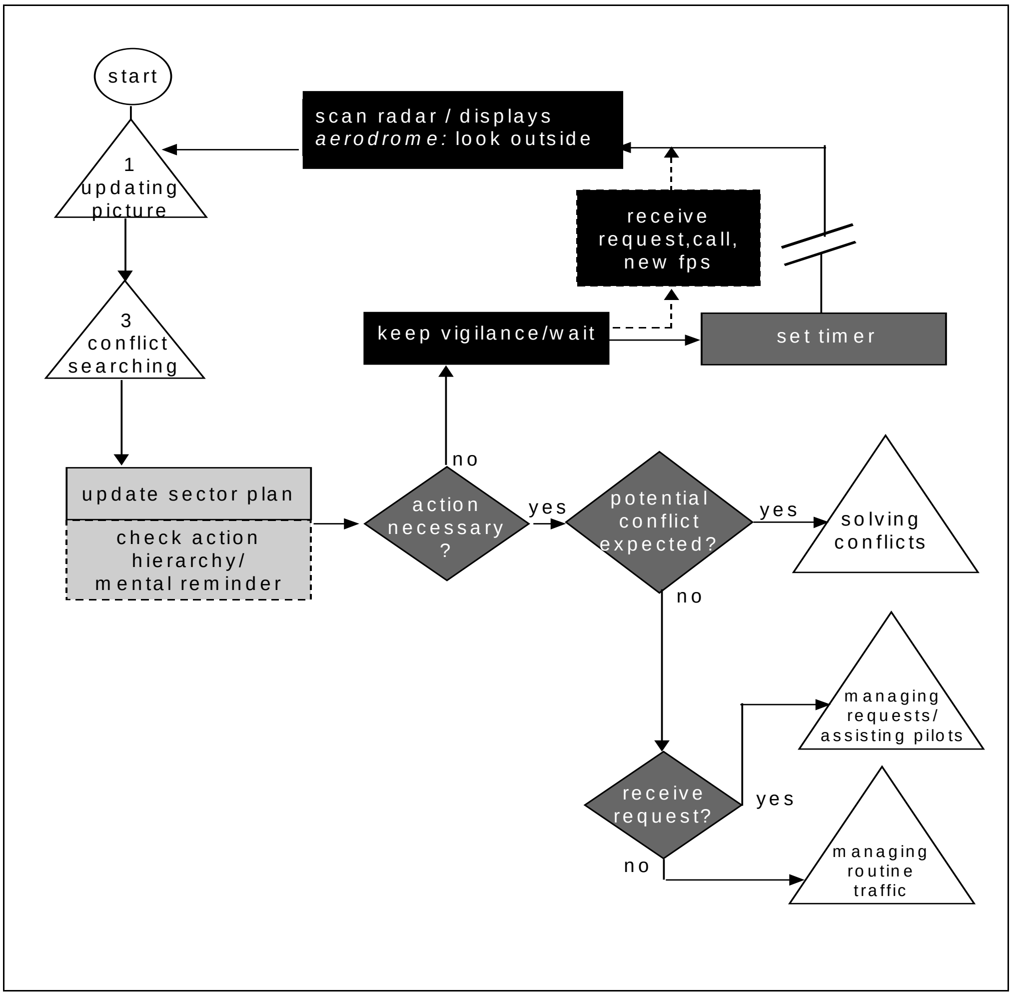


Figure 11: Task process 2: 'Monitoring'

If no action is required and there are no new inputs such as requests, calls or new FPSs, en-route controllers have to wait for things to happen. This situation occurs in low traffic periods: suddenly there is nothing to do, but en-route controllers must nevertheless remain vigilant. In such situations they often pursue side activities or chat with their colleagues. From time to time they have to switch their attention back to the radar screen to update their mental picture and re-do the monitoring task process. This switching back seems to be ruled by a kind of subconscious/highly-automated timer that en-route controllers set when turning their attention away from a task. The switching back of their attention is triggered immediately when receiving new inputs like requests, calls or new FPSs, symbolised by the independent action field.

If, during this period of waiting, remaining vigilant, their attention is distracted, this can be a major source of error. Most en-route controllers report that, in low traffic periods when activation decreases and concentration lapses or the controller becomes distracted, mistakes are more likely to occur, especially if the low traffic period follows a high traffic period.

Arrival/departure control

The monitoring task processes of arrival/departure control and en-route control are basically the same.

Aerodrome control

The monitoring task processes of aerodrome control and en-route control are basically the same.

3.4.3 Task Process 3: Managing Routine Traffic

En-route control

Figure 12 describes the management of routine traffic, with the cognitive sub-processes of conflict searching, checking and updating the mental picture which results in maintaining situational awareness and also the 'issuing instructions' sub-process, which are part of routine traffic management.

Standard management of routine traffic takes place as long as normal calls from pilots and flight progress information are coming in. The cognitive sub-processes of checking and conflict searching determine whether the en-route controller has to continue monitoring or to resolve a potential conflict.

Arrival/departure control

The routine traffic-managing process of arrival/departure control is structurally the same as for en-route control.

However, there are some slight differences regarding the parameters for the processes. Arrival/departure positions can differ considerably: they may include, for example, combined arrival/departure positions, arrival-only or departure-only positions, approach and final approach positions. This variety suggests that the main tasks to be conducted on a given position may appear different.

In general, the main task of a controller on an arrival/departure position is to build the sequence of incoming traffic and send the departing traffic safely to the en-route control. For this sequencing task some information about the aircraft takes on more significance, such as speed, performance, weight category and entry flight level of the aircraft. Particularly in final approach positions the controller focuses mainly on establishing the sequence of aircraft and his task is therefore more uniform.

There is less time available for pre-planning of the traffic in arrival/departure control than in en-route control. It is still possible for an arrival/departure controller to plan in advance, but compared to en-route, he cannot plan that far in advance and has to react more often to events triggered by the situation.

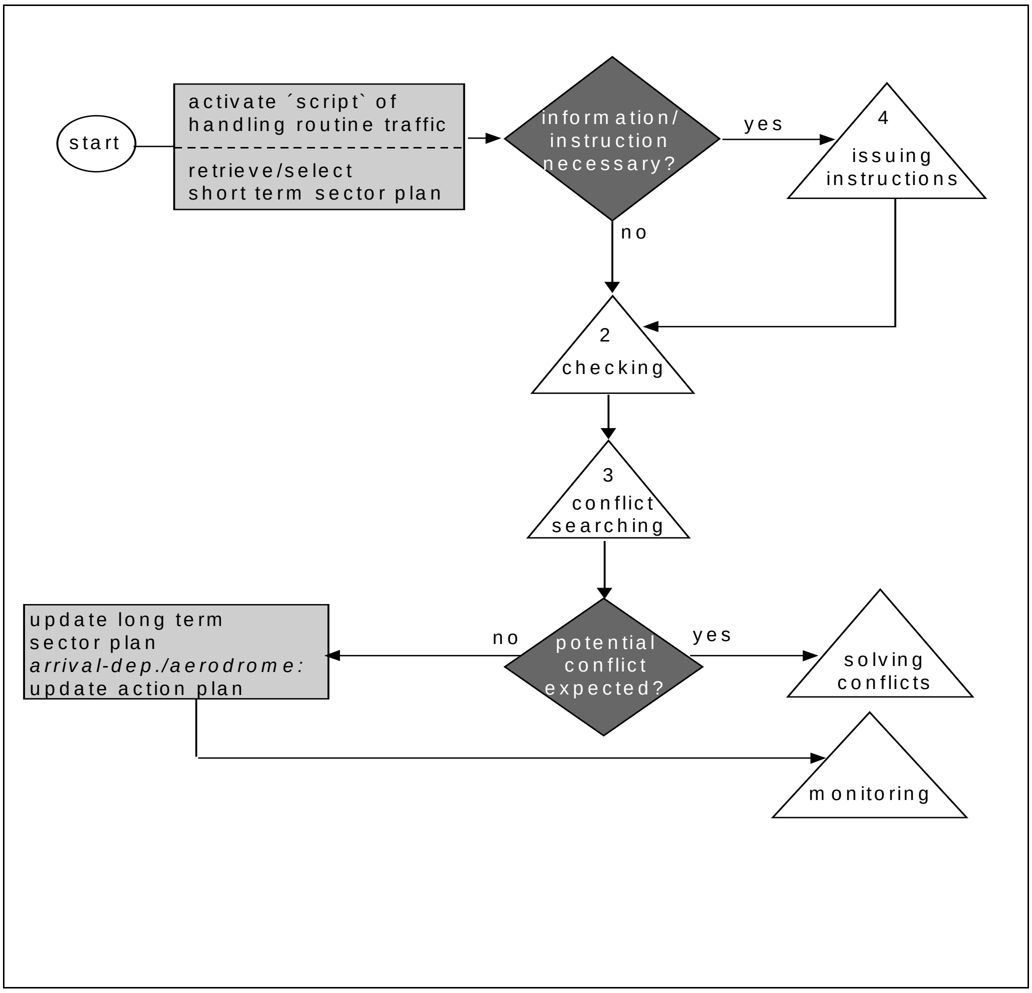


Figure 12: Task process 3: Managing routine traffic

Aerodrome control

Regarding the structure of the process there are no major differences between aerodrome control and arrival/departure or en-route control. However, there is quite a difference regarding the parameters for the 'managing routine traffic' process, particularly regarding the speed of changing situational conditions and, therefore, the speed of decision-making and the selection of appropriate action.

A peculiarity of the aerodrome control task is that most aerodrome controllers also report that, under high workload conditions, they have to work more expeditiously. This is most probably true for all controllers as the traffic is continuously increasing. For aerodrome controllers, it implies a **reduction** in the number of safety buffers. As regards the safety-efficiency dimension of decision-making criteria, the balance will move more in favour of efficiency and aerodrome controllers may make more risky decisions in order to keep the traffic flowing.

As an example, if there is only one runway or crossed runways for arrivals and departures,

- in low traffic density the task is not very demanding or may even be boring, because the aerodrome controllers can always make sure that they have sufficient separation before they give takeoff-clearance to departing aircraft;

- in high traffic load situations, the time windows for putting a departure between two arrivals are much tighter, and aerodrome controllers have to make very precise estimations and to reach instant decisions. In such situations aerodrome controllers rely a lot on their experience, e.g. which airline pilots they can rely on to do immediately as requested.

Most aerodrome controllers regard this situation as very demanding or stressful. This is quite understandable especially if it is seen in the light of most en-route controllers` 'instinctive' strategy to **increase** the number of safety buffers in order to cope with high workload situations, e.g. by establishing more level-based separations instead of lateral separations (see Sperandio, 1977).

Another difference between routine traffic management in en-route and aerodrome positions is the possibility of pre-planning the traffic. In contrast to en-route controllers who are usually able to pre-plan their traffic up to ten or fifteen minutes in advance, aerodrome controllers have to work very much on an ad hoc basis. According to our data, the time between first noting the new traffic to taking over responsibility does not exceed a maximum of five minutes and in most cases is even shorter (see Chapter 4.1.4). In routine traffic situations the aerodrome controllers hardly need to plan their task deliberately, but simply implement a highly automated standard action plan.

3.4.4 Task Process 4: Managing Requests/Assisting Pilots

This process refers only to 'normal' requests of pilots, e.g. requests for direct routings or different flight levels on economic grounds. It does not apply in cases of priority or emergency.

En-route control

Additional decisions (see Figure 13) are made in the case of pilot requests. Based on the current mental picture and sector plan, the alternatives have to be evaluated according to the following criteria: safety, own workload and workload of the adjacent controller. If the current workload is heavy, en-route controllers usually deny requests (e.g. for direct routing) in order to relieve their own workload or that of their colleagues.

If the workload is moderate, the time or resources are available and no conflicts or problems are expected for the requested course of action, the requests are normally approved. If conflicts are expected but sufficient time is available, alternative plans might be coordinated. In this case, even in routine traffic management, concentration levels must be changed. As soon as a decision is reached about the request, the 'issuing instructions' sub-process is activated. The managing request process ends by returning to the monitoring process.

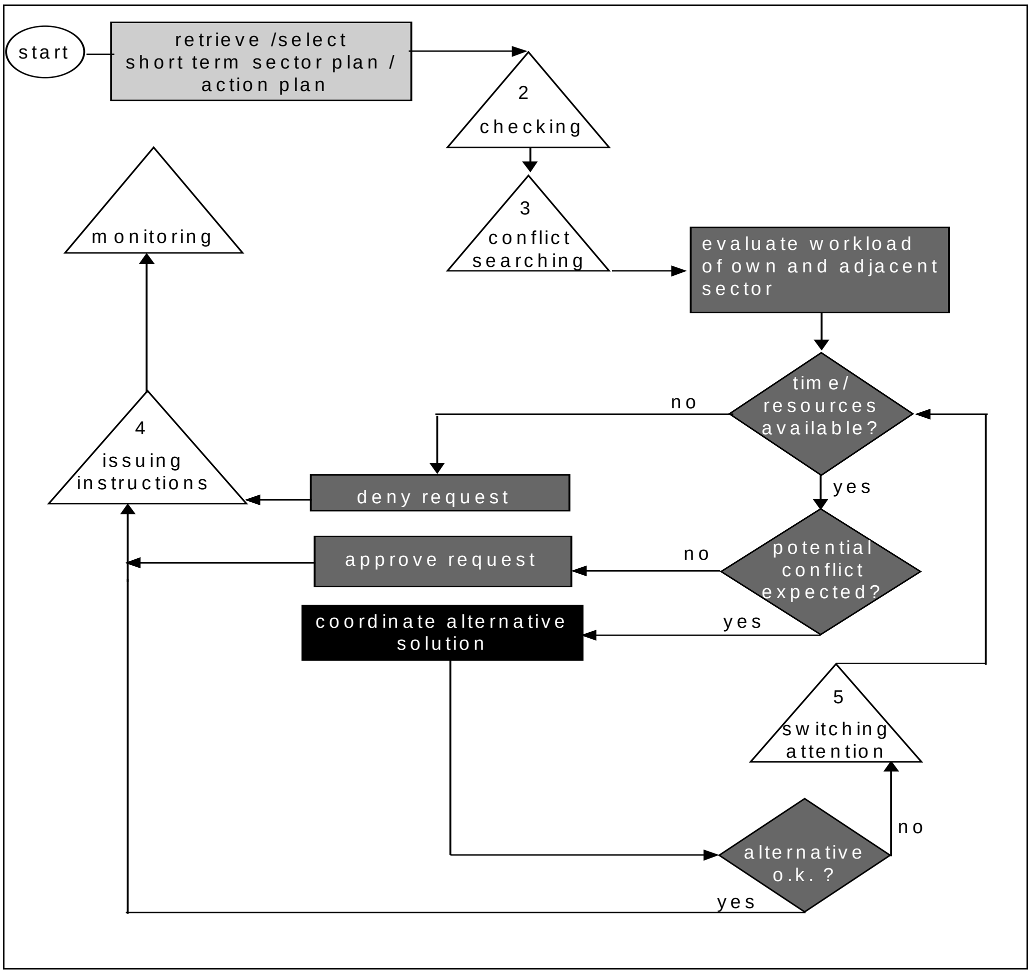


Figure 13: Task process 4: Managing requests / assisting pilots

Arrival/departure control

The 'managing requests/assisting pilots' process also applies to arrival/departure control.

Aerodrome control

The structure of the process is basically the same for aerodrome control. The only differences concern the parameters of the process:

Owing to the time constraints of their task, aerodrome controllers usually make final decisions about requests instantly. Coordinations with pilots and colleagues about alternative solutions in the event that a request cannot be approved, are rather rare. In contrast to this, many en-route controllers reported that they coordinate alternative plans if they cannot approve a request. However the number of possible alternatives for TWR is smaller as a/c become less free to manoeuvre when close to landing or during departure.

3.4.5 Task Process 5: Solving Conflicts

En-route control

The 'solving conflicts' process (see Figure 14) starts when a potential conflict is expected. The en-route controllers have to decide whether they are going to act regarding the conflict right away or whether they are going to monitor the potential conflict for a while. If they decide on 'monitoring', they have to direct their attention to the problem from time to time, symbolised by the 'attention switching' process.

When they decide to act to resolve the conflict they must try to retrieve an instant solution from their experience-based memory. According to one en-route controller's statement in the interview, it was called a ‘conflict solution library’. Since the most common and frequently used solutions are thought of first, they may also be called ‘routine solutions’. This process can be disturbed by requiring a switch of concentration to another task or problem, e.g. when receiving calls. The retrieved solutions also have to be evaluated, taking into account the current situational conditions. If routine solutions cannot be applied or are regarded as unsatisfactory, the en-route controllers have to review their ‘conflict solution library’ for less habitual solutions or have to switch to knowledge-based problem-solving. After the en-route controllers have found the best solution for the present they must then coordinate with colleagues where necessary. In many cases the “issuing instructions” process has to be run prior to coordination owing to the urgency “

Before the en-route controllers actually issue the instruction to the pilots, there may be a requirement to switch attention to a task of higher priority. After having issued and checked the instruction, represented by an 'issuing instructions' sub-process, a decision field is reached. If the problem or conflict is finally resolved, the mental picture is updated and the en-route controllers turn to the next problem, starting the conflict resolution process again or switch back to monitoring. If the problem is not solved by the en-route controllers' action, they must resort to their backup plan.

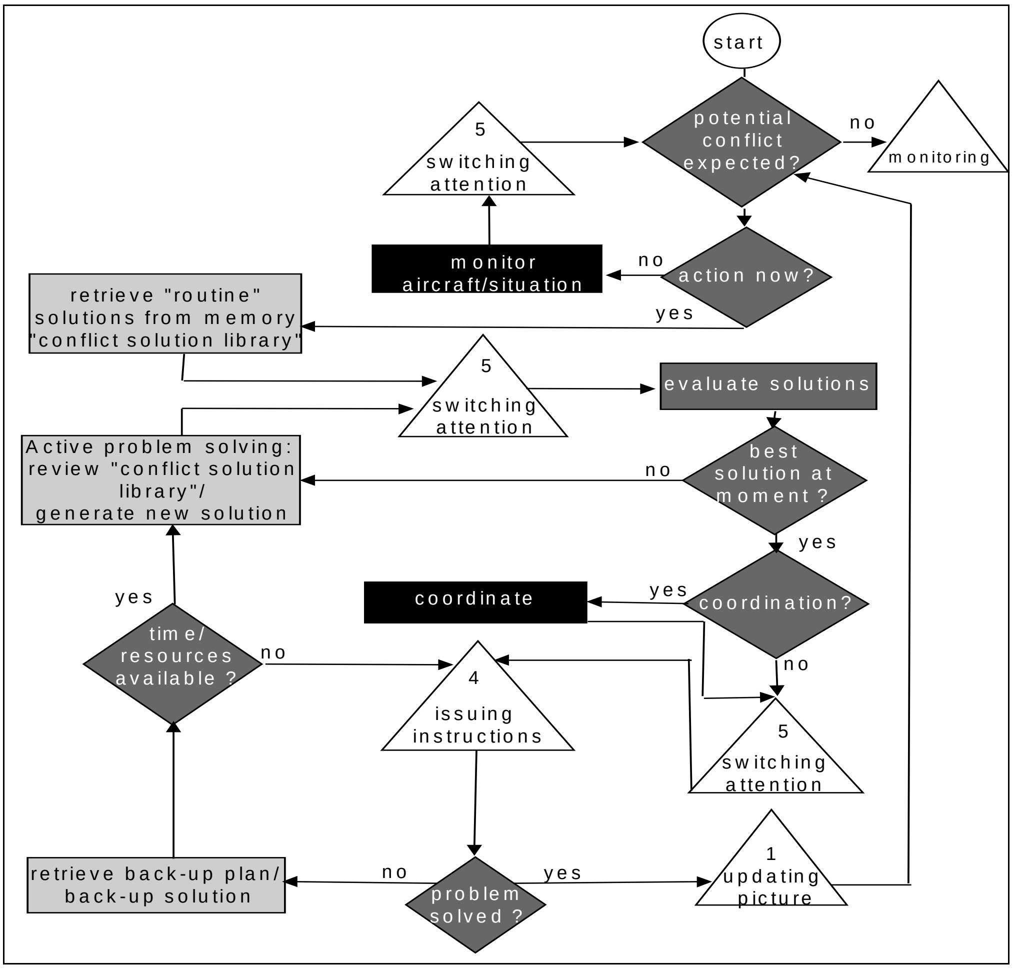


Figure 14: Task process 5: Solving conflicts

A backup plan is usually characterised by being safe but not efficient. For this reason, if there is some time available, the en-route controllers will try to find a new solution other than the backup plan. If there is no time left they will implement the backup plan and continue with the 'issuing instructions' sub-process.

Arrival/departure control

In arrival/departure control the conflict-resolving process is structurally the same as in en-route control. The only differences relate to the parameters of the process:

One difference concerns the monitoring of a conflict situation. Even if the controller decides to monitor the situation instead of acting on it right away, he still retrieves a conflict solution from his memory as a kind of backup plan. This is necessary in order to be able to react immediately should the situation become more dangerous.

As there is less pre-planning time in arrival/departure control, the time left to resolve a potential conflict is shorter as well. The 'conflict solving' process itself is not changed due to this fact even if the speed of its execution may be accelerated.

Aerodrome control

The structure of the process also applies to aerodrome control. The only differences identified concern the parameters of the process such as an increased speed of execution:

In aerodrome control the time windows for resolving potential conflicts or safety problems are usually very short and require immediate action. Aerodrome controllers also do checks for other tasks of high priority, as is symbolised by the attention-switching process but, because of time pressure resolving the potential conflict is usually the task of highest priority.

Similarly, in situations where their original plan does not work out because of time constraints, aerodrome controllers rarely review their ‘conflict solution library’, but rather instantly implement the backup plan.

3.5 Feedback from Participating Controllers

A feedback and validation meeting was held with controllers involved in Phases 2 and 3 of the project.

The objectives of the meeting were:

- To receive the feedback from the controllers on the results and mainly on the structure of the cognitive processes description
- To ensure that no mistakes were introduced as a result of the way the data was processed;
- To ensure that the wording and terminology used in the cognitive processes are corrected;
- To get the controllers’ views on how useful the results could be in operational units.

Ten controllers from nine units representing en-route, arrival/departure and aerodrome control attended the meeting.

Minor changes were suggested to improve the cognitive process diagrams and the wording.

Initially, slight differences were identified between the cognitive processes of en-route, arrival/departure and aerodrome controllers. In the controllers’ view, the differences were due mainly to situational differences such as the time constraints in the different services being provided. They believed that the structures of the processes remain the same. Based on that comment, most of the diagrams presented in Chapters 3.2 to 3.4 are similar for the different services.

The need to highlight some limitations arising from the use of the diagrams for depicting the cognitive process was suggested. Those limitations, such as the fact that the diagrams are a kind of common denominator of what was said by the controllers involved in the study, are mentioned in Chapter 3.1.

The participants felt that the cognitive process diagrams reflected the job very well and could be very useful for the OJT instructors (most of them were OJT instructors) as a support for explaining the job to trainees, even if it might be assumed that this was done during pre-OJT.

In order to provide instructors with a more handy presentation of the cognitive processes and their interrelation, a poster was designed. This poster is available in different sizes (for more details contact EUROCONTROL - DIS/HUM fax: +32-(0)2-729.9149).

3.6 Basic Cognitive Processes of Air Traffic Control: Summary

Ten basic processes could be identified in the en-route controllers' task in Phase 2 of the project:

Five task processes:
- Taking over position / building up mental picture
- Monitoring
- Managing routine traffic
- Managing requests / assisting pilots
- Solving conflicts

One control process:
- Switching attention

Four sub-processes:
- Updating mental picture
- Checking
- Searching conflicts
- Issuing instructions

In Phase 3, the ITA method was also applied to arrival/departure and aerodrome positions and the validity of the basic cognitive processes derived from the analysis of en-route controllers' tasks was re-checked regarding arrival/departure and aerodrome controllers' tasks.

The results were as follows: the basic cognitive processes also apply to arrival/departure and aerodrome positions. The structure of the processes developed for en-route control remains basically the same despite some slight adaptations.

For the four sub-processes and the control process there seem to be no major differences between the three services. Of course, some situational conditions vary, e.g. the view outside or the wind display are crucial information sources for aerodrome controllers.

For the five task processes no major differences emerged as far as the structure of the processes between en-route and arrival/departure control was concerned. For aerodrome control only the 'taking over position' task process had to be slightly adapted. General differences between the three positions were found to relate mainly to the **parameters of the processes** such as timing, speed of processing or frequency of certain processes. In arrival/departure, and even more so in aerodrome control, traffic cannot be planned so far in advance as in en-route control, which has a serious effect on the ATCOs' timing. In addition, compared to en-route control, some basic cognitive processes are performed more often (e.g. issuing instructions) or their speed of execution is accelerated (e.g. solving conflicts).

4. COGNITIVE PROFILES OF AIR TRAFFIC CONTROL

This chapter describes the procedure and the respective results of the analysis of cognitive interview data and data from the flight progress reconstruction interview. The obtained results were called ‘cognitive profiles’.

4.1 Cognitive Interview

The following section focuses on the analysis of the cognitive interviews and the resulting cognitive profiles.

4.1.1 Cognitive Interview: Data Processing and Analysis

The first step in the data analysis of the cognitive interview was a transcription of the tape-recorded interview. An experienced interviewer carefully cross-checked the transcript. In cases of doubt, the original recording and the written transcript were compared and any differences were corrected.

Top-down/Bottom-up Ratings

Ten different basic processes could be identified in the en-route controllers’ task in Phase 2 of the project. In Phase 3 of the project the ten basic processes were then used to demonstrate the similarities and differences of ATC working positions in the ECAC area. In order to be able to compare the basic processes of different ATC working positions, an appropriate common dimension for their assessment had to be found. For this purpose the concept of top-down versus bottom-up information processing was chosen. The importance of top-down information processing has already been stressed in EATCHIP (1997a). In general, top-down and bottom-up processes were defined as follows:

Bottom-up processes are those activities that are controlled by external cues and commands. The term is also used to describe behaviour that is primarily driven by incoming information. Bottom-up behaviour can be characterised as being reactive or data-driven behaviour. The automation process turns simple activities into situational-driven bottom-up behaviour, i.e. highly automated activities are often simply triggered by external cues.

Top-down processes are activities that are governed by plans, mental models, intentions and rules. Top-down behaviour can be characterised as being proactive or concept-driven behaviour. Coping with a new traffic situation is typically top-down.

Actions can be characterised by their position on the bottom-up/top-down scale. The following box shows the rating scale that was defined to assess the basic cognitive processes:

Bottom-up / top-down rating scale

0 Rating not possible

1 definitely bottom-up

2 more bottom-up

3 equally bottom-up and top-down

4 more top-down

5 definitely top-down

Since the general definition was too broad to be of any use in assessing the basic cognitive processes, criteria were defined. The ATCOs' statements in the cognitive interview were used as indicators to refine the rating from a bottom-up/reactive to a top-down/proactive way of doing the task.

Certain criteria were laid down for the basic processes. The sub-process 'checking' was omitted, as it is by definition a top-down process. Additionally, a rating of ATCOs' information processing in general was introduced in order to be able to give a rating about their tendency to work bottom-up or top-down, even where the interview did not provide enough information to rate every single basic process. Table 6 shows the most important defined criteria for the top-down/bottom-up ratings. A complete table of the rating criteria is given in Annex A.

A trained analyst rated each of the basic cognitive processes and the general information processing. '0-ratings' (where a rating is not possible because of lack of information) were excluded from further statistical calculations, which resulted in various numbers of valid cases for each of the basic processes.

The analyst also documented his subjective certainty in doing the ratings (certainty rating). For this purpose a seven-point-scale ranging from 0 ('not at all') to 6 ('very high') was used.

A total number of 80 cognitive interviews were analysed. Two interviews with a certainty rating below 3: ('medium certainty') were excluded from statistical analysis. All ratings were documented in a structured evaluation sheet.

Table 6: Criteria for top-down/bottom-up ratings

Basic Process	Clues for a Data-guided Bottom-up Process	Clues for a Concept-guided Top-down Process
Take over position/ build up MP	• less directed intake of information or rather no active search for information • only a very short period of pre-planning or very little/ no active pre-planning • active planning only starts after take over of position	• directed intake of information considered relevant: 'active' process; ATCOs know exactly what information they need and obtain this information • transformation into a traffic plan of their own, possibly after the evaluation of the previous ATCOs' plan (adopt or alter plan) • ATCOs' own planning before the position is taken over
Monitoring	• the ATCOs emphasise scanning of the 'whole picture'; often use 'monitoring' and 'scanning' as synonyms • all aircraft are monitored simultaneously , each getting the same amount of attention • backup rate: the more traffic, the more scanning	• clue for 'foreground- background' picture (i.e. action-relevant aircraft become the focus of attention, 'hello-goodbye' aircraft get less attention) • certain aircraft are scanned more often, generally getting more attention
Managing routine traffic	• only very short 'pre-planning'; automated schematic handling of routine traffic • often short-term changes of action- relevant situational conditions, so that the plan must be changed quickly • the (sector)-plan is quite rough or schematic, so that it can be adjusted quickly to take account of changed situational conditions • planning is mainly based on radar picture/ looking outside	• pre-planning over as long a time as possible • emphasis on importance of pre-planning • planning is based on FPSs
Managing requests/ assisting pilots	• requests are not anticipated; no 'pre-planning' of pilot's requests • requests are handled in a re-active way • no clues for adjustment with ATCO's own plan (i.e. in order to accept requests the ATCO is ready to make quite demanding or short-term alterations to the plan) → not valid for 'emergency-requests'	• certain requests have already been anticipated and been included in the plan • 'expected' communication problems are 'included in the plan' • the criterion 'capacity of the colleague in the next sector' is included in the decision to accept a request • clues, that request is only accepted if it does not interfere too much with the ATCO's own plan

Table 6: Criteria for top-down/bottom-up ratings (continued)

Basic Process	Clues for a Data-guided Bottom-up Process	Clues for a Concept-guided Top-down Process
Solving conflicts	• tendency to 'monitor' a potential conflict, in order to act only when absolutely necessary • extremely automated, schematic 'resolving' of conflicts • emphasis on ability/ necessity to react quickly, to find solutions quickly	• early resolution of potential conflicts; pre-planning of conflict solutions over longer term • emphasis on necessity to resolve potential conflicts by planning/ prevention • 'backup' plan exists • clue for 'conflict solution library' (i.e. when resolving conflicts, the ATCO falls back on his experience)
Updating mental picture	• scanning: very broadly and very frequently • no experience-guided categorisation of aircraft (except by type, performance) • error detection: (e.g. by scanning everything)	• rather selective/ or specific checking and global check is quite rare • experience-guided categorisation of aircraft • clue for 'foreground-background' picture • error-detection: (i.e. certain potential errors are anticipated from experience)
Searching conflicts/ Checking safety	• conflicts are mainly detected by scanning the radar • radar screen or rather a look outside from the tower are the main sources of information in detecting conflict situations	• role of FPSs: planning function, conflict detection function, FPSs are used for searching for potential conflicts • frequent use of radar tools for pre- planning, conflict-assessment • clue for 'conflict possibility library' (i.e. ATCO knows from experience in which part of the sector conflicts are more likely to occur)
Issuing instructions	• requests are not anticipated; no pre-planning of pilots' requests • clearances are handled in a re-active way (only when requested by pilot) • all readbacks get the same amount of attention	• certain requests have already been anticipated and included in the plan • 'expected' communication problems are 'included in the plan'; ATCO adjusts his instructions according to the language and experience level of the pilot • special attention for readbacks in certain situations

Table 6: Criteria for top-down/bottom-up ratings (continued)

Basic Process	Clues for a Data-guided Bottom-up Process	Clues for a Concept-guided Top-down Process
Switching attention	• 'action plan' is rather rough, so it can be adapted quickly to meet changed situational conditions • emphasis on flexibility, on ability 'to switch quickly and change the plan'	• emphasis over the long term, proactive pre-planning of air traffic; tendency to stick to action plan with explicitly established priority
General information processing	• there is virtually no active pre-planning or rather there is only very short-term pre-planning • traffic is handled schematically, extremely automated • clue/ statement, that planning is hardly possible, e.g. because there is no time for it • conflict search/ detection mainly by 'scanning' of the (whole) traffic situation • no experience-guided categorisation of aircraft • 'holiday' question: when it is no problem getting used to work again, settling in period is not necessary, when the ATCO says that he has achieved 100% performance after e.g. 1-2 hours	• ATCO works with his mental model to a great extent or rather often mentions that personal experience is very important. • emphasis on pre-planning • pre-planning function of FPSs • preventive planning of 'safety buffers' into situations that are difficult to predict • detection of conflicts by experience / knowledge of 'conflict points' or critical points in the sector • experience-guided categorisation of aircraft, e.g. by airlines. • anticipation/ planning of possible 'disturbances' • 'holiday question': answers that e.g. he is not as fast any more, has to pay greater attention, first works on a more quiet position; it takes some time to get used to work again (e.g. 1 day or more)

4.1.2 Factor Analysis of Ratings

In order to check the interrelations of ratings for the ten basic processes the data was subjected to a factor analysis[3]. For this purpose 0-ratings (where a rating is not possible because of lack of information) were excluded. It showed that the ratings of some basic processes are highly correlated whereas other basic processes are not correlated at all. Ratings for basic processes that have a high correlation can be grouped together as a factor. Three factors were extracted:

‘Pre-planning style’, includes the basic processes of taking over position, managing routine traffic, resolving conflicts, searching for conflicts and switching attention.

[3] Factor Analysis is a statistical technique commonly used to identify a relatively small number of factors which can be used to represent relationships among sets of many interrelated variables.

'Updating the mental picture style' contains monitoring and updating the mental picture.

'Pilot instructing style' includes managing requests and issuing instructions.

General information processing is equally correlated with the 'pre-planning' and 'updating the mental picture style' factors.

For every cognitive interview factor counts were calculated by computing the mean ratings of the underlying basic processes. These three factor counts were used for some statistical analyses instead of the original ten process ratings in order to account for missing data due to 0-ratings. The distribution of 0-ratings is documented in the appendix.

4.1.3 Top-down/Bottom-up Ratings: Differences between En-route, Arrival/ Departure and Aerodrome Positions

Figure 15 shows the mean ratings of en-route, arrival/departure and aerodrome controllers` basic cognitive processes. The numbers in the diagram represent the levels on the rating scale: 1 ('definitely bottom-up'), 2 ('more bottom-up'), 3 ('equally bottom-up and top-down'), 4 ('more top-down') and 5 ('definitely top-down'). This implies that highly bottom-up rated processes are positioned towards the centre of the circle whereas highly top-down rated processes are positioned at the edge of the circle. The statistical significance of differences between the three profiles is shown in Table 7.

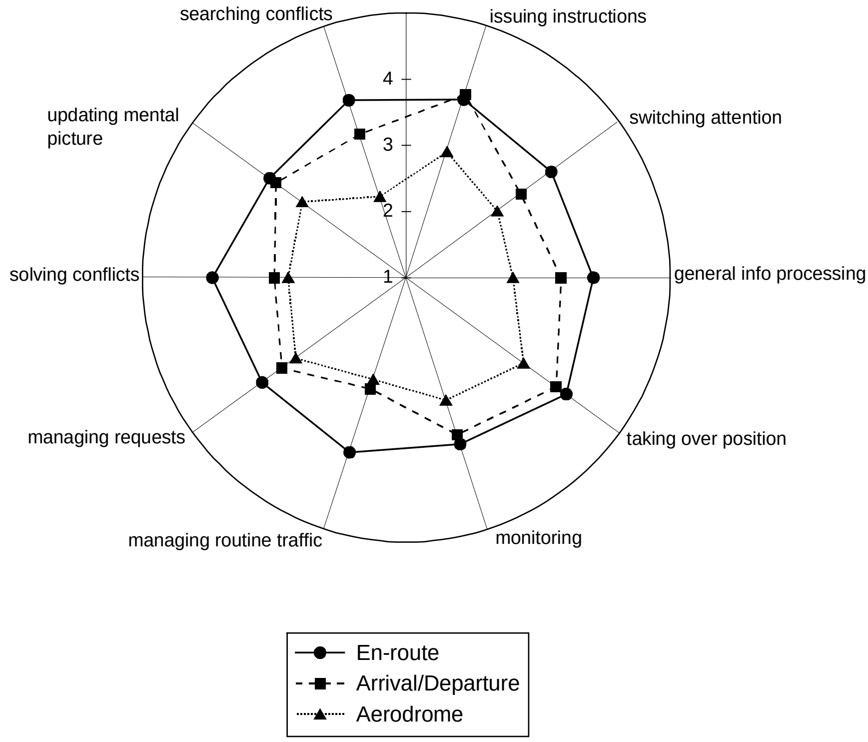


Figure 15: Cognitive profiles of en-route, arrival/departure and aerodrome controllers regarding top-down/bottom-up ratings of the basic cognitive processes

All basic processes of **aerodrome controllers** have clearly been rated as being more bottom-up/reactive than those of en-route controllers, where a preference for top-down information processing could be found. These differences are significant, some of them are even highly significant.

Most basic processes of **arrival/departure controllers** can be divided into two categories: the ones showing a high similarity to those of aerodrome controllers, the other ones resembling those of en-route controllers.

The basic processes ‘taking over position’, ‘monitoring’, ‘updating the mental picture’ and ‘issuing instructions’, have significantly been rated more top-down than those of aerodrome controllers while no difference could be found with respect to en-route controllers.

Significant differences for en-route controllers’ but not for aerodrome controllers’ processes were found for ‘managing routine traffic’ and ‘solving conflicts’. Both processes have been rated more bottom-up/reactive for arrival/departure controllers.

Ratings for ‘searching conflicts’ and ‘general information processing’ show significant differences for both en-route (en-route being more top-down) and aerodrome controllers’ (aerodrome being more bottom-up) processes.

Table 7: Top-down/bottom-up ratings: significant differences between services

Service / Processes	En route/ Arr./Dep.	En route/ Aerodrome	Arr./Dep./ Aerodrome	N (En route/ Arr./Dep. / Aerodrome)
Taking over position	n.s.	* * *	*	35 / 16 / 20
Monitoring	n.s.	* *	*	37 / 18 / 19
Managing routine traffic	* * *	* * *	n.s.	37 / 17 / 21
Managing requests	n.s.	*	n.s.	27 / 9 / 14
Solving conflicts	* *	* * *	n.s.	31 / 15 / 14
Updating the mental picture	n.s.	* *	*	36 / 18 / 21
Searching conflicts	* *	* * *	* * *	38 / 18 / 21
Issuing instructions	n.s.	*	*	23 / 11 / 12
Switching attention	(*)	* * *	n.s.	29 / 13 / 14
General information Processing	*	* * *	* *	37 / 17 / 21

Note:
N — number of cases (ATCOs) included in the analysis
n.s. — no significant difference
(*) $p \leq 0,1$ — slightly significant difference
* $p \leq 0,05$ — significant difference
* * $p \leq 0,01$ — highly significant difference
* * * $p \leq 0,001$ — highly significant difference

En-route profile

All processes have been rated rather top-down. This means that most en-route controllers reported that they do their job in a pro-active or concept-driven way. ‘Long-term plans’ and anticipation play an important part in the en-route controller’s task.

‘Taking over position’ is usually done in a top-down / concept-driven way since relevant information is actively gathered and an individual action plan is usually formulated before the position is taken over.

‘Managing routine traffic’, **‘switching attention’**, **‘searching conflicts’** and **‘solving conflicts’** have also been rated top-down / pro-active. Usually en-route controllers plan their traffic in advance, including a search for conflicts over as long a period as possible. Evidence for this is the use of

FPSs for this purpose. The resolution of potential conflicts can normally be planned some time in advance as well.

'Issuing instructions' and **'managing requests'** are also done in a concept-driven way by most en-route controllers, e.g. a lot of them reported that they adjust their instructions according to the language and supposed experience level of pilots or they pay special attention to pilot readbacks in certain situations. Anticipated requests of pilots can often be acceded to in a pro-active way as well. The advantage of such a working style is twofold: to provide a service to pilots and to reduce R/T-communication.

The only processes, which have a tendency towards being equally top-down and bottom-up are **'updating the mental picture'** and **'monitoring'**. Despite the fact that most en-route controllers actively manage their attention resources by focusing their attention on certain action-relevant aircraft (see Phase 2 Report [EATMP, 1999a]), this finding is plausible since these processes include an input of external information which is to some extent independent of the ATCO's plans and intentions.

Arrival/departure profile

The ratings of arrival/departure controllers vary considerably.

'Taking over position' and 'issuing instructions' have been rated top-down. **'Taking over position'** is usually done in a concept-driven way because relevant information is actively gathered and an action plan is usually formulated before the position is taken over. **'Issuing instructions':** good timing of their instructions is quite important for arrival/departure controllers and this is achieved by giving instructions in a pro-active, anticipation-guided way. But, on the other hand the relatively high percentage of '0-ratings' must be considered, i.e. 39% of the arrival/departure interviews didn't provide enough information to give a rating for 'issuing instructions' (see Chapter 4.3 psychometric quality of the cognitive profiles).

'Managing routine traffic' and **'solving conflicts'** have been rated equally top-down and bottom-up with a tendency towards a bottom-up / data-driven way of carrying out the processes. This emerges from a broad range of answers. Most arrival/departure controllers report that their pre-planning of routine traffic or conflict resolutions is on a short-term basis and often has to be adjusted quickly to take account of changed situational conditions. On the other hand 28% reported having a concept-driven top-down way of managing routine traffic, i.e. pre-planning is considered very important and traffic is planned ahead over as long a period as possible. In **'solving conflicts'** the contrast is even starker: in about 40% percent of the interviews the process was rated bottom-up or reactive and in another 40 % it was rated top-down or pro-active. The same applies in the case of **'switching attention'**: here the average rating is equivalently bottom-up and top-down, but this results from ratings equally distributed to the categories 'more bottom-up' and 'more top-down'.

'Searching conflicts' has an average rating of equivalently top-down and bottom-up with a tendency towards top-down: conflict detection is guided by anticipations and experience but it is not done so far in advance as in the case of en-route control. This is also supported by the fact that arrival/departure controllers mainly use the radar screen rather than FPSs for conflict searching.

The ratings for **'updating the mental picture'** and **'monitoring'** range between equivalently top-down and bottom-up and top-down. Arrival/departure controllers actively manage their levels of concentration but nevertheless these processes always are to a certain extent data-driven.

'Managing requests' is difficult to interpret since 50% of the arrival/departure interviews did not contain enough information to give a rating.

In summary, the results suggest that arrival/departure controllers' cognitive working style varies more than that of en-route or aerodrome controllers. Potential factors which influence cognitive working style range from situational conditions, e.g. sector characteristics, equipment and average traffic load to the ATCO's individual characteristics e.g. professional experience (see below '<u>impact of job experience</u>'), age or personality.

<u>Aerodrome profile</u>

The ratings for most processes in aerodrome control range between an equal amount for top-down and bottom-up and more bottom-up ratings.

'Taking over position' shows a tendency towards a pro-active /concept-driven way of information processing. Like en-route and arrival/departure controllers, aerodrome controllers actively look for relevant information to build up their picture, but most of them reported that they simply adopt the previous controller's action plan when taking over the position instead of developing a plan of their own. This is done because, under normal traffic conditions the task is quite uniform and leaves less room for individual preferences regarding the handling of traffic.

'Managing routine traffic' was rated equally top-down and bottom-up with a tendency towards a bottom-up / data-driven way of carrying out the process. Most aerodrome controllers report that their pre-planning of routine traffic is on a short-term basis and often has to be adjusted quickly to take account of changed situational conditions. **'Switching attention'** shows a similar result: most aerodrome controllers emphasise the importance of being able to switch and change their plan quickly.

'Searching conflicts' was rated clearly bottom-up / data-driven. Potential conflicts cannot be detected in advance as in the case of en-route control. They are usually detected by looking outside from the tower or by scanning the radar screen and are, therefore rather short-term based. The same applies in the case of **'solving conflicts'**: potential conflicts in aerodrome control have to be resolved instantly, should they arise. It is important for aerodrome controllers to react quickly in making the right decision. These time constraints suggest that solutions are chosen and implemented in a highly automated way.

The mean ratings of **'updating the mental picture'** and **'monitoring'** consist of a broad variety of ratings, ranging from bottom-up/data-driven to top-down/concept-driven. Aerodrome controllers also actively manage their attention resources by paying increased attention to certain aircraft. However, compared to en-route and arrival/departure controllers they perform these processes in a more data-driven way, which is probably due to the fact that traffic situations change very quickly in aerodrome control.

The mean ratings of **'issuing instructions'** and **'managing requests'** also consist of a variety of ratings, ranging from bottom-up / data-driven to top-down / concept-driven. This means that different styles of carrying out these processes seem to exist within our sample of aerodrome controllers: some aerodrome controllers explicitly give instructions and manage requests in a pro-active and anticipation-guided way, whereas others reported that they are mainly reacting to the situation. It should also be kept in mind that quite a high percentage ('issuing instructions' 43%; 'managing requests' 33%) of aerodrome interviews did not provide enough information to give a rating for these processes.

In summary, in aerodrome control, processes that to some extent address the topic of pre-planning the task (managing routine traffic, searching conflicts, resolving conflicts, switching attention) have been rated as being carried out in a more bottom-up or data-driven way. This means that in aerodrome control, pre-planning of the traffic over a longer term is hardly possible. This finding is reinforced by the fact that routine traffic is usually handled in a very automated schematic way.

Impact of job experience

Working style may be influenced by the ATCO's job experience. An additional analysis was carried out in order to assess the impact of job experience on ratings. The three variables which resulted from the factor analysis, 'pre-planning', 'updating the mental picture style' and 'pilot instructing style' were used for this analysis (see Chapter 4.1.2). The ATCOs were categorised into three groups, according to their job experience. Table 8 shows the distribution of ATCOs across services and categories of job experience. The results are based on 80 controllers' interviews.

Table 8: Number of ATCOs distributed across services and categories of job experience

Job Experience in Years	En-route	Arrival/Departure	Aerodrome
< 4	2	6	6
4 → 9	25	7	7
> 9	11	5	11
Total	38	18	24

As shown in Table 8 the number of ATCOs is not equally distributed across services and categories of job experience. It was necessary to do separate analyses for en-route, arrival/departure and aerodrome services in order to determine the impact of job experience on the mean ratings of the variables 'pre-planning', 'updating the mental picture style' and 'pilot instructing style'. Table 9 shows the results.

Table 9: Significant differences between categories of job experience regarding the mean ratings of the factor variables

Factor variable	En-route	Arrival/Departure	Aerodrome
Pre-planning	n.s.	*	n.s.
Updating the mental picture style	n.s.	*	(*)
Pilot instructing style	n.s.	n.s.	n.s.

Note: n.s. no significant difference
(*) $p \leq 0,1$ slightly significant difference
* $p \leq 0,05$ significant difference
* * $p \leq 0,01$ highly significant difference
* * * $p \leq 0,001$ highly significant difference

Significant job experience related differences between ATCOs could only be found for **arrival/departure control**:

'pre-planning': ATCOs with little experience (less than four years) were rated more bottom-up /data-driven than ATCOs with medium or long experience. This means that ATCOs with medium or long experience show a tendency towards putting more emphasis on pre-planning the traffic than ATCOs with little experience.

'update mental picture style': ATCOs with long experience (more than 9 years) were rated more bottom-up / data-driven than ATCOs with little or medium experience. A similar trend was found in aerodrome control: ATCOs with long experience were rated more bottom-up than those with little experience. This finding can be interpreted in two different ways: either highly experienced ATCOs update their picture and distribute their attention in a data-driven way, e.g. they scan and check their traffic very broadly and frequently while selective, anticipation-guided checking is seldom done. Or they update their mental picture in such an extremely automated way that they are not able to report about the implicit criteria that they use when scanning and checking the traffic.

In summary, results suggest that the broad variation of cognitive working styles in arrival/departure control is partly due to job experience. In aerodrome control a similar trend was identified in ‘updating the mental picture style’ which might provide an explanation for the broad variety of ratings of the respective processes. No effects due to job experience were found in en-route control, but it should be taken into account that the en-route sample included only two ATCOs with little experience.

Differences between regions

As a result of the major effects of ATC working positions on the ratings, separate analyses for en-route, arrival/departure and aerodrome services had to be done in order to check for potential differences between the geographical regions of North, Central, South-East and South-West. The reduced number of cases remaining for each statistical analysis makes it more difficult to obtain any significant results. In order to avoid the loss of too many cases, the aggregated ratings for ‘pre-planning’, ‘updating the mental picture style’ and ‘pilot instructing style’ were used for this analysis (see Chapter 4.1.2).

- No significant differences between regions were found for en-route controllers.
- For arrival/departure controllers there was a significant difference in ‘pilot instructing style’, i.e. the South-East has been rated being more bottom-up/ data-driven than Central and South-West. This should be interpreted very cautiously as only a small number of cases could be used for the analysis.
- In aerodrome control a significant difference was found in ‘pre-planning’, i.e. the South-West and the South-East were rated more bottom-up /reactive than the North sample.

In summary, no major differences in cognitive working style were identified between ATCOs of different geographical areas. Compared to the strong effects of the ATC working positions on the cognitive working style, regional peculiarities are so insignificant that they may be ignored. However, one should bear in mind that only a relatively small number of cases/interviews could be used for this analysis. A larger sample might have given a more satisfactory answer to the question of regional differences in cognitive working style.

4.1.4 Analysis of Pre-planning Time

In the cognitive interview the ATCOs were asked the question 'When do you start to integrate new traffic into your plans?' In some cases the ATCOs reported how many minutes they usually pre-plan traffic before it enters their sector. Table 10 shows the percentage distribution of pre-planning time for en-route, arrival/departure and aerodrome control.

Table 10: Pre-planning time rated by ATCOs; percentage relates to columns

Pre-planning time in minutes	En-route*	Arrival/Departure*	Aerodrome
less than 2	3 %	11 %	13 %
between 2 and 5	3 %	50 %	8 %
between 5 and 10	24 %	11 %	8 %
between 10 and 15	16 %	-	-
more than 15	24 %	-	-
no statement	30 %	28 %	71 %

*All qualified radar controllers

The statistical analysis of differences between en-route, arrival/departure and aerodrome controllers showed the following results: **The pre-planning time in en-route control is significantly ($p < 0.01$) higher than in arrival/departure and aerodrome control.** No significant difference was found between arrival/departure and aerodrome control.

4.2 Flight Progress Reconstruction

This chapter focuses on the analysis of the flight progress reconstruction interviews.

4.2.1 Flight Progress Reconstruction: Data Processing and Analysis

The first step in the analysis of the data from the reconstruction interview was a transcription of the tape-recorded interview. An experienced interviewer carefully cross-checked the transcript. In cases of doubt, the original tape and the written transcript were compared and any differences were corrected. Subsequently a trained analyst evaluated the transcript. Each non-routine case in the reconstruction interview was rated on the two following scales:

Rating of the required cognitive resources / attention:
0 rating not possible
1 no increased attention required
2 increased attention for a short period of time
3 increased attention for a longer period of time
4 intensively increased attention

Rating of the required level of behaviour
0 rating not possible
1 skill-based level
2 rule-based level
3 knowledge-based level

The levels of behaviour were defined according to Rasmussen (1983 & 1986).

On the **skill-based level** stimuli are applied to responses in a rapid automatic mode with minimum investment of resources. However, the stimuli need not necessarily be simple: after extensive training and experience even complex stimuli can trigger skill-based behaviour.

On the **rule-based level of behaviour** a response is selected by reminding the subject of a hierarchy of rules: ‘if x occurs then do y’. After mentally scanning the ‘if - then’ rules the decision-maker will initiate the appropriate action. The situation may be familiar but the mental processing is considerably less automatic and takes more time than on the skill-based level.

Knowledge-based behaviour is demonstrated when new or unfamiliar problems are encountered. Neither rules nor automatic mappings exist and more general knowledge concerning the behaviour of the system, the characteristics of the environment and the goals to be obtained must be integrated in order to formulate a new plan of action.

Figure 16 demonstrates the interrelation of levels of behaviour with automation and required cognitive resources. Skill-based behaviour is highly automated and requires few cognitive resources whereas knowledge-based behaviour is not automated at all and requires a lot of attention.

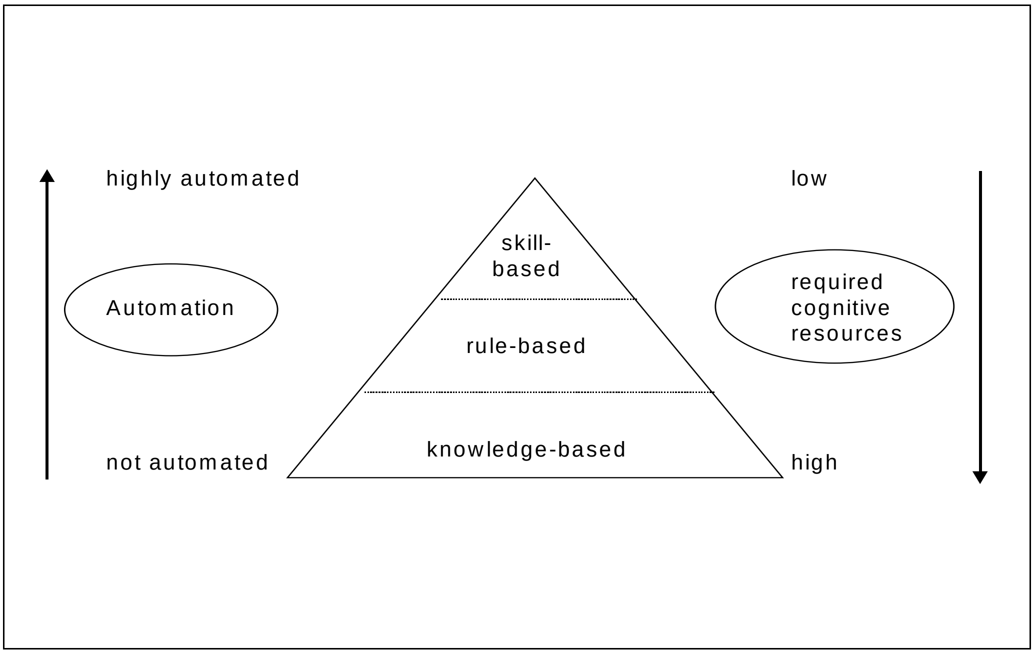


Figure 16: Interrelation between levels of behaviour, required cognitive resources and automation of behaviour

Detailed rating criteria for the evaluation of the reconstruction interview can be found in the appendix.

At the same time as the ratings of required attention and levels of behaviour, the analyst documented the following supplementary characteristics of each non-routine case:

- The number of the pilot requests which were part of the non-routine situation.
- The number of additional coordinations with adjacent sectors.
- The existence of a potential conflict situation?
- The number of aircraft involved.
- The categorisation of the situation:
  - potential conflict with climbing or descending aircraft
  - potential conflict with aircraft flying at the same level
  - other situation: no potential conflict
  - categorisation not possible
- The subjective certainty of the analyst in doing the ratings (certainty rating). For this purpose a seven-point-scale ranging from 0 (‘not at all’) to 6 (‘very high’) was used.

A total number of 439 non-routine cases have been analysed. Non-routine cases with a certainty rating below 3 (‘medium certainty’) were excluded from statistical analysis. The distribution of excluded cases over services and regions is documented in the appendix. A total number of 66 reconstruction interviews including 332 non-routine cases were included in the statistical analysis.

4.2.2 Results: Ratings for 'level of behaviour' and 'required cognitive resources/attention'

At the outset a check was done to see if there were any differences in the number of non-routine cases reported in en-route, arrival/departure and aerodrome working positions. The average number of non-routine cases was slightly higher in en-route positions but, given the very high standard deviations within the groups, no significant differences were found.

In order to take account of the varying number of non-routine situations per ATCO, mean ratings for the rating dimensions 'level of behaviour' and 'required cognitive resources' were computed. This aggregated data was submitted to statistical analysis.

Differences between En-route, Arrival/departure and Aerodrome positions

There are no significant differences between the three services concerning the rating dimension for 'required cognitive resources/attention'. Concerning the rating dimension for 'required level of behaviour' the results show that:

- in aerodrome the mean ratings are significantly lower than in en-route and arrival/departure.
- no significant differences could be found between en-route and arrival/departure

Figure 17 depicts the mean ratings for en-route, arrival/departure and aerodrome.

The mean ratings for en-route and arrival/departure do not exceed 1.7, i.e. the majority of ratings range between 1 ‘skill-based’ and 2 ‘rule-based’. Almost no knowledge-based behaviour was found, which is no surprise, considering the extensive training ATCOs get before they are fully qualified and the experience they gain on the job.

The mean ratings of aerodrome controllers’ levels of behaviour is even more on the skill-based side, i.e. even in non-routine situations aerodrome controllers work in a rapid, highly automatic mode.

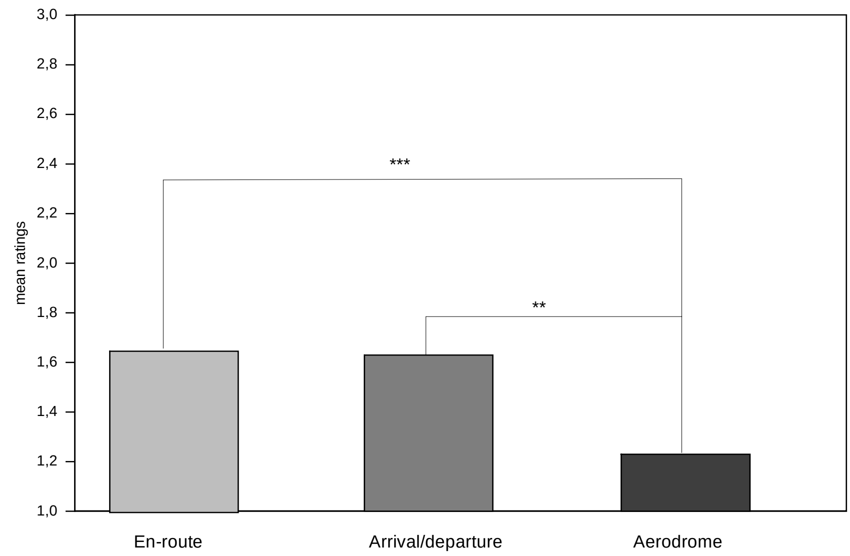


Figure 17: Mean ratings of levels of behaviour

Note: * * $p \leq 0{,}01$ highly significant difference
* * * $p \leq 0{,}001$ highly significant difference

These differences in levels of behaviour raise the question as to why no significant differences in the required cognitive resources could be found. This might be due to the fact that non-routine cases in aerodrome control often involved monitoring aircraft. For experienced controllers, the act of monitoring, i.e. scanning an aircraft and assessing its separation from time to time, is definitely skill-based and requires few resources. On the other hand it has to be done repeatedly, thus the aircraft has to be kept in mind, which again requires increased attention. This explains the apparent contradiction of why ATCOs who manage their traffic mainly on a skill-based level of behaviour do not necessarily have spare cognitive capacity.

Differences between geographical regions

Given the marked effects of ATC-working positions on the ratings, separate analyses for en-route, arrival/departure and aerodrome services had to be done in order to check for potential differences. The small number of cases remaining for each statistical analysis makes it less likely to detect any significant effects.

For both rating dimensions no significant differences between the geographical regions were found.

Influence of the situation

The impact of situation characteristics of non-routine cases on the rating dimensions has been analysed. Separate analyses were carried out for en-route, arrival/departure and aerodrome services. Raw data, i.e. not aggregated data was used for the analysis. Table 11 shows the significant results of these analyses.

Table 11: Influence of the situation on the ratings

Was a pilot's request part of the situation?		
Rating of:	**Service:**	**Result:**
additional attention	en-route arrival/departure aerodrome	no significant differences between situations with or without pilots' requests
level of behaviour	arrival/departure aerodrome	no significant differences between situations with or without pilots' requests
	en-route	situations with pilots' requests were rated higher in level of behaviour (∗ ∗)
Was there a potential conflict?		
Rating of:	**Service:**	**Result:**
additional attention	aerodrome	no significant differences between potential conflict situations and other situations
	en-route arrival/departure	potential conflict situations were rated higher (∗ ∗)
level of behaviour	arrival/departure aerodrome	no significant differences between potential conflict situations and other situations
	en-route	potential conflict situations were rated higher in level of behaviour (∗ ∗ ∗)

Note:

n.s.		no significant difference
(∗)	$p \leq 0,1$	slightly significant difference
∗	$p \leq 0,05$	significant difference
∗ ∗	$p \leq 0,01$	highly significant difference
∗ ∗ ∗	$p \leq 0,001$	highly significant difference

Table 11: Influence of the situation on the ratings (continued)

How many aircraft were involved in the situation? (1 or 2 aircraft vs. '3 or more aircraft')		
Rating of:	**Service:**	**Result:**
additional attention	arrival/departure aerodrome	no significant differences between situations involving 1 or 2 vs. '3 or more aircraft'
	en-route	'3 or more aircraft' were rated higher (∗ ∗ ∗)
level of behaviour	arrival/departure aerodrome	no significant differences between situations involving 1 or 2 vs. '3 or more aircraft'
	en-route	situations with '3 or more aircraft' were rated higher in level of behaviour (∗ ∗ ∗)
How many coordinations have been necessary to solve the situation? (0, 1, 2, 3 or more coordinations)		
Rating of:	**Service:**	**Result:**
additional attention	en-route arrival/departure aerodrome	no significant differences regarding the number of coordinations
level of behaviour	en-route arrival/departure aerodrome	situations requiring '3 or more coordinations' were rated higher in level of behaviour (∗)

Note:
- n.s. — no significant difference
- (∗) $p \leq 0,1$ — slightly significant difference
- ∗ $p \leq 0,05$ — significant difference
- ∗ ∗ $p \leq 0,01$ — highly significant difference
- ∗ ∗ ∗ $p \leq 0,001$ — highly significant difference

Most significant effects show up for en-route controllers, which can be explained by the relatively large sample of en-route controllers in the study. Table 11 demonstrates that situational characteristics such as potential conflict or lack thereof, the number of aircraft involved, the number of coordinations and the requests of the pilot have influenced the ratings of 'required cognitive resources/attention' and/or 'required level of behaviour'.

4.3 Psychometric Quality of the Cognitive Profiles

4.3.1 Cognitive Interview: Top-down/Bottom-up Ratings

In total 80 cognitive interviews were analysed by doing top-down/bottom-up ratings. In order to determine the objectivity of the ratings, 40 interviews (50%) were analysed each by two independent evaluators.

At the outset one needs to differentiate between '0-ratings', which means, that in the evaluators’ opinion there is not enough information for rating and 'positive ratings' which means, that in the evaluators’ opinion there is sufficient information for giving a rating. Then one has to determine from a theoretical point of view to what extent deviations between 'positive ratings' are acceptable. For the purposes of this study a deviation of one point of the rating scale seemed tolerable and theoretically acceptable.

Table 12: Top-down / bottom-up ratings: concordance between independent evaluators (percentage of concordance)

Basic Process	Concordance 0-rating / positive rating N = 40	Positive ratings: Exact Concordance and Concordance +/- 1	Positive ratings: Exact Concordance	Positive ratings: Concordance +/- 1
Taking over position	95.0 %	86.8 % N = 38	42.1 %	44.7 %
Monitoring	97.5 %	92.1 % N = 38	42.1 %	50.0 %
Managing requests	75.0 %	82.2 % N = 23	60.5 %	21.7 %
Update mental picture	97.5 %	97.4 % N = 39	43.6 %	53.8 %
Searching conflicts	95.0 %	92.1 % N = 38	44.7 %	47.4 %
Issuing instructions	67.5 %	90.0 % N = 20	75.0 %	15.0 %
Managing routine traffic	100 %	97.5 % N = 40	37.5 %	60.0 %
Solving conflicts	77.5 %	85.7 % N = 28	60.7 %	25.0 %
Switching attention	65.0 %	95.9 % N = 24	79.2 %	16.7 %
General information processing	97.5 %	100.0 % N = 39	64.1 %	35.9 %

Note: N: number of cases (ATCOs) included in the analysis

Table 12 shows the percentage of concordance between evaluators for the basic processes and general information processing. The first column shows the concordance in choosing a '0-rating' or 'positive rating'. Column two shows the sum of exact concordances and one-point divergences for positive ratings. Below the percentages the absolute numbers of positive ratings are depicted. The third column further illustrates the percentage of exact concordances of positive ratings between evaluators and the fourth column shows the percentage of positive ratings with a divergence of one point of the rating scale.

It is clear from column one that for the basic processes ‘managing requests’, ‘issuing instructions’, ‘solving conflicts’ and ‘switching attention’ there was only a 65% to 80% concordance as to whether there was enough information in the interview to give a top-down/bottom-up rating. This might be due to the fact that these basic processes were not always explicitly addressed in the interview. Compared to processes which were explicitly addressed it would appear to be more difficult to gather this information.

Column two shows the sum of exact concordances and one-point divergences for the positive ratings. This measure of similarity between evaluators for six of the ten processes is higher than 90%. For the basic processes ‘taking over position’, ‘managing requests’, ‘issuing instructions’ and ‘solving conflicts’ it ranges still from 82 to 90%. The three last-mentioned items are the same processes that have a lower concordance in 0-ratings versus positive ratings. Again, these inconsistencies may be attributed to the fact that information about these processes could not be found in a specific part of the interview but had to be ascertained from the overall interview.

In summary the double ratings showed that the reliability of ratings of the basic processes ‘taking over position’, ‘monitoring’, ‘updating the mental picture’, ‘searching conflicts’, ‘managing routine traffic’ and ‘general information processing’ can be assessed as quite acceptable. Individual ratings of the basic processes ‘managing requests’, ‘issuing instructions’, ‘solving conflicts’ and ‘switching attention’ should be interpreted more cautiously since the evaluators seemed to have some problems in identifying relevant information about these processes and thus in obtaining exact concordance of ratings.

4.3.2 Reconstruction Interview: Ratings for 'Level of Behaviour' and 'Required Cognitive Resources/Attention'

From a total number of 66 reconstruction interviews (332 non-routine cases), 18 interviews (84 non-routine cases) were analysed by two independent evaluators.

Table 13 shows the percentage of concordance between evaluators for the rating dimensions of ‘level of behaviour’ and ‘required cognitive resources / attention’. The first column shows the concordance in choosing a '0-rating' or 'positive rating'. The second column depicts the percentage of exact concordances between evaluators for the positive ratings. The third column shows the percentage of positive ratings with a divergence of one point on the rating scale. Column four sum up columns two and three and shows the percentage of positive ratings with exact concordances and a divergence of one point on the rating scale.

Table 13: Ratings of required additional attention and level of behaviour: concordance between independent evaluators (percentage of concordance)

Rating dimension	Concordance 0-rating/ positive rating N = 84	Positive ratings: Exact Concordance N = 83	Positive ratings: Concordance +/- 1 N = 83	Positive ratings: Exact Concordance and Concordance +/- 1 N = 83
Required cognitive resources/ attention	98.8 %	54.2 %	44.6 %	98.8 %
Required level of behaviour	98.8 %	66.3 %	33.7 %	100.0 %

Note: N: number of non-routine cases included in the analysis

Column one shows that the concordance between evaluators regarding the decision as to whether there was enough information to give a positive rating was very high for both rating dimensions. The percentage of concordances for the positive ratings can be assessed as being satisfactory. For the required cognitive resources/attention, the exact concordance (54.2 %) added to “concordance +/- 1 point” (44.6 %) gives a total concordance of 98.8 %. For the required level of behaviour, the exact concordance (66.3 %) added to “concordance +/- 1 point” (33.7 %) gives a total concordance of 98.8 %. Divergences of ratings in ‘level of behaviour’ do not exceed one point of the rating scale. A closer look at the data showed that in most cases the distinction between ‘skill-based’ and ‘rule-based’ proved difficult. On the other hand, in no case could a ‘skill-based’/’knowledge-based’ divergence be found. Divergences of ratings in ‘required cognitive resources/ attention’ show a similar pattern: in only 1.2 % of all cases did the ratings diverge by more than one point on the rating scale.

4.4 Cognitive Profiles: Summary

The basic cognitive processes of ATC were used to demonstrate the similarities and differences of ATC working positions in the ECAC area. In order to compare the basic cognitive processes of different working positions, an appropriate common dimension for their assessment was chosen. For this purpose the concept of top-down/bottom-up rating was introduced. This concept implies that actions or processes can be characterised by their position on the bottom-up / top-down scale.

The resulting cognitive profiles showed remarkable differences between ATCOs working in en-route, arrival/departure and aerodrome control.

In en-route control all basic cognitive processes have been rated top-down, i.e. most en-route controllers reported they are doing their job in a fairly top-down / proactive way. Long-term plans and anticipations play an important role in the en-route controller’s task.

The arrival/departure controllers’ cognitive working style varies considerably: some work in a top-down / proactive way while others carry out their tasks in a bottom-up / reactive way. An analysis including job experience suggests that this variation may be partly due to differences in job experience.

In aerodrome control, processes that to some extent include pre-planning the task have been rated as being carried out in a more bottom-up/ reactive way, i.e. in aerodrome control, pre-planning the task over a longer period of time is hardly possible. Ratings of the processes involving communication with pilots and updating the traffic picture show broad variations. As for arrival/departure controllers, this might be due to differences in job experience.

An analysis of the pre-planning span rated by the ATCOs supports the results of the top-down/bottom-up ratings: The pre-planning time in en-route control is significantly higher than in arrival/departure or aerodrome control.

In contrast to the notable differences between services / working positions, no significant differences in cognitive working style have been found between ATCOs of different geographical areas. Compared to the strong effects of the ATC working positions on the cognitive working style, regional peculiarities are so insignificant that they may be ignored.

Interview data from the flight progress reconstruction method was analysed by rating the following aspects per non-routine case: the required cognitive resources / attention and the required level of behaviour.

No significant differences between the services were found regarding the required cognitive resources / attention. As for the required level of behaviour, the mean ratings of aerodrome controllers were significantly lower than those of en-route and arrival/departure controllers. The mean ratings for en-route and arrival/departure range between skill-based and rule-based. Almost no knowledge-based behaviour could be found. The mean rating of aerodrome controllers’ levels of behaviour is even more on the skill-based side, i.e. even in non-routine situations aerodrome controllers work in a rapid, highly automatic mode.

For both rating dimensions no significant differences between ATCOs of different geographical areas were found.

A further step analysed, how the following situational characteristics of the non-routine situations had an impact on the ratings: potential conflict situation or lack thereof; the number of aircraft involved and the number of additional coordinations required.

The psychometric quality of the cognitive profiles was evaluated by determining the concordance of two independent evaluators. The double ratings showed that the reliability of ratings of most basic cognitive processes is acceptable. The same applies to the ratings of the flight progress reconstruction interview.

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5. BEHAVIOURAL PROFILES

A total number of 82 observations at the working position were conducted during Phase 3 of the project. The observed positions were categorised using the following classification:

En-route positions

- ACC/ACC: en-route sector with other en-route sectors as main adjacent sectors.
- ACC/APP: en-route sector with an approach sector as an important adjacent sector.

Arrival - Departure positions

- APP/FEED: approach sector with a final approach sector (feeder) as main adjacent sector.
- APP/TWR: approach sector with tower as main adjacent sector (usually final approach position).

Aerodrome positions

- TWR: tower position.
- GND: ground position.

Three out of the 82 observations were excluded from the statistical analysis; because they did not fit within this classification. These were one departure position and two planner positions. The final total number of units in the calculation was 79.

Table 14 shows the resulting number of observations per position which were included into the statistical analysis.

Table 14: Number of observations per position that were included into statistical analysis

Position	Number of observations
ACC/ACC	27
ACC/APP	10
APP/FEED	6
APP/TWR	11
TWR	17
GND	8
Total	79

Observational data was collected using three different observation grids, by means of a time sampling method. (The observation grids are shown in the Technical Supplement.)

- Task Units: The occurrence of different task units such as accepting an aircraft, accepting FPSs, descending an aircraft, turning an aircraft, communication with adjacent sectors, etc. was recorded during an 8-minute interval.
- Call survey: The various aircraft and types of communication during a 10-minute interval were listed.
- Information flow sheet: The communication partners (e.g. pilots, planners, coordinators, adjacent sector controllers) and the frequency and direction of the communications were recorded. How often the communication resulted in a dialogue apart from standard answers (like e.g. readbacks, simple yes / no answers) was also registered.

The three grids were filled in twice during the observation period.

5.1 Traffic Load in the Observation Period

In every unit, an attempt was made to conduct the observation during high traffic period (70% or more of the sector maximum capacity). Owing to operational constrains this was not possible everywhere. In order to take account of the traffic situation in the data analysis, the ATCO's subjective rating of the traffic load collected during the post-observational interview was used as a co-variating variable.

The rating scale was as follow

1. low traffic
2. average traffic with silent periods
3. average traffic
4. average traffic with peaks
5. high traffic

There is a significant difference in the ratings of the average traffic load between the various positions: e.g. in final approach positions the traffic load was rated particularly high compared to pure en-route positions.

Figure 18 depicts the mean ratings and standard deviations for the different ATC positions.

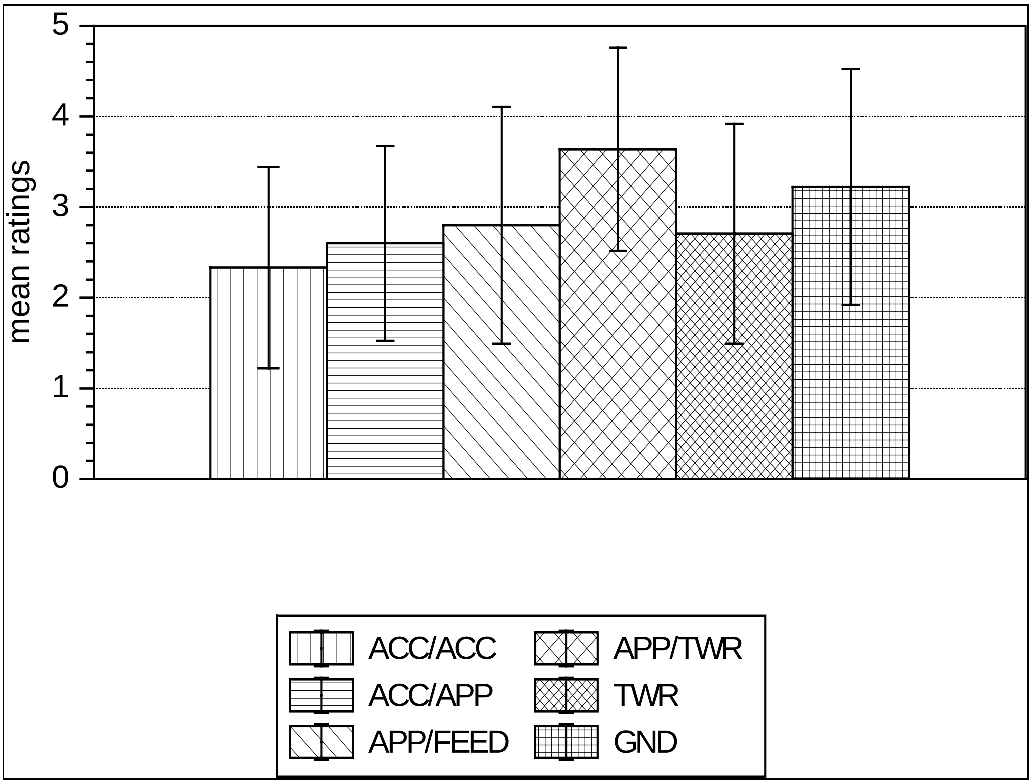

Figure 18: Rating of the average traffic load in the observation period: means and standard deviations

The ratings were included in statistical analyses as a co-varying variable so that significant differences between positions that are simply due to differences in traffic load would not have an influence.

5.2 Task Units

5.2.1 Task Units: Data Processing and Analysis

Using the task unit grid, the actions of the observed ATCOs were classified according to one of 32 categories or task units (e.g. accept aircraft, turn aircraft). As they proved to be the more reliable (see inter-observer reliability in Table 17), only task units of the second part of the observation were analysed (each observation grid was filled twice)

For the purpose of comparing positions, the task units were broken down into task categories in order to represent more high-level processes. Table 15 shows the resulting task categories and the underlying task units. The task categories were used for the statistical analysis.

Table 15: Task categories and underlying task units

Task Category	Task Units
Routine communication with pilots	– accept a/c – dismiss a/c – climb a/c – descend a/c – turn/direct a/c – speed instructions – instruct pilot (with something else) – give clearance
Special communication with pilots	– accept pilot's request – request information – give special information to pilot
Technical activities	– input radar data (light pen/label) – zoom radar – use planning tools (if available) – other radar/tool activities – check other information
Work related communication, other than to pilots	– communication with planner – coordination with adjacent sectors – communication with flight data assistant
Work-unrelated communication	– private communication – communication with observer
FPS activities	– receive FPSs – include FPSs in active board – change arrangement of FPSs – highlight (flag) FPSs – mark (write on) FPSs – dismiss FPSs – other FPS activities

5.2.2 Task Units: Results

Differences between working positions

Figure 19 shows the differences between positions regarding the frequency of observed task categories. Significant differences can be identified for ‘technical activities’ and ‘work-related communication other than to pilots’. The difference in ‘routine communication with pilot’ is only slightly significant. For a significant result a statistical probability of 95% for this difference being ‘true’ (not due to random effects) would be required. The statistical probability for the difference in ‘routine communication with pilot’ is about 91%, which can at least be seen as a hint that the difference is not entirely determined by the traffic load.

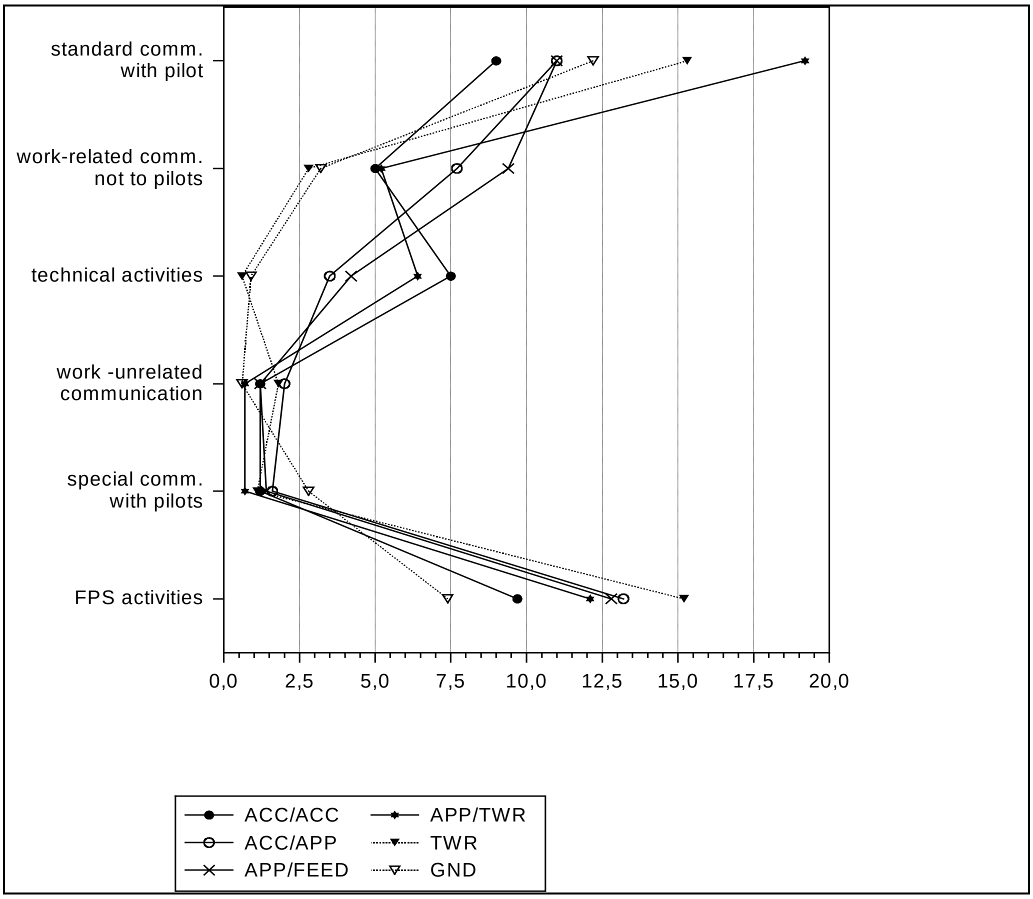

Figure 19: Frequency of task categories: differences between positions

Significantly fewer ‘technical activities’ (e.g. zoom radar, use radar planning tools) were observed in aerodrome positions (TWR and GND) than in radar working positions. The aerodrome equipment can explain this because those tools are not available in all places.

Compared to aerodrome positions (TWR and GND) and final approach positions (APP/TWR), approach positions (with final approach as main adjacent sector: APP/FEED) and en-route positions with an approach sector as main adjacent sector (ACC/APP) show a significantly higher 'work-related communication other than to pilots', i.e. communication with planners, coordinations with adjacent sectors.

Final approach positions (APP/TWR) and tower positions (TWR) show an increased 'routine communication with pilot', i.e. within the eight-minute period of observation, task units (e.g. accept aircraft, instruct aircraft, dismiss aircraft) were observed more frequently at these positions than at en-route positions or approach positions (APP/FEED).

In summary, these findings support to some extent the results from the cognitive interviews: Regarding the differences in technical activities: compared to en-route or arrival/departure radar workplaces, in aerodrome positions planning activities are usually not reflected by the use of radar tools. However, according to the interview data, in aerodrome positions there are generally fewer pre-planning activities. The differences in 'work-related communication other than pilots' reflect the amount of coordination and communication with adjacent sectors and planning controllers. For interpretation purposes it is necessary to differentiate between these communications. 'Work-related communication other than to pilots' is considerably less frequent in aerodrome positions, which can be explained by the fact that in aerodrome positions there are usually no planner positions whereas communication with planners was observed most frequently in en-route positions. Coordination with adjacent sectors was observed most frequently in approach-related positions (especially APP/FEED) and rather seldom seen in en-route positions (ACC/ACC).

Regarding 'routine communication with pilots', this indicates that in aerodrome positions and in final approach positions the frequency of routine communication with pilots appears to be considerably higher than in en-route positions. According to the ATCO's ratings of the average traffic load within the observation period this effect is partly due to higher traffic load conditions in these positions, but cannot be fully explained by this. Thus, it is presumably partly due to different working styles as described in Chapters 3 and 4. Highly automated activities are often simply triggered by external cues, i.e. they are done in a bottom-up or data-driven way. In aerodrome positions and in final approach positions the working style has been rated being more bottom-up or data-driven. In normal traffic conditions the work is usually more routine and repetitive, e.g. when continually giving landing or take-off clearances. The relatively high frequency of 'routine communication with pilots' can be interpreted as supporting the results from the cognitive interviews.

No significant differences at all emerged regarding 'non-work related communication', 'special communication with pilots', which was relatively seldom observed, and 'FPS activities', which show a high variance even within single positions.

Differences between regions

Figure 20 shows the differences between the geographical regions regarding the frequency of observed task categories. Significant differences can be discerned for 'work-related communication other than to pilot' and 'FPS activities'.

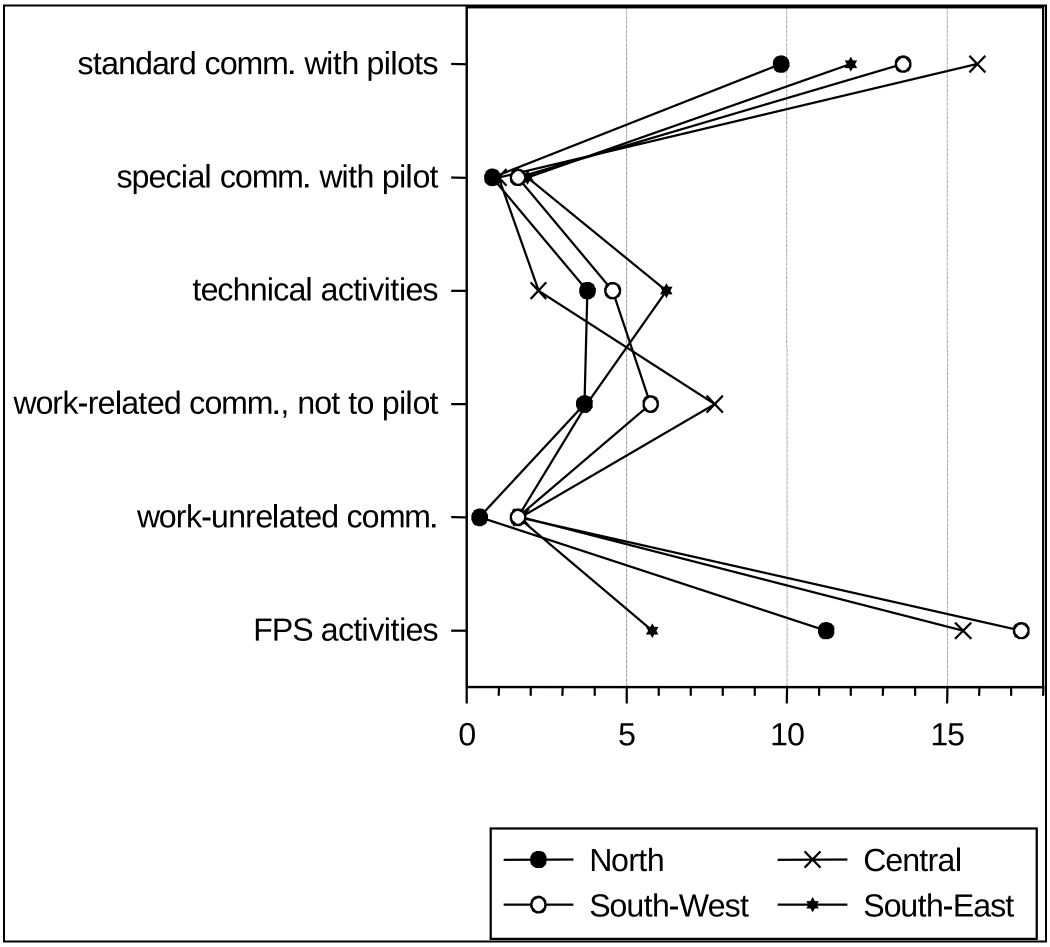

Figure 20: Frequency of task categories: differences between geographical regions

The observed ATC positions, particularly aerodrome positions, were not distributed equally over the four geographical regions (see Figure 20 legend), e.g. within the 'Central' region no aerodrome positions were analysed. It is therefore difficult to interpret differences between regions since they are partly grouped with differences between positions.

'Flight Progress Strip (FPS) activities' were observed less frequently in the South-East, which might be due to the increased number of aerodrome positions (at which fewer FPS activities were observed) in the South-East. 'Work-related communications other than to pilot' were observed more often in the Central region, which might be partly explained by the missing aerodrome sample.

5.3 Call Survey

5.3.1 Call Survey: Data Processing and Analysis

Call sign and type of communication (accept aircraft, instruct aircraft, inform aircraft, transfer aircraft) of each ATCO-pilot communication are registered within a 10-minute period. Thus, **the number of individual aircraft and the frequency of communications to individual aircraft** can be analysed. Since it proved to be the more reliable, only data from the second part of the observation was analysed.

The number of contacts to individual aircraft was categorised as follows:

- one contact per aircraft,
- two contacts per aircraft,
- three contacts per aircraft,
- more than three contacts per aircraft.

'Accept aircraft' and 'dismiss aircraft' are included in the number of contacts.

5.3.2 Call Survey: Results

Figure 21 shows the average number of aircraft contacted within the 10-minute observation period. Owing to large variations within the positions and the major influence of traffic load, the differences are not significant.

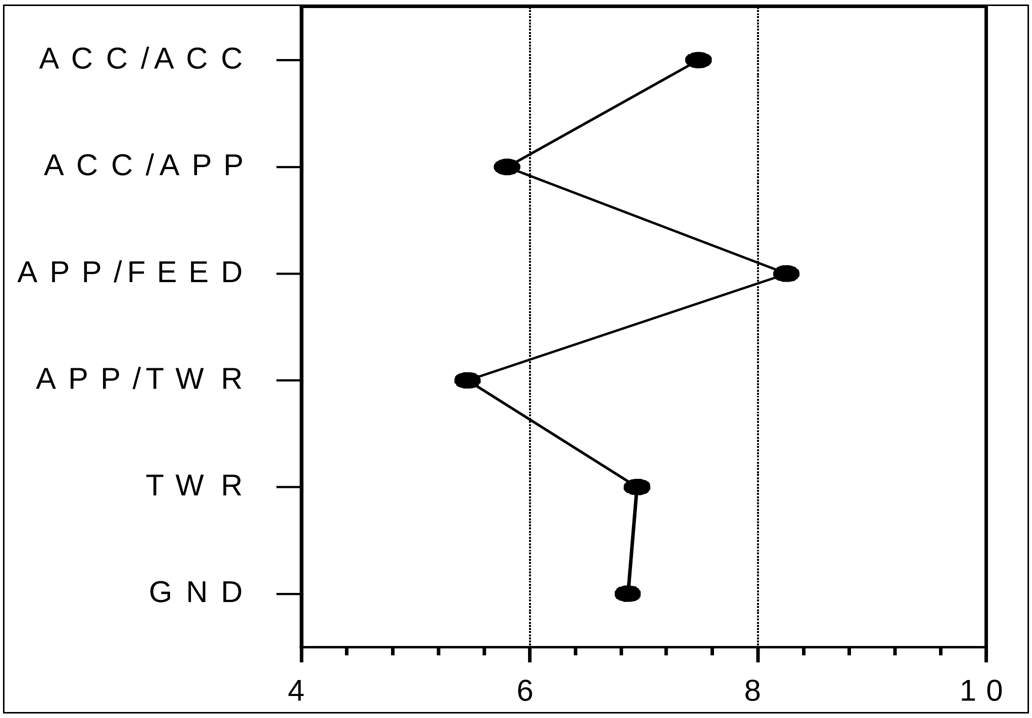

Figure 21: Call survey: average number of contacted aircraft

The frequency of communication with individual aircraft within a ten-minute interval was analysed. Significant differences between positions were found for ‘one contact per aircraft’ and ‘more than three contacts per aircraft’. Figure 22 shows the differences between these positions.

‘More than three contacts per aircraft’ were observed most frequently in approach positions, particularly in final approach positions (APP/TWR), and relatively seldom in en-route positions. On the other hand, only ‘one contact per aircraft’ has happened more often in pure en-route positions (ACC/ACC).

For interpretation purposes it is necessary to bear in mind that the number of contacts per aircraft relates to a time period of ten minutes. Seen in this light, one cannot say that in en-route the total number of contacts per aircraft is lower, but it is smaller within the observation interval of ten minutes. Aircraft usually stay in en-route sectors for a longer period of time compared to arrival/departure sectors. Here the total number of aircraft under control at a given time might be lower, but they pass the sector in a relatively short period and within this period of time they get all the necessary instructions and the handover. These differences in working style which may be observed should have implications for the cognitive processes behind it: if ATCOs have to issue several instructions per aircraft within a few minutes, they have for instance less opportunity to develop particular, individual conflict resolutions. They are probably working in a more automated, situation-driven bottom-up mode as suggested by the results from the cognitive interviews (see Chapter 4).

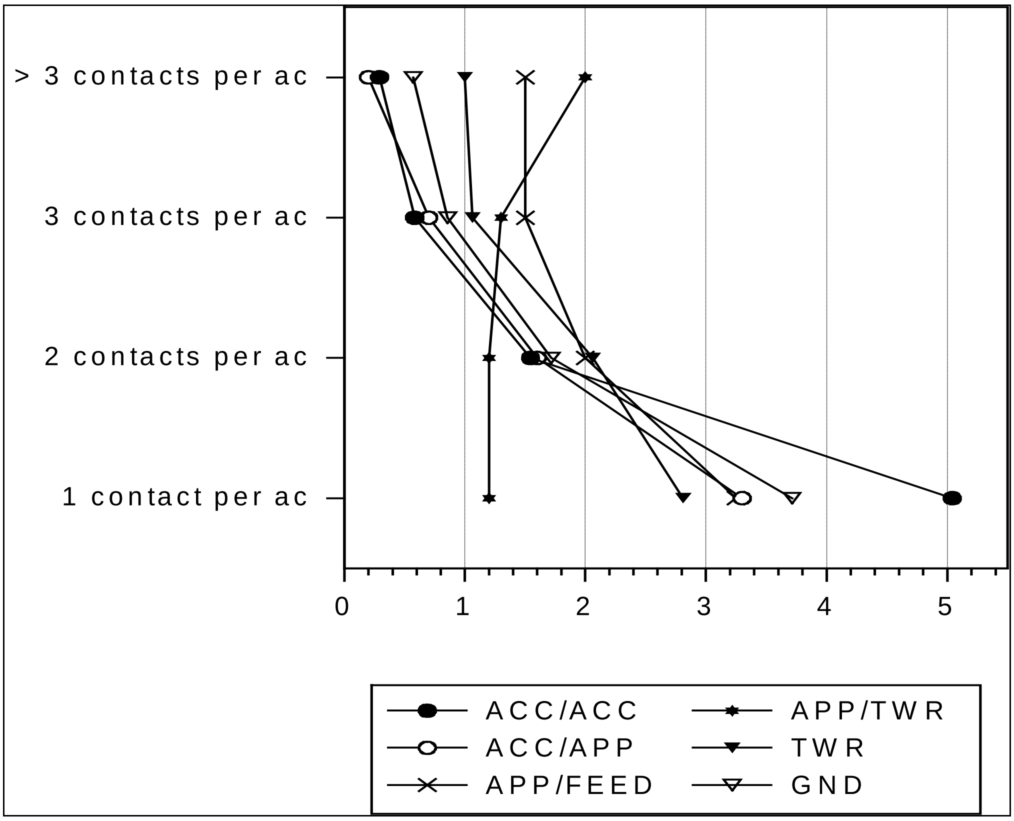

Figure 22: Call survey: frequency of the number of contacts per aircraft

5.4 Information Flow Sheet

5.4.1 Information Flow Sheet: Data Processing and Analysis

The frequency of communication with different communicating partners (e.g. coordinators, adjacent sectors, pilots) with respect to the **initiation of communication** and **dialogues other than yes/no answers and standard answers like readbacks** was registered within a 5 minute period. Only the counts for communications with controllers of adjacent sectors and pilots were included in the statistical analysis, since there is no information on communication with planning controllers for aerodrome positions available and communication with others was very rarely observed. The data was subjected to a statistical variance analysis to check differences between positions and geographical regions.

5.4.2 Information Flow Sheet: Results

Table 16 shows significant differences between the positions and geographical regions regarding the initiation of communication and the frequency of resulting dialogues.

Table 16: Significant differences between positions and regions regarding the observed initiation of communication and the frequency of dialogues

	Initiated by communication partner		**Initiated by observed ATCO**		**Number of dialogues**	
communication partner	**position**	**region**	**position**	**region**	**position**	**region**
Pilots	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Controllers of adjacent sectors	n.s.	* *	n.s.	* *	* *	* *

Note:
- n.s. — no significant difference
- (*) p ≤ 0,1 — slightly significant difference
- * p ≤ 0,05 — significant difference
- * * p ≤ 0,01 — highly significant difference
- * * * p ≤ 0,001 — highly significant difference

Concerning **communication with pilots, no significant differences** regarding the initiation of communication and the number of dialogues between the positions and the regions could be found (see Figure 23).

The variance in the data, particularly the high score in final approach positions (APP/TWR), seems to be due to traffic load in the observation period. But in all positions, the pilots, significantly, initiated communication more often. This may well be explained by the rules applied. Previous sector instructs a/c to call the next sector; number of compulsory reports is linked to number of fixes, etc.

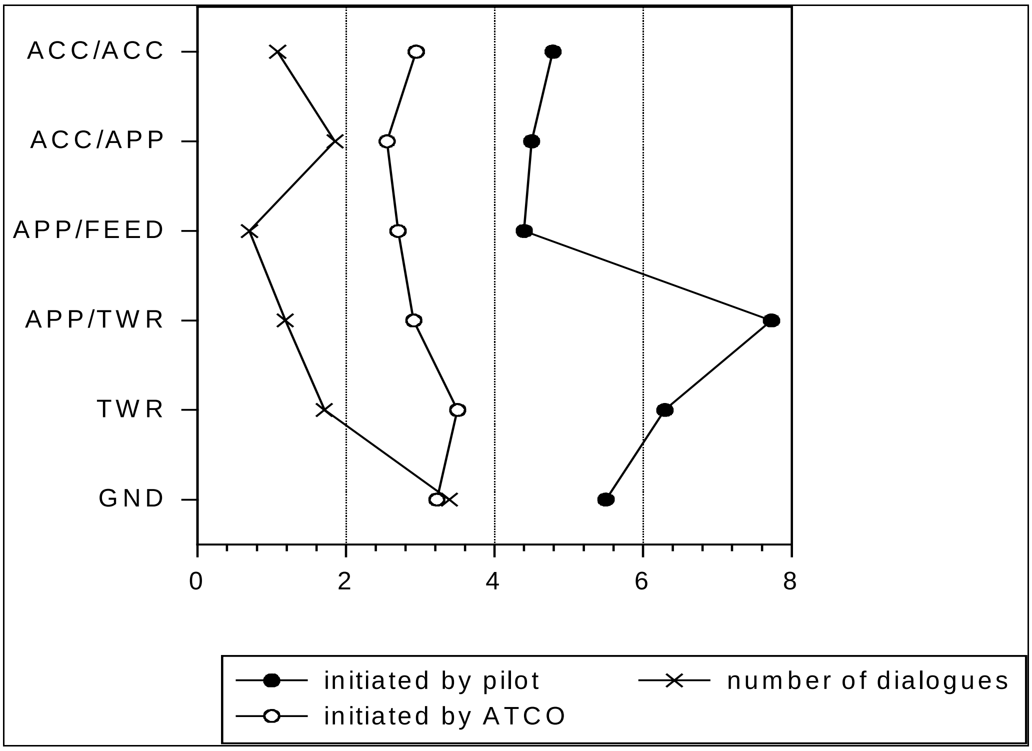

Figure 23: Average frequency of initiation of communication and dialogues with pilots for positions

For the **communication with controllers of adjacent sectors**, there are **significant differences between the geographical regions** (see Figure 24). The frequency of communication with controllers of adjacent sectors was particularly high in the South-West.

Regarding the number of dialogues there is also a significant difference between the positions (see Figure 25). Dialogues with controllers of adjacent sectors were particularly frequent in approach (APP/FEED) and ground (GND) positions.

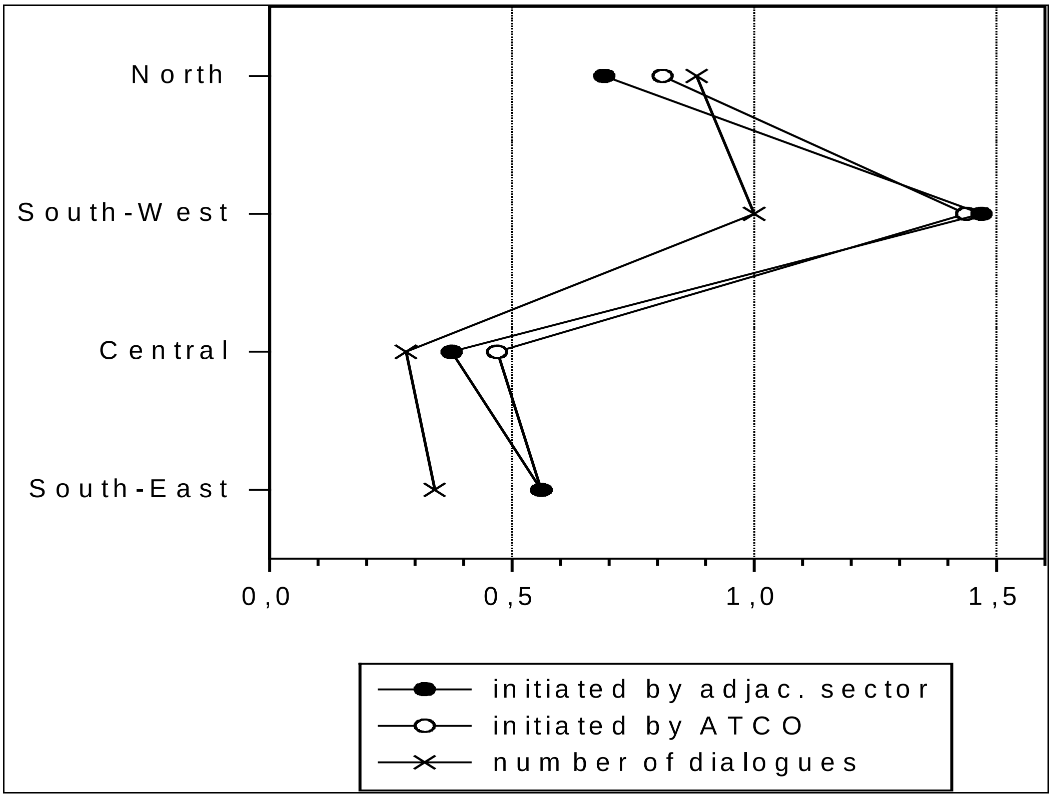

Figure 24: Average frequency of initiation of communication and dialogues with controllers of adjacent sectors for geographical regions

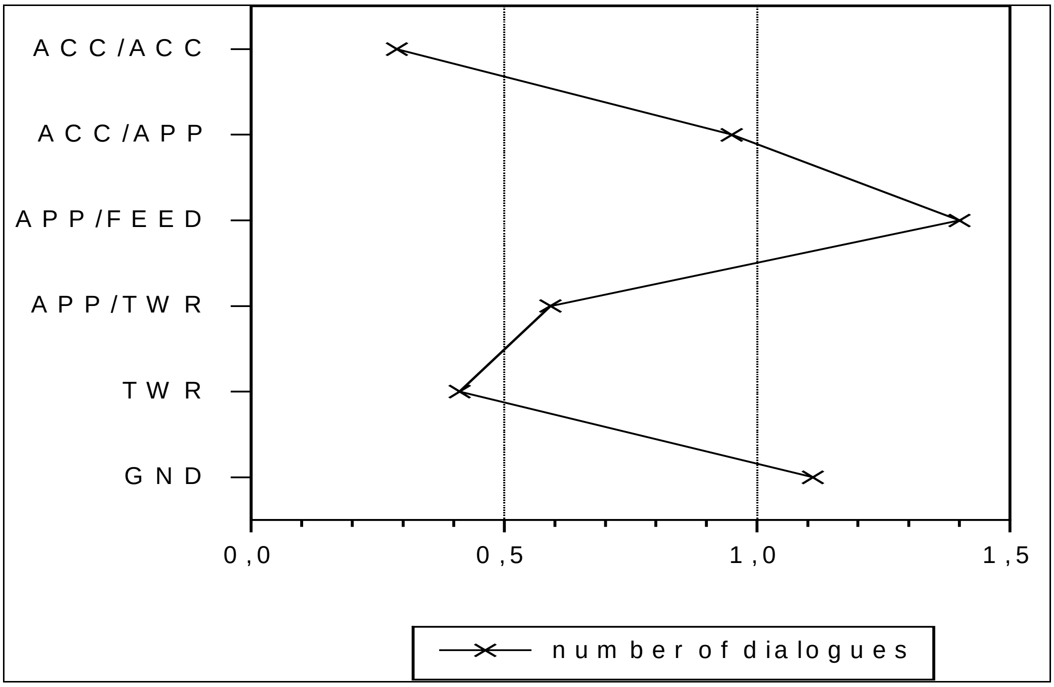

Figure 25: Average frequency of dialogues with controllers of adjacent sectors for positions

5.5 Psychometric Quality of Behavioural Observations

Two independent observers carried out thirty-five observations. Data showed that the reliability of the observation depends on the experience of the observers.

For 26 double-observations with pairs of experienced observers, the reliability of the observation is quite high. An observer can be described as experienced after having done four observations. Table 17 shows the coefficients of the observer consistency for the task categories.

Table 17: Observer consistency for task categories: reliability coefficients for the first and second part of the observation: Coefficients can range between 0 and 1: coefficients which are higher than .80 are considered satisfactory

Task Categories	Reliability First part of observation	Reliability Second part of observation
routine communication with pilot	.91	.91
special communication with pilot	.81	.46
technical activities	.86	.83
work-related communication, not to pilot	.67	.72
work-unrelated communication	.81	.91
FPS activities	.83	.89

A high level of consistency was obtained for ‘routine communication with pilot’, ‘technical activities’, ‘FPS activities’ and ‘non-work related communication’. This means the observers’ consistency for the core activities of ATCOs is high. The task categories ‘special communication with pilot’ and ‘work-related communication other than to pilot’ show lower levels of consistency (.46 and .72). The use of the native language for internal coordination and sometimes for communication with pilots’ also made the identification of work-related communication more difficult for the observers. Consistency between the observers involved in ITA and an observation by a qualified controller was not planned as part of the study.

Table 18 shows the observer consistency for the call survey and the flow of information sheet. Regarding the call survey, the reliability of the second part of the observation is generally higher and more satisfactory than the reliability of the first part. As a consequence, only data from the second part of the observation was analysed. Regarding the flow of information sheet, it seemed to be easy for the observers to identify the (usually verbal) communication with pilots and ATCOs of adjacent sectors, whereas the communication with planners / coordinators appears to be difficult to recognise, since it is often done in a non-verbal way.

Table 18: Observer consistency for the call survey and the flow of information sheet: reliability coefficients for the first and second part of the observation; coefficients can range between 0 and 1: coefficients which are higher than .80 are considered satisfactory

	Reliability First part of observation	**Reliability Second part of observation**
Call survey		
accept aircraft	.67	.86
dismiss aircraft	.73	.89
instruct pilot	.76	.98
Flow of information		
from / to pilot	.97	.83
from / to adjacent sector	.86	.72
from / to planner/ coordinator	.53	1.00

5.6 Behavioural Profiles: Summary

Observational data was collected by using three different observation grids:

Task units: The occurrence of different task units such as accepting an aircraft, accepting FPS, descending an aircraft, turning an aircraft, communication with adjacent sectors etc. was recorded during an eight-minute interval. For evaluation and the comparison of positions, the task units were broken down into more high-level task categories.

Call survey: The various aircraft and types of communication during a ten-minute interval were listed.

Information: flow sheet: The communication partners (e.g. pilots, planners, coordinators, adjacent sector controllers) and the frequency and direction of the communication were recorded. How often the communication resulted in a dialogue apart from standard answers (like e.g. readbacks, simple yes/no answers) was also registered.

The three grids were filled in twice during the observation period.

In order to prevent the determination of significant behavioural differences between working positions that are simply due to differences in traffic load, ATCOs' ratings of the average traffic load in the observation period were included in statistical analyses.

The following significant differences between working positions in ATC were determined:

Regarding the frequency of observed task categories:

- fewer 'technical activities' (e.g. zoom radar, use radar planning tools) were observed in aerodrome positions than in radar working positions. The aerodrome equipment can explain this because those tools are not available in all places.
- compared to aerodrome or final approach, approach positions (other than final approach) and approach-related en-route positions show a higher 'work-related communication other than to pilots' (e.g. communication with planner, coordination with adjacent sectors);
- compared to en-route positions or approach positions (other than final approach), final approach and tower positions show an increased 'routine communication with pilot' (e.g. accept, instruct , dismiss aircraft). This difference can only partly be explained by differences in traffic load but presumably reflects differences in cognitive working style as described in Chapters 3 and 4.

Concerning the frequency of communications to individual aircraft as registered in the call survey:

- Only 'one contact per aircraft' was observed more often in pure en-route positions.
- 'More than three contacts per aircraft' was observed most frequently in approach positions, particularly in final approach positions and relatively seldom in en-route.

This observable difference in working style has implications for the cognitive processes behind it. If ATCOs have to issue several instructions per aircraft within a few minutes, they are probably working in a more automated, bottom-up mode, as suggested by the cognitive profiles.

Regarding the information flow sheet:

- Dialogues with controllers of adjacent sectors were particularly frequent at approach (other than final approach) and ground positions.
- Over all positions, the pilots initiated communication more often.

Two independent observers carried out 35 observations in order to determine the reliability of the observation. Data showed that the reliability of the observation depends on the experience of the observers. For double observations with pairs of experienced observers, the inter-observer reliability is high (see Tables 17 and 18).

6. STRESS AND STRAIN ANALYSIS

Three questionnaires were used in order to evaluate stress and strain:

- **Synba-GA**: Addresses the stress imposed by working conditions.
- **Rest-Q**: Addresses the strain level resulting from stress and compensating recovery activities.
- **TQ**: Addresses aspects of team quality.

The three questionnaires are set out in the technical supplement.

Stress or more precisely stressors are the external demands of the job, while strain considers the reactions of individuals to a specific stressor or stress situation.

6.1 Description of the Questionnaires

6.1.1 Synba - GA: Synthetic Strain Analysis for Mental Work

The standardised Synba-GA questionnaire (Grüne and Wieland-Eckelmann, 1996) assesses the stress imposed on the ATCO by a variety of working conditions. Originally, it was developed for people working at office workstations. Synba-GA aims at giving hints for an optimal design of the task.

Three task components can be sources of stress:

- individual work task;
- cooperation and communication with others in order to comply with the individual task;
- human-machine interaction (e.g. computer workstation, controller ATC system).

A score is computed for each of the three task components, indicating the level of stress imposed by the task component.

To analyse the stress resulting from the task components in more detail, Synba-GA also addresses the following five task characteristics.

1. **Demands of the task**

   The completeness and demands of the task are evaluated.

   Example of items from the questionnaire:

- You have to work on difficult tasks that need a high level of concentration and accuracy.
- Your work mainly consists of short, non-complete tasks.

Optimum: tasks should be complete (e.g. one can see the results) and demanding in an appropriate way in order to enhance motivation and to promote skills and abilities.

2. **Scope of the task**

Evaluates the scope of decision-making and the possibilities of arranging the task according to individual preferences.

Example of items from the questionnaire:

- Your work demands quick decisions and you are responsible for the consequences.
- You have to plan the optimal progress of your work yourself.

Optimum: people should be able to make decisions and rearrange their tasks according to situational conditions and individual preferences (a goal can be achieved in different ways).

3. **Impediments in task execution**

Addresses the existence of obstacles or factors which block or impede task execution.

Example of items from the questionnaire:

- You have involuntary waiting times.
- Your working conditions are bad, the progress of your work is often disturbed.

Optimum: should be reduced to a minimum in order to avoid additional strain.

4. **Supervision of performance**

Addresses the level of supervision of performance.

Example of items from the questionnaire:

- You are told how you have to do your work and how much you have to achieve.
- You have to perform your task within a given time limit.

Optimum: an appropriate level of supervision facilitates performance.

5. **Cooperation and communication**

Evaluates the amount of cooperation and communication the task requires.

Example of items from the questionnaire:

- Your work repeatedly requires arrangements and cooperation with others.
- You mainly work alone.

Optimum: tasks should require an appropriate amount of communication and cooperation with others.

A score is computed for each of the five task characteristics, indicating the level of stress, according to whether the demands of work are functional or dysfunctional respectively. An **overall score** for stress is computed by summing up the scores of the task components and the task characteristics.

6.1.2 Rest-Q: Recovery-Stress-Questionnaire

The RestQ (Kallus, 1995; Kallus & Kellmann, 1999) measures different areas of stress and recovery, revealing the individual's state of strain. Work-related and non-work-related stress, as well as recovery, contributes to the individual person's strain. In order to infer a person's state of strain, both aspects have to be considered, i.e. a person's state of strain is determined by asking how often different stress situations and stress reactions appeared over the past days **and** how often stress-compensating recovery activities and recovery states were experienced over that time.

Four items each are used to measure the various aspects of stress/strain and recovery. ATCOs were asked to rate the frequency of certain activities or the state of mind they had been in, within the last three days/nights. For this purpose the Rest-Q offers a seven-point rating scale, ranging from 0 'never' to 6 'always'.

Stress/strain-aspects, with a sample item and figures which reflect the precision of measurement for the current controller sample ('internal consistency' using Cronbach´s formula alpha) are given in Table 19.

Table 19: Stress/strain and recovery aspects, example items and internal consistency (precision of measurement; ranging from 0 to 1, scores above 0,7 are considered 'fairly good').

Scale		Example	α
1	General Stress	... I felt down	.82
2	Emotional Stress	... I was in a bad mood	.73
3	Social Stress	... I was angry with someone	.80
4	Conflicts/Pressure	... I felt under pressure	.65
5	Fatigue	... I was overtired	.81
6	Lack of Energy	... I was unable to concentrate well	.72
7	Physical Complaints	... I felt uncomfortable	.74
8	Success	... I finished important tasks	.64
9	Social Relaxation	... I had a good time with my friends	.81
10	Physical Relaxation	... I felt at ease	.64
11	General Recovery/Well-being	... I was in a good mood	.80
12	Sleep Quality	... I had a satisfying sleep	.81

6.1.3 TQ: Team Quality Questionnaire

The team quality questionnaire (Kallus, 1996) measures different aspects of team quality. A short form was used, which addressed four aspects of team quality:

- team atmosphere: Implies aspects of having a good/bad relationship with one's colleagues;
- team support: Asks about support within the team;
- good mood: Asks for the ATCO's general mood;
- exemption from stress: Addressees the stress level of the ATCO.

6.2 Results of the Stress and Strain Analysis

6.2.1 Synba - GA: Results

A statistical analysis checked whether the stress imposed by working conditions differed significantly between the services (en-route, arrival/departure, aerodrome), the regions (North, Central, South-West, South-East) and the individual units (e.g. Athens, Barcelona, Bremen). Table 20 shows the significant differences of the overall score, the task components and task characteristics regarding service, geographical regions and units.

Table 20: Synba-GA: significant differences between positions, regions and units. (N=70)

Synba sub-scale Strain caused by:	**Service**	**Region**	**Unit**
Overall score	n.s.	∗ ∗	∗ ∗
Task components	n.s.	n.s.	n.s.
Individual work task	n.s.	∗	n.s.
Cooperation/communication with others	n.s.	∗	n.s.
Human-machine interaction	n.s.	∗	n.s.
Task characteristics	n.s.	n.s.	n.s.
Demands of task	n.s.	∗ ∗	∗ ∗ ∗
Scope of task	n.s.	∗	∗ ∗
Supervision of performance	(∗)	n.s.	n.s.
Cooperation/communication	n.s.	n.s.	∗ ∗ ∗

Note: n.s. no significant difference
(∗) $p \leq 0{,}1$ slightly significant difference
∗ $p \leq 0{,}05$ significant difference
∗ ∗ $p \leq 0{,}01$ highly significant difference
∗ ∗ ∗ $p \leq 0{,}001$ highly significant difference

Hardly any significant differences could be found between the different services of ATC, i.e. en-route, arrival/departure and aerodrome positions show no systematic differences regarding the stress imposed by the working conditions. Stress seems to be determined by situational conditions within the different geographical regions or, more plausibly, within the units.

For illustration, Figure 26 depicts the overall scores (means and standard deviations) of the participating units. The units are coded according to the type of services that were analysed. The overall scores are evaluated in a normative way:

- **Overall score is lower than 15:** the demands of the task are functional; no re-design or improvement required.

- **Overall score is between 15 and 19:** an improvement or re-design of task demands is not necessarily required, but might be recommended depending on the scores for the single task components and task requirements.

- **Overall score is higher than 19:** the task demands are rather dysfunctional; an improvement or re-design of task demands is highly recommended.

Only two of the units show fully satisfying results below 15. Most of the participating units show intermediate scores, indicating that a re-design of task demands might be recommendable though it is not absolutely necessary. A more detailed analysis of the scores for the task characteristics and task components would be required. Four units, one en-route, one arrival/departure and two aerodrome units exceed the critical score of 19, which means a re-design of task demands would be highly recommended. In two exceptions (en-route 6 and aerodrome 4) en-route units generally show a lower (thus better) score than aerodrome units.

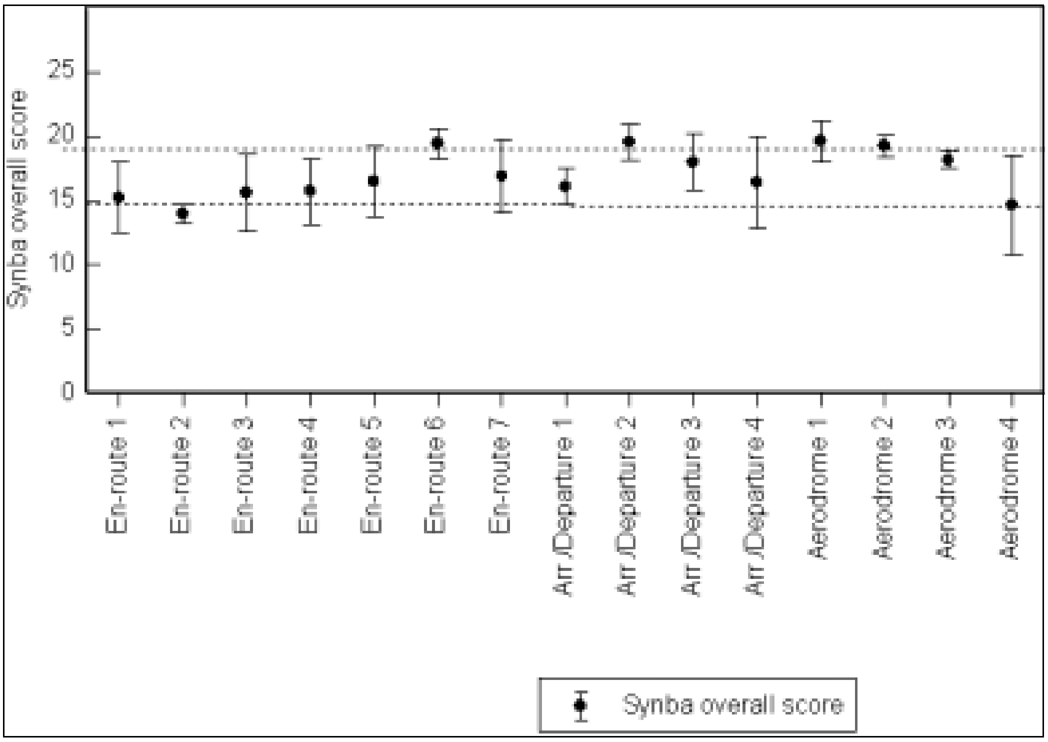

Figure 26: Synba-GA overall score for the participating units (means and standard deviations)

6.2.2 Rest-Q: Results

It was ascertained whether significant differences existed regarding the stress and strain aspects between the services, the geographical regions or the units.

The Rest-Q shows significant differences between the different regions and the individual units only for the aspect 'general stress'. No significant differences between the services emerged.

Figure 27 depicts the means and standard deviations of the participating units regarding the 'general stress' aspect. Average scores and standard deviations of the volunteer controllers are given. High means indicate a comparable high level of general strain. Large standard deviations indicate that the strain level within the group of participants varies considerably between the controllers. The units are coded according to the type of service they represent.

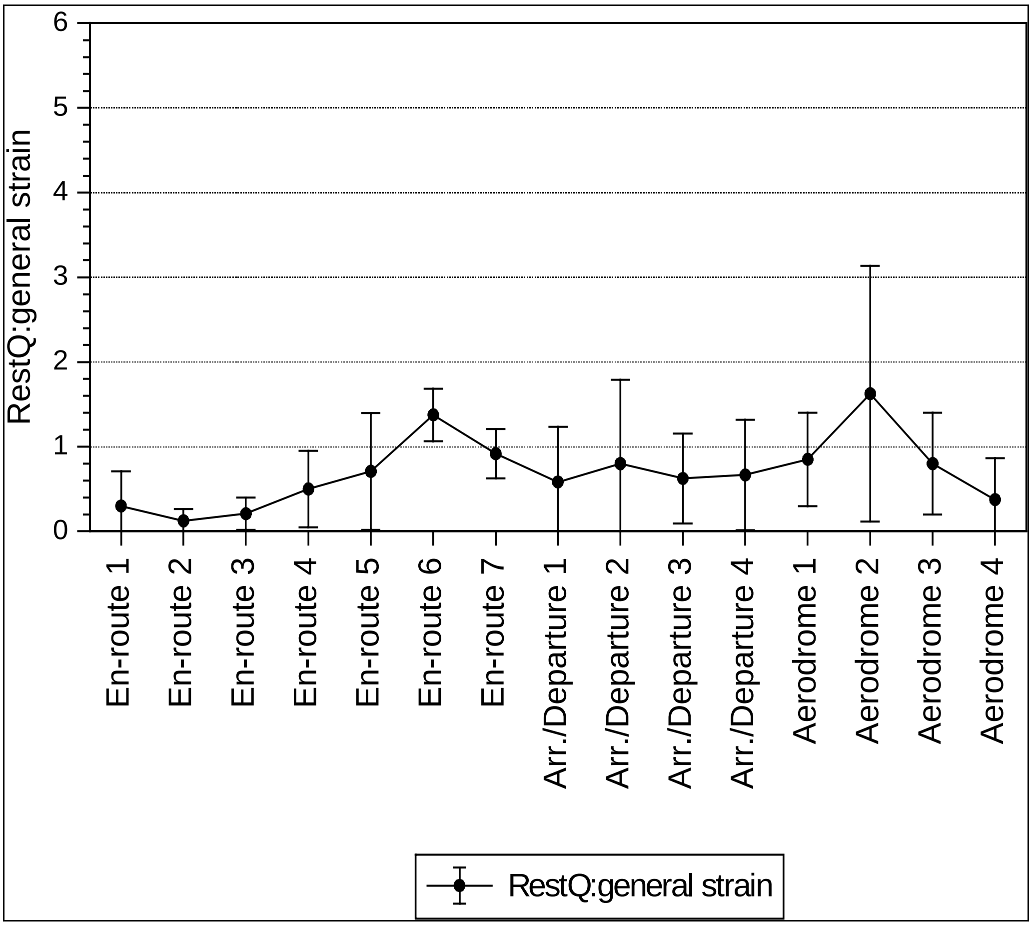

Figure 27: RestQ, 'general stress' aspect: means and standard deviations of units; the scale on the vertical axis reflects the rating scale of the RestQ, i.e. the higher the score, the higher the level of 'general stress'. (N=77)

Figure 27 shows that there are fairly low strain levels for controllers in most of the units participating in the study. This can partially be explained by the fact that some controllers were back for their first shift after some days off. Thus, for shift work scores can be artificially low. The overall low scores should not lead us to overlook the remarkable differences in the general stress of ATCOs working in different units. Whereas controllers of units 'en-route 2' and 'en-route 3' report hardly any 'general stress' (low mean score with a very small standard deviation), the scores of controllers from 'en-route 6' and 'aerodrome 2' are significantly higher. 'Aerodrome 2' on the other hand has quite a large standard deviation, i.e. there seem to be considerable differences in the 'general stress' between the individual controllers.

In summary, as for the Synba questionnaire, strain and recovery from strain seem to be determined by situational and organisational conditions within the units rather than by service or working position.

As it was not the purpose of this study, the impact of personal criteria on strain, such as age, was not evaluated.

6.2.3 Team Quality Questionnaire: Results

A statistical analysis was carried out to check whether team quality differed significantly between the services, the regions and the individual units. No significant differences emerged.

By way of illustration Figure 28 shows the mean scores and standard deviations of the participating units for 'team atmosphere'. The units are coded according to the type of service they represent. High-mean scores indicate a good team atmosphere. Large standard deviations (see e.g. en-route 2 or aerodrome 2) imply that the evaluation of team atmosphere varies considerably between the individual ATCOs.

For 'absence of stress' (see 6.1.3) a tendency toward differences between units was found which corresponds to the findings of the RestQ. Figure 29 depicts the means and standard deviations for the units. High mean scores indicate a low stress level. Large standard deviations indicate that the stress level experienced by the controllers varies considerably. As for the 'general stress' aspect of the RestQ, the units 'en-route 2' and 'en-route 3' report hardly any stress whereas 'aerodrome 2' shows a comparably high stress level.

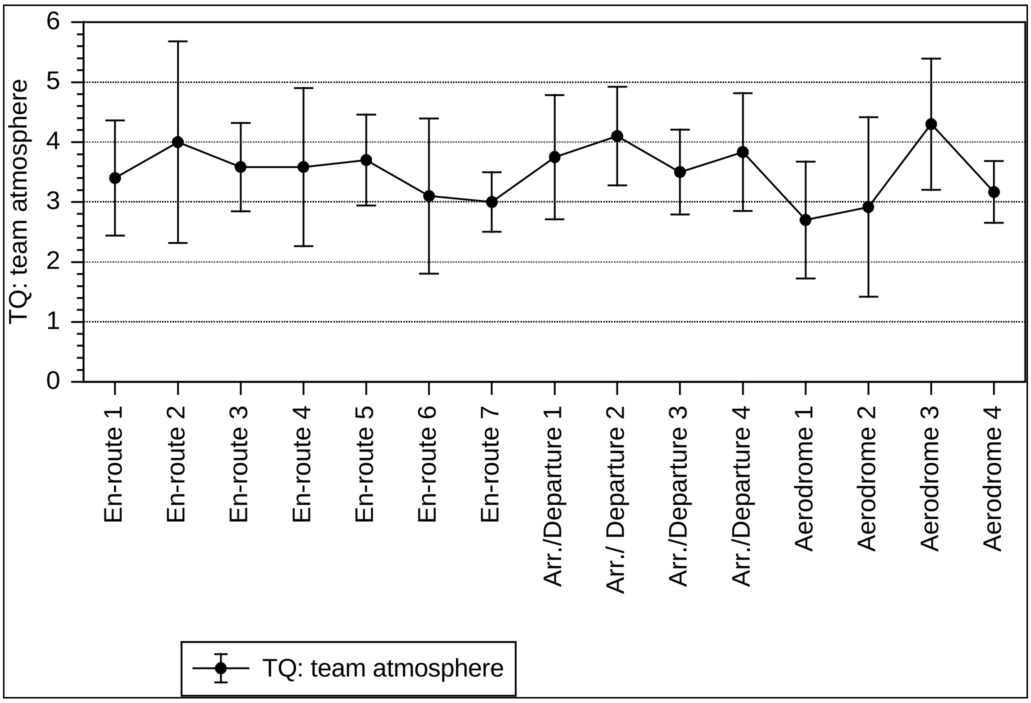

Figure 28: TQ, 'team atmosphere'; means and standard deviations of units; the score on the vertical axis reflects the rating scale of the TQ, i.e. the higher the score, the better the team atmosphere. (N=75)

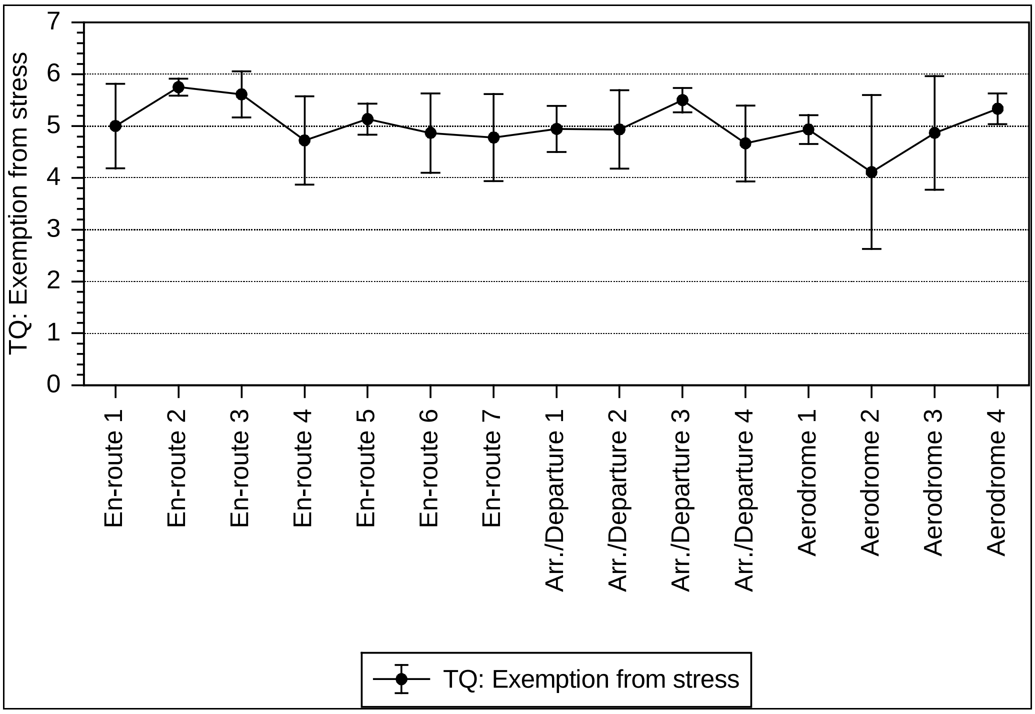

Figure 29: TQ, 'absence of stress' aspect; means and standard deviations of units; the score on the vertical axis reflects the rating scale of the TQ, i.e. the higher the score, the less stress ATCOs experience.

6.3 Stress and Strain Analysis: Summary

Three questionnaires were used to evaluate the ATCOs' stress and strain level:

- the **Synthetic Strain Analysis for Mental Work (Synba-GA)** addresses the stress imposed by working conditions;

- the **Recovery-Stress-Questionnaire (Rest-Q)** addresses the strain level resulting from stress and compensating recovery activities;

- the **Team Quality Questionnaire (TQ)** addresses different aspects of team quality.

In statistical analyses a check was made to see whether stress and strain or team quality differ significantly between the services (en-route, arrival/departure, aerodrome), the regions (North, Central, South-West, South-East) and the individual units (e.g. Athens, Barcelona, Bremen).

Based on the questionnaires used, only a few significant differences could be found between the different services of ATC, i.e. en-route, arrival/departure and aerodrome positions show no systematic differences regarding the stress and strain level of ATCOs or the experienced team quality.

Significant differences regarding the stress imposed by working conditions were found between the individual units. These differences are also reflected by differences between the geographical areas.

For the ATCOs' strain-recovery balance, which is also influenced by non-work-related stress, the differences between units are less distinct. Scores show a general picture of the participating ATCOs' strain level, which is only partly due to their work.

For the team quality, no significant differences were found between units.

In contrast to cognitive working style, stress and strain are not determined by the kind of service ATCOs provide, i.e. according to whether they are working in en-route, arrival/departure or aerodrome control. Instead, the stress imposed by working conditions seems to be governed by situational conditions within the different units. However, the ATCOs' resulting level of strain depends to a great extent on their individual ability to compensate stress by means of recovery activities.

7. RESULTS INTEGRATION

This chapter deals with the integration of the findings from the different ITA methods. The core results of ITA Phase 3 are the cognitive profiles of ATCOs working in en-route, arrival/departure or aerodrome control. Evidence was found of a strong interrelation between working position/service and cognitive working style. However, cognitive working style might also be determined by factors other than working positions. In order to determine which situational or individual characteristics might influence the cognitive working style of ATCOs, the top-down/bottom-up ratings of the ATCOs' cognitive processes were submitted to a cluster analysis.

7.1 Data Processing: Cluster Analysis

A cluster analysis is a statistical procedure that allows the grouping or clustering of subjects according to particular characteristics. In this case the subjects (ATCOs) were clustered according to their rated cognitive working style (top-down/bottom-up ratings given by observers / interviewers).

In order to avoid having to exclude too many ATCOs from the analysis because of missing data ('0-ratings'), three summarised ratings as suggested by the factor analysis (see Chapter 4.1.2) were used for the cluster analysis. They are reviewed in the following box.

'Pre-planning' = mean rating of taking over position, managing routine traffic, solving conflicts, searching conflicts and switching attention

⇨ Comprises the reported importance of pre-planning traffic and how far ahead they pre-plan the traffic, including conflict search and conflict resolution, e.g. how much time in advance potential conflicts are detected and resolved?; do the ATCOs have explicit individual action plans or is traffic worked off as it comes? *Top-down ratings* imply that pre-planning is considered to be important and that ATCOs pre-plan their traffic as far ahead as possible. *Bottom-up ratings* indicate that traffic is handled in a reactive way; traffic is usually not (or cannot be) planned in advance.

'Updating the mental picture style' = mean rating of monitoring and updating the mental picture.

⇨ Asks whether ATCOs update their picture or monitor their traffic in a more selective or more global way. *Top-down ratings* point to a selective way of updating the picture, e.g. 'problematic' aircraft are checked more often than others. *Bottom-up ratings,* on the other hand, indicate a global way of updating the picture: attention can seldom be focused only on parts or details, because the task requires continuous monitoring of the whole situation.

'Pilot instructing style' = mean rating of managing requests and issuing instructions.

⇨ Asks whether instructions to pilots, including the handling of requests, are managed in a proactive or reactive way. *Top-down ratings* point to a proactive way of instructing, e.g. if potential communication problems are usually actively avoided by adjusting the instruction to the anticipated language or experience level of the pilot, or if pilots' requests are usually anticipated and approved before pilots need to ask. *Bottom-up ratings* imply a more reactive way of instructing, e.g. most instructions are given in a highly automated, schematic way by reacting to a certain event (e.g. pilot's call), or pilots' requests cannot usually be predicted and approved in advance.

7.2 Results: Four Clusters of Cognitive Working Styles

Four clusters of cognitive working styles were identified. Fifty-nine (59) out of eighty (80) ATCOs were included in the analysis. Twenty-one (21) were dropped because of missing data. Table 21 shows the characteristic cognitive features of the clusters.

Means and ranges can be interpreted according to the top-down/bottom-up rating scale: *1 'definitely bottom-up', 2 'more bottom-up', 3 'equally bottom-up and top-down', 4 'more top-down' and 5 'definitely top-down'.*

Table 21: Cluster analysis: cognitive working style of the four identified clusters

Cluster	Factor	Range	Mean	SD	Interpretation
1 N = 9	pre-planning	3.50-4.00	3.89	0.18	top down
	updating the mental picture style	2.00-4.00	3.39	0.65	equally t-d and b-u with a tendency towards top-down
	pilot instructing style	2.00-3.00	2.78	0.44	equally t-d and b-u with a tendency towards bottom-up
2 N = 26	pre-planning	3.33-4.33	3.88	0.28	top-down
	updating the mental picture style	3.00-4.50	3.73	0.43	top-down
	pilot instructing style	3.50-4.50	3.98	0.22	top-down
3	pre-planning	2.00-3.25	2.67	0.39	bottom-up with a tendency towards equally t-d and b-u

Table 21: Cluster analysis: cognitive working style of the four identified clusters (continued)

Cluster	Factor	Range	Mean	SD	Interpretation
N = 14	updating the mental picture style	2.00-4.00	3.25	0.51	equally t-d and b-u with a tendency towards top-down
	pilot instructing style	4.00	4.00	0.00	top-down
4 N = 10	pre-planning	2.00-3.00	2.23	0.32	bottom-up
	updating the mental picture style	2.00-4.00	3.10	0.78	equally t-d and b-u (large variance)
	pilot instructing style	1.00-3.00	2.35	0.67	bottom-up

Note: N: Number of included subjects (ATCOs)
SD: Standard Deviation
t-d: top-down
b-u: bottom-up

Cluster 1 consists of nine ATCOs; regarding the factor '**pre-planning'** their values range between 3.5 and 4; with a mean rating of 3.9 and a very small standard deviation. This means that, regarding the extent of pre-planning the task, ATCOs which belong to this cluster were rated top-down/concept-driven, i.e. pre-planning the task is considered to be very important and traffic is planned as far in advance as possible. **Updating the mental picture style** includes ratings ranging from bottom-up to top-down, with an emphasis on equally top-down and bottom-up or rather top-down, i.e. the distribution of attention is more selective, guided by the ATCOs' plans or intentions. In some cases it is also considerably determined by the actual situation. **Pilot instructing style** ranges between 2 'more bottom-up' and 3 'equally top-down and bottom-up' with an emphasis on the latter, i.e. the communication with pilots is usually handled in an equally reactive and proactive style.

Cluster 2 is rather large and comprises 26 ATCOs. All three factors show top-down ratings. **Pre-planning:** this means that ATCOs which belong to this cluster usually pre-plan their traffic and consider planning to be very important. **Updating the mental picture style**: ATCOs of this cluster monitor the traffic in a concept-driven or anticipation-guided way. Although they regularly have to update their picture of the whole traffic situation, they are often able to focus their attention on important details ('foreground - background picture'). **Pilot instructing style**: when issuing instructions and dealing with pilots' requests, ATCOs from this cluster usually work in a proactive, anticipation-guided way, e.g. predictable requests are considered in advance or instructions are adjusted to the anticipated experience level of the pilot.

Cluster 3 consists of 14 ATCOs. The values for **pre-planning** are bottom-up with a slight tendency towards equally top-down and bottom-up. This means that ATCOs which belong to this cluster do not usually pre-plan their traffic over a longer period of time. Traffic is managed in a more reactive, short-term way. **Updating the mental picture style** includes ratings ranging from 2 'bottom-up' to 4 'top-down', with an emphasis on equally top-down and bottom-up or mostly top-down, i.e. the distribution of attention is to some extent selective, guided by the ATCOs' plans or intentions, but it is also necessary frequently to update the picture of the whole traffic situation. **Pilot instructing style**: ATCOs of this cluster often issue instructions and deal with pilots' requests in a proactive, anticipation-guided way, e.g. predictable requests are considered in advance or instructions are adjusted to the anticipated experience level of the pilot.

Cluster 4 comprises a group of 10 ATCOs. The values for the factor **pre-planning** range between 2 'bottom-up' and 3 'equally top-down and bottom-up', but the mean shows that the emphasis is clearly on the bottom-up side, i.e. ATCOs of this cluster manage their traffic in a reactive, situation-driven way. They do not generally have long-term traffic plans. The values for **updating the mental picture style** vary considerably from 2 'more bottom-up' to 4 'more top-down'; i.e. ATCOs of this cluster have different cognitive styles. **Pilot instructing style** again is clearly bottom-up, this means, most instructions to pilots are given in a highly automated, schematic way, e.g. by reacting to a pilots' calls. As well, pilots' requests cannot usually be predicted and considered in advance.

In summary, in cluster 2 the cognitive working style is apparently top-down/concept-driven whereas cluster 4 consists of ATCOs with a bottom-up/situation-driven cognitive working style. Clusters 1 and 3 contain ATCOs with a 'mixed' cognitive working style, particularly concerning the factors pre-planning and pilot instructing style.

The differences between the clusters regarding the factors 'pre-planning', 'updating the mental picture style' and 'pilot instructing style' are statistically highly significant.

7.3 Contingency between Clusters and Characteristics of Air Traffic Controllers

7.3.1 Service Provision

A further step determined which of the ATCOs' characteristics, e.g. the service they provide, the units at which they work, their age and their experience, might be related to the clusters, or the cognitive working style they represent, respectively.

Table 22 shows the contingency between service (i.e. en-route, arrival/ departure and aerodrome) and cluster.

Table 22: Frequencies of en-route, arrival/departure and aerodrome controllers across clusters: absolute numbers (column percent)

	En-route	**Arrival/Departure**	**Aerodrome**
Cluster 1	7 (23%)	1 (8%)	1 (6%)
Cluster 2	19 (63%)	5 (42%)	2 (12%)
Cluster 3	4 (13%)	4 (33%)	6 (35%)
Cluster 4	0	2 (17%)	8 (47%)

Table 22 demonstrates that the clusters are to a great extent determined by the service that the ATCOs provide, i.e. if they are working in en-route, arrival/departure or aerodrome positions.

Cluster 2 ('top-down'-cluster) consists mainly of en-route controllers; 63 % of all en-route controllers are in this cluster. There are also considerable numbers of arrival/departure controllers: 42% of all arrival/departure controllers belong to cluster 2, but only few aerodrome controllers.

In contrast to this **cluster 4** ('bottom-up'-cluster) consists of mainly aerodrome controllers; 47% of them belong to cluster 4, and a small number of arrival/departure ATCOs. This cluster includes no en-route controllers.

The 'mixed' **cluster 1** (pre-planning: top-down; pilot instructing style: tendency to bottom-up) again consists mainly of ATCOs working in en-route control.

In contrast to the above finding **cluster 3** (pre-planning: bottom-up; pilot instructing style: top-down) consists of an equal amount of aerodrome controllers (35% of all aerodrome controllers) and arrival/departure controllers (33% of all arrival/departure controllers), whereas only 13% of the ATCOs working in en-route control belong to cluster 3.

In summary, **en-route controllers** can mainly be found in cluster 2 ('top-down'-cluster) and to a lesser extent in cluster 1 (pre-planning: top-down; pilot instructing style: tendency to bottom-up). **Aerodrome controllers** are mainly represented in clusters 4 ('bottom-up'-cluster) and 3 (pre-planning: bottom-up; pilot instructing style: top-down). **Arrival/departure controllers** are most often represented in clusters 2 ('top-down'-cluster) and 3 (pre-planning: bottom-up; pilot instructing style: top-down).

These results suggest that the factor 'pre-planning' distinguishes particularly among the three services: a top-down cognitive working style seems to be typical for en-route controllers, whereas aerodrome controllers are usually characterised by a bottom-up style. Arrival/departure controllers are not homogeneous; some have a top-down style of 'pre-planning', while others work more bottom-up. These results correspond to the conclusions drawn from the cognitive profile of top-down/bottom-up ratings (see Chapter 4.1.3): in en-route control all cognitive processes have been rated rather top-down. Long-term plans and anticipation are crucial for the en-route controllers' task. In aerodrome control, cognitive processes involved in pre-planning the task were rated as being carried out in a more bottom-up way. Aerodrome controllers usually do not pre-plan their task over a longer period of time. In arrival/departure control the ratings for the cognitive processes varied considerably owing to a broad range of answers.

This raises the question of what other conditions apart from the working position are related to, or influence, cognitive working style. Important characteristics or results from other ITA methods were selected and checked for any **significant differences between the four clusters**. Table 23 summarises the results.

Table 23: Variables/characteristics checked for significant differences between clusters of cognitive working style

Analysed variables / characteristics	**Significance level of differences between clusters**
Age (years)	n.s.
Job experience (years)	n.s.
Observation: frequency of task categories	
Routine communication with pilots	* * *
Work-related communication, other than to pilots	* *
Other task categories	n.s.
ATCOs' ratings of traffic load, time pressure, feelings of stress and frequency of being idle during the observation period	n.s.
Stress and strain questionnaires	
Synba-GA: overall score	(*)
RestQ: sub-scale 'conflicts'	*
RestQ: sub-scale 'lack of energy'	*
RestQ: sub-scale 'physical relaxation'	(*)
RestQ: other sub-scales	n.s.
Team quality questionnaire	n.s.

Note:

n.s.		no significant difference
(*)	$p \leq 0,1$	slightly significant difference
*	$p \leq 0,05$	significant difference
* *	$p \leq 0,01$	highly significant difference
* * *	$p \leq 0,001$	highly significant difference

7.3.2 Age and Job Experience

There are no significant differences in age and job experience between the four clusters of ATCOs. Thus, experience seems to play only a minor role in determining cognitive working style. Nevertheless, analyses of job experience which were done separately for en-route, arrival/departure and aerodrome control services suggested that experience does have an impact at least for arrival/departure controllers (see Chapter 4.1.3).

7.3.3 Observation: Frequency of Task Categories

Highly significant differences were found regarding the frequencies of two task categories observed at the working position on 'routine communication with pilot' and 'work-related communication, other than to pilot'. Figure 30 depicts the average frequencies of both task categories across the clusters.

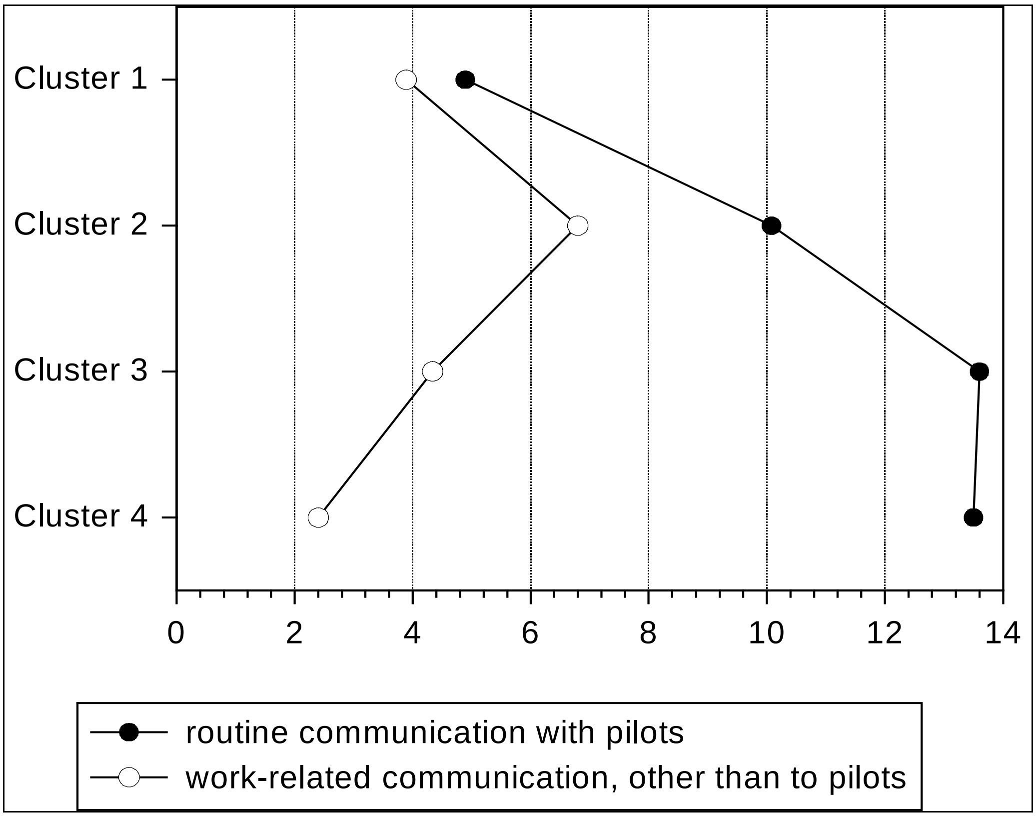

Figure 30: Average frequencies of the task categories 'routine communication with pilot' and 'work-related communication, other than to pilot' across clusters of cognitive working style

Figure 30 shows that the ATCOs of clusters 3 and 4 ('bottom-up'-clusters) had more frequent communication with pilots than those of clusters 1 and 2 ('top-down'-clusters). Particularly in cluster 1 the communication frequency was very low. Compared to this, work-related communication other than to pilots (e.g. to planner, flight data assistant, ATCO of adjacent sector) was most often observed with ATCOs in cluster 2 but only rarely in cluster 4.

These findings correspond to the distribution of ATC-services across the clusters: aerodrome controllers have been rated as having a bottom-up cognitive working style, whereas en-route controllers are usually working in a top-down way and arrival/departure controllers show a broad variety of cognitive working styles. In aerodrome and arrival/departure positions, particularly on final approach, the frequency of routine communication with pilots is very high compared to that of en-route positions (see Chapter 5.2.2). In normal traffic conditions, when continually giving landing or takeoff clearances, aerodrome and final approach controllers work in a rather repetitive and highly automated way. Highly automated activities are usually simply triggered by external events, e.g. all first calls of pilots are usually answered with the same instruction, which means that it is not necessary to 'pre-plan' these instructions. They are given in a bottom-up or reactive way. This interrelation explains why clusters 3 and 4, which consist mainly of aerodrome and arrival/departure controllers, show a higher frequency of routine communication with pilots.

'Work-related communication other than to pilots', on the other hand occurs most often in cluster 2, which consists mainly of en-route and arrival/departure controllers and is considerably less frequent in cluster 4, which predominantly comprises aerodrome controllers. Differences can be explained by the fact that in en-route and arrival/departure positions radar controllers frequently communicate with planning/coordinating controllers whereas in aerodrome control there are usually no planner positions (see Chapter 5.2.2).

7.3.4 Air Traffic Controllers' Ratings of the Observation Period

After the observation period, the ATCOs were asked to rate the frequency of the following events on a seven-point rating scale (ranging from 'never' to 'always'):

- How often did time pressure occur during the observation period?
- How often did you feel tense?
- How often have you been idle ('nothing to do')?

They were also asked to give a rating of the average traffic load in the observation period on the following rating scale: low traffic; average traffic with silent periods; average traffic; average traffic with peaks; high traffic. The common core aspect that is addressed by these ratings can be called subjective workload within the observation period. The ratings show no significant differences between clusters owing to high standard deviations within each cluster. For time pressure and feelings of tension, cluster 4 tends to be the one with the highest scores, i.e. compared to the other clusters, time pressure and feelings of tension occurred more often with ATCOs of cluster 4. On the other hand, compared to the other clusters, in cluster 1 time pressure and feelings of tension occurred less often. The opposite tendency can be found on the question of idle periods: ATCOs of cluster 1 were idle more often than ATCOs of the other clusters. Also, ATCOs of clusters 1 and 2 rated the average traffic load slightly lower than ATCOs of clusters 3 and 4. Thus, the results suggest there is a relation, however small, between workload and cognitive working style; i.e. ATCOs with a bottom-up style have slightly higher subjective ratings of workload.

7.3.5 Stress and Strain Questionnaires

Significant differences between clusters could also be found for stress and strain.

The **RestQ** questionnaire measures the ATCO's individual level of stress/strain and recovery from stress (see Chapter 6). Scores indicating high stress are not necessarily due to the ATCO's work but can also result from private life, i.e. RestQ reflects the general stress level of the individual. The RestQ indicates significant and slightly significant differences between clusters in aspects of 'lack of energy', 'conflicts' and 'physical relaxation'. High scores in the factor 'lack of energy' can be an indication of non-effective work due to a lack of concentration, energy and determination. 'Conflicts' shows high scores if subjects were dealing with unresolved conflicts or other unpleasant issues, and where goals could not be attained. High scores in 'physical relaxation' indicate psycho-physiological fitness and relaxation.

Figure 31 shows the mean scores of these aspects across the four clusters.

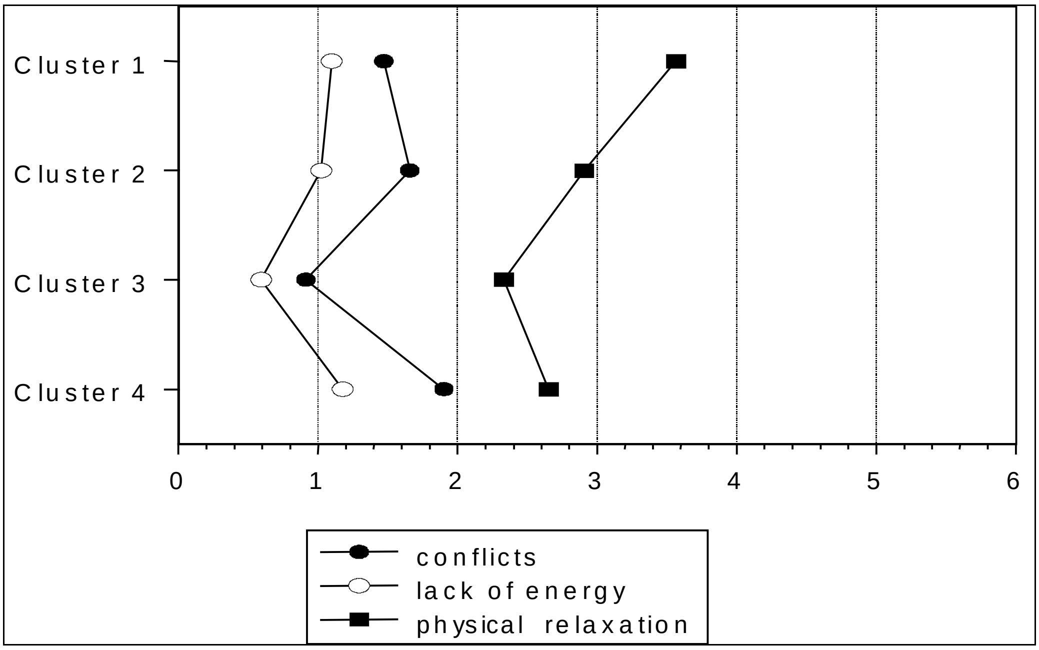

Figure 31: RestQ: mean scores of the sub-scales 'conflicts', 'lack of energy' and 'physical relaxation' across the clusters

Compared to the other clusters, cluster 3 shows clearly lower scores in the stress aspects 'conflicts' and 'lack of energy'. On the other hand ATCOs of cluster 1 show the highest scores in 'physical relaxation'.

The **Synba-GA** questionnaire assesses the stress imposed on the ATCOs by a variety of working conditions (see Chapter 6). The slightly significant difference between clusters in the Synba overall-score of stress is shown in Figure 32.

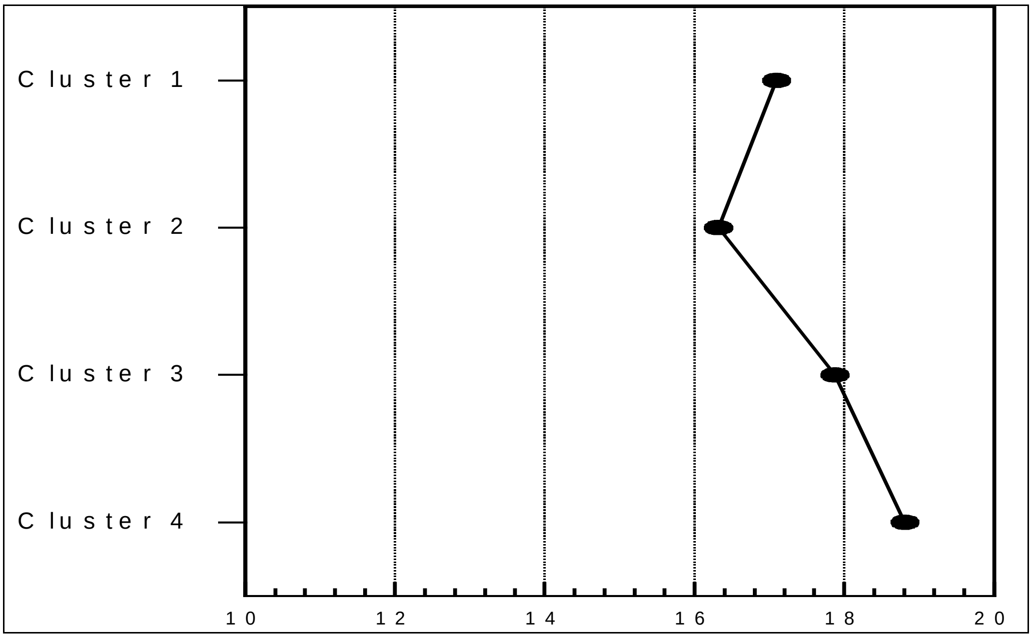

Figure 32: Synba-GA overall score: mean scores across the clusters

ATCOs of cluster 2 ('top-down'-cluster) have a distinctly lower overall score of stress than ATCOs of cluster 4 ('bottom-up'-cluster), i.e. ATCOs with a bottom-up cognitive working style reported having more dysfunctional or stressful working conditions than ATCOs with a top-down cognitive working style.

7.4 Results Integration: Summary

A strong interrelation between working position/service and cognitive working style was found. However, cognitive working style might also be determined by factors other than working positions. In order to determine which situational or individual characteristics might influence the ATCOs' cognitive working style, the top-down/bottom-up ratings of the ATCOs' cognitive processes were submitted to a cluster analysis.

A cluster analysis is a statistical procedure that allows the grouping or clustering of subjects according to particular characteristics. In this case the subjects (ATCOs) were clustered according to their rated cognitive working style (top-down/bottom-up ratings).

Four clusters of cognitive working styles were identified.

In cluster 2 the cognitive working style is apparently top-down/concept-driven, whereas cluster 4 consists of ATCOs with a bottom-up/situation-driven cognitive working style. The clusters 1 and 3 contain ATCOs with a 'mixed' cognitive working style, particularly in pre-planning and pilot instructing style.

A further step determined which characteristics of the ATCOs, e.g. the service they provide, the units at which they work, their age and their experience, might be related to the clusters, or to the cognitive working style they represent, respectively.

It was found that the clusters are to a large extent determined by the service the ATCOs provide (en-route, arrival/departure or aerodrome positions).

En-route controllers are found mainly in cluster 2 ('top-down'-cluster) and to a lesser extent in cluster 1 (pre-planning: top-down; pilot instructing style: tendency to bottom-up).

Aerodrome controllers are mainly represented in the clusters 4 ('bottom-up'-cluster) and 3 (pre-planning: bottom-up; pilot instructing style: top-down).

Arrival/departure controllers are most often represented in the clusters 2 ('top-down'-cluster) and 3 (pre-planning: bottom-up; pilot instructing style: top-down).

These results correspond to the conclusions drawn from the cognitive profile of top-down/bottom-up ratings (see Chapter 4.1.3): in en-route control all cognitive processes were rated top-down. Long-term plans and anticipation are crucial for the en-route controllers' task. In aerodrome control, cognitive processes concerned with pre-planning the task were rated as being carried out in a more bottom-up way. Aerodrome controllers usually do not pre-plan their task over a longer period of time. In arrival/departure control the ratings for the cognitive processes varied considerably as a result of the broad range of answers given.

Further characteristics of ATCOs that differentiate significantly between the clusters were determined:

- Observational data: the frequency of the task categories 'routine communication with pilot' and 'work-related communication other than to pilot'. These results concur with other findings in this study about the interrelation of the named task categories and ATC services (see Chapter 5.2).

- Stress and strain questionnaires: the 'conflicts', 'lack of energy' and 'physical relaxation' aspects of the RestQ and the overall score of the Synba-GA.

No significant differences between the clusters could be found regarding age, job experience and subjective workload in the observation period. In summary, the results suggest that the cognitive working style of ATCOs is mainly determined by the service or working position.

To this end, the following chapter provides a summary of the most important results regarding the differences between en-route, arrival/departure and aerodrome control.

8. COMPARISON OF AIR TRAFFIC CONTROL SERVICES: SUMMARY OF RESULTS

Ten basic cognitive processes were identified in the en-route controllers' task in Phase 2 of the project:

Five task processes:
- Taking over position / building up the mental picture,
- Monitoring,
- Managing routine traffic,
- Managing requests / assisting pilots,
- Solving conflicts;

One control process:
- Switching attention;

Four sub-processes:
- Updating the mental picture,
- Checking,
- Searching conflicts,
- Issuing instructions.

These basic cognitive processes also apply to arrival/departure and aerodrome positions. The structure of the processes developed for en-route control remains basically the same despite some slight adaptations.

For the four sub-processes and the control process, there seem to be no major differences between the three services. Of course, some situational conditions vary, e.g. the view outside or the wind display are crucial information sources for aerodrome controllers. For the five task processes no major differences emerged in the structure of the processes between en-route and arrival/departure control. In the case of aerodrome control, only the task process of 'taking over position' had to be slightly adapted. General differences between the three positions were found to relate mainly to the **parameters of the processes** such as timing, speed of processing or frequency of certain processes:

The differences in the parameters of the processes are reflected in the **cognitive profiles** of en-route, arrival/departure and aerodrome controllers. The differences in the cognitive profiles are supplemented and supported by the findings from behavioural observations.

8.1 En-route Control

All basic cognitive processes have been rated top-down. This means that most en-route controllers reported they do their job in quite a pro-active or concept-driven way. 'Long-term plans' and anticipation play an important part in the en-route controller's task.

Usually en-route controllers plan their traffic in advance, including a search for conflicts as far in advance as possible. Evidence for this is the use of FPS for this purpose. The resolution of potential conflicts can normally be planned quite some time in advance as well.

For communication with pilots, such as issuing instructions and managing requests, many reported that they adjust their instructions according to the language and assumed experience level of pilots or that they pay special attention to pilot readbacks in certain situations. Anticipated requests of pilots can often be acceded to in a pro-active way as well. The advantage of such a working style is twofold: it provides a service to pilots and reduces R/T-communication.

The only processes that tend to be equally top-down and bottom-up are those of traffic monitoring and updating the mental picture. Despite the fact that most en-route controllers actively manage their attention resources by focusing their attention on certain action-relevant aircraft (see Phase 2 Report [EATMP, 1999a]), this finding is plausible since these processes include an input of external information which is to some extent independent of the ATCO's plans and intentions.

The ratings for 'level of behaviour' which the ATCO required in order to deal with non-routine traffic situations ranged between 'skill-based' and 'rule-based' (see Chapter 4.2). 'Knowledge-based' behaviour was rarely found.

The behavioural profile gleaned through observation at the working position showed that at en-route control the frequency of communication with pilots was lower than at arrival/departure or aerodrome positions. The same applies to the number of contacts per aircraft within a 10-minute interval. This might be due to the fact that aircraft usually stay in en-route sectors for a longer period of time than with arrival/departure or aerodrome control.

8.2 Arrival/Departure Control

The ratings of arrival/departure controllers vary considerably, i.e. their cognitive profile is less homogeneous than that of en-route controllers.

The position is usually taken over in a concept-driven way because relevant information is actively gathered and an action plan is usually formulated in advance. Concerning the communication between ATCOs and pilots, good timing of their instructions is quite important for arrival/departure controllers and this is achieved by giving instructions in a pro-active, anticipation-guided way.

Some controllers manage routine traffic in a more reactive, situation-driven way, while others prefer a pro-active, top-down style. The same applies to the processes of conflict resolution and attention switching. Most arrival/departure controllers report that their pre-planning of routine traffic or conflict resolutions is done on a short-term basis and often has to be adjusted quickly to take account of changed situational conditions. On the other hand, 30% to 40% reported having a concept-driven top-down way of managing routine traffic or resolving conflicts, i.e. pre-planning is considered to be very important, traffic is planned ahead over as long a period of time as possible and the ATCO tries to stick to his elaborated action plan.

Anticipation and experience guide conflict detection in arrival/departure control but it cannot be done as far in advance as for en-route controllers. This is also supported by the fact that arrival/departure controllers mainly use the radar screen rather than FPSs for conflict detection.

For the processes of traffic monitoring and updating the mental picture, arrival/departure controllers actively manage their levels of concentration, but nevertheless these processes always are to a certain extent data-driven.

In summary, the results suggest that arrival/departure controllers' cognitive working style varies more than that of en-route or aerodrome controllers.

Job experience was identified as a factor which influences cognitive working style: compared to experienced arrival/departure controllers, ATCOs with little experience tend to show a more reactive, situation-driven cognitive working style in the processes which concern pre-planning the task (e.g. management of routine traffic, conflict resolution, attention switching). On the other hand, highly experienced controllers show a more reactive / situation-driven style of traffic monitoring or distribution of attention in general.

The ratings for 'level of behaviour' which arrival/departure controllers required in order to deal with non-routine traffic situations ranged between 'skill-based' and 'rule-based'. As for en-route controllers, 'knowledge-based' behaviour was rarely found.

The behavioural profiles showed that in arrival positions, routine communication with pilots is particularly high. In addition, the frequency of contacts per aircraft within a ten-minute interval is especially high at approach positions, particularly during final approach. These findings support the finding that most arrival/departure controllers pre-plan their traffic in the short-term: if they have to issue several instructions per aircraft within a few minutes, they are probably working in a more automated, situation-driven bottom-up mode.

8.3 Aerodrome Control

The ratings for most processes in aerodrome control show a tendency towards a situation-driven, bottom-up way of information processing.

An exception to this is the take-over of a position. Like en-route and arrival/departure controllers, aerodrome controllers actively look for relevant information to build up their mental picture, but most of them reported that they simply adopt the previous controller's action plan when taking over the position instead of developing a plan of their own. This is done because, under normal traffic conditions, the task is quite uniform and leaves less room for individual preferences in handling the traffic.

For the management of routine traffic, most aerodrome controllers report that their pre-planning of routine traffic is on a short-term basis and often has to be adjusted quickly to take account of changed situational conditions. The same applies to the control process of attention switching: most aerodrome controllers emphasise the importance of being able to switch and change their plan quickly.

Conflict detection is done in a clearly bottom-up / data -driven way. Potential conflicts cannot be detected as far in advance as in the case of en-route control. They are usually detected by looking outside from the tower or by scanning the radar screen and are therefore short-term. The same applies in the case of conflict resolution: should potential conflicts arise in aerodrome control, they have to be resolved instantly. It is essential for aerodrome controllers to react quickly and make the right decision. These time constraints suggest that conflict resolutions are chosen and implemented in a highly automated way.

Aerodrome controllers' styles in updating the mental picture and traffic monitoring are represented by a broad variety of ratings, ranging from bottom-up / data-driven to top-down / concept-driven. Aerodrome controllers actively manage their attention resources by paying increased attention to certain aircraft. However, compared to en-route and arrival/departure controllers they perform these processes in a more data-driven way. This is probably due to the fact that traffic situation changes very quickly in aerodrome control.

Regarding the management of pilots' requests and controller-pilot communication in general, a variety of working styles was found: some aerodrome controllers give instructions explicitly and manage requests in a pro-active and anticipation-guided way, whereas others reported that they are mainly reacting to the situation.

In summary, in aerodrome control, processes which concern pre-planning the task (managing routine traffic, searching conflicts, solving conflicts, switching attention) were rated as being carried out in a more bottom-up or data-driven way. This means that in aerodrome control, pre-planning of the traffic over the long term is barely possible. This finding is reinforced by the fact that routine traffic is usually handled in a very automated, schematic way.

The 'level of behaviour' aerodrome controllers require to deal with non-routine traffic situations was mainly rated 'skill-based', i.e. even in non-routine situations aerodrome controllers work in a rapid, automatic mode.

The behavioural profiles of aerodrome controllers indicated the following peculiarities: rather few 'technical activities' (e.g. zooming radar, using radar-planning tools) were observed. This could be related to the fact that fewer tools are available in aerodrome positions. In aerodrome positions, the frequency of routine communication with pilots is quite high; only final approach positions showed a higher frequency. Again, this points to an interrelation between communication frequency and cognitive working style. In aerodrome control the cognitive working style was rated more bottom-up / data-driven and skill-based, i.e. in normal traffic situations the work is usually more routine and repetitive, e.g. when the ATCO is continually giving landing or take-off clearances. However, a high communication frequency presumably can only be maintained if the task is highly practised and can be carried out in an automatic way without requiring too many cognitive resources e.g. for planning activities.

A peculiarity of the aerodrome control task is that most aerodrome controllers report that under high workload conditions they have to work more expeditiously implying a reduction in the number of safety buffers. On a safety / efficiency dimension for decision-making criteria the balance will move in favour of efficiency and the aerodrome controllers might make more ‘risky’ decisions in order to keep the traffic flowing. In such situations they have to make very precise estimations and to reach instant decisions. Most aerodrome controllers regard this situation as very demanding or stressful. This is quite understandable, especially seen in the light of most en-route controllers’ ‘instinctive’ strategy to increase the number of safety buffers in order to cope with high workload situations, e.g. by rather making use of separations instead of lateral separations (cf. Sperandio, 1977).

8.4 Comparison of the Services: Air Traffic Controllers' Statements

At the end of the cognitive interview, ATCOs were asked for the particular differences between their position in, for example, en-route control and positions in arrival/departure or aerodrome control.

Their answers were categorised according to the following criteria:

- Pre-planning / possibility of pre-planning the traffic vs. working ad hoc / reacting to the situation;

- Scope of the task / scope of decision-making: working in a highly automated mode / doing routine work vs. being able to make own decisions and to structure the task in an optimal way according to individual preferences;

- Frequency of action-relevant events; importance of quick decision-making, quick (re)actions.

The frequency of these categories was determined.

Because of its position at the end of the interview, the question often had been skipped owing to time constraints. Therefore the total number of ATCOs who commented on the question is rather limited. The distribution is shown in more detail in the appendix. However, results are complementary to the findings of the cognitive profiles:

As for the particular differences between **en-route and arrival/departure** control,

- 50% of the arrival/departure controllers stated that at arrival/departure positions the pre-planning time was shorter than in en-route control and that arrival/dep. controllers worked more ad hoc,

- 39% of the arrival/dep. controllers said that in arrival/dep. control it was more important to (re-)act and decide quickly than in en-route control.

Regarding the differences between **arrival/departure and aerodrome** control,

- 25% of the aerodrome controllers and 33% of the arrival/dep. controllers said that in aerodrome control the pre-planning time was shorter than in arrival/dep. control,

- 33% of the arrival/dep. controllers stated that in aerodrome control the scope of decision-making was more restricted than in arrival/dep. control, i.e. the work in aerodrome positions was more routine than at arrival/dep. positions,

- 22% of the arrival/dep. controllers and 25% of the aerodrome controllers mentioned that in aerodrome control the frequency of action-relevant events was higher than in arrival/dep. control and therefore, in aerodrome positions, quick reactions and decisions were more important.

As for the differences between **en-route and aerodrome** control,

- 29% of the aerodrome controllers said that in aerodrome control the pre-planning time was shorter and there were less possibilities to pre-plan the traffic than in en-route control.

In conclusion, the ATCOs' statements concerning the differences between en-route, arrival/departure and aerodrome control support and confirm ITA results.

9. FIELD OF APPLICATION

This chapter gives a summary of the outcome of several working groups and a workshop that were organised at the end of Phase 3, with experts from the different domains of selection, training and system development, in order to elicit their views on how to use the results of the ITA project. The purpose of the working groups was to generate initial ideas for the utilisation and application of ITA results.

9.1 Working Groups

Three working groups and a workshop attended by around 40 people were organised with EUROCONTROL internal experts and with Members States experts in selection, training and system development.

The objectives of the working groups were to identify:

- those ITA results which might be interesting to the various domains;
- the potential utilisation and application of both the ITA methods and the achieved results.

9.2 Potential Contribution of Integrated Task Analysis Results in the Development of New Air Traffic Control Systems

9.2.1 Cognitive Aspects within the Development of New Air Traffic Control Systems

The ATCO's job is mainly cognitive. Any system, existing or new, has an impact on the cognitive activity of controllers. In some cases, the system will support the cognitive processes; in other cases, it could create additional workload for the controllers. The objective in developing new systems should always be to support and facilitate the cognitive activity by adapting system functionality and the Human-Machine Interface (HMI) to the task demand.

New concepts or any changes in ATM will definitively impact on the ATCO's cognitive activity, processes or demand. For example any route network or sector modification will involve as a pre-requisite that the controllers develop a new mental model. The importance of the mental model for a safe and expeditious handling of the traffic was stressed in this study. All the cognitive processes of en-route controllers are mainly top-down, which means that their mental model supports them.

9.2.2 Relevance of Integrated Task Analysis Results in the Development of New ATC Systems

The ITA results were considered as interesting for the system development area because they show a way to describe the cognitive processes in ATC and a broad model of ATCO activity. This description would for example allow any person involved in a new system development to have an initial idea of what the job of an ATCO consists of.

The concept of cognitive profile also stresses the need to develop an HMI that could support different working styles.

Nevertheless, since ITA results are very general and the cognitive processes diagrams are the common denominator of all the interviews, a clear area of application for current ITA results was deemed to be missing. It would be necessary to adapt and refine ITA methods and the respective results for the specific purposes of system development. As they currently stand, the ITA results can be used as a support in different areas of application but additional work would be required to consolidate the results.

Despite this restriction, some potential applications were suggested.

9.2.3 Potential Application of Integrated Task Analysis Results in the Development of New Air Traffic Control Systems

As shown in Figure 33, few fields of application were identified.

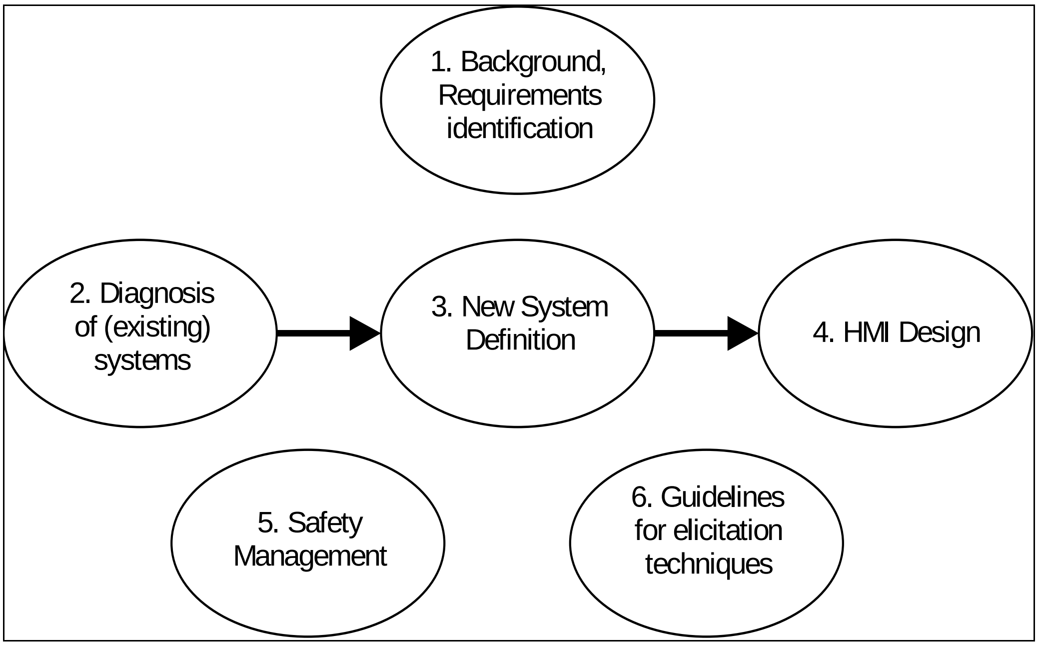

Figure 33: Structure on potential applications of a cognitive approach in general in the development of new systems

The main contribution was seen in the process of:

- diagnosing the existing system leading towards the definition of new systems and HMI design;
- setting the background for system development and identification of requirements;
- defining safety management;
- providing guidelines for elicitation techniques.

Background

In setting the scene for system development, ITA methods could help in establishing an operational concept for analysis and design. The methods would introduce and emphasise cognitive processes in system development and prototyping. A cognitive focus would call for multi-disciplinary teams in which a critical approach to the methods used would be applied.

Diagnosis of existing systems

An important step towards developing a new system is the understanding of the workings of the existing system. The understanding is important regardless of whether the new design is an increment to the existing design or a radically new design. The techniques would be helpful in the diagnosis and evaluation of existing systems to understand the mapping between tasks and functions and to understand the interrelation of bottom-up and top-down task approaches.

New system definition

In defining a new system the methods could be useful in identifying which type of assistance is needed from the system and in validating the level of automation. This would have an impact on new regulations and coordination procedures, such as future civil-military integration.

From the concept development phase of a new system, the cognitive process diagrams could be used as structured material to make an 'impact analysis'. Such an approach should be conducted with experienced controllers and facilitated by human factor specialists.

Human-Machine Interface (HMI) design

One aspect of system development that attracts a large amount of attention is the design of the Human-Machine Interface (HMI). The understanding of cognitive processes could improve HMI development and help design better and more intuitive interfaces. The display and presentation of information on screen could benefit from an understanding of the bottom-up and top-down task approaches.

The cognitive processes could be used to develop simulation scenarios in order to evaluate and validate system functionality and the HMI.

Safety management

Integrated Task Analysis (ITA) methods could be helpful in providing principles and background knowledge for the safety management of system development. Sources of stress and errors and how these tie in with system interaction could help in identifying requirements for error-resistant systems and fail-soft design.

Guidelines for elicitation techniques

The ITA methods themselves could form an initial part of guidelines on how to gather users' knowledge through interview and observations.

To summarise, potential applications of ITA results in the development of new ATC systems were neither neglected nor directly obvious. It was commonly agreed that the approach towards cognitive aspects of the ATCO's job itself is valuable. The ITA project was a first approach and to that extent a success. In fact, as a result of methodological shortcomings, the ITA approach has to be supplemented by other work done already or currently in progress in the European R&D environment.

9.3 Potential Contribution of Integrated Task Analysis Results in Selection

9.3.1 Cognitive Aspects in Selection

The cognitive aspects are only one of the issues in the selection of ATCOs.

Selection has however not only to deal with choosing the right candidate that has the appropriate cognitive abilities to do the job. The scope of selection is much wider. EATCHIP/EATMP Selection Task Forces (STFI & STFII), as well as the "Consequences of future ATM systems for air traffic controller Selection and Training" (CAST) Project have put a lot of effort into answering some important questions, such as:

- Are people selected for their abilities to do the job? Or are they selected to pass the training and being able to perform the job. (EATCHIP, 1998b)[3.1.1][4], (CAST, 1999a) [Vol.III,1.21][2],
- Because of the fast-changing environment ATM, should candidates be tested and selected for their learning/adaptation abilities instead of specific cognitive abilities? (EATCHIP, 1998b) [4.31 & 7.2.1][2], (CAST, 1999c) [WP5, 8 &10.2.1][2],

[4] numbers in [ ] refers to the section of the document

- Is having the basic cognitive ability sufficient to become a good controller? What are the other important aspects? Social, psychological, personality qualities such as: stress resistance, balanced risk-taking, team spirit, etc. (EATCHIP, 1996b) [4.3.3][2], (CAST, 1999a) [Vol.III,1.3.5][2],

- Is the philosophy of selecting only the best the right approach? For some aptitudes would average scores not be more suitable? (EATCHIP, 1998b) [4.5.2, 10.1 & 10.2][2],

On the other hand, our expectations should not exaggerate the role of selection in providing suitable ATCOs. Training is often seen as more important than selection in the process. A ratio of 80-20% was mentioned, meaning that the contribution of training counts for 80 % in the success of a potential candidate. Clear-cut answers are still missing to some basic questions, for example:

- Should candidates be selected only on their basic abilities, those that are not trainable, or should they be selected based on their abilities, skills and knowledge because we do not want to train them on certain matters? (For example English, reading, writing, arithmetic, etc.). In other terms, what are the skills and knowledge acquisition that an organisation is prepared to spend time and money on?

- Is the success in training depending only on students' abilities? What is the weighting to be given to the failure/success rate of the training philosophy (training for success), methods and tools used, its organisation (flexibility, modularity, etc.) and student supervision and support?

Most of these pending questions could certainly not be answered by any task analysis. The expectation concerning the results of ITA should therefore be put into the proper context.

9.3.2 Relevance of Integrated Task Analysis Results for Selection

Despite the above restrictions, the experts saw some of the ITA results as valuable for the selection area. Additional data about the same subjects are also available in the references from the HRT Selection Task Forces (STFs) as mentioned below)

- The flow diagrams of the cognitive processes provide a good picture of the job in the operational environment;

- They help to understand the task better and give a good inside view of how the job is done;

- The cognitive processes description and the task breakdown could be used as structured material to identify basic abilities and the skills that can or cannot be learnt (EATCHIP, 1998b) [7.2.3][2],

- The results of the cognitive profiles (bottom-up/top-down working style) could be of interest to those selecting *ab initios* for the various types of ATC service.(EATCHIP, 1998b) [2.3 & 11.2], (CAST, 1998b) [3.4],

9.3.3 Potential Application of Integrated Task Analysis Results and Methods in Selection

This section gives an overview and a summary of the ideas produced during two working groups held with selection specialists.

Two perspectives were suggested for using the ITA results and methods for the selection domain.

<u>Checking the existing selection process</u>

The first perspective consists in the evaluation for adequacy and completeness of current selection practices with regards to the cognitive processes and cognitive profiles. This could include the identification of gaps in the actual selection procedure, tests, tools and methods concerning the cognitive aspects and the task demanded of ATCOs as identified within the ITA.

For the first perspective, thanks to the cognitive processes description, some important aspects of the ATCO's tasks are highlighted such as:

- the prime importance of the 'switching attention' control process and the correlated multi-tasking demand of the task;
- the complexity of the decision-making under specific constraints;
- the emphasis on anticipation and planning;
- the 4-D mental picture.

Ensuring that existing selection tests assess these aspects could help identify missing elements. (EATCHIP, 1998b) [13.1], (EATCHIP, 1998e) [3.3.2],

The cognitive profiles highlight other cognitive aspects, for example:

- The working styles (bottom-up vs top-down) in the various ATC services are dependent upon situational aspects;
- The planning span is shorter in arrival/departure as compared with en-route, and even shorter in aerodrome than in arrival/departure;
- Such facts could support the idea that the skills needed for different ATC positions are not equal and could be given consideration as part of the selection process or at the time of student's assignment to operational training.

Identifying appropriate cognitive skills

The second perspective consists mainly of looking at the ITA results in order to identify the skills needed to achieve the job from the cognitive point of view and then to identify the most appropriate way to evaluate them within the selection process.

The ITA results could be used as a structured way of identifying the abilities and skills supporting the cognitive processes. A set of abilities and skills could be identified for each of the cognitive processes. Different approaches could support such an exercise.

Some existing task analysis focusing on abilities and skills required could be used to support this approach. Well-known methods are for example the Fleishman Job Analysis Survey (F-JAS) or the Strategic Job Analysis (SJA) developed by the FAA, which is based on the identification of Knowledge, Skills, Abilities and Other personal characteristics (KSAO).

Development of new tests

ITA results were also seen as interesting for the development of new tests that might be more task-related. The main idea would be to develop new dynamic selection tools, using simplified simulation exercises. The input from ITA would be the design of job related scenarios in order to assess complex cognitive abilities such as: decision-making, attention switching, anticipation and planing, etc. (EATCHIP, 1997c) [3],

Understanding applicants cognitive processes

The FPS reconstruction method used in ITA, which consists of a post-observation interview focusing on special events, was seen as an interesting method for use in selection. It would help the tester to identify the underlying reasoning of the candidate in the accomplishment of simulation exercises and to explain performance in the same test.

In conclusion, we can say that the ITA results are of interest for selection and that there are interesting fields of application. Nevertheless, ITA does not provide an ad hoc solution but might be used to support some of the above-mentioned issues.

9.4 Potential Contribution of Integrated Task Analysis Results in Training

9.4.1 Cognitive Aspects in Training

Focusing the task analysis on cognitive aspects brings a particular insight to the job to be done. It allows a holistic approach. ITA, by identifying the cognitive processes of ATCOs, will not directly help to define the Common Core Content (CCC) which normally specifies the declarative knowledge needed to do the job, but rather helps improve the definition of procedural knowledge to be acquired. Procedural knowledge is implicit information on how to do tasks while declarative knowledge is factual and explicit information.

The Fits' Three Phases Theory describes the skill development process. The first phase is called the cognitive phase, which mainly consist in acquiring declarative knowledge. The second one is called the associative phase, this is when the declarative knowledge is put into practice, some procedural knowledge is acquired, skills are developing but the cognitive demand is still high. At the last phase, the autonomous phase, skills are internalised, cognitive processes become automatic and the attention resource needed to achieve the tasks are decreasing.

Integrated Task Analysis (ITA) results are seen as a more useful support to improve mainly the two last phases of skill acquisition. Nevertheless, some interesting uses were identified for the knowledge-acquisition phase.

9.4.2 Relevance of Integrated Task Analysis Results and Methods for Training

The cognitive processes description, the cognitive profiles and the results concerning the level of behaviour, were seen as the most interesting results from ITA.

The Flight Reconstruction Method was seen as an interesting method for the instructors to understand the students' reasoning better, at different stages in their training and could support the development of a cognitive assessment tool.

The flow diagrams depicting the cognitive processes that give a complete overview of the job could be used at different levels of training. In basic training they can be used to explain the job. In rating training they can help to highlight some procedural aspects of the job. Finally, in simulator pre-on-the job and on-the-job training, they can support skill acquisition.

The cognitive profiles are of special interest because they have identified the fact that there are different working styles and that all processes are not conducted identically. They will allow trainers and instructor to focus the skill acquisition in the right way.

The results on the level of behaviour (skill-based, rule-based and knowledge-based behaviour) emphasise the fact that the ATCO's operational job is mainly skill-based. It means that during training the basic skills need to be over-learnt and to become internalised, in order to make the operational transition easier for the student and safer for the traffic.

9.4.3 Potential Application of Integrated Task Analysis Results and Methods in Training

This section gives an overview of the ideas produced at the working groups held with training specialists.

Basic training

The cognitive processes' description, diagrams and verbal descriptions (EATMP, 1999a) could be used from the very beginning of *Ab Initio* training (Basic Training - training Phase I[5] EATCHIP, 1997b). The first use could be to show to students the in-depth complexity of the job. Secondly, the diagrams could be used as motivational support to show the relevance and necessity of theoretical (declarative) knowledge requirement.

Motivating the students

It is well known that too much theory without reference to the application of knowledge in an operational context can be inefficient. Helping the trainees to identify the link between theory and application, to understand how to convert declarative knowledge into usable data, how any theoretical information can be used or is needed to do the job, could be an efficient motivator for the student. The cognitive processes description provided in the ITA results can support this identification by linking each of the processes with the knowledge necessary to conduct it. The exercise of matching the required knowledge for each cognitive process should not take a lot of time for an experienced controller or instructor.

Checking training content

This exercise could also assist the training designers in checking the completeness and relevance of the training content with regard to the cognitive needs of the job (training cognitive needs analysis), to structure training plan, to refine training objectives and specify the best teaching methods and tools.

Rating training

The ITA results and methods were identified as of most relevance to the further training phases (rating training) but also to pre-operational training, OJT training, instructor training, emergency training and error management training.

Structuring the skill acquisition process

In the rating training as defined in the 'Guidelines for Common Core Content Training for Air Traffic Controllers training' (EATMP, 2000) students are trained to acquire basic skills such as 'issuing instructions to the pilots' using the standard phraseology, 'coordinating with adjacent sectors', etc. The cognitive processes' descriptions were seen as a complementary tool to structure the basic skill acquisition.

[5] Within this section, the ATCO's training phases terminology refers to the EATCHIP/EATMP work on Common Core Content and Training Objectives for Air Traffic Controllers Training undertaken by the HRT Training Sub-Group (TSG). Full references are listed in the Appendix 'References' of this document.

Practising the cognitive process

To supplement existing simulator exercises, new exercises could be constructed in order to allow students to practice the cognitive processes up to the point that they become automated for them.

Two different approaches were suggested.

'Step-by-step' training

The first one would be to create exercises of increasing difficulty in order to give progressive training on the cognitive aspects. For example, the training could start with exercises concentrating on the acquisition of the sub-processes then going on with the task processes that are to some extent more complex. This approach was called the 'task' or 'step-by-step' training, meaning that the simulator training from the very beginning would be structured following the cognitive tasks. New sequences of training could be defined.

'Total immersion' training

The other approach that was called 'total immersion', which means that the students from the very beginning of simulator training, would be faced with very complex situations in which all processes would be trained and tested together. The idea was supported by the view that the best way to learn is by 'doing'. It was seen as a very efficient way for the instructors to identify potential aptitudes of the trainees. It could help the instructor to check that the trainees take into consideration all the aspects of the situation and that they do not make the wrong decision based on insufficient attention to certain data.

Both 'step-by-step' and 'total immersion' approaches are valuable and can be very complementary. They can both help to define new training objectives and structure. This was seen as a potential way of reducing the length of training and more specifically of OJT.

<u>Instructor training</u>

The ITA results on the cognitive processes the cognitive profiles and levels of behaviour were seen as very valuable for the instructor training. Up to now, instructor training has not stressed the cognitive aspects of the job. It concentrates more on methodological aspects such as communication and coaching practice (EATMP, 1999c). The purpose is not to underestimate the importance of such methods: on the contrary, they will be the ideal methods to support both students and instructors in focusing more specifically on the cognitive aspects, for example during the debriefing of simulator sessions.

Awareness of cognitive aspects

On-the-Job Training (OJT) and simulator instructors thought that having a better understanding of the cognitive processes would help them to coach the student more efficiently. It could, for example, allow the instructor to identify shortcuts taken by the trainee within a specific cognitive process that leads him to make errors. It was recognised that the cognitive processes are so automated for experienced controllers that it makes it difficult for them to explain the process in detail to the trainees. Having a deeper awareness about the cognitive aspects of the job and their complexity could help instructors in diagnosing student cognitive difficulties, thereby giving them better support in identifying, resolving problems and improving their progress. The description of the cognitive processes will also help the instructor to access his own expertise and make it accessible and available for the trainees.

Identification of cognitive difficulties

For the identification of the student's cognitive difficulties, the Flight Reconstruction Method principles could be used during student's debriefing. The basic principle of the method is to question a situation, the solution chosen to resolve the problem and the analysis of other potential solutions. The questioning process should also help the student to identify his own strength and weakness. Focusing the debriefing on the cognitive aspects will also allow the instructor to have a better understanding of the failures and errors in the student's reasoning. Problems that might appear are: shortcuts in the cognitive processes, misuse of the data available, wrong decision based on incomplete information, difficulty in switching attention from one task to the other.

<u>Assessment tools and methods</u>

The idea of developing assessment tools based on cognitive aspects was also addressed. Different aspects seem to be of interest in this area. Based on ITA results, cognitive criteria should be defined, then assessment tools and objectives measures should be developed. The working style (bottom-up vs top-down) of the students and its suitability for the situation could also be evaluated. Finally, the level of behavioural concept (skill-based, rule-based and knowledge-based behaviour) will increase the instructors' awareness about the skill acquisition process and help them identify whether the trainee has reached the right level of skill acquisition.

<u>General use</u>

In general terms, the poster on the cognitive processes could be used to explain the ATCO job to anyone who has to be involved in any kind of activity related to ATCOs and who needs an introduction about the job.

In conclusion, we can say that the ITA results are a kind of raw material that can be used for further work.

In specific terms, declarative knowledge to conduct each process can be identified. A training package on cognitive aspects can be developed for instructors. Cognitive assessment tools and methods could provide an objective means of evaluating trainees' progress.

It was suggested that usability study cases be performed to evaluate the applicability of the results in training.

9.5 Conclusion

The various working groups identified numerous uses for the ITA results.

The material provided in this report can be used as such, to increase awareness about the importance of the cognitive aspects in ATC. It provides a clear and synthetic view on the job and allows a better understanding of the task demand and complexity.

However, additional work would be needed to meet more specific needs in the area of human factors and human resource management.

ANNEX A: TOP-DOWN/BOTTOM-UP RATING CRITERIA

Table 24 shows the defined complete criteria for the top-down/bottom-up ratings. Criteria printed in italics were considered more important for the rating.

Table 24: Criteria for the top-down/bottom-up ratings

Basic process	Clues for a data-guided bottom- up process	Clues for a concept-guided top- down process
over position/build up mental picture	• *less directed intake of information or rather no active search for information.* • *only a very short period of pre-planning or very little/no active pre-planning.* • *active planning only starts after taking over the position.* • plan of previous ATCO is simply adopted. • traffic is worked off schematically, the 'plan' always remains the same and so does the number of situationally determined variations which are chosen (extremely automated). • the picture is built-up gradually after take over of position. • emphasises importance of radar picture, emphasises watching the radar and needs slightly more time to get the picture of the radar in medium to high traffic load.	• *directed intake of information considered relevant: 'active' process; ATCO knows exactly what information he needs and obtains this information.* • *transformation into a traffic plan of his own, possibly after the evaluation of the previous ATCO's plan (adopt or alter plan).* • ATCO's own planning before the position is taken over. • compares own picture with that of previous ATCO. • clue for mental sector model. • Flight Progress Strips (FPSs) are more important than or as important as the radar picture.
Monitoring	• *the ATCO emphasises scanning of the 'whole picture'; often uses 'monitoring' and 'scanning' as synonyms.* • all aircraft (a/c) are monitored similarly, each getting same amount of attention. • backup rate: the more traffic, the more scanning. • purpose of the picture: clues for bottom-up perception	• *clue for 'foreground-background' picture (i.e. action-relevant a/c become the focus of attention, 'hello-goodbye' a/c get less attention).* • *certain a/c are scanned more often, generally getting more attention.* • emphasises the importance of experience for the ATC work. • clues for selective use of radar information. • purpose of the picture: clues for top-down perception.

Table 24: Criteria for the top-down/bottom-up ratings (continued)

Basic process	Clues for a data-guided bottom- up process	Clues for a concept-guided top- down process
ging routine traffic	• *only very short 'pre-planning'; automated schematic handling of routine traffic.* • *often short-term changes of action- relevant situational conditions, so that the plan must be changed quickly.* • *the (sector)-plan is quite rough or schematic, so that it can be adjusted quickly to take account of changed situational conditions.* • *planning is mainly based on radar picture/ look outside.* • effect of absence from the job: no problem getting used to the work again, no settling-in period, after 1-2 hours 100% performance. • purpose of the picture: bottom-up, no clues for planning/anticipation. • backup rate: the more traffic, the more scanning.	• *pre-planning over as long a term as possible.* • *emphasis on importance of pre-planning.* • *planning is based on FPSs.* • effect of absence from the job: statement, that he has to pay more attention, is not as fast anymore; adjustment takes longer (one day or more). • purpose of the picture: top-down; explicit clues for planning and anticipation. • language/ orientation problems of pilots are resolved by own activity, in the sense of preventing problems.
ging requests/ assisting pilots	• requests are not anticipated; no 'pre-planning' of pilots' requests. • requests are handled in a re-active way. • no clues for adjustment with ATCO´s own plan (i.e. in order to accept requests the ATCO is ready to make quite demanding or short-term alterations of his plan) → not valid for 'emergency requests'.	• certain requests have already been anticipated and been included in the plan. • 'expected' communication problems are 'included in the plan'. • the criterion 'capacity of the colleague in the next sector' is included in the decision to accept a request. • clues, that request is only accepted if it does not interfere too much with the ATCO´s own plan.
Solving conflicts	• tendency to 'monitor' a potential conflict, in order to act only when it is absolutely necessary. • extremely automated, schematic 'resolving' of conflicts. • emphasis on ability/ necessity to react quickly, to find solutions quickly.	• early resolution of potential conflicts; pre-planning of conflict solutions over longer term. • emphasis on necessity to resolve potential conflicts by planning/ prevention. • 'backup' plan exists. • clue for 'conflict resolution library' (i.e. when resolving conflicts, the ATCO falls back on his experience). • emphasis on importance of experience when asked about active decision-making.

Table 24: Criteria for the top-down/bottom-up ratings (continued)

Basic process	Clues for a data-guided bottom- up process	Clues for a concept-guided top- down process
Updating mental picture	• *scanning: very broadly and very frequently.* • *no experience-guided categorisation of a/c (except by type, performance).* • *error detection: bottom-up (e.g. by scanning everything).* • purpose of the picture: bottom-up. • FPSs are only used as 'memory support'.	• *rather selective/ or specific checking and global check is quite rare.* • *experience-guided categorisation of a/c.* • *clue for 'foreground-background' picture.* • *error detection: top-down (i.e. certain potential errors are anticipated from experience).* • emphasis on experience in decision-making or rather in ATC- work as such. • purpose of the picture: top-down. • FPSs are used as 'planning tool'.
Searching conflicts/ Checking safety	• *conflicts are mainly detected by scanning the radar.* • *radar screen or rather a look outside from the tower are the main sources of information in detecting conflict situations.* • conflict detection by conflict alert system or by hints from colleagues or pilots.	• *role of FPSs: planning function, conflict detection function, FPSs are used for searching for potential conflicts.* • *frequent use of radar tools for pre-planning, conflict assessment.* • clue for 'conflict possibility library' (i.e. ATCO knows from experience in which part of the sector conflicts are more likely to occur. • clue that the ability to detect conflicts has increased significantly with more experience. • selective checking of a/c.
Issuing instructions	• requests are not anticipated; no pre- planning of pilot´s requests. • clearances are handled in a re-active way (only when requested by pilot). • all readbacks get the same amount of attention.	• certain requests have already been anticipated and included in the plan • 'expected' communication problems are 'included in the plan'; ATCO adjusts his instructions according to the language and experience level of the pilot. • special attention for readbacks in certain situations.

Table 24: Criteria for the top-down/bottom-up ratings (continued)

Basic process	Clues for a data-guided bottom- up process	Clues for a concept-guided top- down process
Switching attention	• *'action plan' is rather rough, so it can be adapted quickly to meet changed situational conditions.* • *emphasis on flexibility, on ability 'to switch quickly and change the plan'.* • working method in complex situations/ times with high traffic load is more flexible, more expeditious. • topic 'multitasking': responses convey the idea: 'the more traffic there is, the more tasks are to be done one after the other'.	• *emphasis over the long term, proactive pre-planning of air traffic; tendency to stick to action plan with explicitly established priority.* • working method in complex situations/ times with high traffic load rather: more standard, less service. • Multitasking: answer in the sense of 'the more traffic, the more multitasking'.
General information processing	• interview questions are often answered with: It depends on the situation/ I cannot answer it just like that.' • there is virtually no active pre-planning or rather there is only very short-term pre-planning. • traffic is handled schematically, extremely automated. • clue/ statement, that planning is hardly possible, e.g. because there is no time for it. • conflict search/ detection mainly by 'scanning' of the (whole) traffic situation. • no experience-guided categorisation of a/c. • error detection: bottom-up • 'holiday'- question: when it is no problem getting used to work again, settling-in period is not necessary, when the ATCO says that he has achieved 100% performance after e.g. 1-2 hours. • teamwork: no anticipation of peculiarities of colleagues (e.g. because colleagues change very often).	• general: ATCO works with his mental model to a great extent or rather often mentions that his personal experience is very important for him. • emphasis on pre-planning. • pre-planning function of FPSs. • preventive planning of 'safety buffers' into situations that are difficult to predict. • question 'purpose of the picture': planning function of the picture. • detection of conflicts by experience. • knowledge of 'conflict points' or critical points in the sector. • experience-guided categorisation of a/c, e.g. by airlines. • error detection: top-down. • anticipation/ planning of possible 'disturbances'. • 'holiday question': answers that e.g. he is not as fast anymore, has to pay more attention, first works on a more quiet position and that it takes some time to get used to work again (e.g. one day or more). • teamwork: anticipation/ planning of peculiarities of colleagues.

ANNEX B: TOP-DOWN/BOTTOM-UP RATINGS: DISTRIBUTION OF ‘0-RATINGS’ ACROSS SERVICES

	En-route (absolute numbers column percent)	**Arrival/Departure** (absolute numbers) column percent)	**Aerodrome** (absolute numbers column percent)
Taking over position	3 7,9 %	2 11,1 %	1 4,8 %
Monitoring	1 2,6 %	---	2 9,5 %
Managing routine traffic	1 2,6 %	1 5,6 %	---
Managing requests/ Assisting pilots	11 28,9 %	9 50,0 %	7 33,3 %
Solving conflicts	7 18,4 %	3 16,7 %	7 33,3 %
Updating mental picture	2 5,3 %	---	---
Searching conflicts	---	---	1 4,8 %
Issuing instructions	15 39,5 %	7 38,9 %	9 42,9 %
Switching attention	9 23,7 %	5 27,8 %	7 33,3 %
General information processing	1 2,6 %	1 5,6 %	---

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ANNEX C: RATING CRITERIA FOR THE EVALUATION OF THE FLIGHT PROGRESS RECONSTRUCTION INTERVIEW

Examples from Reconstruction Interviews

Rating of level of behaviour

1. **Skill-based level**: stimuli are applied to responses in a rapid automatic mode with a minimum investment of resources (e.g. applying the brake of a car when the traffic light is red). But the stimuli need not necessarily be simple: after extensive training and experience even complex stimuli can trigger skill-based behaviour (e.g. an experienced doctor might be able to classify a pattern of symptoms just by giving one look and instantly knows what treatment is necessary). → highly automated behaviour.

   Example
   This aircraft had to descend to L.. He came from M. and he had close traffic below. I just had to pay attention to see if there was enough vertical separation.

   Did you have to do anything?
   No, just pay attention.

   Assumptions
   → for experienced controllers such estimation and evaluation processes, when monitoring aircraft, are highly automated.

2. **Rule-based behaviour**: a response is selected by bringing into memory a **hierarchy of rules: 'if X occurs then do Y'.** After mentally scanning the 'if - then' rules the decision maker will initiate the appropriate action. The situation may be familiar but the mental processing is considerably less automatic and takes more time than on the skill-based level (e.g. a medical student or a doctor with far less experience will evaluate the same symptoms in a much more time-consuming way to reach the same conclusion).

   Example
   The aircraft experienced turbulence at flight level 310 ... and wanted to change level because it was so uncomfortable at 310. I asked him first if he could climb but he was too heavy to climb and so I had to descend him below level 290. It is not my sector anymore then. It is radar 1 sector. But I had to descend him to an even level, otherwise C. won´t accept him. So I coordinated quickly with radar 1 for descent and then I coordinated with C. because he was only 5 minutes away from C.- FIR and usually in this case we have to coordinate before changing level.

Assumptions

→ the actions suggest that 'if-then' rules stored in memory are applied: if the aircraft cannot climb (easiest solution), then it must descend. If it descends, then it goes to an even level, because otherwise it wouldn't be accepted by C. If it has to be an even level, then it will come to radar 1 sector and I have to coordinate ...

3. **Knowledge-based behaviour** is shown when **unfamiliar/new problems** are encountered. Neither rules nor automatic mappings exist and more general knowledge concerning the behaviour of the system, the characteristics of the environment and the goals to be obtained must be integrated to formulate a **new plan of action**. → active problem-solving.

Example

This was a very unusual flight, it was not common at all. It is coming from G.- area and climbing up southbound to S. and usually we wouldn't have traffic climbing descending at the west coast of our sector. He is requesting flight level 350 but I have a conflict from the southbound traffic. So I was unable to climb him that level. And also we had a conflict on the eastbound traffic at 330 coming from C. But I received the traffic from radar 1 and he is coordinating with me: 'what level do you want him?'. We had to check the normal routes to see whether the traffic was conflicting with the eastbound and southbound traffic and also we had to coordinate with C because they had already received a strip with 350, but they accepted him 330.

Did you have to change your initial plans?

No, the plan we had was that he had to stop on a flight level below 350 because it was impossible to get him up there. But in the beginning we even thought that he had to stop at level 310, but finally we decided to climb him to 330 because he was at least 20 miles beside the other traffic and C accepted it.

Assumptions

→ suggests active problem-solving for the following reasons:

- special emphasis on the fact that the case is very unusual;
- inclusion of several decision criteria (check eastbound and southbound traffic for conflicts); agreement/coordination with various authorities;
- the fact that the original idea to send the aircraft to 310 was changed in the end in favour of a higher level.

Rating of the cognitive resources/attention required by a problem, e.g. by:

- radio contact with pilot,
- coordinations,
- bearing in mind a problem that has not been solved yet,
- visual checks,
- time to think.

→ Nevertheless, the **explicit statements** of the interviewed controller concerning additional attention and time, are of higher importance.

→ When classification seems impossible or would be mere speculation, because e.g. the case has not been explained explicitly enough, do **not** give any rating.

0 Rating not possible

1 No additional attention

→ According to the controller's statement, there was a 'non-routine' situation, but it didn't require any additional cognitive resources.

2 Increased attention for a short period of time

→ The controller has concentrated on the problem only for a short period of time:

- no repeated 'switching' from the problem to other tasks;
- quick decision on the solution of the problem, little planning effort;
- the case was finished quickly;
- the case required no or only little additional coordination effort (1 - max. 2 additional coordinations).

3 Increased attention for a longer period of time

→ i.e. it is obvious, that the controller has dealt with this problem over a longer period of time:

- he had to 'switch' repeatedly from other tasks back to the problem;
- he had to keep the case in the 'back of his head' beside other tasks;
- the solution of the problem was complex and required high planning effort;
- the controller had to 'monitor' an aircraft;
- a decision required repeated coordination (with colleagues and pilots).

4 Intensively increased attention

→ It is obvious that the controller directed his attention **exclusively** to the problem for a limited period of time:

- the problem requires full concentration,
- he has faded out or postponed other tasks,
- the problem was safety-relevant.

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ANNEX D: FLIGHT PROGRESS RECONSTRUCTION RATINGS: DISTRIBUTION OF EXCLUDED NON-ROUTINE CASES

	En-route	**Arrival/ Departure**	**Aerodrome**	**Total**
analysed non-routine cases	254	99	85	438
excluded non-routine cases	49 19,29 %	17 17,17 %	34 40,00 %	100 22,83 %

Note: The first line shows the number of analysed non-routine cases, and the second line shows the absolute and relative number (percentage) of cases which had to be excluded from analysis because of low certainty ratings.

	North	**South-west**	**Central**	**South-east**	**Total**
analysed non-routine cases	155	82	89	112	438
excluded non-routine cases	33 21,29 %	14 17,07 %	9 10,11 %	44 39,29 %	100 22,83 %

Note: The first line shows the number of analysed non-routine cases, and the second line shows the absolute and relative number (percentage) of cases which had to be excluded from analysis because of low certainty ratings.

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ANNEX E: COMPARISON OF SERVICES: AIR TRAFFIC CONTROLLERS' STATEMENTS

Comparison: en-route control/arrival/dep. control

	En-route Controllers	Arrival/Departure Controllers
No statement	28 73.7%	6 33.3%
In arrival/dep. control the pre-planning time is shorter than in en-route / arrival/dep. controllers work more ad hoc	5 13.2%	9 50%
In arrival/departure control the work is more routine than in en-route	-	2 11.1%
In arrival/dep. control the work is less routine than in en-route	1 2.6%	4 22.2%
In arrival/dep. control it is more important to (re-)act quickly, to decide quickly than in en-route	3 7.9%	7 38.9%

Comparison: arrival/departure control / aerodrome control

	Arrival/Departure Controllers	Aerodrome Controllers
No statement	7 38.9%	9 37.5%
In aerodrome control the pre-planning time is shorter than in arrival/ departure control /aerodrome controllers work more ad hoc	6 33.3%	6 25%
In aerodrome control the work is more routine than in arrival/departure control	6 33.3%	2 8.3%
In aerodrome control the work is less routine than in arrival/departure control	-	1 4.2%
In aerodrome control it is more important to (re-)act quickly, to decide quickly than in arrival/dep. control	4 22.2%	6 25%

Comparison: en-route control / aerodrome control

	En-route Controllers	**Aerodrome Controllers**
No statement	32 84.2%	13 54.2%
In aerodrome control the pre-planning time is shorter than in en-route control / aerodrome controllers work more ad hoc	1 2.6%	7 29.2%
In aerodrome control the work is more routine than in en-route control	-	-
In aerodrome control the work is less routine than in en-route control	-	1 4.2%
In aerodrome control it is more important to (re-)act quickly, to decide quickly than in en-route control	1 2.6%	4 16.7%

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GLOSSARY

For the purposes of this document the following definitions apply (EATCHIP, 1996; Seamster et al, 1997):

Action: An intentional or goal-directed behaviour.

Anticipation-action-comparison unit: A set of nervous components allowing us to predict changes in the environmental input as a consequence of our own changes in position and posture.

Automated skill (Automaticity): Cognitive and/or physical activities performed fast, effortlessly, and with little or no attention, or conscious mental processing that is developed after consistent, repeated practice. Not all skills can be automated; usually skills can be automated if there is a relatively consistent stimulus or context and response ('automated skills' does not refer to 'system automation').

Automatic processing: The type of cognitive processing that requires little or no conscious attention or thought. Tasks processed automatically are done rapidly and with little or no effort. Not all tasks are amenable to automatic processing.

Bottom-up process: An activity controlled by external cues and commands. This term is also used to describe behaviour which is primarily driven by incoming information.

Checking: One of the basic functions of ATC which consists of selecting information from a new situation in order to update the actual mental picture.

Cognition: Human thought processes and their component parts such as perception, memory and decision-making.

Cognitive skills: Almost all skills (and job tasks) have both cognitive and non-cognitive components, but a cognitive skill is predominantly cognitive in nature.

Cognitive Task Analysis (CTA): The framework and methods used to analyse cognitive structures and/ or processes that support job performance. CTA differs from traditional task analysis in many ways, including the goals, methods used, and data produced.

Cognitive Task Analysis (CTA) Methods: A combination of data collection and analysis techniques used to perform a cognitive analysis.

Controlling: One of the basic functions of ATC. It is a process of intervention which includes the selection of a strategy, the allocation of time, and a decision to terminate it. The ATCO directs single a/c or groups of a/c to obtain a desired traffic situation according to the rules and procedures of ATC.

Decision-making: This is another basic functions of ATC. It is an active cognitive process which selects a set of possible courses of action. It includes a weighing-up of the pros and cons of different alternatives.

Decision-making skill: A skill that involves choosing the best among several alternatives which is an essential part of good decision-making. Decision-making skills include tactics which are applied in response to specific situations. These tactics are learnt with experience, and serve to support and enhance the controller's decision-making.

Decision-making strategy: High level skills for managing cognitive resources and performance and a specific form of strategy.

Decomposition: A structured analysis that breaks down higher-level tasks into their component part such as the skills required, decision required, consistent components, task complexity, or concurrent tasks.

Diagnosing: Another basic function of ATC. It is the active cognitive process which takes place in order to assimilate new unexpected situational conditions into the actual mental picture of the traffic situation or to change the mental picture to account for the new information.

Expertise: This is characterised by superior performance and mastery of the three phases of skill acquisition. There are a number of cognitive characteristics of expertise: It is usually acquired after extensive and deliberate practice and true expertise often takes at least ten years to develop.

Input/Output (I/O)-system: One of the four components of the structural model of the cognitive processes of ATC. It is responsible for the selection of information and the selection of responses.

Integrated Task Analysis Methodology (ITAM): A generic methodology that conducts a CTA alongside a traditional task analysis in three progressive stages of data collection and analysis.

Job: Tasks, sub-tasks, and task elements performed by an individual or team. The higher-level unit of analysis is often used in personal selection and assignment and work classification.

Job description: Describes the job and its purposes; the major activities, duties, and responsibilities involved; and the primary knowledge, skills, and mental and physical abilities required to perform them competently.

Knowledge: Knowledge is the information required to develop skills. Job concepts or rules (DECLARATIVE knowledge) and their interrelationship (STRUCTURAL knowledge).

Long-term Memory (LTM): It is one of the four components of the structural model of the cognitive processes of ATC. LTM stores the mental model, information, information processing routines and programmes.

Memory: A psychological construct representing the repository of knowledge held in the brain. The human memory is divided into a short-term sensory store (SM), sometimes referred to as working memory (WM) (Atkinson and Shiffrin, 1968) and Long-term Memory.

Mental model: Mental models are the cognitive processes/representations whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states and predictions about future system states (according to Rouse and Morris, 1986).

Mental picture: The actual mental picture of a situation represents a moment-to-moment snapshot of the actual situation as represented with the brain. It is based on the mental model and the actually perceived external cues. A series of mental pictures represents the actual mental model including the actual parameterisation.

Monitoring: One of the basic functions in ATC. It is a process of continuous or discrete comparison between the actual state of the system and the expected state of the traffic situation. Monitoring is a top-down process governed by the expected state of the system.

Multitasking: Performing job tasks or sub-tasks simultaneously or switching among multiple competing tasks.

Process Control System (PCS): One of the four components of the structural model of the cognitive processes of ATC. It is an internal evaluation system which makes sure that action takes place as planned by the controller.

Reliability: The extent to which two or more coders of data agree in their coding. It is important to establish good levels of inter-coders reliability to ensure that the coding scheme is valid and the coders are coding accurately.

Self-monitoring: A skill used to evaluate, monitor, and regulate self-performance, including attention allocation, workload management, and recognition of problem areas in performance. Self-monitoring skills are a specific form of strategy.

Situational awareness: The perception of the elements in the environment within a volume of time and space, comprehension of their meaning and the projection of their status in the near future (Endsley, 1995). This also means the continuous extraction of environmental information and the integration of this information with previous knowledge to form a coherent mental picture and the use of that picture in directing further perception and anticipating future events.

Skill: Goal-directed actions, both cognitive and psychomotor, which are acquired through practice. A skill is evaluated through performance. A skill is linked with one or more tasks. Some examples include gross motor, perceptual motor, perceptual, procedural, decision-making, and representational skills.

Stress: High stress in terms of H. Selye (1982) is characterised by central and vegetative arousal, which is prolonged during a longer time period. The individual departs from their normal homeostatic equilibrium. Stress will also change information processing.

Sub-task: A distinct step or activity required to complete a task; used extensively in CTA with analyses focused on sub-tasks that are repeated across tasks.

System: A group or combination of interrelated, interdependent or interacting elements forming a collective entity. The fundamental characteristic feature of a system is the interdependence of its parts or variables.

Task: A basic unit of work with a clear beginning and end point, a goal, and one or more products. A task is the basic unit of analysis for both CTA and traditional task analysis. Task activities may be observable or non-observable.

Task element: A step required to complete a sub-task, normally used when a very detailed analysis is required.

Time horizon: The time window in which a worker anticipates and plans into the future, allowing them to plan and stay ahead of a situation.

Top-down process: ‘Top-down’ behaviour is governed by plans, mental models, intentions and rules and is used to decribe behaviour which is derived from cognition.

Validity: The extent to which theories, models, or data accurately describe the phenomena of interest; or the degree to which a test or measure accurately measures that which it is intended to measure.

Working memory: Also known as short-term memory. Stores information currently being used or attended to. It has as a capacity of between 5-9 ″chunks″ of data at any one time, and data not attended to is lost within about 30 seconds. Skilled representations and mental models are active in working memory when used to support task performance.

ABBREVIATIONS AND ACRONYMS

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

ACC	Area Control Centre
APP	Approach Control
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer / Air Traffic Controller *(UK/US)*
ATM	Air Traffic Management
CTA	Cognitive Task Analysis
DED	EATCHIP Development Director(ate) (*EUROCONTROL)*
DED5	Human Resources Bureau *(EUROCONTROL, EATCHIP; DED; now known as 'DIS/HUM' or 'HUM Unit' standing for 'Human Factors and Manpower Unit')*
DEL	DELiverable *(EATCHIP/EATMP)*
DFS	*Deutsche Flugsicherung GmbH (Germany)*
DIS	Director(ate) Infrastructure, ATC Systems & Support *(EUROCONTROL, SDE, EATMP)*
DIS/HUM	See 'HUM Unit''
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(now EATMP)*
EATMP	European Air Traffic Management Programme *(formerly EATCHIP)*
EEC	EUROCONTROL Experimental Centre *(France)*
ECAC	European Civil Aviation Conference
ET	Executive Task *(EATCHIP/EATMP)*
EWP	EATCHIP\EATMP Work Programme

FAA	Federal Aviation Administration
FEED	Feeder
F-JAS	Fleishman Job Analysis Survey
FPL	Flight Plan
FPS	Flight Progress Strip
GND	GrouND
GUI	Guidelines *(EATCHIP/EATMP)*
HSP	Human Factors Sub-Programme *(EATMP, HUM, HRS)*
HFSG	Human Factors Sub-Group *(EATCHIP/EATMP, HUM, HRT)*
HMI	Human-Machine Interface
HRS	Human Resources Programme *(EATMP, HUM)*
HRT	Human Resources Team *(EATCHIP/EATMP, HUM)*
HUM	Human Resources (Domain) *(EATCHIP/EATMP*)
HUM Unit	Human Factors and Manpower Unit (*EUROCONTROL, EATMP, SDE, DIS; also known as 'DIS/HUM'; formerly stood for 'ATM Human Resources Unit '; before that, was known as DED5 standing for 'Human Resources Bureau)*
IANS	EUROCONTROL Institute of Air Navigation Services *(Luxembourg)*
I/O	Input/Output (system, unit, device, loop, etc.)
IfB	*Institut für Begleitforschung* Institute for Evaluation Research *(Germany)*
ITA	Integrated Task Analysis
ITAM	Integrated Task Analysis Methodology
KSAO	Knowledge, Skills, Abilities and Other personal characteristics
LTM	Long-Term Memory

MP	Mental Picture
PAQ (FAA)	Position Analysis Questionnaire
PCS	Process Control System
R/T	Radio Telephony
REP	REPort *(EATCHIP/EATMP)*
RESTQ	Recovery-Stress Questionnaire
SA	Situational Awareness
SDE	Senior Director, EATMP Principal Directorate *or, in short,* Senior Director(ate) EATMP *(EUROCONTROL; formerly SDOE*)
SDOE	Senior Director(ate) Operations and EATCHIP *(EUROCONTROL; now SDE)*
SJA	Strategic Job Analysis
ST	Specialist Task *(EATCHIP/EATMP)*
STF	Selection Task Force *(EATCHIP/EATMP, HUM, HRT)*
SYNBA-GA	*Synthetische Beanspruchungs- und Arbeitsanalyse* Synthetic Strain and Task Analysis
TDH Unit	Training Development and Harmonisation Unit *(EUROCONTROL, IANS)*
TWR	Aerodrome Control Tower
WM	Working Memory
WP	Work Package *(EATCHIP/EATMP)*

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