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Integrated Task and Job Analysis of Air Traffic Controllers - Phase 2: Task Analysis of En-route Controllers

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Abstract

This report presents results from the Air Traffic Controllers' (ATCOs') task analysis conducted in five different en-route control centres in Europe. The approach of an Integrated Task Analysis (ITA) was employed, using cognitive interviews, behavioural observations, post-observational interviews and flight progress reconstruction methodology to allow a process description of the en-route controllers' tasks, which focuses on the cognitive aspects. Furthermore, a generic structural breakdown of the job level is provided. The report reviews some of the current results of controllers' job and task analyses and it describes the methods of data collection. The cognitive processes and structures of the controllers' tasks are described at different levels in this report.

Keywords

Cognitive Interview	Flight Progress	Process Analysis
Reconstruction	Cognitive Task Analysis (CTA)	
En-route Controller	Integrated Task Analysis (ITA)	

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EXECUTIVE SUMMARY

This document reports the progress of Integrated Task Analysis (ITA) which has been contracted out to the Institut für Begleitforschung (Institute of Evaluation Research, IfB), Germany, by the Human Resources Domain (HUM) of the European Air Traffic Harmonisation and Integration Programme (EATCHIP), now the European Air Traffic Management Programme (EATMP). It provides the reader with the results of task analyses conducted with 36 en-route Air Traffic Controllers (ATCOs) in five different Air Traffic Control (ATC) units in Europe. The ITA combines Cognitive Task Analysis (CTA) methods with classical observational and supplementary methods. The objective of the ITA is basically concerned with the cognitive processes of ATC. In contrast to most current task analysis results, the ITA approach allows the inference of the underlying cognitive processes as well as a process description of the ATC tasks.

The ITA approach is based on the 'Model of the Cognitive Aspects of Air Traffic Control' (EATCHIP, 1997). The ITA methods are described in more detail in the Report 'Integrated Task Analysis of Air Traffic Controllers - Phase 1: Development of Methods' (EATCHIP, 1998). The method material will be available in a Technical Supplement.

Chapter 1, 'Introduction', gives a brief outline of the purpose and scope of the project.

Chapter 2, 'Principles of Integrated Task Analysis', outlines the basic principles of task analysis and briefly reviews the approach of ITA. Furthermore, this chapter outlines the results obtained by different research groups on the cognitive aspects of ATC which have been reported up to now.

Chapter 3, 'Model of the Cognitive Aspects of Air Traffic Control', briefly reviews the structural components and the basic processes of the model of cognitive aspects of ATC.

Chapter 4, 'Methods of Integrated Task Analysis', sums up the elements of the ITA methods (cognitive interview, observational method, flight progress reconstruction, organisational interview and supplementary methods).

Chapter 5, 'Data Collection', describes the procedure of data collection and processing.

Chapter 6, 'Psychometric Quality of Integrated Task Analysis', comments on the problem of the reliability and validity of the methods employed.

Chapter 7, 'Structural Analysis of the Air Traffic Control Job', provides a structural breakdown of the en-route controllers' job.

Chapter 8, 'Process Analyses of En-route Controller's Tasks', gives flow diagrams and verbal descriptions of the core cognitive processes of ATC in this environment.

Chapter 9, 'Conclusions' focuses on implications of the results.

Chapter 10, 'Outlook', gives an outlook on Phase 3 of the project.

The Annexes contain References, a Glossary of definitions and a list of Abbreviations & Acronyms.

1. INTRODUCTION

1.1 Purpose

The integration of human factors into the future Air Traffic Management (ATM) system development requires a better understanding of the current cognitive processes in Air Traffic Control (ATC).

In order to derive robust recommendations for future ATM developments, questions must be asked which consider the problems of establishing and maintaining Situational Awareness (SA) and the updating of an adequate Mental Picture (MP) of the traffic situation. At the same time the selection and training of Air Traffic Controllers (ATCOs) may benefit from a better understanding of the cognitive processes involved in ATC and their change with the growing expertise of the controllers.

For this reason a set of methods for the task analysis was developed to assess the ATCOs' job and tasks from a cognitively-oriented point of view. The development of these methods, called 'Integrated Task Analysis (ITA)' has already been described in the first ITA Report (EATCHIP, 1998) and the related material will be available in a 'Technical Supplement'. The development of the ITA methods and the analysis of the en-route controllers' tasks were guided by the 'Model of the Cognitive Aspects of Air Traffic Control' (EATCHIP, 1997).

The present report is the result of Phase 2 of the ITA project and focuses on the job and tasks of en-route controllers.

1.2 Scope

The particular focus of the present study is directed towards better understanding of the cognitive processes of en-route controllers. The results are intended to supplement the structural task descriptions of behaviourally-oriented task analyses. Important cognitive aspects of the ATC task can therefore be seen as complementary to the task breakdown obtained by prior studies (e.g. Cox, 1994).

The results obtained from 36 en-route controllers in five control centres of the ECAC area are illustrated in a format which allows the presentation of the structure and processes of the job from an integrated point of view.

Results and conclusions will serve as a basis for a fairly representative ECAC Study comprising Phase 3 of the ITA project. This phase will not only compare a number of ATC units but also the en-route control with arrival and departure and the aerodrome control in the main geographical areas of ECAC. It will propose the actual task description of ATCOs and could be used as a baseline reference to which changes introduced by an evolving environment could be compared.

2.

PRINCIPLES OF INTEGRATED TASK ANALYSES

2.1

Classical Task Analyses

The objective of this report is to describe and discuss an analysis of the cognitive processes of the en-route controllers' tasks.

A task is defined as a sequence of simple movements or mental operations which are allocated to the same goal and can be derived from this goal. In many instances tasks are formalised. Formal tasks end with passing on the result. The beginning and end of a formal task are clearly detectable. Tasks can be regarded as concrete requirements ATCOs have decided to manage. The sum of tasks defines the ATCOs' jobs. Jobs are usually operationalised in an organisational structure.

Classical task analyses focus on formal structured job descriptions and observational methods. These methods are normally supplemented by post-observational interviews. Classical task analyses outline the structure of the tasks and the hierarchical dependencies between different task elements on different levels. The analysis conducted by Cox (1994) is a recent example of a more classically-oriented hierarchical task analysis of ATC. He describes seven tasks of the en-route controllers' job, nine tasks of the tower/arrival controllers and nine tasks of the approach controllers. En-route radar controllers' tasks are supplemented by generic task aspects consisting of four different elements. These task elements are again supplemented by sub-tasks for recognition and resolution of conflicts and management of airborne emergencies. What is of special interest with the analysis undertaken by Cox is that a brief outline of the processes of ATC is provided in addition to the classical task breakdown. Another interesting feature is that most of the categories do not address behavioural aspects of the ATCOs' tasks but are only concerned with cognitive aspects. This result indicates again that the cognitive aspects are of crucial importance for ATC. That is why analyses focusing on the cognitive processes would appear be urgently needed.

2.2

Cognitive Task Analyses

Recent reviews of the ATCOs' tasks analyses (e.g. Seamster, Redding & Kaempf, 1997) highlight the most important cognitive aspects. They do not rely on a standardised task analysis procedure, which can be considered as a disadvantage of the Cognitive Task Analysis (CTA) to date. It would seem that different methods have been selected according to the special interests of the different research groups. As Seamster et al. (1997) repeatedly point out, results diverge drastically due to the specific task analysis methods used by different groups. Another feature of the CTAs conducted up to now is a bias towards the knowledge structure of the ATCOs. This is a consequence of the expert-novice research paradigm which has been repeatedly used in CTA. In spite of the fact that different research groups have highlighted different

cognitive aspects of the ATC work due to different research methods, a set of so-called 'cognitive core tasks' of ATCOs has been well defined:

- maintaining SA,
- making decisions for control actions,
- developing and updating a sector traffic plan.

Maintaining SA is only possible if a mental traffic picture has adequately been built up and, therefore, a continuous anticipation of future situations is possible. The anticipated traffic picture will continuously be compared with the traffic information from the radar screen during the process of traffic monitoring. Planning and anticipating the future situation, therefore, are the central cognitive tasks of en-route controllers. The cognitive tasks of ATCOs are basically mental processes. For a cognitively-oriented task analysis, the processes should be the major focus.

2.3 Results from Research Groups Investigating Cognitive Task Analysis

For en-route controllers a set of so-called 'key tasks' (Redding & Seamster, 1994) or 'core tasks' (see EATCHIP, 1996) or 'task units' (Cox, 1994) can be distinguished. These core tasks can be identified irrespective of the specific approach used by the task analysts.

In Table 1 an overview is given of the different basic tasks of en-route controllers identified by different task analyses. It also shows that there is a considerable overlap between these tasks. There are different task titles and the three research groups allocate a different weight to the same tasks. Most researchers would agree that decision-making for control actions is an important part of the en-route controllers' tasks but only EATCHIP (1996) lists 'decision-making' as a core task. However, this working group does not discuss the differences between decisions on **what to do** and decisions on **when to do something**.

Table 1: Overview of several task analyses of en-route control

A= Redding & Seamster (1994) D= Glaser & Dahl (1995). Airport/3
 B= EATCHIP (1996) E= NLR (1996). RHEA
 C= Cox (1994)

Core Tasks Listed by Various Task Analyses		A	B	C	D	E
1 Maintain SA		x	x		x	x
Build up MP of traffic situation		x			x	
Perform routine sector 'maintenance' task				x		
2 Develop and receive sector control plan		x		x	x	x
Perform actions before aircraft (a/c) arrives in sector				x		
Handle and process flight plan information		x			x	
Manage air traffic within area of responsibility		x				
3 Make decision for control actions		x	x			
4 Solve a/c conflicts		x				
Provide separation		x	x			
Conduct recognition and resolution of conflicts in en-route airspace			x			
5 Provide tactical ATM		x			x	
Route a/c through sector airspace/manage overflight/re-route a/c		x		x	x	x
Conduct a/c movements			x	x		
Initiate/point out/transfer control		x		x	x	
Receive pointout/accept a/c		x		x	x	x
Receive handoff/carry out handover from previous controller		x		x	x	
Initiate handoff/carry out handover to next controller		x		x	x	
Manage arrivals		x		x		
Manage departures		x		x		
Issue advisory/provide pilots and colleagues with all relevant info		x	x	x	x	
Issue safety alert		x				
Provide assistance in abnormal situations		x				
Manage airborne emergency			x			
Ensure correct co-ordination		x		x		
Conduct Radiotelephony (R/T) communication		x	x	x		
Manage pilot-initiated communication			x			
Perform actions after a/c has left sector			x			
Conduct pre-shift briefing			x			
Handle, manage Flight Progress Strips (FPSs)		x		x		
Check technical equipment at working position		x			x	
6 Complementary tasks			x	x		
Train		x		x		
Update working knowledge		x				
Supervise control room/team		x		x		
Co-ordinate with customers/users		x		x		
Manage sector/position resources				x		
Assess situational conditions				x	x	

Table 1 demonstrates that the results from the five different task analyses can be grouped into six task clusters, as described below:

1. 'Maintain SA' is identified by all analyses except Cox (1994). He both identified the performance of the routine sector management requiring SA

and the pre-shift briefing that helps to establish SA. SA itself is not mentioned in the Cox analysis. In order to maintain SA en-route controllers have to 'have the picture'. This means that a mental traffic picture has first to be built, then the picture has to be continuously projected into the future and this anticipation has to be checked with the actual traffic situations. Under normal working conditions the MP is built up when taking over the position.

2. 'Develop and receive sector control plan'. Flight progress information and traffic forecast have to be integrated into a future plan of the traffic situation, allowing a safe and expeditious flow of traffic. In many instances this step can be called a 'conflict avoidance' task.
3. 'To make decision for control actions' and active decision-making are closely related to the development and revision of the sector control plan and are sometimes triggered by pilots' requests.
4. 'Solve a/c conflicts' includes the provision of separation and solving a/c conflicts.
5. 'Provide tactical ATM' includes accepting an a/c, carrying out handover, providing pilots with relevant information, providing assistance in abnormal situations, and a long list of specific activities.
6. 'Complementary tasks' includes briefing and update of the working knowledge of en-route controllers.

The overall principle of ATC is 'ensuring safety', meaning that everything works according to the safety rules and that there is continuous checking of the whole situation for abnormal or unexpected events. This checking includes self-monitoring and team monitoring.

The different task clusters will be addressed again in Chapter 8 of this report.

2.4

Integrated Task Analysis

As mentioned previously the ITA approach of the current project is conceptually based on the 'Model of the Cognitive Aspects of Air Traffic Control' (EATCHIP, 1997).

A standardised set of methods for task analysis accounting for the cognitive aspects of ATC has been developed and established. These methods include a cognitive interview, a flight progress reconstruction, a behavioural observation, a post-observational interview, an organisational interview and other supplementary methods for the analysis of workload and stress. Information about the development of methods can be found in the first Report of the ITA Project (EATCHIP, 1998). A technical supplement containing the methods and materials is under preparation.

The data processing allowing analysis of the cognitive processes of en-route control based on the data from the cognitive interviews and the flight progress reconstruction method is summarised in Chapter 5.

The added value offered by the ITA can be summarised as follows:

In addition to an improved understanding of the ATCOs' activity and the demands placed upon ATCOs, the analysis of cognitive processes should highlight new important perspectives. It will be especially useful for examining the processes involved in maintaining the MP of the traffic situation, the decisions in conflict situations and the planning of the traffic flow.

Three areas of application will possibly benefit from ITA:

- Selection

ATC includes complex monitoring and controlling systems, decision-making decisions in complex situations and multitasking. However, these specific mental demands have not been fully integrated into some of the existing test batteries. The cognitive abilities of ATCOs have been considered in a general or indirect way only. Therefore, based on an integrated task analysis, the development of specific simulation and selection instruments with emphasis on the cognitive processes of en-route control can be created and optimised.

- Training

The weaknesses and limitations in human thinking and reasoning should be compensated by training. From the point of view of the cognitive model it is desirable to integrate planning and situation-related predictions more explicitly into the different areas of training. Cognitive processes like anticipation can be easily included into some training methods. In addition, there should be a routine testing of the self-assessment regarding own performance (prediction training). The results of the cognitive-oriented ITA will be very useful to optimise simulation training. The CTA, especially flight progress reconstruction, will provide concrete situational examples. New results on how to optimise simulation training may be of crucial importance to overcome this problem.

- Human-Machine Systems

An exact analysis of en-route controllers' information processing is not only helpful for the optimisation of the human-machine system and the design of user interfaces, but it also contributes to the development of future ATM systems. With increasing technological possibilities the risk that the ATCOs' activity will be more and more reduced to a monitoring task is increasing. Monitoring without action is one of the weaker skills in human information processing and is also a risk factor in the sense that in the event of equipment failure the ATCOs are unable to take over in a

procedural or semi-automated way. A major reason for this is that, while they are exclusively carrying out monitoring tasks over a prolonged period of time, their SA and traffic picture cannot be fully maintained. From a cognitive-oriented job and task analysis one can deduce a more appropriate distribution of tasks between en-route controllers and technology. The aim would be to transfer the ATCOs' tasks which take advantage of the strengths of human information processing abilities to the controllers and not to the system.

The introduction of new systems or functionalities to an existing system has an influence on the tasks performed by the operator. In some cases tasks can be automated, collapsed, split or integrated and the nature of the tasks can change. Having a baseline reference to which one can compare the new situation is very valuable. This is one of the purposes of Phase 3 of the ITA Project.

3. MODEL OF THE COGNITIVE ASPECTS OF AIR TRAFFIC CONTROL

3.1 Structural Model

Further details on this issue are given in EATCHIP (1997). The model can be roughly divided into a structural part and a process part of ATC. The structure describes different Input/Output (I/O) loops, Long-term Memory (LTM), Working Memory (WM) and a Process Control System (PCS). A sketch of this structure is depicted in Figure 1.

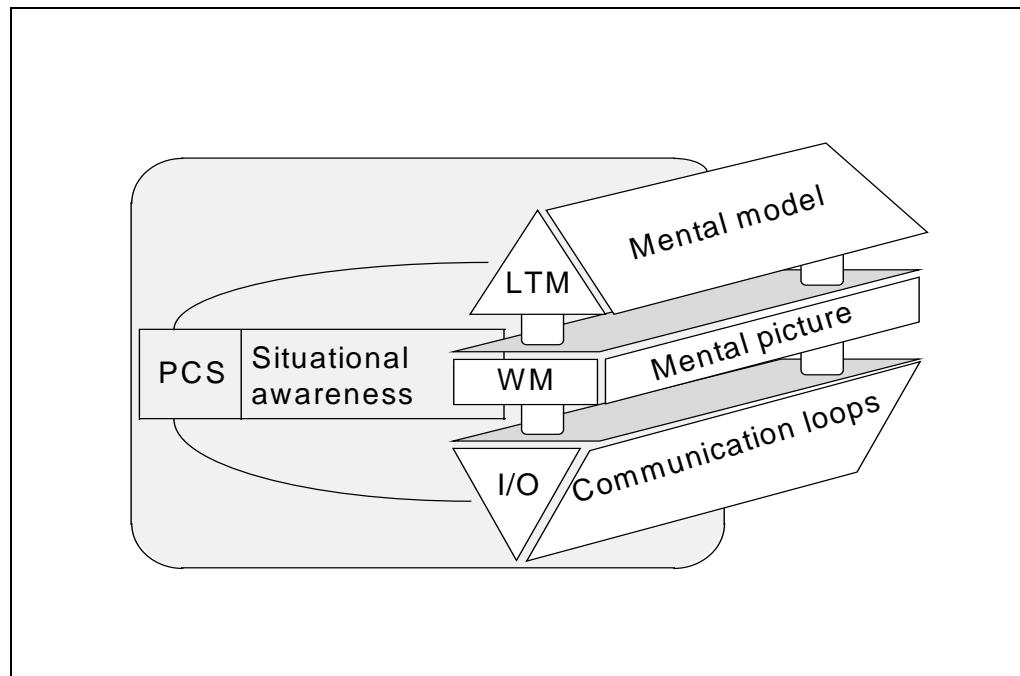


Figure 1: Structure of the cognitive aspects in ATC

3.1.1 Long-term Memory

The Long-Term Memory (LTM) contains different sorts of knowledge: the 'heuristic knowledge' (the knowledge how'), used to solve problems and adapt to new situations, and the 'epistemic knowledge' (the 'knowledge about') containing data, events and rules. The episodic memory allows the solving of problems, conflicts or emergency situations by drawing analogies from experience.

The Mental Model (MM) is the knowledge of the system and is part of the LTM.

3.1.2 Working Memory

The Working Memory (WM) is the central element of the cognitive model of ATC that links the LTM, the PCS and the different I/O loops. It is a system that keeps actual information up-to-date.

The MP of a situation represents a moment-to-moment snapshot of the actual situation and is mainly stored in the WM.

Actual information can originate from I/O loops, may be retrieved from the LTM or can result from the information processing (e.g. the evaluation or information integration). The short-term memory system can be divided into at least two different parts (Baddeley, 1986). One is responsible for processing visuo-spatial information, while the other is responsible for processing acoustical information and language. Research has shown that these two parts can be used simultaneously without major interference, at least after a short training period. An important aspect of the WM is its limited capacity and, therefore, it can become the central bottleneck of the human information processing. An easy method to demonstrate the limits of the WM is the readback of numbers. This simple experiment shows that the maximum number of digits which can be repeated without error ranges from seven to twelve. Call signs in ATC can, at least for a moment, occupy a large space of WM. From this perspective it is quite reasonable that, in many instances, pilots and ATCOs tend to use abbreviated call signs for communication. The WM does not only have a limited capacity but it is also liable to interference from the I/O loops, emotions, LTM and PCS. Finally, information in the WM is lost quickly unless it is rehearsed or updated in short intervals.

3.1.3 The Process Control System

The PCS is responsible for distributing attentional resources, keeping plans in mind, timing action, evaluating and self-monitoring. Its most important feature is to ensure the Situational Awareness (SA). The PCS is closely linked to the WM and, from the conceptual point of view, it is an extension of the central executive of the WM concept proposed by Baddeley (1986). It has to monitor long-term processes in the course of a goal-oriented action and closely interacts with the LTM structures as well. It is therefore justified to consider the PCS a stand-alone part of the cognitive model. The PCS can be related to attention and goal-oriented behaviours, which show marked disturbances after lesions of the frontal areas of the human brain according to neuropsychological studies. The PCS is also closely connected to the WM which is prone to interference and memory loss. Whilst focusing on an action one can forget the overall long-term goal of the task. The 'protocol memory' (Dörner, 1993) or 'prospective memory' (Wickens, 1992) is also a function of the PCS and is claimed by several researchers to be a kind of store of ongoing activity.

3.1.4 The Input/Output-System

The sensori-motor components of human information processing are termed the Input/Output (I/O) system. The I/O system possesses a short-term

sensory store and is organised in functional feedback loops. These loops direct the behaviour of the perceptual systems; for instance, the eye will move in the direction of the anticipated input. The same is also true for motor responses: without the correct anticipation of the situation one would not be able to grasp moving objects. Therefore, most of the activities of the I/O system have a strong top-down component. These top-down processes are determined both by the Mental Model (MM) and the Mental Picture (MP).

Higher level activity of the I/O system, i.e. the active selection of information and response, is monitored in the WM and controlled by the PCS.

3.2 The Process Model

The main process components of the ATC task are monitoring, controlling, decision-making, diagnosing and problem-solving. The model of the cognitive aspects of ATC argues that the most important processes in ATC are top-down processes, which means they are governed by plans, intentions and rules. Top-down processes follow the principle of the so-called 'Anticipation-Action-Comparison loop (AAC loop)'. The AAC loop is derived from the principle of the anticipatory regulation of actions, which can be used to describe very simple task elements as well as complex task structures. Therefore, it is claimed that this principle can be applied to goal-oriented behaviour at different levels of organisation, from simple eye movements to complex strategy-driven behaviour at work.

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4.

INTEGRATED TASK ANALYSIS METHODS

To obtain a thorough picture of the cognitive core processes of ATC and allow a comparison of the cognitively-oriented analysis with results from previous classical task analysis, an ITA approach was selected. ITA Methodology (ITAM) was first proposed by Redding and Seamster (1993). Following these guidelines the present ITA combines methods from classical task analysis and Cognitive Task Analysis (CTA). A more detailed description of the methods of ITA for ATC is provided in EATCHIP (1998).

4.1

Elements of the Integrated Task Analysis

Classical task analysis provides a hierarchical breakdown of jobs into tasks, sub-tasks and task units, which are guided by the various goals of action. Modern classical task analysis systems are therefore called 'goal-oriented' or 'action-oriented' task analysis. At least for the standardised task analysis systems that were obtainable in German, a full survey of analyses was conducted. Based on this survey, behaviourally-oriented observational methods were developed. This development was based on data from en-route controllers' observations in three different en-route control centres in Europe. The observations were then followed by a post-observational interview and an organisational interview, both adjusted to the ATC environment.

From the set of different methods of CTA the cognitive interview technique and cognitive reconstruction method (adapted as flight progress reconstruction technique) were selected for the ITA of ATC. The ITA therefore consists of a cognitive interview, observational methods, a post-observational interview, a flight progress reconstruction technique, an organisational interview and supplementary methods concerned with workload and stress.

4.2

The Cognitive Interview

The cognitive interview refers to the gathering of information during one en-route controllers' working period and within this process twelve different topics are addressed. For each topic one or more compulsory primary questions are to be asked by the interviewers. They are then supplemented by a set of optional secondary questions. These optional questions allow the interviewers to ask the controllers to describe the issue at hand in further detail. The topics of the cognitive interview are listed below:

- I. Takeover of the position.
- II. Takeover of an aircraft (a/c).
- III. Traffic monitoring.
- IV. Decision-making.
- V. Multitasking.
- VI. Communication with pilots.
- VII. Situationally-driven behaviour.

- VIII. Conflict situations.
- IX. Handover of an a/c.
- X. Self-monitoring.
- XI. Handover of the position.
- XII. Teamwork.

4.3 Observational Methods

The observational methods consist of a set of protocol sheets focusing on different aspects of the en-route controllers' behaviour. These methods address the following areas:

Task Units

The occurrence of different task units, such as accepting an a/c, accepting Flight Progress Strips (FPSs), rearranging FPSs, descending an a/c, turning an a/c, communicating with adjacent sectors, is recorded during an eight-minute interval.

Call Survey

The various a/c and the type of communication used by en-route controllers during a ten-minute interval are listed.

Information Flow Sheet

The communication partners (e.g. pilots, planners, co-ordinators and adjacent sector controllers) and the frequency and direction of the communications are recorded.

These three observational sheets are applied twice for each controller during the observation period.

Adjacent Sectors Traffic Density

The number of a/c transferred to the different adjacent sectors is counted.

Observational rating scales are used to account for rare events and those events that can be better evaluated from an overall perspective, such as the number of interruptions and the time pressure.

Additional Protocol Sheets

A sheet for writing down unusual observations and another for drawing a sketch of the work position are provided.

4.4 Post-Observational Interview

The post-observational interview allows the collection by the controllers of some additional ratings concerning workload, time pressure and idle periods. In addition, formal aspects of the work and the workplace such as workload and overtime are addressed as well as the use of 'automated support tools' (that is technical tools or aids which support cognitive processes).

4.5 Flight Progress Reconstruction

Flight progress reconstruction consists of twelve interview questions which are addressed to cover each of the specific traffic events of the observation period. A reconstruction technique is used to obtain an almost perfect recollection of the events in the observational period. As most of the relevant information is documented on the FPSs they are collected and used as reconstruction tools for the analysis (either paper strips or printouts from electronic strips).

The major advantage of FPSs is that they can be initially sorted into two categories. The first category consists of a/c which are routine and those which need no additional attention, termed in most situations 'hello-goodbye' a/c. The second category refers to a/c which can be characterised as those with special interest, requiring some additional co-ordination or being in potential conflict with another a/c.

After the relevant a/c are sorted out the controllers are allowed to arrange these a/c on the table or small pin board according to their own criteria. The sequence of a/c in time is used as the default criteria. After this preparation controllers are asked the twelve questions, starting from outlining what was special with the a/c and ending with the question concerning technical devices, which are used as tools in the situation.

4.6 Supplementary Methods

Two questionnaires, one addressing the working conditions and the other the resulting stress level of en-route controllers, are used. These questionnaires include some personal and private background stressors and recovery processes in order to map a comprehensive workload-stress profile. In Phase 1 of the project heart-rate recordings were conducted to test the additional possibility of obtaining physiological data as an objective workload indicator.

4.7 Organisational Interview

The organisational interview consists of collecting background information on the structure of the ATC unit. These issues include:

- the size,

- the number of workplaces and different positions,
- the hierarchical structure,
- the shift system and team structure,
- the sectorisation,
- the 'automated support tools' (i.e. technical tools or aids which support cognitive processes).

5. DATA COLLECTION

5.1 Control Centres

Data from 36 en-route controllers in five control centres in Europe were collected in Phase 2 of the project. This gave a fairly representative picture of the en-route controllers' job and tasks. Table 2 describes the centres and sectors used in this Study.

Table 2: ACC centres used in Phase 2

Control Centre	Radar	Planner	Total	Observed Sector
Vienna ACC	6	6	12	
				North Sector
				Upper North Sector (290+)
				West Sector combined
				West Sector
Copenhagen ACC	8	-	8	
				Upper and Lower Sectors A and B combined
				Upper Sector C (245-460)
				East Sector D (lower air space, up to 245)
Zürich ACC	7	-	7	
				Upper Sector 2 (290-330)
				Lower East Sector
				Lower West Sector
Stockholm ACC	5	-	5	
				Radar Sector 1
				Radar Sector 2
				Radar Sector 3
				Radar Sector 5 (sequencer Arlanda)
				Radar Sector 7
Malmö ACC	4	-	4	
				Radar Sector 4
				Radar Sector 8

5.2

Subjects

The overall sample consisted of 36 en-route controllers: 30 radar controllers and 6 planning controllers. Complete data sets are available for 31 en-route controllers. For 5 en-route controllers a part of the task analysis is incomplete (2 observations, 3 FPSs reconstructions, 1 cognitive interview) because of technical or organisational reasons.

A brief description of the sample is given in Table 3.

Table 3: Description of the sample

Gender	6 female, 30 male
Age	mean = 34,9 years; s^* = 6,7 years; range: 27 - 50 years
Experience (licence)	mean = 10,5 years; s^* = 8,0 years; range: 0,5 - 30 years

* s = standard deviation

The sample consisted of mainly experienced and very experienced en-route controllers. Some controllers had worked at other national centres or abroad. All en-route controllers in Malmö were also licensed to handle military traffic and ten en-route controllers also had valid licences for approach-departure sectors. Only four en-route controllers had valid licences for tower control.

5.3

Organisational Interview

Setting and Procedure

The organisational interview was conducted before the rest of the task analysis took place and adhered to the interview guidelines.

Time Frame

The organisational interview took from 45 to 60 minutes.

Comments

Only little information on the equipment could be provided because the equipment in the centres had been evolving during the course of the past years.

Detailed information was collected from internal documents regarding:

- rostering systems,
- hierarchical structure of the national ATC organisation,
- sectorisation of the ATC centre.

5.4 Cognitive Interview

Setting and Procedures

Before the interview started the interviewees were informed about the purpose and procedure of the project and the confidentiality of the data. They were then allowed to ask the interviewer questions concerning the purpose of the interview. All interviewees agreed to have the interview tape-recorded. Interviewees and the manager of the en-route control unit were assured that, in the case of literal citations, which could allow identification of specific persons or specificities of the centre involved, an additional agreement would be obtained before publishing the data. That is why most individual results are not cited in this report, although there are exceptions that have been approved for release. One interviewer normally conducted the interviews, with one en-route controller at a time.

Time Frame

The interview lasted about 90 minutes, varying from 60 to 105 minutes and was usually conducted in a separate room.

Comments

After the interview the interviewees were asked whether the interview had been strenuous and whether there were any aspects which had not been tackled. All of them evaluated the interview positively even if some of them rated it as quite strenuous. They also stated that it was interesting and covered the most relevant aspects of their job.

5.5 Behavioural Observations

Setting and Procedures

Behavioural observations were conducted during regular duty periods. They were co-ordinated with the watch managers in all instances. The en-route controllers were instructed to select a sector with medium to high level traffic and an appropriate time within a busy period.

Before the observation started the observers introduced themselves to the adjacent colleagues (e.g. flight data assistants, planners and controllers of the adjacent sectors) and they made sure that the FPSs could be collected. Either an arrangement with the flight data assistants was made or the collecting box

was emptied at the beginning of the observational period, in such a way that the discarded FPSs would be collected for the observational period in the normal process. From the constructional Phase 1 of the project it became evident that it was necessary for the controllers not to change the highly automated process of discarding FPSs. When the controllers wore their headsets the observers also plugged themselves in, in order to follow the radio communications. The observers usually took a seat slightly behind the controllers so that they could simultaneously have a view on the screen, the flight progress board and the controllers. The observers adjusted their seat in such a way that the controllers were not disturbed in their work.

Time Frame

The observational period took about 60 minutes, varying between 45 and 90 minutes according to the duty periods in the control unit. During the observational period the observers went through the protocol sheets of the behavioural observation in a fixed sequence with small pauses (30 to 60 seconds) between the different working sheets. Usually, the observational period was followed by a break.

Comments

Dialogue between en-route controllers and observers normally took place before observation started. This was when the observers asked for the radio frequencies of adjacent sectors and gave some brief introductory remarks. After this the dialogue was restricted to shared breaks. During idle intervals it usually took some time before the controllers resumed normal conversation with their colleagues.

5.6 Post-observational Interviews

Setting and Procedures

Questions were asked according to the guidelines. The post-observational interview, whenever possible, was combined with the flight process reconstruction.

Time Frame

The post-observational interview usually took about ten minutes.

5.7 Flight Progress Reconstruction

Setting and Procedures

The flight progress reconstruction and the post-observational interview were usually presented as one session to the en-route controllers. Once the instructions were given the controllers went through all the FPSs from the observational period and grouped them into two categories. The first group

consisted of flights that needed no additional effort, were routine and could be termed 'hello-goodbye' aircraft (a/c). The second group of a/c had received some additional co-ordination and attention or was involved in a potentially conflicting situation. To some extent the proportion of these 'non-routine' a/c not only depended on the actual traffic load within the observation period, but also on the amount of vertical movements of a/c in the sector.

These non-routine FPSs were usually arranged by the controllers according to their timely sequence on either a table or a pin board. Some of the controllers grouped a/c involved in the same non-routine traffic situation or conflict. Consequently, some of the FPSs were regarded as a group of a/c. Each controller was allowed to add strips in order to complete the description of the relevant non-routine traffic situation.

A standard set of twelve questions was asked for each individual a/c or group of a/c. At the end of each FPS or strip group reconstruction the en-route controllers rated the additional effort, then proceeded to the next one. This procedure was tape-recorded.

Time Frame

The flight progress reconstruction took between 15 and 45 minutes.

The flight progress reconstruction interview was also tape-recorded, transcribed and submitted for subsequent qualitative analysis.

Comments

Some deviations from the standard procedure occurred when more than one interviewee was present. In four cases the planning controllers joined the reconstruction interview and in one case they gave additional comments. The comments indicated that, for the planner position, it was possible to use the flight progress reconstruction technique to make more transparent the decision-making and the working strategies of the planning controllers.

5.8 Supplementary Methods

Setting and Procedure

Usually following the cognitive interview - however, in some instances after the observations - the en-route controllers were provided with two questionnaires and instructed to fill them in individually. They were informed that the first questionnaire (SYNBA-questionnaire D) was more concerned with the stress and strain of the working situation and that the second one (RESTQ) addressed the personal reactions to stress and could be used to establish an individual stress and recovery score. The procedure took about 10 to 15 minutes.

5.9 Data Processing

While observations and ratings were immediately converted into a data set for statistical analysis, results from the organisational interview, the cognitive interview and the flight progress reconstruction interview were submitted to qualitative data analysis. Below are the basic steps that were conducted:

1. The transcription of interviews was done as literally as possible. Non-verbal expressions and pauses were omitted in the first transcriptional stage.
2. The transcription was checked by one of the interviewers after it had been printed. The proofread transcript was then used for the next step in the analysis.
3. A set of questions for the analysis was formulated and the answers and remarks of the en-route controllers were rearranged accordingly. This qualitative grouping allowed detailed consideration of the task units and the inference of the related cognitive processes.
4. Based on the recorded interviews the responses of the controllers were summarised in storyboards of about eight hundred words each. These storyboards depicted how the en-route controllers conducted the most important tasks.
5. Based on these storyboards flowcharts were developed which represented the central behavioural, cognitive and evaluative process components of the ATC tasks. These flowcharts were validated and supplemented using the results from the flight progress reconstruction interviews.
6. In addition to the process descriptions a structural breakdown of the en-route controllers' job was conducted. This breakdown was cross-checked against the results of the review of current task analyses, which were summarised in Table 1 (see Chap. 2.3).

Additional situational information was obtained for the flight progress reconstruction data as the interview questions were asked for each of the FPSs or group of FPSs.

A category matrix for the evaluation of the flight progress reconstruction encompassed typical situations and categories for the management of the different situations.

This matrix will not be used within the task breakdown or process description, which is situationally not specific.

6.

PSYCHOMETRIC QUALITY OF THE INTEGRATED TASK ANALYSIS

The first criteria needed to evaluate the quality of the Integrated Task Analysis (ITA) methods concern the usability in operational environments and the acceptability by the observed en-route controllers. Up to this point no problem has occurred as far as these two basic criteria are concerned. Compared to other task analysis systems a time of about six hours per controller can be considered as economic. Due to the fact that some parts of the process (cognitive interview, flight progress reconstruction) are qualitative the data analysis is still time-consuming. This is, however, well justified in the current development of a generic human-oriented task analysis.

At the same time ITA should provide results that are independent of the observers (objective), reproducible (reliable) and valid, which means that the results could be used to improve selection and training, and the design of the Human-Machine Interface (HMI) in future ATM systems. As the ITA consists of different types of methods there is no one unique measure to evaluate the psychometric quality of the data. Psychological test theory allows the assessment of the quality of questionnaires and psychological tests. The classical concepts of reliability and validity cannot be applied to qualitative data. Instead, other approaches like grounded theory (Strauss & Corbin, 1990) and measures can be used to assess the inter-rater consistency of observations and of the data analysis. Detailed results on reliability and validity and some additional studies of the methods under controlled conditions will be provided after the completion of Phase 3.

First estimates on the reliability of the observations and on the categorisation of the interviews proved that behavioural observations and qualitative analysis of data require well-trained personnel who have at least a basic understanding of the en-route controllers' job and task and human-oriented understanding of ATC operations in the ECAC area.

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7. STRUCTURAL ANALYSIS OF THE AIR TRAFFIC CONTROL JOB

7.1 Display of Structural Job Analysis

A hierarchical decomposition (Cox, 1994 & Hacker, 1997) is used for the structural analysis of the ATC job. The hierarchical decomposition takes different aspects of the en-route controllers' job and tasks into account, following the logic of the ITA and the cognitive model of ATC. This means that the job and tasks are split to simultaneously consider the following components of the tasks:

- **the behavioural and sensori-motor components,**
- **the cognitive/memory components,**
- **the evaluative and decision-making components.**

These aspects respectively correspond to the Input/Output (I/O) loops, Working Memory (WM) / Long-Term Memory (LTM) and Process Control System (PCS) of the model on cognitive aspects of ATC.

A full analysis of the en-route controllers' job should include duty-period activity as well as rest periods and standby duties. The importance of rest periods for re-establishing full performance is obvious and should therefore be considered as part of the job.

The waiting periods at the working position also have to be considered because according to many en-route controllers one of the most demanding aspects of their job is the necessity to switch within an extremely short lapse of time from zero to nearly 100% performance demand, because sometimes the traffic complexity drastically increases in a very short time and so does the workload, non linearly.

Figures 2 to 4c illustrate, for each job element found in the en-route controllers' job, the three aspects described earlier, i.e. the behavioural and sensori-motor components, the cognitive/memory components and the evaluative and decision-making components.

The basic presentation concept for the structural breakdown is given in Figure 2.

Each figure is made of four triangles: a central triangle and three surrounding triangles:

- The job elements or tasks are indicated in the central triangle. These elements can be viewed as the goals to be achieved by the means that are depicted in the three surrounding triangles.

- The triangle on the left lists the behavioural and sensori-motor aspects of the job element or task indicated in the central triangle. The behavioural and sensori-motor aspects relate to the 'I/O' of the cognitive model.
- The triangle on the right lists the evaluative and decision-making aspects of the job element or task indicated in the central triangle. The evaluative and decision-making aspects closely relate to the PCS of the cognitive model.
- The triangle on top lists the cognitive/memory aspects of the job element or task indicated in the central triangle. The cognitive/memory aspects relate to the WM and LTM of the cognitive model.

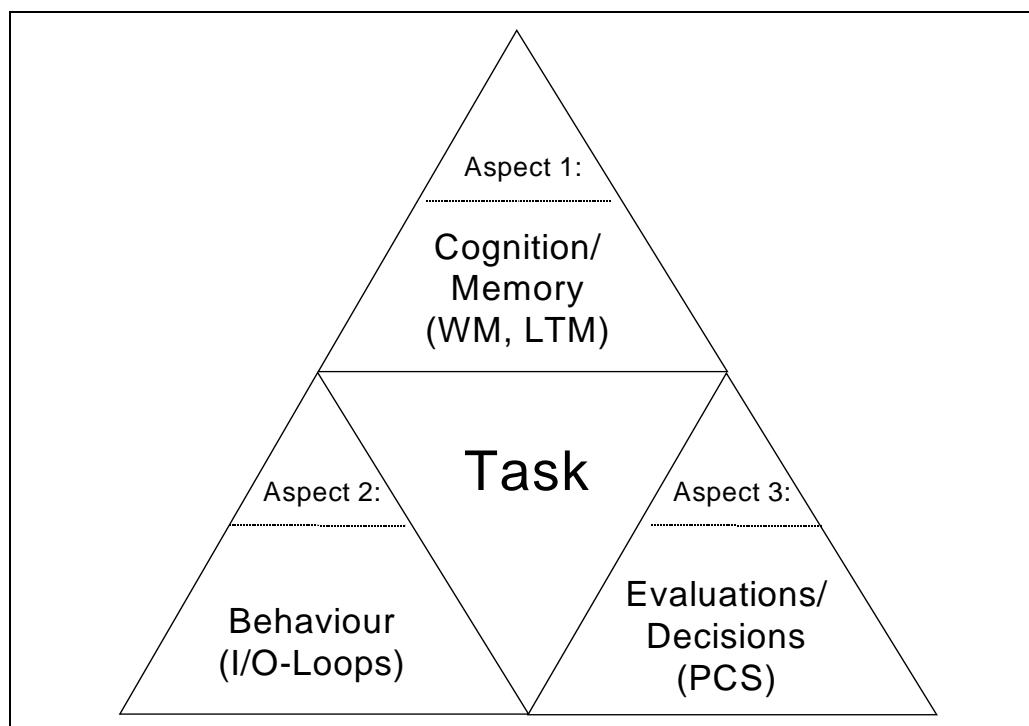


Figure 2: Basic presentation concept for the structural task breakdown

In Sub-Chapter 7.2 only the job level elements are detailed. Analysing these elements in further detail is possible by using, at the job level, each component of each triangle as a new starting point for further finer task breakdown. In Chapter 8 further details on tasks are described by using a process description with flowcharts to account for their complexity and nature.

7.2

Job Elements

In this sub-chapter examples of the structural breakdown are provided.

Two levels are considered: the first one is about the main elements of the ATCOs' job and the second one provides a finer breakdown, taking one component of each of the three aspects described earlier as a starting point.

7.2.1

Main Elements of the Air Traffic Controllers' Job

Applying the presentation concept described in Sub-Chapter 7.1 the main elements of the ATCOs' job are given in Figure 3. It contains the three aspects mentioned earlier and their components as follows:

1. The components of the **cognitive/memory aspects** are:
 - Updating general knowledge;
 - *Updating ATC knowledge*;
 - Updating knowledge about the team.
2. The components of the **behavioural and sensori-motor aspects** are:
 - Attending team meetings;
 - *Conducting shiftwork*;
 - Conducting recreation;
3. The components of the **evaluative and decision-making aspects** are:
 - Evaluating one's personal situation;
 - *Evaluating the job situation*;
 - Deciding on one's shift cycle.

Each of the above components can be subdivided into further elements which contribute to the next level of the job. As an example a further breakdown is given in Sub-Chapters 7.2.2 to 7.2.4 for each of the job elements printed in *italics*. These elements are shown in further detail in Figures 4a to 4c.

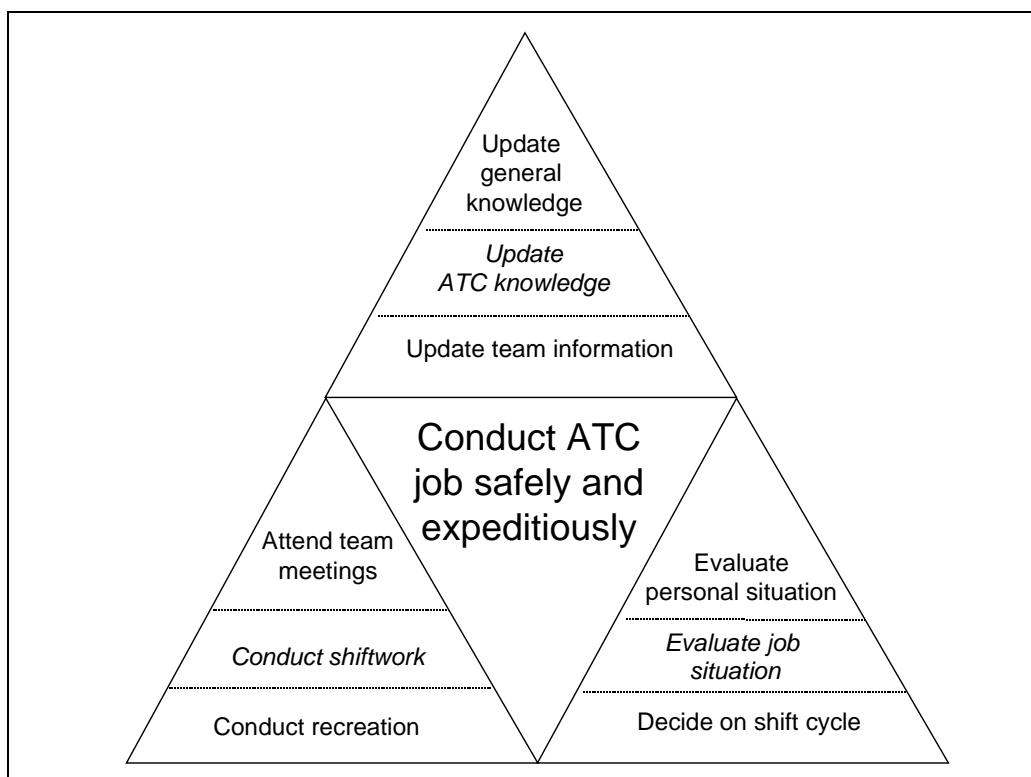


Figure 3: Main elements of the ATCOs' Job

7.2.2

Updating Air Traffic Control Knowledge

The job element 'update ATC knowledge' is depicted in Figure 4a.

1. The components of the cognitive/memory aspects are:
 - Updating the sector model with new information;
 - Updating the knowledge on regulations and aircraft (a/c);
 - Updating the knowledge on new/future developments.
2. The components of the behavioural and sensori-motor aspects are:
 - Asking / talking to colleagues;
 - Informing oneself about new rules and regulations by briefing or reading written information;
 - Attending courses.
3. The components of the evaluative and decision-making aspects are:
 - Evaluating own knowledge on the future development;
 - Evaluating the Mental Model (MM).

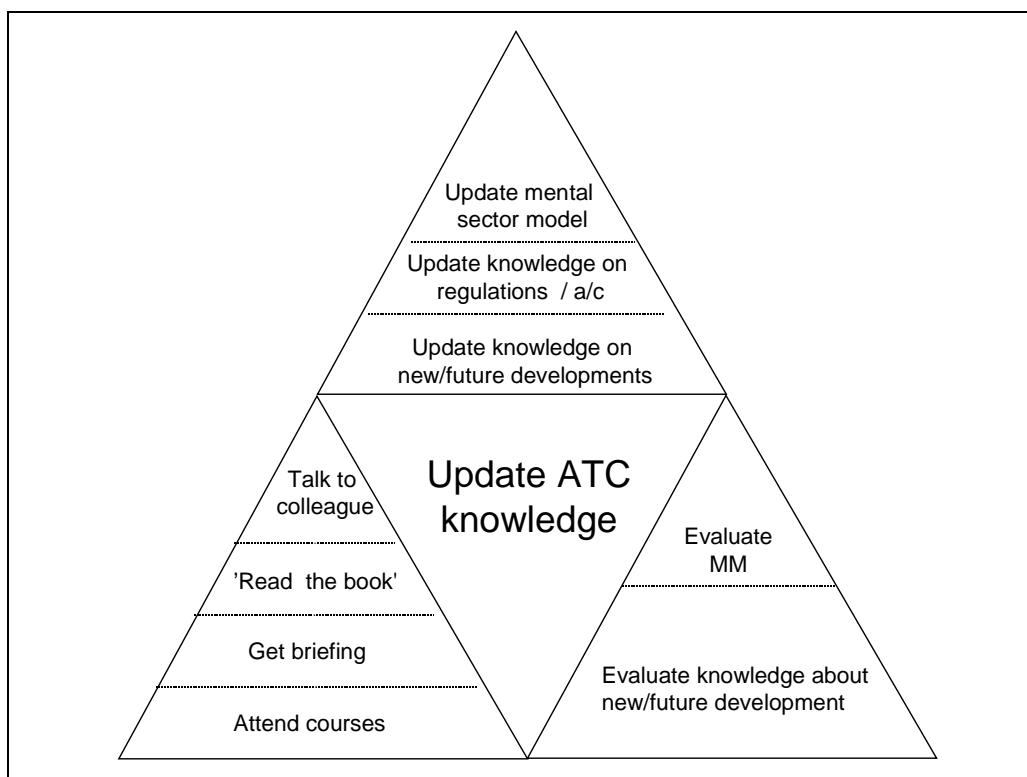


Figure 4a: Update ATC knowledge

7.2.3

Evaluating Job Situation

The job element 'evaluate job situation' is depicted in Figure 4b.

1. The components of the cognitive/memory aspects are:
 - Updating knowledge of technical development;
 - Updating knowledge of the team situation;
 - Updating knowledge of one's own state.
2. The components of the behavioural and sensori-motor aspects are:
 - Communicating with the management;
 - Communicating with colleagues;
 - Conducting prototyping of future systems and the like.
3. The components of the evaluative and decision-making aspects are:
 - Evaluating technical changes;
 - Evaluating the personal state;
 - Evaluating the team state.

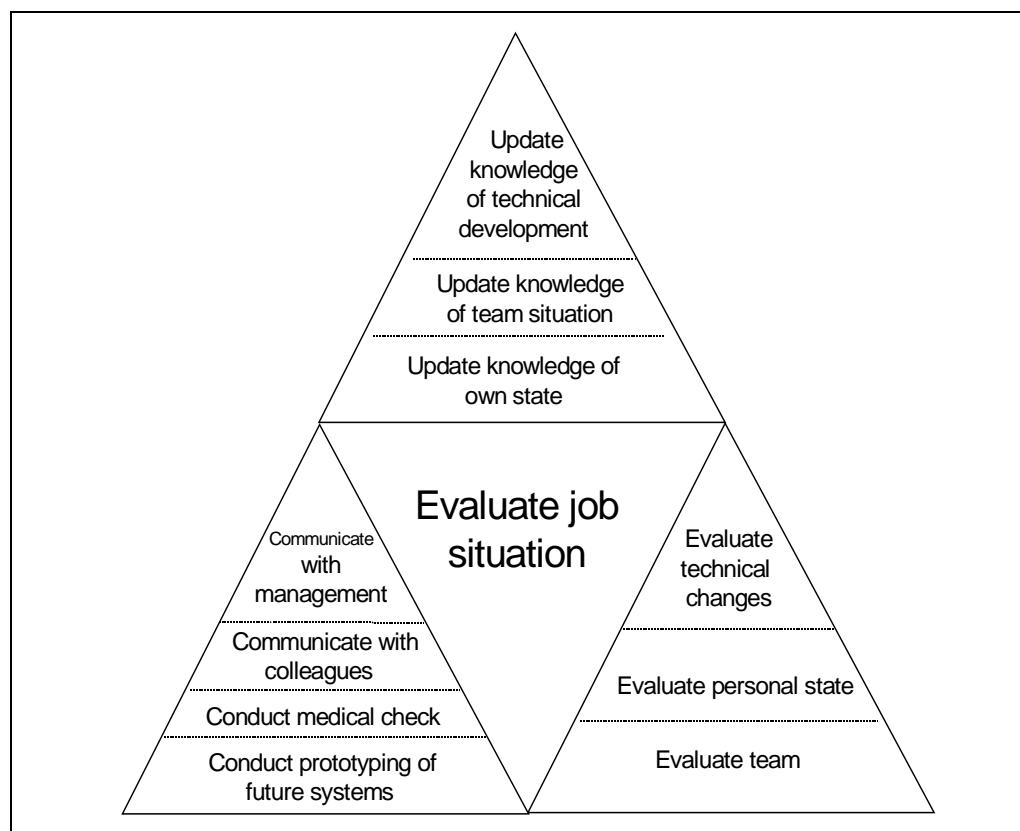


Figure 4b: Evaluate job situation

7.2.4

Conducting Operational Shiftwork

The job element 'conduct operational shiftwork' is depicted in Figure 4c.

1. The components of the cognitive/memory aspects are:
 - Updating weather information;
 - Updating the MM of the sector;
 - Updating shift information.
2. The components of the behavioural and sensori-motor aspects are:
 - Receiving briefing;
 - Conducting the duty-period activities;
 - Conducting the rest-period activities;
 - Communicating with the watch manager and team members.
3. The components of the evaluative and decision-making aspects are:
 - Evaluating the actual workload;
 - Evaluating the team situation;
 - Evaluating one's own capacity to cope with the actual workload.

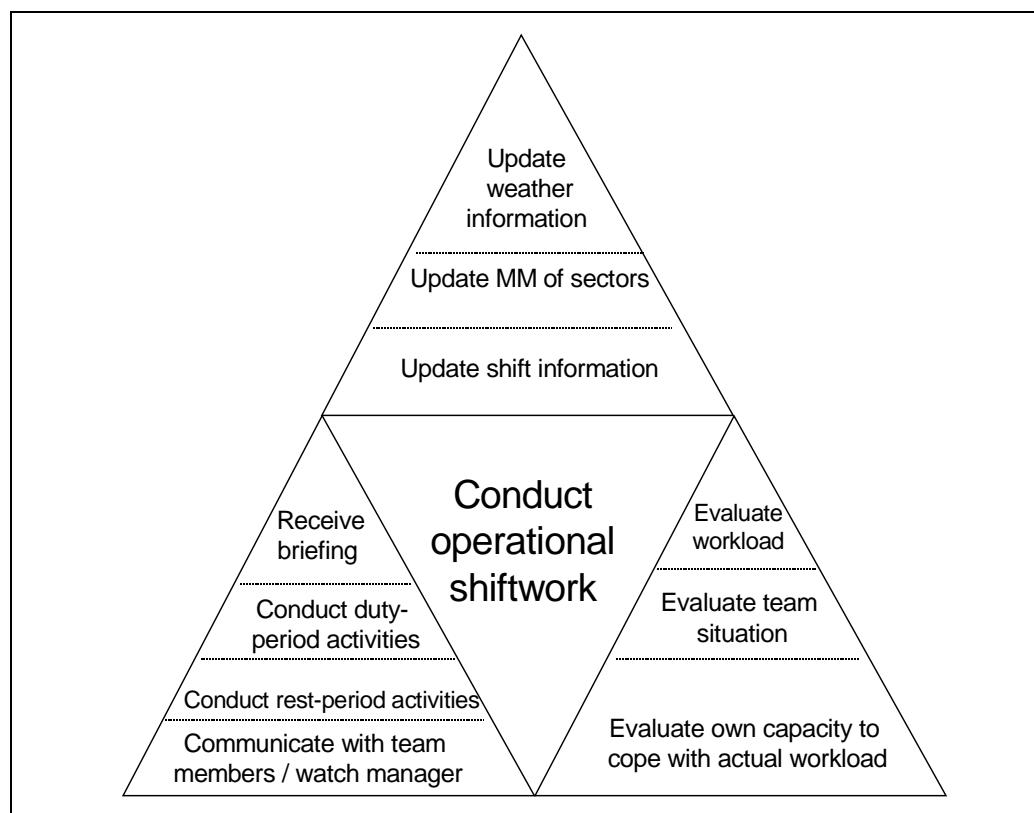


Figure 4c: Conduct operational shiftwork

In order to sum up the results for the en-route controllers' job, one has to conclude that conducting duty-period activities is the central job element even if not the only relevant one. The ATCOs also have to attend team meetings and conduct certain activities in the area of recreation.

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8. PROCESS ANALYSIS OF THE EN-ROUTE CONTROLLERS' TASKS

8.1 Introduction

The processes of the en-route controllers' tasks are presented in two different ways: in Sub-Chapters 8.2 to 8.6 the most frequent activities of en-route controllers are depicted in flowcharts, including cognitive, evaluative and observable activities. In Sub-Chapter 8.7 the most important cognitive processes are provided as verbal descriptions.

The differentiation was made for the following two reasons:

- Flowcharts provide a clearer arrangement, simplify the processes and help to give an overall view of the several processes.
- From the interview data quite a lot of verbal descriptions of the processes of the ATC tasks were obtained. Since these descriptions are an easy, understandable and lively way to show how en-route control works from the en-route controllers' point of view, they should not be given up in favour of a more abstract means of presentation like flowcharts.

8.2 Graphical Representation of the Processes

A classical flowchart approach is used to present the core processes of the ATC tasks. The symbols used for the flowcharts are depicted in Table 4.

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

Table 4: Symbols and notation used in the flowcharts

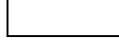
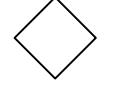
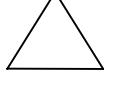
	Action field/activity
	Optional action field; skipped under certain conditions
	Decision field
	Named task process or sub-process
	Simultaneous action/activity

Table 4: Symbols and notation used in the flowcharts (continued)

	Start: indicates start of process
	Exit: return to another process
	And/or junction
	Comment
	Time buffer

8.3

The Basic Processes of En-route Control

In EATCHIP (1997) a summary of the basic processes was provided. 'Monitoring', 'controlling', 'checking', 'diagnosing' and 'problem-solving' were hierarchically interrelated as per the idea of basic Anticipation-Action-Comparison loops (AAC loops) and the different possibilities of fit according to the en-route controllers' expectations. This hierarchical sequence of cognitive processes is a theoretical prototype which has to be specified according to the complex interrelations of cognitive and behavioural processes of tactical en-route control. With respect to the results of our observations, the process descriptions from the interviews and the Flight Progress Strips (FPSs) reconstruction analysis, the prototypical global loop of the cognitive model has to be broken down into sub-processes and to be extended. **Table 5** shows that the basic processes of the model of the cognitive aspects of ATC are still represented in the task processes. 'Diagnosing' and 'problem-solving' are hidden in the 'confirming/updating Mental Picture (MP)' sub-process and the 'solving conflicts' task process. The control process of 'switching attention' had to be introduced to account for the fact that multiple tasks have to be handled by en-route controllers as soon as traffic density or traffic complexity increases. This function of the Process Control System (PCS) was not included in the basic process components of the model.

The ten processes are not independent but are illustrated as interrelated processes in the flowcharts. Five are hidden as sub-processes within the more global task processes (see **Table 5**). These are the sub-processes 'updating MP – maintaining Situational Awareness (SA)', 'checking', 'searching conflicts' and 'issuing instructions'. 'Switching attention' in one situation is a sub-process of the 'solving conflicts' and 'managing requests' processes, but in other situations it governs the whole action in the case of multitasking.

Table 5: Basic processes of ATC

Control process 1	Switching attention
Task process 1	Taking over position/building up MP
Task process 2	Monitoring
Task process 3	Managing routine traffic
Task process 4	Managing requests/assisting pilots
Task process 5	Solving conflicts
Sub-process 1	Confirming/updating MP – maintaining Situational Awareness (SA)
Sub-process 2	Checking
Sub-process 3	Searching conflicts/checking safety
Sub-process 4	Issuing instructions

An overview of the interrelations of the processes is given in [Figure 5](#). The arrows show these interrelations. The 'switching attention' control process has an open exit saying 'go to task of higher priority'. For clarity, the frequently used sub-processes 'confirming/updating MP', 'checking', 'issuing instructions' and 'searching conflicts' are omitted in [Figure 5](#). The interrelation of these sub-processes is given in [Figure 6](#). 'Confirming/updating MP' is the most elementary sub-process and which is part of all other sub-processes. 'Checking' is a second sub-process which is an element of 'searching conflicts/ checking safety' and 'issuing instructions'.

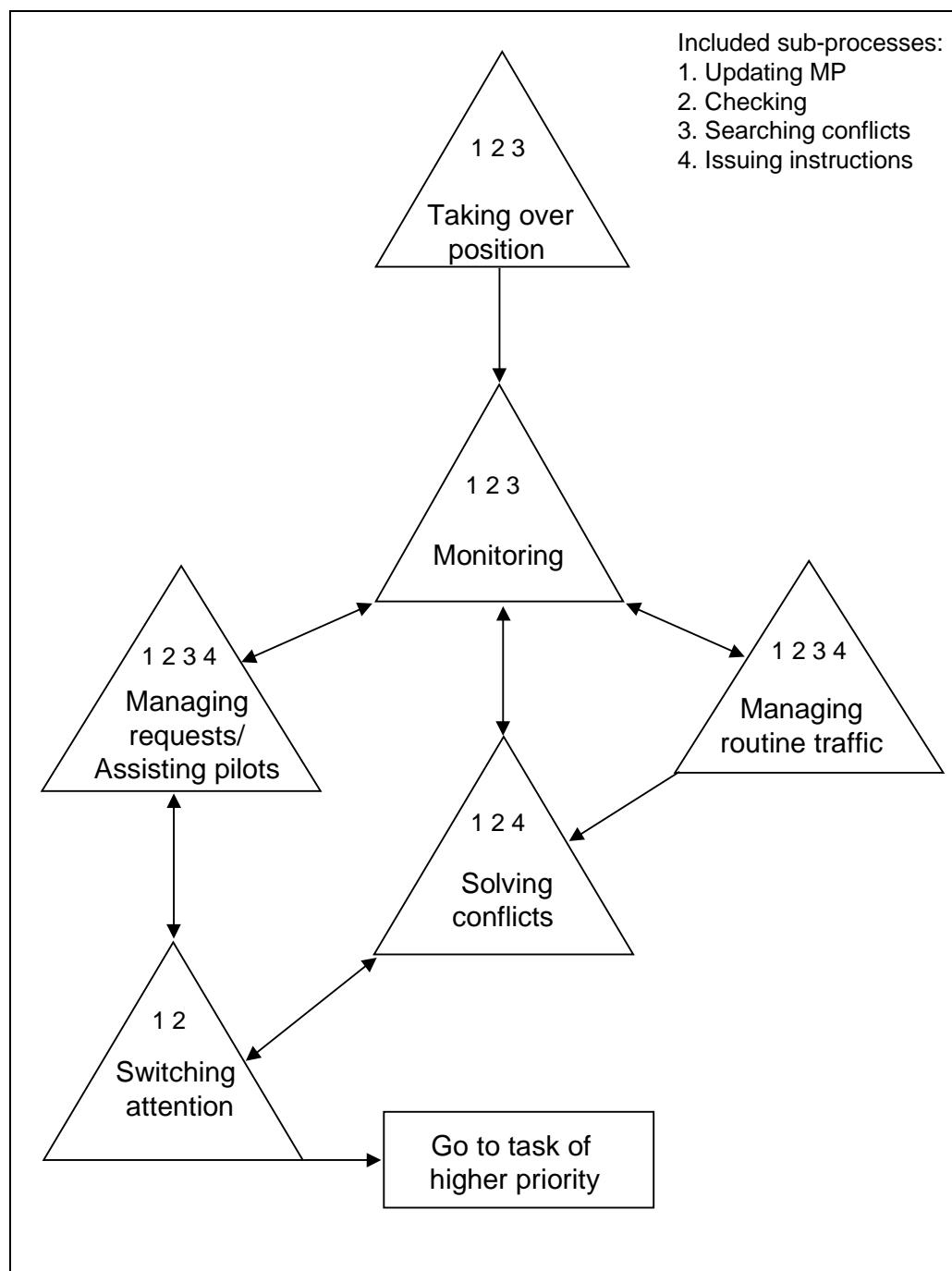


Figure 5: The interrelations of task processes

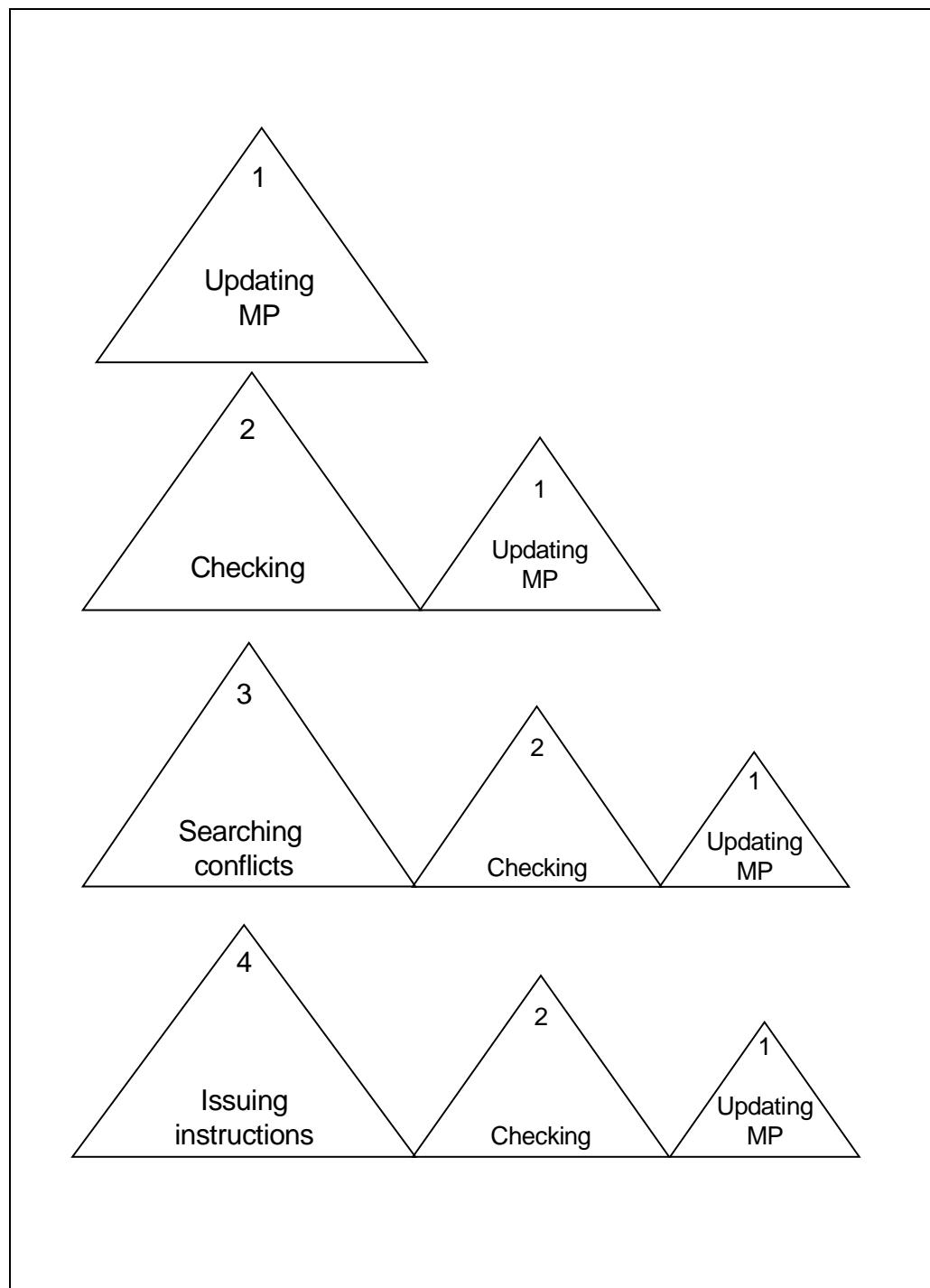


Figure 6: Sub-processes of en-route ATC

8.3.1

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

According to [Figure 7](#), the 'taking over position' process starts with a pre-shift briefing. The pre-shift briefing is not compulsory: if the en-route controllers have been working on a regular cycle and there has not been any major change since their last shift, it may be skipped.

The en-route controllers walk up to the position. While they are doing this, they already recall the sector peculiarities regarding the actual conditions such as traffic density and weather.

Most en-route controllers first check the radar, then the Flight Progress Strips (FPSs). Shortly afterwards they are briefed by the previous en-route controllers. In high density traffic situations it may happen that they have to monitor the ongoing action for a while before the previous en-route controllers have the time to brief them. By first checking and integrating the actual information into their Mental Model (MM) they establish the Mental Picture (MP) and the first inferences about the previous en-route controllers' sector plan.

The next step is to anticipate or predict the future traffic development, including a first check for conflicts. If there is no conflict expected a sector plan is established, the MP is updated again and the en-route controllers evaluate the situation as safe; they 'feel happy' and take over the position.

If conflicts have to be solved en-route controllers normally adopt the previous controllers' plan and take over. As soon as the active controllers find time they develop their own sector plan and switch to their personal way of handling the traffic.

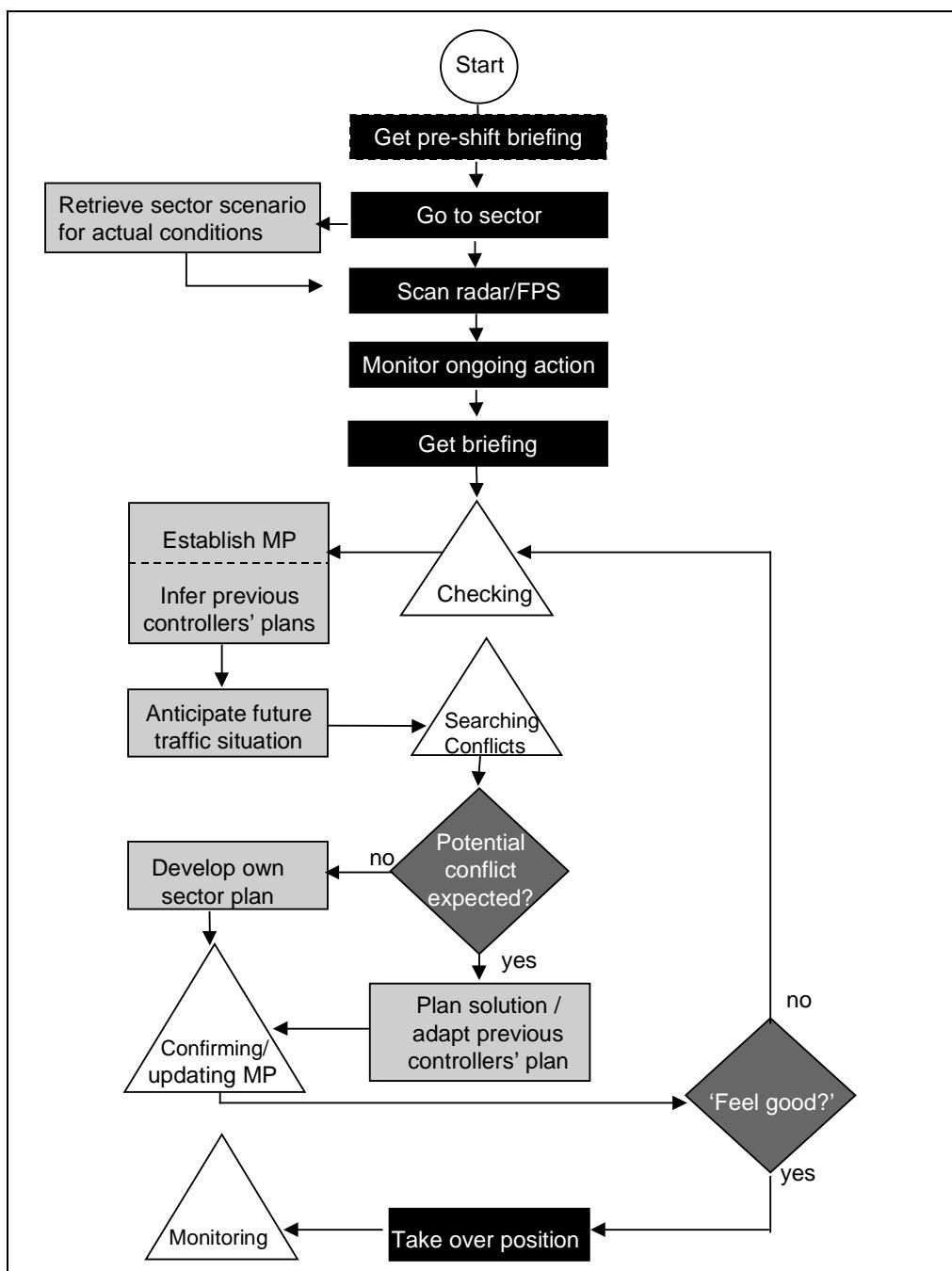


Figure 7: Task process 1: taking over position/building up MP

8.3.2

Task Process 2: Monitoring

The 'monitoring' process (see Figure 8) is closely related to routine traffic management and is constantly repeated while en-route controllers are working on position. It starts with an update of the MP and a conflict search. When the MP is confirmed the en-route controllers update their sector plan and, at the same time, particularly under high workload conditions, they check their action hierarchy, i.e. what the next most urgent things to do are.

If it is necessary to take some 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 controllers receive a request the 'managing requests/ assisting pilots' task process is run;
- Otherwise the 'managing routine traffic' task process is activated.

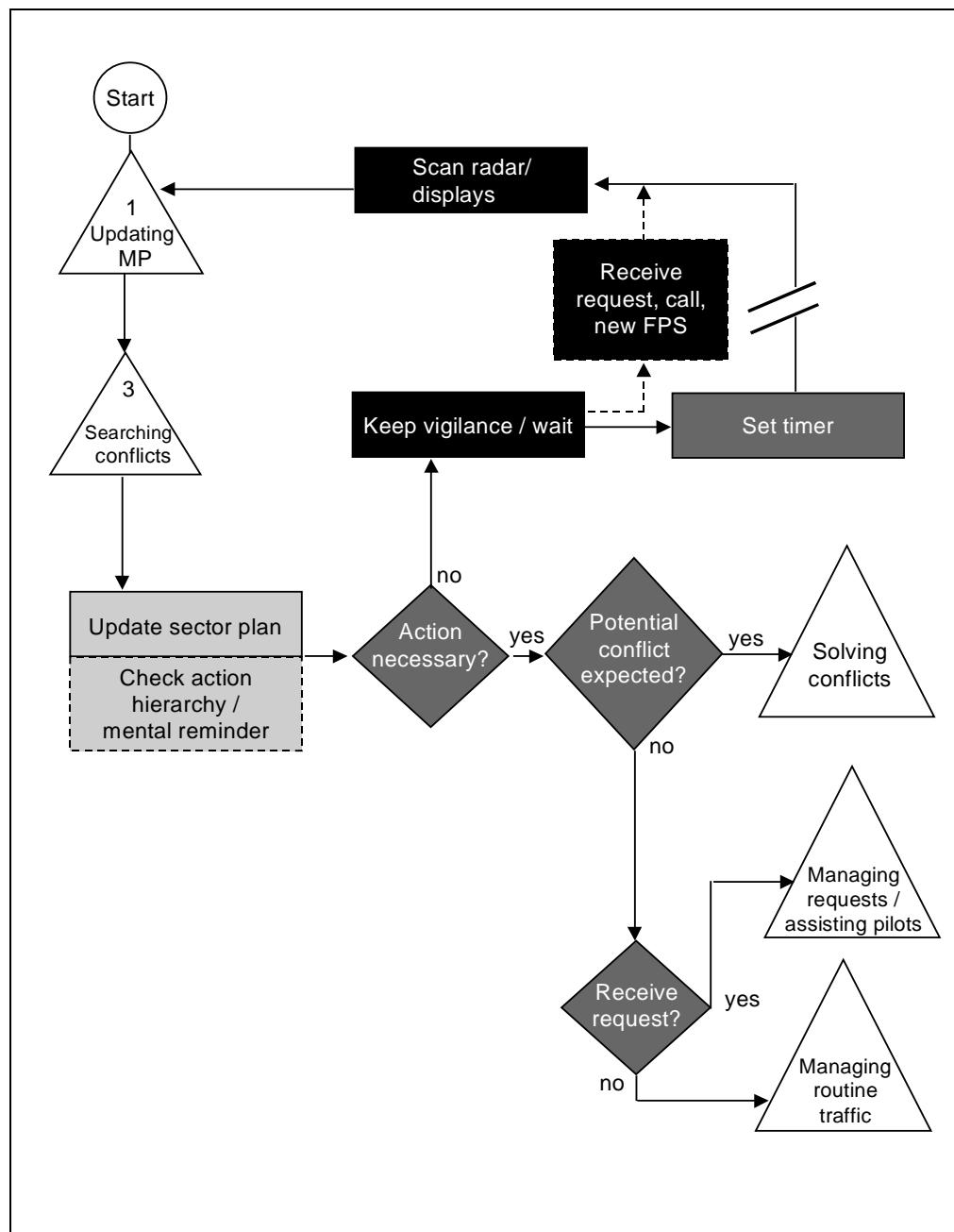


Figure 8: Task process 2: monitoring

If there is no action required and there are no new inputs like requests, calls or new FPSs, en-route controllers have to wait for things to happen. This situation is found in low traffic periods; although there is suddenly nothing to do they still have to keep their vigilance. In such a context they often pursue side activities such as reading a paper or chatting with their colleagues. From time to time they have to switch back their attention to the radar screen in order to update their MP and redo the 'monitoring' task process. This switching back seems to be governed by a kind of unconscious/highly-automated timer set by en-route controllers when turning their attention away from the task. The switching back of their attention is immediately triggered when they receive new inputs such as requests, calls or new FPSs, symbolised by the independent action field.

This period of waiting, vigilance keeping and distracted attention can be a major source of error. Most en-route controllers report that, in low traffic periods when activity decreases and attention drops or is distracted, mistakes are more likely to occur, especially if a low traffic period follows a high traffic episode.

8.3.3 Task Process 3: Managing Routine Traffic

Figure 9 describes the management of routine traffic, including the following cognitive sub-processes: 'checking', 'searching conflicts' and 'issuing instructions'.

Standard management of routine traffic takes place as long as normal calls from pilots and flight progress information come in. The cognitive sub-processes of 'checking' and 'searching conflicts' determine whether en-route controllers have to continue their monitoring or solve a potential conflict.

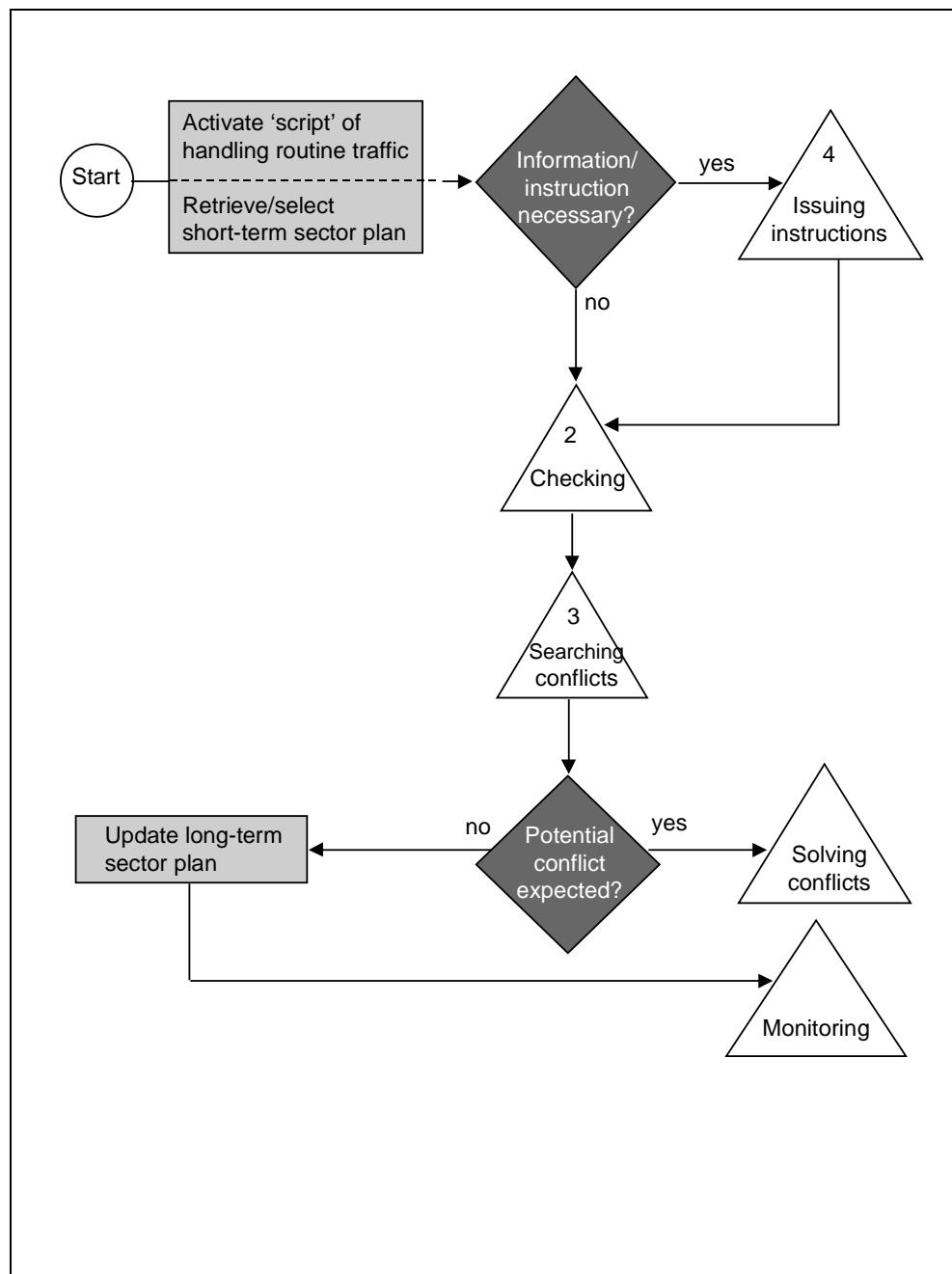


Figure 9: Task process 3: managing routine traffic

8.3.4

Task Process 4: Managing Requests/Assisting Pilots

Additional decisions (see Figure 10) take place in the case of pilots' requests. Based on the current MP and sector plan the alternatives have to be evaluated regarding the criteria of safety, own workload and workload of the adjacent controllers. If the current workload is high the en-route controllers usually deny requests (e.g. for direct routing) in order not to relieve the load

on themselves or their colleagues. If workload is moderate, 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 there is enough time available, alternative plans may be co-ordinated. In this case, even in routine traffic management, attentional switches have to be performed. As soon as there is a decision made about the request the 'issuing instructions' sub-process is activated. The 'managing requests' process ends by returning to the 'monitoring' process.

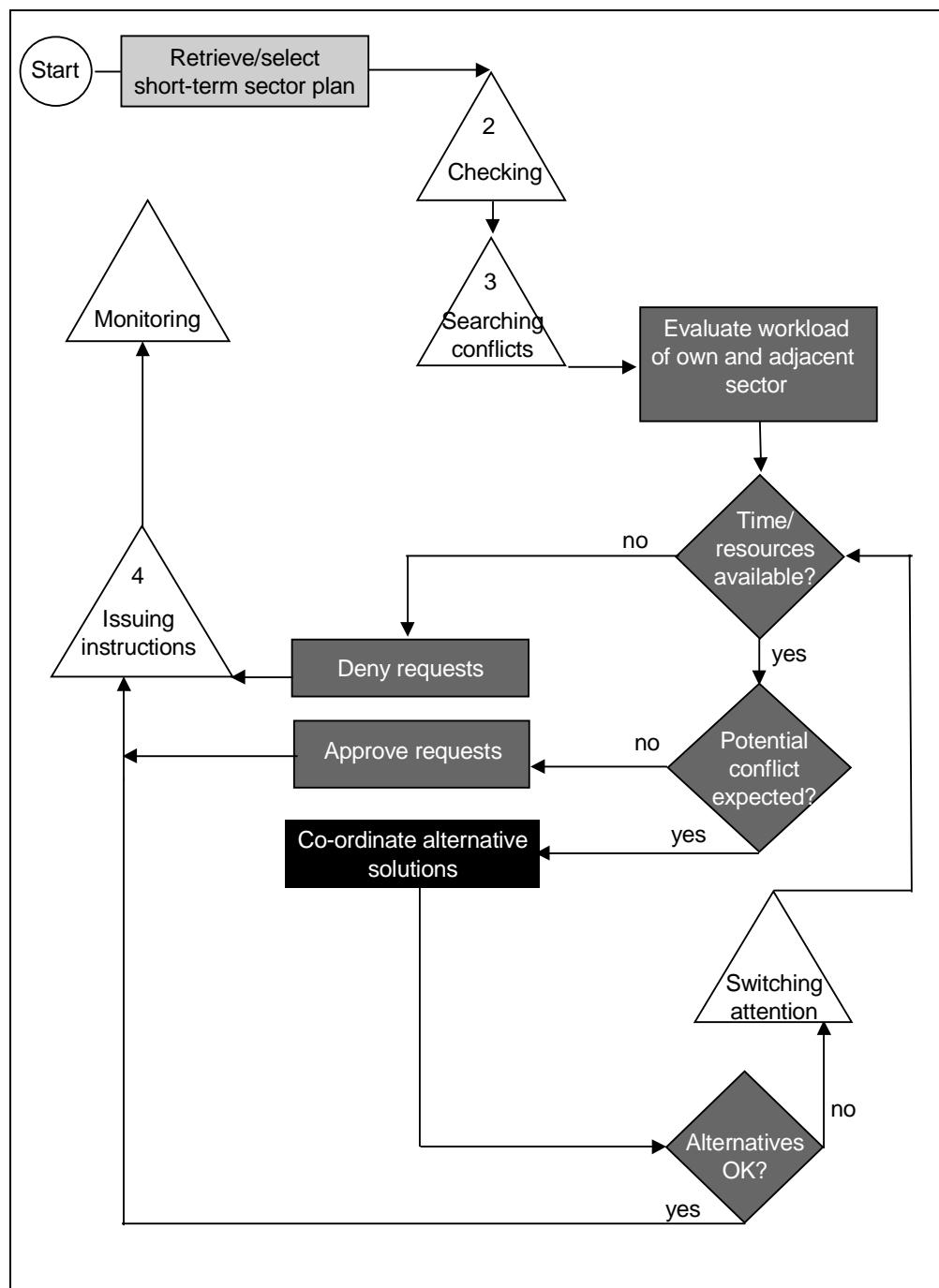


Figure 10: Task process 4: managing requests/assisting pilots

8.3.5

Task Process 5: Solving Conflicts

The 'solving conflicts' process (see [Figure 11](#)) starts when a potential conflict is expected. The en-route controllers have to decide if they are going to act on the conflict right away or 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, which is symbolised by the 'switching attention' process.

When they decide to act on the conflict they must try to retrieve an instant solution from their experience-based episodic memory. According to an en-route controller's statement during the interview, it is called a 'conflict solution library'. Since the most common and frequently used solutions are thought of first, one can also call them 'routine solutions'. This process can be disturbed if the en-route controllers need to switch their attention to another task or problem, for instance when they receive calls.

The retrieved solutions also have to be evaluated, taking the current situational conditions into account. If routine solutions cannot be applied or are regarded as unsatisfactory, the en-route controllers have to review their conflict solution library for more uncommon solutions or switch to knowledge-based problem-solving. Once they have found the best solution they have to co-ordinate with a colleague if necessary.

Before the en-route controllers actually issue the instruction to the pilots, they may have to switch attention to a task of higher priority. After issuing and checking the instruction represented by an 'issuing instructions' sub-process, a decision point is reached. If the problem or conflict is finally solved, the MP is updated and the en-route controllers turn to the next problem, starting the 'solving conflicts' process again or switching back to monitoring. If the problem is not solved by their action, they have to retrieve their backup plan. A backup plan is usually characterised by being safe but not efficient. This is why, if there is some time available, the en-route controllers try to find another solution in addition to the backup plan. If there is no time left they implement the backup plan and go on with the 'issuing instructions' sub-process again.

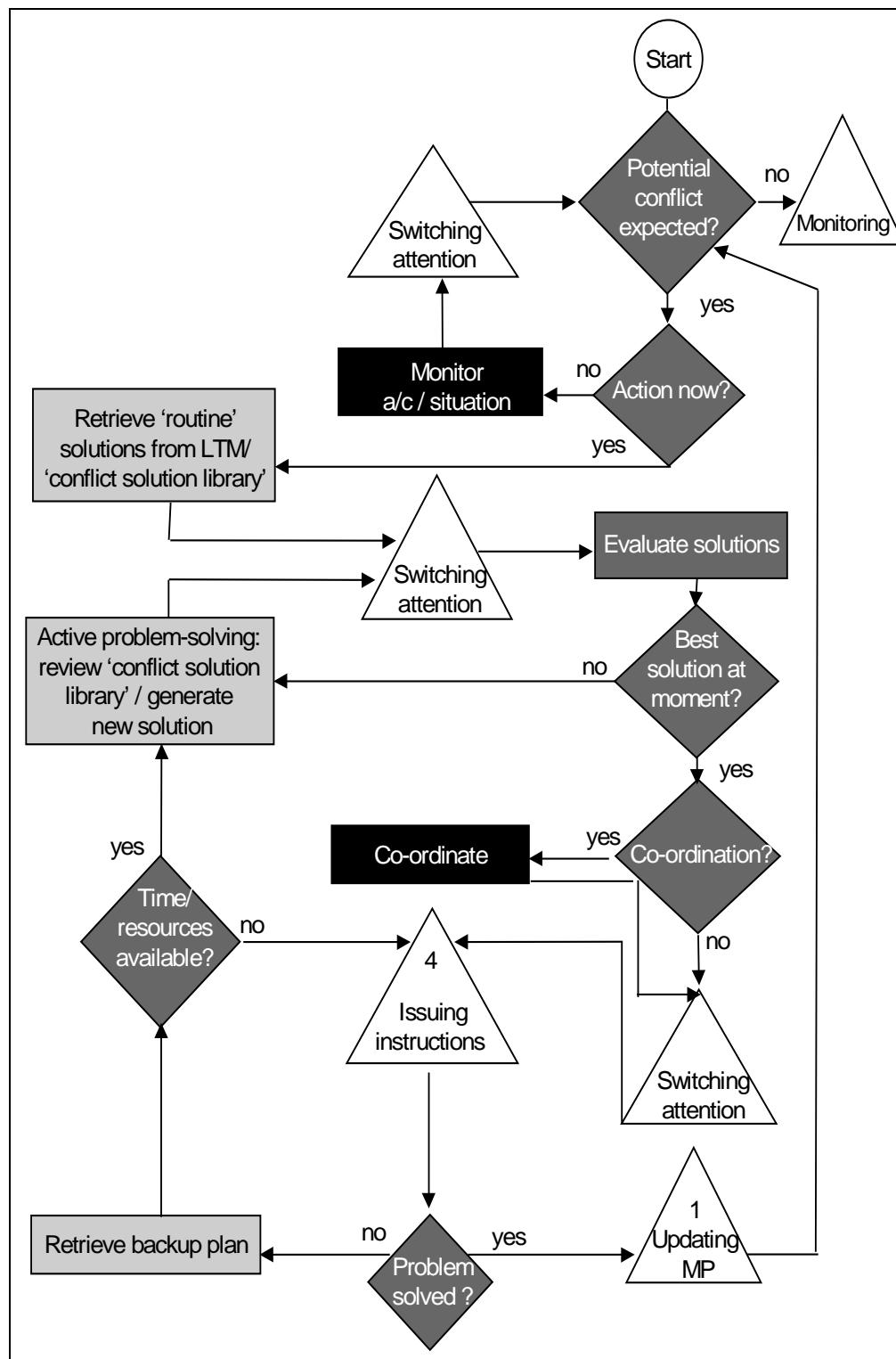


Figure 11: Task process 5: solving conflicts

8.4 Sub-processes of Air Traffic Control

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

The process of 'maintaining Situational Awareness (SA)' 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. The process, starting with the MP, is represented in Figure 12.

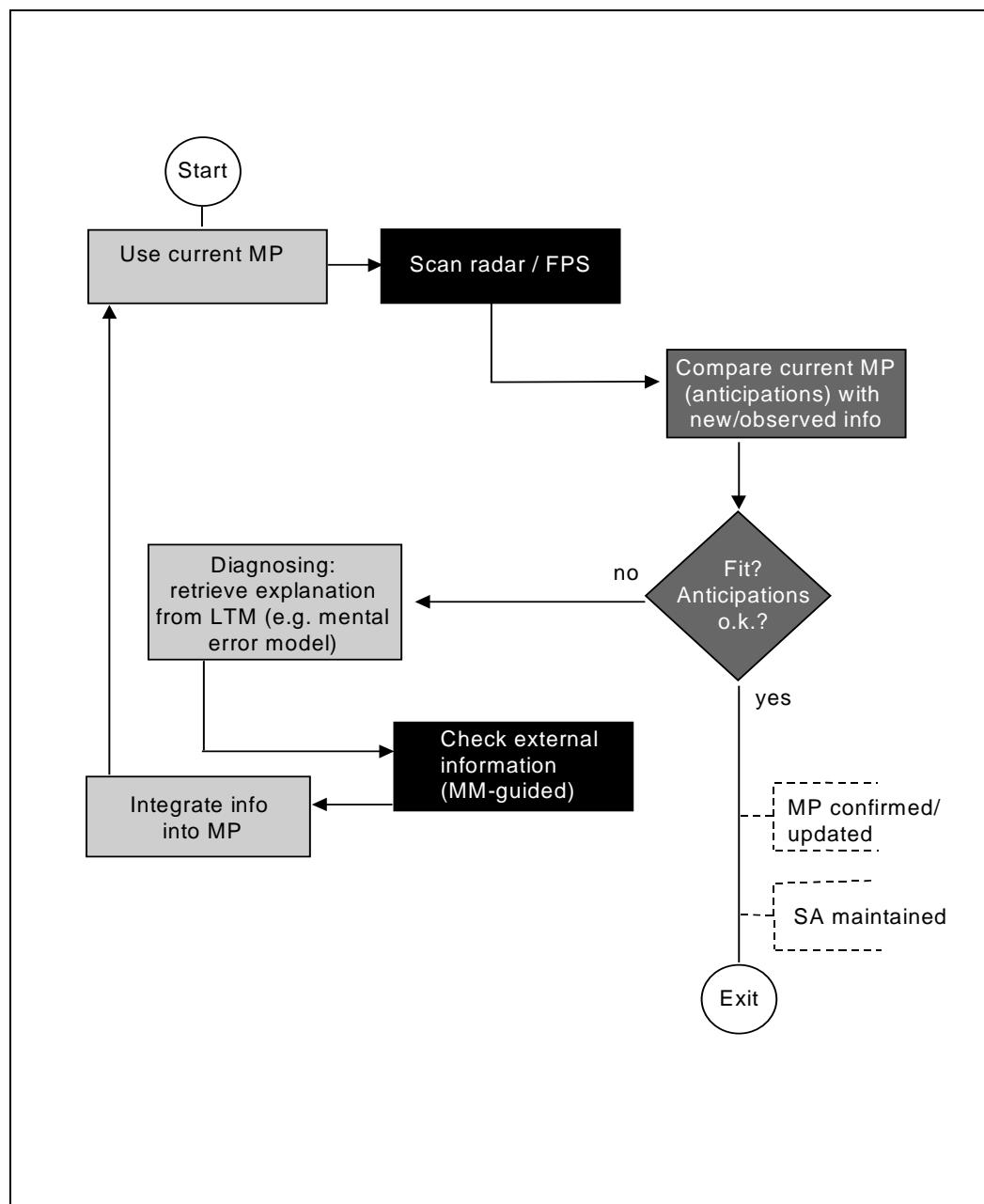


Figure 12: Sub-process 1: confirming/updating MP - maintaining SA

Normally the en-route controllers' anticipations come true, which confirms that the MP and their SA are maintained. In those cases in which the MP and the actual situation do not fit beyond the en-route controllers' mismatch tolerance, the en-route controllers try to find an explanation (diagnosing). The MM of the sector and similar situations are normally used for that purpose. Repeated mismatches between the en-route controllers' expectations and the actual situation can lead to building up an erroneous MM, for instance diagnosing an unidentified blip on the radar screen as a radar reflection after having experienced this several times. Erroneous MMs can be sources of error when they are not recognised as such, for instance when the unidentified blip is not a radar reflection but an unidentified aircraft (a/c). The diagnosis of a mismatch normally includes the active check of external information that has to be integrated into the MP.

8.4.2 Sub-process 2: Checking

Checking (see [Figure 13](#)) is the second central sub-process based on the cognitive process of checking as described in EATCHIP (1997).

When the en-route controllers conduct the checking they deliberately direct their attention to external information sources like the radar screen, the FPSs, certain information displays, reminders they have set, or they may ask for particular information. This information check is triggered when the en-route controllers receive new or unexpected information or by the en-route controllers' suspicion or presumption that perhaps something is not going the expected or planned way.

After a deliberate check for information the MP is confirmed or updated.

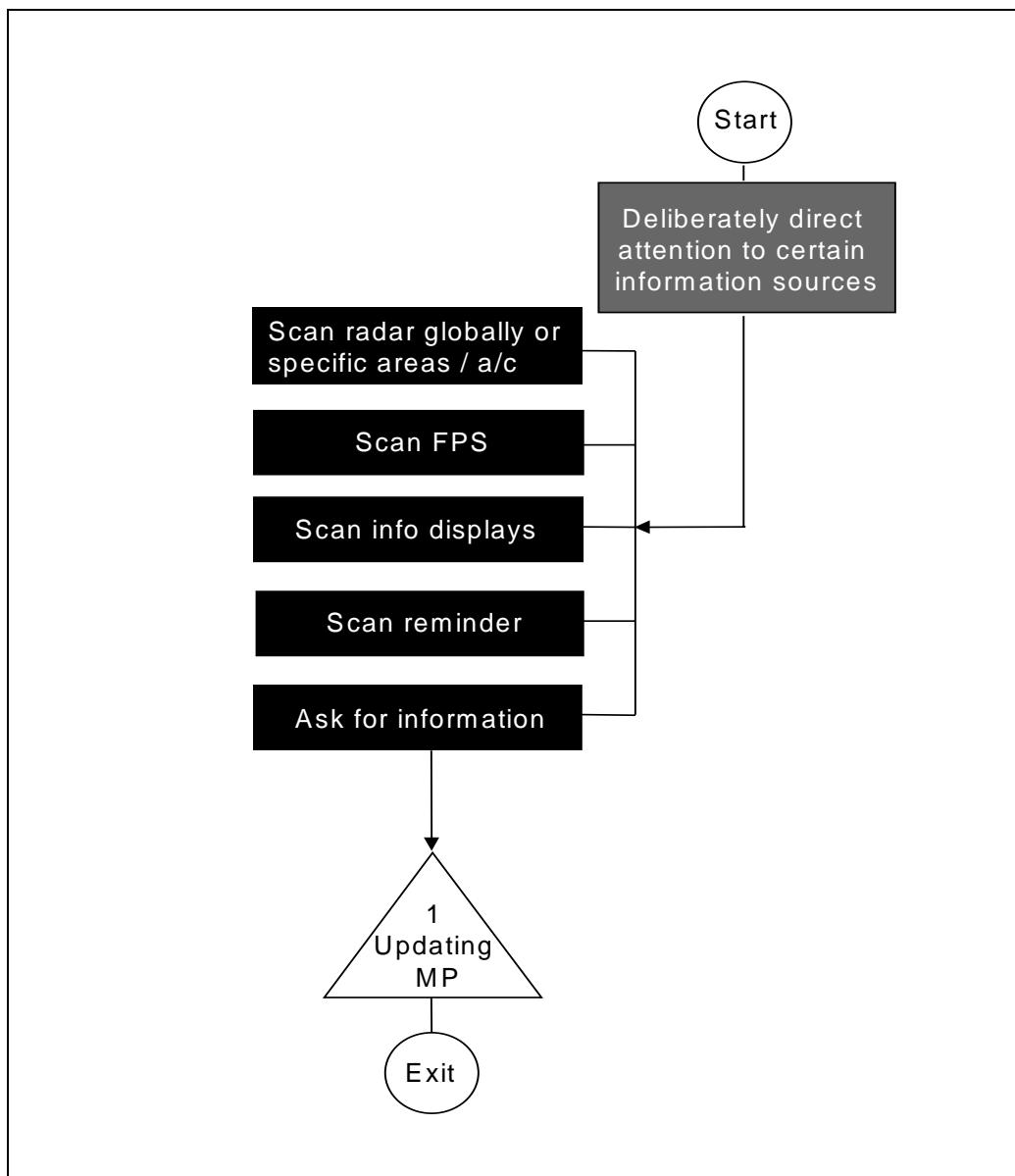


Figure 13: Sub-process 2: checking

8.4.3

Sub-process 3: Searching Conflicts/Checking Safety

Detecting conflicts is another cognitive core task of en-route controllers and it is depicted in [Figure 14](#). The conflict search starts with the en-route controllers receiving external information, e.g. by monitoring a/c 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: the level, route, time estimates and speed of the a/c. By doing this checking they retrieve other, possibly conflicting a/c including their relevant data. This is not a random process but rather a process guided by the en-route controllers' MM, since they usually know where in the sector conflicts are more likely to

occur. This is termed the 'conflict possibility library'. For a more fine-grained assessment radar tools are used. The data of the a/c are mentally integrated and the future development is anticipated or predicted: the en-route controllers estimate whether the a/c are going to conflict or not. This is followed by an update of the MP.

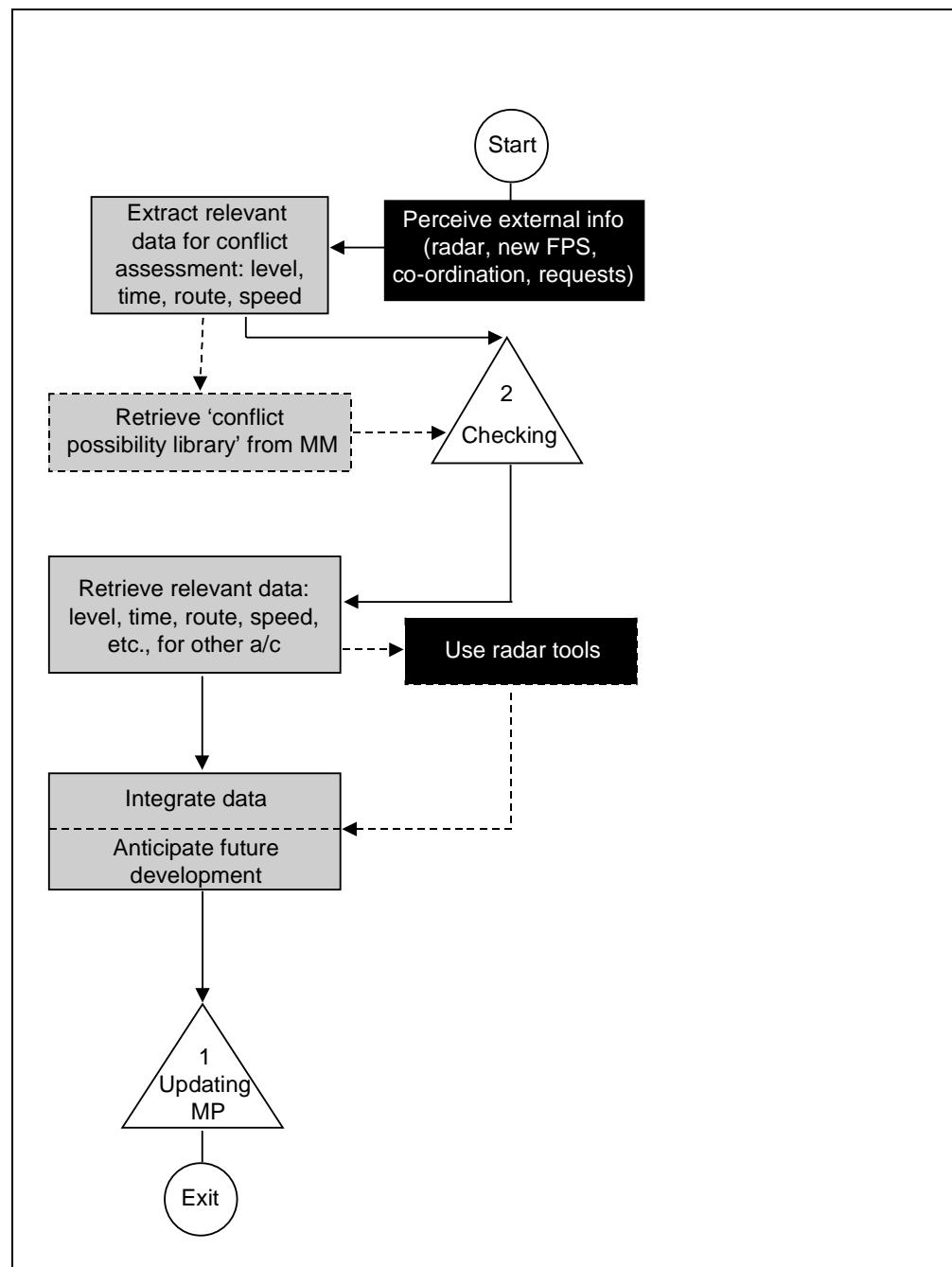


Figure 14: Sub-process 3: searching conflicts/checking safety

8.4.4

Sub-process 4: Issuing Instructions

Issuing an instruction is one of the most common actions of en-route controllers. The 'issuing instructions' sub-process depicted in [Figure 15](#) is always activated if instructing or informing pilots is necessary in a given time frame. Accordingly, timing is the most important decision function of the 'issuing instructions' sub-process. The instruction or information is governed by the MP, the short-term sector plan and a cognitive script of the control action. This script is highly automated and normally subconscious. Monitoring the readback and the expected changes are fixed elements of the 'issuing instructions' sub-process. Usually, the en-route controllers do a brief checking after each instruction. If the pilots do not follow the instructions properly or do not receive the given information the en-route controllers evaluate the consequences of the deviation or failure regarding safety and the plan. If the deviation is safety critical or 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 controllers leave the 'issuing instructions' sub-process and return to the task process. Sometimes several routine instructions, for instance handing over a/c to the next sector, are given in one block or sequence. In this case the en-route controllers repeat the 'issuing instructions' sub-process several times before returning to the task process.

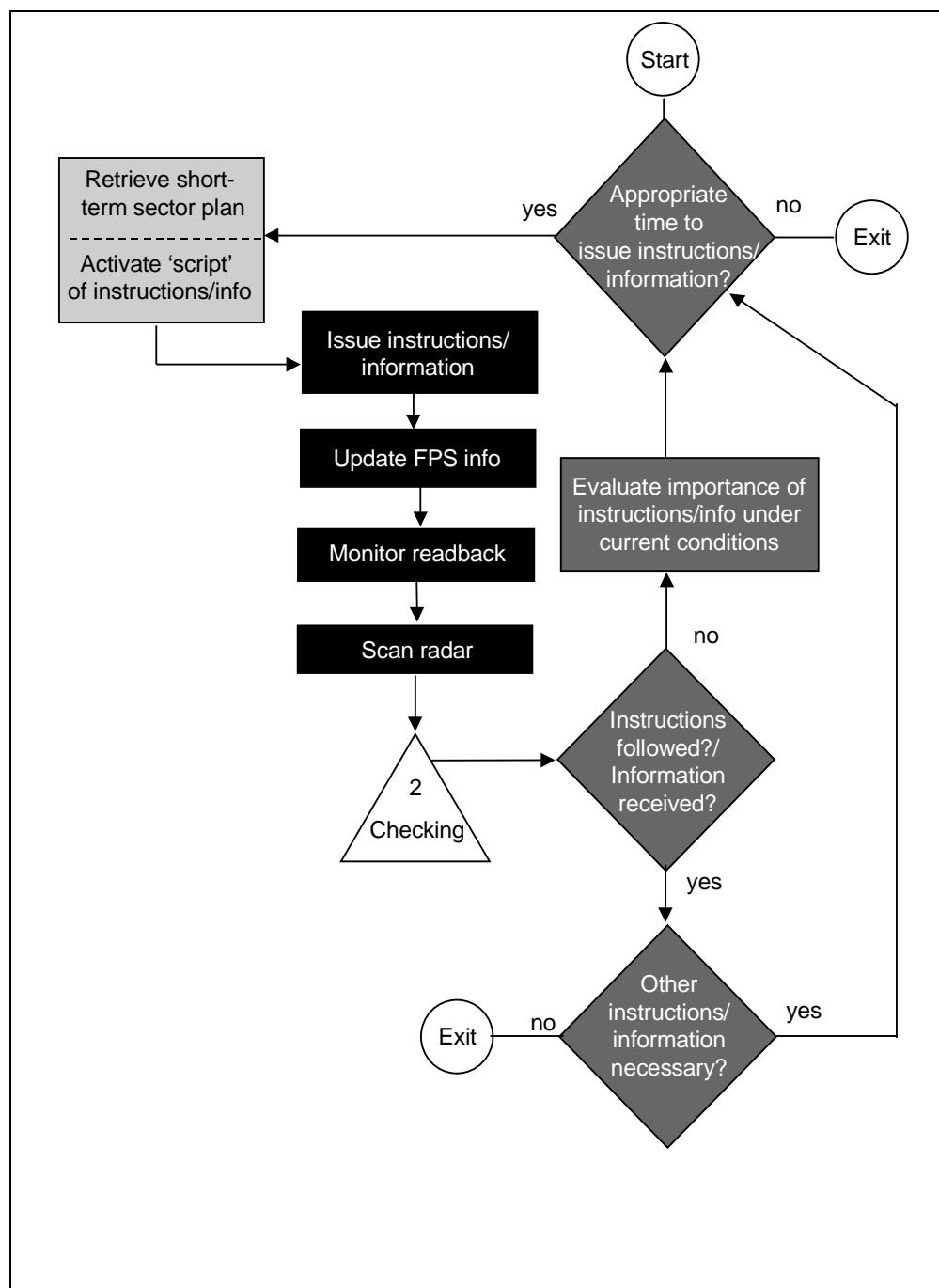


Figure 15: Sub-process 4: issuing instructions

8.5

Control Process: Switching Attention

This process takes into account those aspects of multitasking in which several tasks are carried out by alternate switching of attention. If a given task requires heavy attentional resources, attention has to 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, RadioTelephony (R/T) communication) increases, as does the number of potential conflicts. Solving a conflict is a task that requires heavy attentional resources and, therefore, in situations where several conflicts have to be solved, attention has to be switched almost all the time. This is also why 'switching attention' is a very important process in conflict resolution. En-route controllers actively try to avoid too many pending tasks. They state that, especially in high workload conditions, they follow a fixed sequence of (part-)tasks, which allows them to deliberately do one thing after the other. This requires an adaptable and sound anticipatory sector plan.

The process (see [Figure 16](#)) starts with reviewing the sector plan or action hierarchy. Based on the current MP the en-route controllers check and assess whether there is a task of higher priority than the high-priority task being undertaken (e.g. monitoring a potential conflict in the 'solving conflicts' task process). If the result is negative the controllers focus on the current task or activity and exit the 'switching attention' process. In this case this process is just a check for higher priorities.

If there is a task of higher priority the en-route controllers unconsciously set a 'time window' and integrate it into the sector plan. In the mind they do an update of the action hierarchy and, in order to ensure that they return to the unfinished previous task, they may set a reminder, for instance flag an FPS. Then there is a switch to the task of higher priority. Within the 'time window' they fade out the other tasks while they focus on the task of highest priority. As long as the 'time window' is not exceeded, the en-route controllers focus on this task of highest priority. At the end of the 'time window' a 'checking' sub-process is undertaken. In case the task of highest priority is highly automated and of predictable length (e.g. answering pilots' first call), there may be no need to monitor the time window. At the end of such a task the en-route controllers directly switch to the 'checking' sub-process.

If the task of highest priority has been completed the en-route controllers review their action hierarchy, checking again, then come back to the assessment of whether there is a task of higher priority than the current task. If there is they repeat the 'switching attention' process. If there is not they return to the task process.

If the task of highest priority is not finished at the end of the time window the en-route controllers set a mental or visible reminder, and update and review the action hierarchy. After undertaking another check they come back to the assessment of whether there is a task of higher priority than the current task process activity. This can be, depending on their action hierarchy, a new task or the previous unfinished task. If they consider the previous unfinished task is of highest priority they repeat the sub-process by setting a new time window. If a new task is considered the highest priority they open up a new time window, keeping an open or unfinished task in mind.

One can see that, in the case of unfinished tasks of higher priority, the 'switching attention' process cannot be left. This means the en-route controllers are caught in tasks of higher priority and there is a risk they may

not come back to the unfinished previous task. In such a situation there is always a risk that the en-route controllers forget something important. This risk increases the more often the en-route controllers quit an unfinished task in favour of a task that to them seems to be of higher priority. Especially for students or inexperienced en-route controllers this can be a major source of error. A high risk of Working Memory (WM) overload arises from this situation.

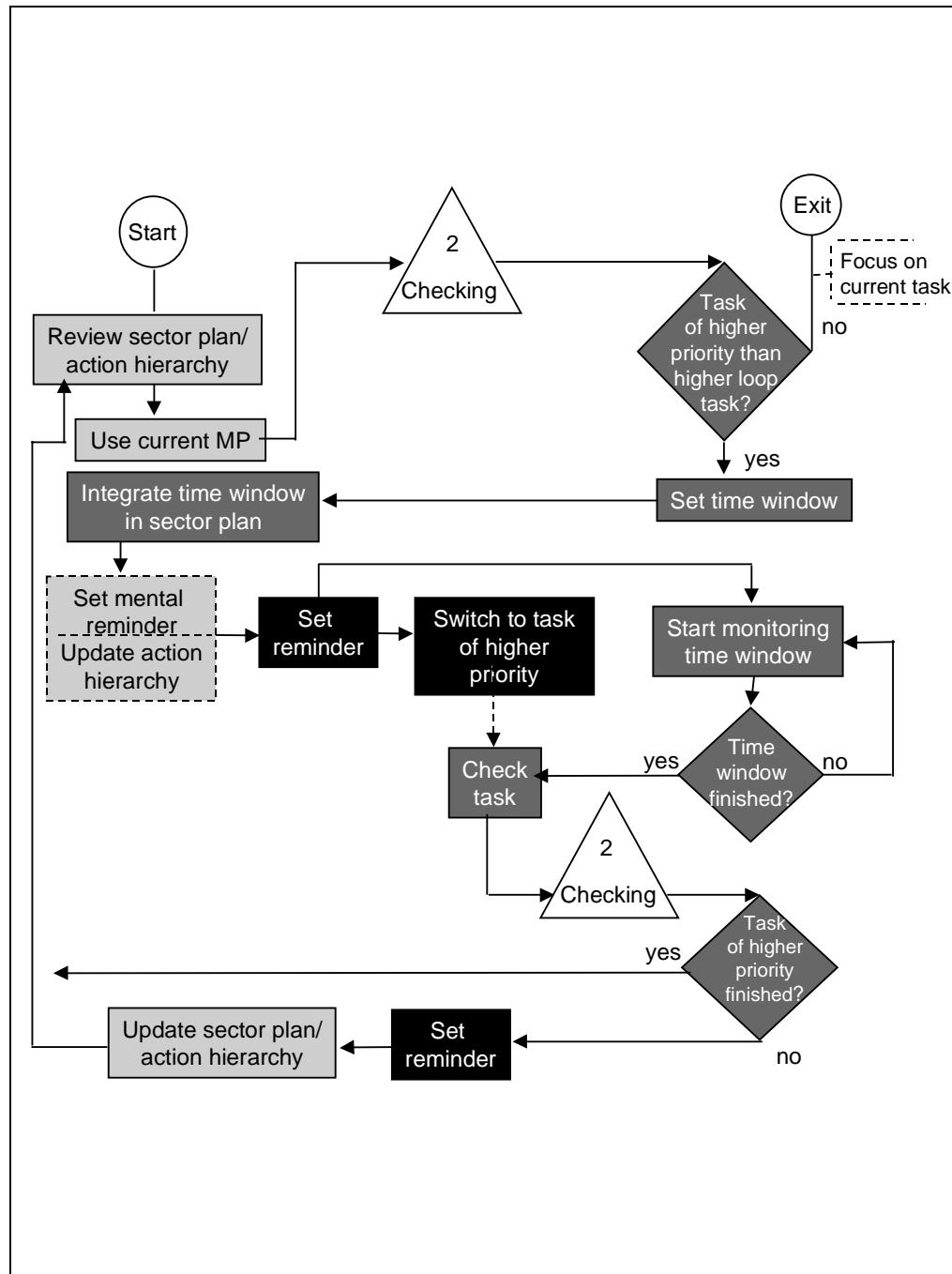


Figure 16: Control process 1: switching attention

8.6 Additional Process Elements

8.6.1 Situational Conditions

The several processes of en-route control are heavily dependent on the actual conditions. First of all, different traffic conditions play an important role. The team organisation and the presence of planners determine which loops have to be conducted by the radar controllers and which loops have to be covered by the planners. In this case it is necessary that good communication is established between planners and radar controllers.

From the flight progress reconstruction of the observed periods one can look closely at all the non-usual conditions or non-standard traffic conditions which occurred. At the same time the different conflict solutions illustrate the conflict solution library of the en-route controllers. A brief taxonomy of the types of non-routine situations is given below, which shows that many non-typical or non-routine situations are due to crossing traffic with different complexities:

- crossing a/c same level,
- a/c complex crossing,
- a/c crossing with vertical movement,
- a/c crossing (unspecified),
- pilots' requests,
- adjacent sectors' requests,
- a/c unusual routing,
- special situations (e.g. unexpected a/c),
- communication problems,
- climb/descend situations,
- a/c with inadequate speed,
- monitoring potential conflicts,
- technical problems.

As already pointed out in the 'solving conflicts' process, the crossings without traffic climb and descent are much easier to handle than those including climb and descent. The second category of situations can be termed 'pilots' requests and unusual routings'. The next category concerns communication problems and a further category deals with climbing and descending traffic. For en-route controllers a frequent problem is a/c with inadequate speed which need to be reorganised. The 'managing requests/assisting pilots' process already pointed out that there are several situations that can be termed 'potential conflicts'. Adjacent sector requests and technical problems make up the final categories.

8.6.2 En-route Controllers' Actions

The concrete actions of en-route controllers in non-routine situations can be placed into the categories shown below.

- monitoring/preplanning,
- levelling,
- levelling and turning,
- turning/giving routing,
- speed instructions,
- direct routing,
- levelling with timing,
- co-ordination with other sectors,
- multiple actions,
- diagnosing (calling and checking situation).

These different situations were not randomly distributed across all observed sectors. Unusual routings and communication problems as well as a/c with inadequate speed were the main problems encountered in one of the centres. Certain sectors in the units were often concerned with climbing and descending a/c. In some sectors a high proportion of problems was solved by direct routings or speed instructions. In summary, monitoring and levelling the a/c seem to be important strategies to avoid or resolve conflicts.

8.7 Verbal Descriptions

In summary, the verbal descriptions show a more holistic picture of ATC processes and give additional information which cannot be included in the flowcharts. Verbal descriptions also show the complex interrelations of the different task processes depicted in the flowcharts. The flowcharts, however, are more representative in terms of the overall ATC task, showing the most frequent activities of the task including the routine traffic management and the instruction issuing. The verbal descriptions focus explicitly on the important complex cognitive activities explicitly, ignoring simple activities such as giving a routine instruction.

The topics addressed in the verbal descriptions were:

- building up the MP and taking over/handing over the position,
- maintaining/losing the SA,
- discovering and evaluating the conflicts,
- solving conflicts,
- switching attention in complex traffic situations,
- managing attentional resources.

The most important aspects are summarised at the end of each verbal description.

In order to link the verbal descriptions to the processes depicted in the flowcharts, a brief explanation is given at the end of each verbal description about the processes that are explicitly or implicitly addressed.

8.7.1

Building up Mental Picture and Taking over/Handing over Position

Before the en-route controllers take over the position they may have updated the information received about the general working conditions at the time, e.g. frequencies in operation, changed procedures and agreements with adjacent sectors. It can be written information on an information board or verbal information given by a supervisor during a pre-shift briefing.

Then the en-route controllers walk up to the position they are going to take over. Once they know the position they may already mentally recall the sector peculiarities in order to prepare themselves for the task.

The time needed for the en-route controllers to build up the picture and take over the position depends on the actual traffic load. If it is low to moderate the relieving en-route controllers look at the active FPSs and the radar screen and relate the information from the strips to the a/c on the screen. At this stage they know where the a/c are, where they are going (route) and at what level. Based on their knowledge of traffic flow in the sector, they are already aware of the a/c 'standard movements' (e.g. the East-West flow mainly consists of a/c inbound to Schiphol Airport and they want or need to descend them to a certain point). From experience they also know about critical points in the sector, i.e. where conflicts are likely to occur. They may have already checked these points as their main objective in building up the picture is to identify the conflicts and any problem that may occur, so that they can establish a plan of action.

When briefing their successors the previous en-route controllers on shift particularly focus on any potential conflicts and expected problems, and how they have planned to solve them.

They also inform them on any special or abnormal situations, previous co-ordinations made and special weather conditions in the sector.

Either the relieving en-route controllers adopt the plan of the previous en-route controllers (which is what most en-route controllers do), or they make their own plan if they are not satisfied with the proposed solution.

If there is any specific information on the general sector which is not addressed during the pre-shift briefing, such as active runways of airports in the sector or weather conditions, they also check for such information on the displays or are told by the previous en-route controllers.

The relieving en-route controllers also look at the non-active FPSs to see what traffic they can expect within the next 10-15 minutes. They either recognise potential conflicts by themselves and may be informed by the previous en-route controllers or, if the relieved en-route controllers have already initiated a solution by co-ordinating with the previous sector, the latter pass on this information.

During this verbal briefing the relieving en-route controllers have already plugged in their headset and switched places. If there is anything unclear to

them, they ask for more information from the previous en-route controllers who are then released.

At this point the relieving en-route controllers have legally taken over responsibility. They are 'settled' into the position. Some of them adjust the equipment according to their own habits, such as changing settings on the radar screen or arranging the FPSs. They are ready to take over responsibility, which means that they not only know the traffic situation but also the problems. They should at this stage feel able to predict what is going to happen in their sector within the next few minutes (approximately five minutes, depending on the sector). The controllers' criteria for taking over the position are usually unconscious. En-route controllers report that they take over the position once they feel completely comfortable with the situation, when they know 'what's going on'.

Some en-route controllers report that they usually take over the position without having the complete picture, particularly when traffic density is low. They just need to know potential conflicts and what the next and most urgent actions to do are. Once they are settled down at the position they check the traffic again and start to include more and more details into their picture until they have enlarged their planning horizon to a maximum of about 15-20 minutes. This 'completing phase' takes up to five minutes. In low traffic conditions this procedure roughly takes from half a minute to one minute only. The briefing by the previous en-route controllers is considered less important because the relieving en-route controllers can quickly see whether there is any problem or, from the strips, what clearances were given and what co-ordinations were made. Any peculiarity, nevertheless, is usually reported verbally.

In very busy traffic conditions, with no prospect of traffic load decrease in the next few minutes, the procedure looks slightly different. The en-route controllers in charge do not have the time to brief the relieving en-route controllers whilst they are sitting on the position. Therefore, the relieving en-route controllers stand behind the nearly-relieved en-route controllers still in charge for a few minutes and try to build up the picture by themselves, as described above, listening to the R/T exchange. As soon as they feel that they have the picture they switch places. The previous en-route controllers then stay behind the relieving en-route controllers who have assumed responsibility. They give further information about any special situation (see above description) and monitor the situation for a short while in order to make sure that the relieving en-route controllers have the necessary information to manage the traffic safely. In such a case the handover procedure takes about three to five minutes.

En-route controllers often report that, when they know they are going to be relieved soon, they do a number of preparatory actions before handing over the position to their successors. They often do a 'clean up' of the position such as updating the FPSs, putting away strips of aircraft (a/c) which have already left the sector, handing over early those which are about to leave the sector, and finishing their conflict solution plans and all other urgent things to

be done. These actions are aimed at making it easier for the relieving en-route controllers to build up their picture, get settled before taking action and ensure a safe transition. In very low traffic conditions these preparations are not as important. Alternatively, in peak situations it may be impossible for the en-route controllers in charge to do these preparatory actions. They may ask the relieving en-route controllers to come back a few minutes later because they find it easier, in those particularly busy moments, to manage the traffic themselves rather than handing over the position.

Most Important Aspects

- The time required to build up the MP and take over or hand over the position depends on the actual traffic load.
- Building up the picture consists of updating the Mental Model (MM) of the sector with information about the actual traffic situation. The MM of the sector allows en-route controllers to divide the traffic into action relevant categories such as flights on standard routes, inbound and potential conflicts.
- 'Having the picture' means being able to predict what is going to happen in the sector within the next few minutes, being aware of potential conflicts and having a plan or intention about the next actions. It is a pre-requisite for taking over a position.

8.7.2

Maintaining/Losing Situational Awareness

With reference to the cognitive model, Situational Awareness (SA) results from two main sources:

- One is information about the actual traffic situation and other accompanying situational conditions, such as the en-route controllers' awareness of both their own psycho-physical state of fitness and the abilities and capabilities of their colleagues.
- The other source is the en-route controllers' knowledge of ATC and sector structures. This also includes their personal professional ATC experience. These aspects form the MM en-route controllers have about their job. This model is stored in their long-term memory.

When en-route controllers are working on position, the actual situational conditions are integrated into their MM to form their actual Mental Picture (MP) of the situation. The actual MP of the situation is projected into the future;

en-route controllers always try to anticipate and predict how the traffic situation is going to develop. This anticipation is constantly checked against actual events. If the actual events match the en-route controllers' anticipations, their MP is confirmed. Based on the MP en-route controllers also plan their future actions; for instance they do long-term anticipations. As long as they are successful in achieving these predictions and subsequent

action plans, en-route controllers are said to be maintaining SA.

Maintaining Situational Awareness

In the continuous ATC tasks, SA is maintained by scanning the radar screen and strips constantly. 'Constantly' means that en-route controllers usually do this whenever their attention is not required by other tasks such as instructing a/c, co-ordinating, making an input or any mental problem-solving. One en-route controller described this process as follows: 'Normally, I try to scan the picture, then talk to an a/c, scan the picture, make an input, scan the picture, talk to an a/c and so on. If a problem needs that I talk to a/c one after the other, I do this first and then do the scan.' Scanning is serving a dual purpose: it is used both to confirm that everything is going as expected and to look for potential conflicts.

The scanning frequency also depends on the traffic load. En-route controllers report that the scanning frequency (backup rate) not only increases in accordance with the amount of traffic but also with the qualitative complexity of the situation. An indicator is the number of conflicts because in a high traffic load situation the event rate is, within a certain interval of time, much higher. If the traffic load or complexity of the situation has reached a certain limit, there may be an opposite effect: the en-route controllers feel that it is necessary to scan the situation more often even if they have spare capacity to do this; one en-route controller called this a 'vicious circle'.

In a radar position the radar screen seems to be the most important source of information and therefore receives almost constant attention (cognitive process of monitoring). Other information like traffic forecast or active FPSs are only checked when the en-route controllers feel they need additional information (cognitive process of checking). 'I check the radar in cycles and while I am doing this, I know I need some information of something else and then I go to the departure TV or the strips. The radar is my basic and all the other information, I know that it is there but I don't check those.'

An exception is the new FPSs: they are checked as soon as possible in order to see what traffic can be expected, detect potential conflicts and plan the instructions to be given to the a/c. Also calls or requests from pilots or adjacent en-route controllers trigger the process of updating the MP. Calls or requests are usually followed by a deliberate check of certain information, e.g. cleared level on the FPSs, then the important contents of the message are integrated into the MP and a safety check is done.

En-route controllers sometimes report that they try to catch what is going on around them in the control room because there could be something happening that could affect them.

Every new piece of significant information is integrated into their actual MP and influences their predictions and anticipations of the future situation, and, consequently, their future MP.

Losing Situational Awareness

Having an incomplete or wrong Mental Model (MM) or incomplete or wrong information on the 'actual situational conditions' are two potential sources for not having full SA, which are described below:

1. The en-route controllers' MM is incomplete or weak, for instance in the case of on-the-job trainees who do not have enough experience or in that of fully-qualified en-route controllers who are back at work after a long period of time off duty or when they have to change their routines because of a new system or new procedures. Generally, the en-route controllers' MM fades when they are off work for several weeks. Routines and automated actions are degraded, e.g. the keyboard functions are not automatic, the frequencies of the adjacent sectors have to be looked up and the work speed is slower. There was a large range of comments among the en-route controllers when asked the question how long it took them to regain 100% performance after their last long period off work: from 'one or two hours working' up to 'several days' they replied. It seems to become even more difficult with age. It also depends on how long the en-route controllers are off duty, as the longer the time is, the harder it is, and whether there has been any change of procedures during their absence. En-route controllers usually report that, when back from leave, they try to start with a 'calm position' for which the demands are not too high. However, if this is not possible they may not be able to cope with the situation nor maintain full SA. Such an experience is extremely stressful.
2. The perception of the actual situational conditions is wrong or incomplete when the amount and the complexity of the traffic are extreme and/or something unexpected happens. In this situation the en-route controllers are so busy with the actual traffic situation, for instance with answering calls from pilots or trying to solve a given problem, that either they are not able to integrate the new traffic into their plans nor make a backup scan of the traffic situation, or they are only able to carry out one of these tasks. The pre-planning interval shortens until they fall back onto a more reactive working mode. This is what en-route controllers call 'losing the picture', i.e. not to be pre-planning nor ahead of the traffic anymore, but simply reacting to what pilots say and do. For en-route controllers this is an extremely stressful situation. They are therefore very careful to avoid this type of situation.

Most Important Aspects

- Situational Awareness (SA) results from two main sources:
 - the situational conditions, e.g. traffic situation, psycho-physical state of fitness;
 - the Mental Model (MM), e.g. knowledge about ATC, professional experience.

- When the en-route controllers are working on position the actual situational conditions are integrated into their MM to form an actual Mental Picture (MP) of the traffic situation. The MP is projected into the future; they always try to anticipate how the traffic situation will develop. They maintain SA as long as their anticipations become real and the resulting action plan works out.
- In en-route control SA is maintained by scanning the radar screen almost constantly. Scanning serves a dual purpose: confirming that everything is going the intended way and looking for potential conflicts.
- The interrelation of scanning frequency and traffic load seems to follow an inverted U graph: the scanning frequency (backup rate) increases according to the amount and complexity of traffic but decreases again under extreme traffic load conditions.
- Not having full SA can result from an incomplete or weak MM. It can also result from extreme traffic load and/or unexpected events. In this case the en-route controllers may not be able to integrate the new traffic into their plans nor make a backup scan, or they may only be able to carry out one of these tasks. Their pre-planning interval shortens until they fall back on a more reactive working mode. This is what en-route controllers call 'losing the picture'.

The essential process of maintaining SA is shown in the sub-process 'updating MP/maintaining SA'. 'Maintaining SA' is a background process that plays an important role in all the activities depicted in the flowcharts. One can see this in the overview picture of the sub-processes (see [Figure 6](#)); the sub-process 'updating MP' is hidden in all the other sub-processes and therefore in all the task processes.

8.7.3

Discovering and Evaluating Conflicts

A first conflict search is done when the en-route controllers receive the FPSs about 10-20 minutes before the a/c enters the sector. The en-route controllers look at the flight level, the route and therefore the overflying time regarding certain points/beacons in the sector. They still have in mind the present traffic or they check this data again against the other strips they have on the board. At this stage they know where a potential conflict may arise. This 'searching conflicts' process is also guided by the en-route controllers' knowledge of the sector and where conflicts are more likely to occur ('conflict possibility library').

Most of the conflicts (70-80% according to en-route controllers' estimates) are recognised before the new traffic enters the sector. If traffic increases, the pre-planning interval may shorten. In this case the en-route controllers may not be able to instantly check the FPSs when arrived. They can only do that later once they see the a/c approaching the sector boundary on the radar screen.

The general information needed by en-route controllers to detect a conflict is:

- the time (contingency of time and place),
- the level of a/c (whether they are on the same level, climbing or descending through or to the same level),
- the route or direction of a/c.

This information is integrated into the en-route controllers' mind and already allows a rough prediction on a/c being in conflict or not. For a more precise prediction the en-route controllers have to consider additional information such as speed, climb or descent rates, weather (temperatures) and air pressure.

This process also depends on whether there are planning controllers or not, and it therefore depends on the traffic load. If there are planners the en-route controllers do the pre-screening for conflicts. Then they either take action by themselves, e.g. they co-ordinate a solution with the previous sector (telling or showing the radar controllers afterwards), or they make the radar controllers aware of the problem. They discuss together to try to find a solution, suggesting ways, or the problem is left to the radar controllers and they decide what to do. Smooth and efficient teamwork requires the radar and planning controllers to have a tacit understanding. En-route controllers prefer to work with colleagues who have a similar working style and similar attitudes towards providing service and who prefer similar solutions to given problems. Again, tacit understanding is linked with a shared MM and shared anticipations. Teamwork functions more smoothly if controllers are able to anticipate each others' reactions and what the others accept or are capable of.

Depending on the workload and the assessment of how likely it is that a conflict will occur, they decide whether action should be taken right away; for instance, co-ordinate early handing over of a/c with the previous sector's controllers or ask them to do something with it. They may also wait and monitor the a/c coming into their sector. Every time they check this a/c again they automatically follow the same decision process: 'Is the a/c still a potential conflict?' If yes: 'Do I take action now or do I further monitor?' The advantage of taking action ('safe way') is that they do not need to pay attention to this a/c any longer. The disadvantage may be to have additional co-ordination and inconvenience for the a/c in the future.

The en-route controllers also constantly scan the traffic on the radar screen. One of the purposes is to look for conflicts that may have not been seen when scanning the FPSs. When the new traffic calls in, they again check if important features (level) of the a/c fit with the FPSs and, therefore, with their expectations. Since the time estimates on the FPSs may be wrong, they check for a conflict again if they are not absolutely sure that during the pre-screening this new traffic was free of conflicts, or if any other traffic came up which could have affected the new a/c. Among others they do this by using the tool set measures. The en-route controllers are also scanning the traffic which is already in their sector. The scanning serves a dual purpose: confirming that everything is as it should be and looking for potential conflicts.

The en-route controllers look at their traffic and check whether there is anything else around. From practice they are able to scan and see 'that there is one here, no problem, one there, no problem, another one there, could be a problem, I have to do something'. This 'searching conflicts' process is guided by the en-route controllers' knowledge of the place where conflicts are more likely to occur. Then the decision process described above takes place again.

Most Important Aspects

- A first conflict search is made when the en-route controllers receive the FPSs about 10-20 minutes before the a/c enters the sector.
- Most of the conflicts (70-80% according to en-route controllers' estimates) are recognised before the new traffic enters the sector. If the traffic load increases the pre-planning interval may shorten.
- The en-route controllers are also constantly scanning the traffic on the radar screen. One of the purposes is to look for conflicts that may not have been seen earlier when scanning the FPSs.
- Depending on the workload and the assessment of how likely it is that a situation will become a conflict, the en-route controllers decide whether action should be taken right away or whether they should wait and monitor the a/c. Every time they check this a/c again, they automatically repeat this decision process.

The core process of discovering conflicts is depicted in the 'searching conflicts'/'checking safety' sub-process. The overall picture of the processes in [Figure 5](#) shows that the 'searching conflicts' sub-process is hidden in the 'taking over position', 'managing routine traffic', 'managing requests' and 'monitoring' task processes. The decision process about monitoring or taking action on potential conflicts is part of the 'solving conflicts' task process since there is no clear dividing line between evaluating and solving conflicts in the case of a monitoring decision.

8.7.4

Solving Conflicts

The en-route controllers know about potential conflicts. If they decide to wait and monitor these – they may resolve themselves - they have to attend them as long as a/c do not pass each other or until they are sure they will safely pass each other. Since human attention capacity is limited, en-route controllers only do this if other tasks leave enough attentional resources for monitoring this problem. In this case they switch attention from the other tasks to the problem and switch back again. They do this until the problems disappear of their own accord or by finally taking action (e.g. by putting them on radar headings).

In high workload situations en-route controllers tend to solve problems by taking action straight away instead of monitoring, in order to save attentional resources.

If the en-route controllers decide to take action on potential conflicts, they place increased attention on the problems. How much additional attention they place firstly depends on the time available to solve the problem (level of urgency of the problems, safety being the highest priority) and how complex the problem is and, secondly, it depends on what the demands from the remaining traffic in the sector are. 'Safe' traffic moves to the background and gets very little attention. Non-urgent things move back as well and are dealt with later on.

Conflict solution is usually a highly automated process for experienced controllers. Most solutions come to the en-route controllers' mind instantly. Basic strategies are taught in training but en-route controllers also develop personal strategies from experience. By getting to know their sector and traffic they end up by building up a mental 'conflict solution library' from which they can retrieve solutions, adjusting their actions to former similar situations.

The criteria for choosing a solution are first of all safety, then efficiency. Efficiency is with regard to the a/c's movements as well as the workload of en-route controllers and that of their colleagues in adjacent sectors. Solutions have to meet these criteria in this order of priority, depending on the time the en-route controllers can spend on thinking about them. In high workload periods en-route controllers tend to reduce their decision criteria mainly to the safety criterion, in order to prevent overload. Seen in the short term these solutions are safe (e.g. levelling or vectoring) and allow the en-route controllers to manage their sector under extreme workload conditions while, in the long term (10-20 minutes), they may cause additional workload because the en-route controllers do not have the time to consider all the other factors that are affected by their decision. The same is true for time-critical conflict situations because of unpredictable events or the en-route controllers recognising the conflict late, which obliges them to react immediately in order to meet the safety criterion.

If the en-route controllers need to focus on a particular conflict for a longer period of time, they may have to withdraw attention from less important tasks or information, which can include what happens in the control room. This may mean, for instance, not answering the phone or not registering the pilots' requests immediately. Also 'safe traffic' is faded out for a while. If there are other problems needing constant attention the en-route controllers have to switch from one problem to the other, even if the actual or most urgent problem may have to be checked more often than the other problems. Some en-route controllers report that they would rather deal with one problem at a time so that, once they have dealt with one, they are more able to handle the rest.

When the en-route controllers have chosen a solution they co-ordinate with the adjacent sector if necessary. Once they have found an agreement they

instruct the a/c according to their plan. They monitor the readback carefully and also later on check the radar screen to see whether the a/c followed the instructions. The intensity of checking also depends on their expectation which is based on their experience of a/c, pilots or airlines (e.g. VFR; pilots sounding insecure or speaking bad English who demand more attention).

If the problem is not solved by their action the en-route controllers have to retrieve their backup plan. For almost every conflict en-route controllers have a backup plan in mind in case their initial plan does not work. A backup plan is usually characterised by being safe but not very efficient. This is why, if there is enough time available, the en-route controllers try to find a new solution apart from their backup plan. So, if they have no time nor capacity left, they can always implement their backup plan and instruct the a/c accordingly. As soon as the en-route controllers are sure that the conflict is solved they switch their attention and focus on the next task.

Most Important Aspects

- If the en-route controllers decide to monitor a potential conflict, they have to increase their attention, focusing on this particular situation. However, they only do this if their other tasks allow enough attentional resources for monitoring this problem. In high workload situations en-route controllers tend to solve potential conflicts by taking action straight away instead of monitoring, because that saves attentional resources.
- Conflict solution is usually a highly automated process. Basic strategies are taught in training but en-route controllers also develop individual strategies based on their experience. By getting to know their sector and traffic they end up by building up a mental 'conflict solution library' from which they can retrieve solutions, adjusting their actions according to their experience of former similar situations.
- The criteria for choosing a solution are first of all safety, then efficiency. Solutions have to meet these criteria in this order of priority, depending on the time the en-route controllers can spend on thinking about them. In high workload periods the en-route controllers tend to reduce their decision criteria mainly to the safety criterion, in order to prevent overload.
- If the en-route controllers need to focus on a particular conflict for a longer period of time, they may have to withdraw attention from other less important tasks or information. Also 'safe traffic' is faded out for a while. If there are other problems that need constant attention, the en-route controllers have to switch from one to the other.
- For almost every conflict en-route controllers have a backup plan in mind in case their initial plan does not work. A backup plan is usually characterised by being safe but not very efficient. This is the reason why, if there is enough time available, the en-route controllers try to find a more expeditious solution in addition to the backup plan.

The process described above is depicted in the 'solving conflicts' task process. Giving the instruction and monitoring the readback and result of the instruction can be retrieved in the 'issuing instructions' sub-process. In the verbal description as well as in the corresponding flowchart the necessity to switch attention between one or several conflicts and routine traffic is apparent. This is referred to more closely in the next verbal description and the corresponding 'switching attention' process.

8.7.5

Switching Attention in Complex Traffic Situations

The 'switching attention' process takes into account the aspect of multitasking in which parallel tasks are executed by switching between them quickly. Multitasking usually occurs when en-route controllers have to work under time pressure. The question whether en-route controllers can handle different tasks in a truly simultaneous way or switch attention quickly between their different tasks cannot be finally answered by our interview data, since we had a broad variety of answers. However, our interview data can be interpreted to suggest there is a limited pool of cognitive or attentional resources which can be allocated to different tasks. Tasks with low demands or highly automated tasks (e.g. pushing a key for handover function) can be handled in a simultaneous way as long as they do not exceed the given resources. In this case, attention is shared between the different tasks. However, in the case of a technical problem, for example, even standard operations occupy attentional resources. If the task demands exceed the given resources attention becomes selective. In this case, en-route controllers switch between different tasks.

A typical complex conflict situation or complex traffic situation in general is usually characterised by the following criteria: traffic load is medium to high, there is a problem or conflict that involves more than two a/c (including vertical movements), and/or, at the same time, there are several different problems/ conflicts that require constant attention.

In all cases the assessment and evaluation of conflicts which include a/c climbing or descending seem to require more attentional capacity from the en-route controllers than the assessment of a conflict of a/c which are maintaining a certain level. Having to deal with many climbing and descending a/c seems to increase the mental load of the en-route controllers greatly.

A traffic situation is considered complex when the controllers have to solve problems and make decisions under time critical conditions. The en-route controllers may have different problems to solve. Active problem-solving takes time. There may be various solutions. The en-route controllers have to generate these solutions in their mind; they have to anticipate which ones would be sufficient to fulfil the safety and efficiency criteria regarding service, as well as the efficiency regarding their own workload and that of the adjacent controllers. Since the en-route controllers have to solve different problems within a given (usually short) deadline and additionally have to manage their 'routine' traffic (receiving/answering calls from pilots), they are not always able

to find an optimal solution to them. In this case, they only consider the solution in terms of safety.

In terms of management of attention this means that the en-route controllers have to focus on a specific problem for a short while; this problem then moves to the foreground and the other problems as well as the rest of the traffic move to the attentional background.

The en-route controllers set 'time windows' constantly and unconsciously. Within these time windows they fade out certain problems/conflicts or the remaining traffic. At the end of a time window they check the other problems/conflicts or the rest of the traffic again. The 'countdown' of a time window is unconsciously monitored while the en-route controllers are focusing on a given task. The length of a time window depends on the assessment of the problems/conflict or the situation, i.e. how safety critical it is. These assessments again are also influenced by experience, for instance whether the controllers can trust pilots or not. 'Safe traffic has a larger time window and does not need to be checked as frequently as a traffic situation where a climbing a/c has to cross the main traffic flow and therefore needs constant monitoring.'

For actions of well-known duration (e.g. answering pilots' first call), there is no need for monitoring the countdown of the time window. In this case, the other tasks are checked again when this action is finished. In complex situations the time windows of the various problems may be very short: the en-route controllers have to 'jump' from one problem to the other then go back to the first one to check if the solution worked out. The en-route controllers may encounter four different problems: A, B, C and D. If these have more or less the same priority, they may switch from A to B to C to D then back to A to B and so on. If a problem is of high priority and needs almost constant attention the en-route controllers may switch back to this particular problem more often than to the other problems, that is from A to B to A to C to A to D to A.

The focusing process can also be disturbed by calls from pilots or other controllers that need to be answered immediately.

Switching from one task to a task of higher priority puts a significant load on the so-called 'prospective memory' (Wickens, Mavor, McGee, 1997). The en-route controllers in these situations have to keep things in mind, remember to return to a problem, check it or issue a crucial instruction at a certain point, even more than usual. Also, apart from finding solutions for the several problems/conflicts the solutions have to be checked afterwards or even be monitored for a certain lapse of time. This again stresses the importance for the en-route controllers to set visible memory cues, for instance flag a Flight Progress Strip (FPS) or highlight an a/c.

When the en-route controllers forget about switching back to an unfinished task, skip or delay their usual backup scans and checks of the situation, the 'switching attention' process can be a major source of error because there is a line of unfinished tasks waiting which are considered to be of higher priority.

This can lead to a degraded traffic picture or even the loss of the Mental Picture (MP).

This is also the reason why, in complex situations, en-route controllers prefer solutions that do not have to be continually monitored (e.g. put a/c on different levels), which enables them to focus their attention on other problems.

Exact timing and good establishment of priorities are among the most important abilities en-route controllers should have and are obviously among the hardest things to teach a trainee.

Most Important Aspects

- The 'switching attention' process takes the aspect of multitasking into account. Multitasking usually occurs when en-route controllers have to work under time pressure. The interview data can be interpreted as there is a limited pool of cognitive or attentional resources which can be allocated to different tasks. Tasks with low demands or highly-automated tasks can be handled simultaneously, as long as they do not exceed the given resources. If they do, attention has to be switched from one to the other and back.
- Assessing conflicts, which includes a/c climbing/descending, seems to require more attentional capacity from the en-route controllers than assessing a conflict of a/c which are maintaining a certain level. Having to deal with a lot of climbing and descending a/c seems to increase the en-route controllers' mental load greatly.
- If the en-route controllers have to switch their attention between different tasks, they unconsciously set time windows. Within these time windows they fade out certain problems/conflicts or the rest of the traffic. At the end of a time window they check the other problems/conflicts or the rest of the traffic again. The length of a time window depends on the assessment of the problems/conflicts or the situation, i.e. how safety critical it is.
- To switch from one task to a task of higher priority puts a significant load on the so-called 'prospective memory' (Wickens, Mavor, & McGee, 1997). The en-route controllers have to keep things in mind, for instance to remember to return to a problem or check. Again, this stresses the importance of enabling the en-route controllers to set visible memory cues, e.g. flag an FPS or highlight an a/c.
- The 'switching attention' process can be a major source of error when the en-route controllers forget about switching back to an unfinished task, or skip or delay their usual backup scans and checks of the situation, because there is a list of unfinished tasks waiting which are considered of being of higher priority. This can lead to a degraded traffic picture or even to the loss of the MP.

The process described above is also depicted as a flowchart in the 'switching attention' task process.

8.7.6

Managing Attentional Resources

The following verbal description supplements the 'switching attention' process. Within this process the en-route controllers are setting time windows and priorities according to the need of dividing attention between different tasks or activities. They must be able to handle mental load in an efficient way.

The description summarises the criteria according to which the en-route controllers change priorities and, therefore, focus their attention, and which

influences their checking habits and decision-making. It also summarises the strategies used by en-route controllers to cope with mental load.

First of all, a/c that are potential conflicts get more attention, which is no surprise because it is the core task of ATCOs to detect and solve conflict situations. On the other hand, a/c which are free of conflicts get less attention, especially when they are vertically separated from other traffic. Some conflict solutions 'which are not completely clean' require further monitoring and therefore more attention. Also a/c with a minimum lateral separation need increased attention when the en-route controllers are making a sequence for approach.

Overflying 'hello-goodbye' a/c get almost no attention, except that the en-route controllers have to remember to hand them over to the next sector.

Aircraft (a/c) with problems, whether of a major or minor technical nature, and problems due to weather conditions get more attention.

Attention is also guided by how much trust the en-route controllers have in the pilots. This is usually linked to experience. En-route controllers report that they usually pay more attention to pilots with poor English skills or to certain airlines whose pilots are expected to have poor English skills. These expectations also have an impact on their decision-making as regards with which pilots should be instructed and what should be instructed to them, such as using standard phraseology only or keeping the instruction simple. Also pilots who are expected not to be familiar with the airspace ('strange call signs', or prior experiences with certain airlines or small VFR traffic) get increased attention. Military a/c also get more attention because they are faster and less predictable.

Therefore, pilots who are expected to be very experienced and/or familiar with the airspace may get less attention.

More general features of the traffic and the sector structure also guide the attention. The entry points of the sector on the radar screen as well as certain conflict or crossing points in the sector are scanned more often.

Aircraft (a/c) with vertical movements (climbing and descending) are allocated increased attention because within busy terminal areas they change level frequently during landing preparation or when they are climbing to cruise. As a consequence en-route controllers have to manage these level changes, which increases the workload because they have to think, if you consider the time frame, in a three or four-dimensional way rather than in a two-dimensional way. The simple separation by level no longer applies and as a result the required attention is increased.

Also a/c with routings that are different from the main flow demand increased attention. This is also because they are more likely to be in conflict with other a/c, e.g. if they cross the main traffic flow, they do not belong to the en-route controllers' routine. The en-route controllers usually know the traffic flows in the sector well; for instance, they know when to give a clearance and

where problems may occur. So they scan those points routinely. Traffic that is different from the main flow demands more attentional capacity; for instance, it requires the ATCOs to remember to give a clearance or check if the a/c is free of conflicts.

When en-route controllers were asked about how they cope with complex traffic situations and what strategies they use in high workload situations, they gave the following answers:

In en-route control units where planning or co-ordinating controllers are present only in high traffic load situations, one of the first steps for the radar controllers is to call for a planner or co-ordinator. They take over part of the work, e.g. the planning controller takes over the pre-planning of the traffic to avoid conflicts based on proper long-term traffic planning, so that the radar controller can concentrate on the actual situation in the sector. Another step may be to split the sector.

This is complementary to the fact that in a high workload situation the planning window of the radar controllers shortens; their attention is more focused on the actual traffic situation on the radar screen. 'You narrow the picture, you concentrate more on a smaller part, you put your belief in the planning controller.'

When focusing on the individual strategies of en-route controllers in the handling of their traffic in high workload situations, it was found that one major goal of en-route controllers is to reduce their mental load and the number of things which have to be kept in mind. "Switching attention" between different tasks or activities is an error-prone process.

En-route controllers tend to fade out safe, non-conflicting traffic, especially when they do not have to do anything with them, e.g. 'hello-goodbye' a/c transiting their sector in the upper level. While they are planning, they are setting priorities according to urgency and importance, doing urgent and important actions first, and delaying actions of less importance and urgency. The assessment of the urgency and importance of actions is a continuous and flexible process. Every new event has to be considered and can change the order of priority. Of course safety relevant actions have highest priority.

Closely related to prioritising is the tendency to solve one problem after the other in high workload situations. As soon as a problem is solved, it can be removed from the Working Memory (WM) and the chance of forgetting something relevant is less than in a situation where the en-route controllers try to solve several problems simultaneously.

In high workload conditions en-route controllers fall back on standard or routine solutions because it saves some attentional capacity and 'you don't forget anything in between'; pilot requests are considered to be of less importance, 'no more extra things like direct routings'.

Another strategy which seems to be very important in high workload situations is to support the WM with reminders: whenever en-route controllers have to

remember something associated with an a/c, they arrange a visible hint by marking the FPS of that a/c, flagging it in the strip bay or marking the a/c on the radar screen through the 'overbright function' or by reducing the label clutter.

Another strategy is to take control of a potential conflict situation as early as possible. In a low or moderate workload situation en-route controllers often monitor potential conflicts, taking measures with radar tools in order to find a decision which is most appropriate to the a/c. In high workload conditions en-route controllers tend to solve potential conflicts at an early stage to save some attentional capacity.

Closely related to this is the tendency to use 'safe solutions'; i.e. definite easy solutions to problems so that they do not have to be monitored anymore; for instance by using more vertical separation. 'If you have a conflict, solve it as soon as you can, just take an easy solution, take it vertical, just take the easiest solution and go to the next problem.'

In highly demanding situations en-route controllers also fade out or try to fade out their surroundings; they do not notice what is going on around them in the control room. They may even actively try to cut themselves off by using headsets and ignoring phone calls.

A strategy to avoid potential perception errors is to reduce any clutter on the radar screen, e.g. by fading out irrelevant maps, zooming the radar picture so that they only see their own sector, filtering out lower levels or moving overlapping labels on the radar screen.

Also the en-route controllers tend to hand over a/c to the next sector as soon as possible, when they are free of conflicts and there is nothing more to do. A/C are then removed from the WM. Another reason is to enable the adjacent colleagues to take control of the a/c according to the plans as soon as possible.

If an a/c is crossing a given sector for a short time and it is neither conflicting nor needing instructions from the controller of this particular sector, it is often put straight to the frequency of the en-route controller of the next sector in order to save attentional and frequency resources.

The ATCOs' overall goal is to guarantee a safe and expeditious traffic flow. It was found that in high workload situations en-route controllers tend to have a bias towards safety in their planning and decision-making. One can express it in a simple way: 'more safety - less service'.

Some en-route controllers also stress the importance of being flexible in their own plans and making quick decisions, and that they should not be afraid of changing their plans several times if at a later point they see a better way of solving problems.

A second constraint in high traffic load situations, apart from the attentional resources, is the availability of R/T communication. The workload of the

en-route controllers increases in a non-linear way with the number of controlled a/c; most of this load consists of talking to pilots on frequency. The en-route controllers not only have to ensure that they have a plan about when to give instruction to an a/c, but they also have to ensure that they are able to give important instructions to a/c when they need to give them. En-route controllers always carefully try to avoid frequency congestion and often consider the possibility of a blocked or lost frequency in their plans. 'One of the biggest problems is frequency congestion: you may not be able to issue a crucial instruction, so even more than usual, you will not wait to resolve problems if you can resolve them straight away.'

Some en-route controllers report that in high workload situations they change their speaking habits: they give stricter and shorter instructions and raise their voice. This is not only to save frequency time but also to signal to pilots that they should listen carefully.

Most Important Aspects

- The verbal description supplements the process of switching attention. It summarises the criteria according to which the en-route controllers change priorities and therefore their focus and direction of attention. It also summarises the strategies they use in order to cope with mental load.
- Any kind of safety critical traffic situations get increased attention.
- The distribution of attention is guided by the en-route controller's personal experiences with certain types of a/c or airlines.
- A/C with vertical movements and a/c with routings different from the main traffic flow require increased attention.
- In high workload situations en-route controllers try to reduce their mental load, the number of things which have to be kept in mind by prioritising tasks or actions according to urgency and importance. Safety-relevant actions are given highest priority. Other strategies to reduce mental load are to draw back on standard or routine solutions in handling the traffic or to ensure separation early in a potential conflict situation.
- The ATCOs' overall goal is to guarantee a safe and expeditious traffic flow. In high workload situations en-route controllers tend to have a bias towards safety in their planning and decision-making.
- A second constraint in high traffic load situations, apart from attentional resources, is the availability of R/T communication. En-route controllers always carefully try to avoid frequency congestion and often consider the possibility of a blocked frequency in their plans.

9. CONCLUSIONS

9.1 General

The Integrated Task Analysis (ITA) project aims at analysing the ATC jobs and tasks from a cognitive point of view. Any analysis of specialist tasks is a complex undertaking and the analysis of cognitive tasks is no exception.

Hierarchical task decomposition has often been used in previous research particularly in the area of cognitive skills. However, the working environment in ATC possesses special and complex problems and, as such, a more process-oriented approach for the ITA was chosen. This approach demonstrates the level of complexity anticipated in such an exacting working environment and also highlights the complementarity of ITA to the more classical task analyses.

9.2 The En-route Controllers' Task

Phase 2 of the ITA project was undertaken in order to better understand the activities of en-route controllers whilst on position.

It is clear from the results so far that the cognitive processes are an extremely important prerequisite, necessary for any multitasking and decision-making undertaken in this ATC position. Many of the en-route control related tasks can be viewed as top-down processes and, as such, controllers consider that these tasks are governed by a sound MP which represents the actual traffic situation. The central role of anticipating future events based on a MP should be considered as a key for deriving recommendations for future ATM systems.

It was demonstrated that the tasks undertaken by the en-route controllers could be separated into the following three main components: the sensori-motor (behavioural), cognitive and evaluative activities.

It was apparent that the use of different but complementary methods to analyse the tasks of en-route controllers gave a robust assessment of the activities under consideration. The cognitive interviews, the behavioural observations and the flight progress reconstruction allowed a coherent and integrated method in which to explore the link between the en-route controllers' activities and their underlying cognitive processes.

Allocation of attention was regarded as a core process within en-route control. It was also clear that an increase of attention occurred whenever the traffic load increased and/or the traffic became more complex. This issue affects the creation and maintenance of the MP. As sectors increasingly accept more descending/climbing traffic, the MP has to conform to three or four dimensions and as a result the attention reaches its capacity.

Another issue related to this phenomena is the unpredictable nature of some a/c, in particular the military traffic (e.g. ACC Malmö). En-route controllers tend to rely less on their MP but more on a flexible strategy because of the unpredictable behaviour and faster than normal manoeuvrability of the a/c.

Another important factor concerns the time available for planning in an en-route position. This time frame mainly depends on the sector size since a 'terminal position' has a shorter time interval for planning compared to a large en-route sector.

Lastly, en-route controllers take special care in order to avoid R/T clutter or blocked frequencies. These are a major constraint in busy traffic areas and en-route controllers work hard to keep the frequencies free. In this way they are able to attend to the traffic picture, giving themselves more time for conflict detection and resolution.

10. FURTHER STEPS

Phase 3 of the Integrated Task Analysis (ITA) project will compare different positions¹ and sectors within the ECAC area, which will be studied in the same way as in Phase 2. In addition, several geographical areas of the ECAC States will be included in the task analysis in order to build a representative baseline of the ATCOs' job and tasks in these countries.

As part of this process the present descriptive study on en-route controllers will be checked in order to evaluate whether it is applicable to other functions and positions in ATC. The relative importance of the various cognitive activities highlighted in Phase 2 will be considered within the context of other ATC positions within Europe. Finally, the data from the cognitive interviews and the flight progress reconstruction method will be used to derive cognitive profiles in order to compare the various ATC units with respect to their different cognitive demands.

¹ i.e. aerodrome, departure/arrival and en-route positions

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GLOSSARY

For the purposes of this document the following definitions by EATCHIP (1996) and Seamster et al (1997) and by others when indicated shall apply:

Action: Intentional or goal-directed behaviour.

Anticipation-Action-Comparison loop: Set of nervous components allowing prediction of 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 developed after consistent and repeated practice. Not all skills can be automated; usually they can be 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. Automatically-processed tasks are done rapidly and with little or no effort. Not all tasks are amenable to automatic processing.

Bottom-up process: Activity controlled by external cues and commands. 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 (MP).

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

Cognitive processes (Eysenck, 1994): Basic cognitive activities taking place within the memory, involving coding and thinking processes.

Cognitive skills (Eysenck, 1994): Cognitive processes described in terms of the ability of the individuals to carry out certain types of tasks consistently.

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: Combination of data collection and analysis techniques used to perform a cognitive analysis.

Controlling: One of the basic functions of ATC. Process of intervention which includes the selection of a strategy, the allocation of time and a decision to terminate it. ATCOs direct single aircraft (a/c) or groups of a/c to obtain a desired traffic situation according to the rules and procedures of ATC.

Decision-making: Another basic function of ATC. Active cognitive process which selects a set of possible courses of action. Includes a weighing up of the pros and cons of different alternatives.

Decision-making skill: 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 learned from experience, and aim at supporting and enhancing the controllers' decision-making.

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

Decomposition: 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. The active cognitive process which takes place in order to assimilate new unexpected situational conditions into the actual Mental Picture (MP) of the traffic situation or to change the MP to account for the new information.

Expertise: Characterised by superior performance and mastery of the three phases of skill acquisition. There are a number of cognitive characteristics of expertise: 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): 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: Features and purposes of a job; the major activities, duties and responsibilities involved, and the primary knowledge, skills, mental and physical abilities required to perform them competently.

Knowledge: The information required to develop skills. Job concepts or rules (**declarative** knowledge) and their interrelationship (**structural** knowledge).

Long-term Memory (LTM): One of the four components of the structural model of the cognitive processes of ATC. Stores the Mental Model (MM), the information, and the information processing routines and programmes.

Memory: 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 the Working Memory (WM) (Atkinson & Shiffrin, 1968) and LTM.

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

Mental Picture (MP): The actual MP of the situation represents a moment-to-moment snapshot of the actual situation as represented by the brain. It is based on the MM and the actually perceived external cues. A series of MPs represents the actual MM including the actual parameterisation.

Monitoring: One of the basic functions in ATC. Process of continuous or discrete comparison between the actual state of the system and the expected state of the traffic situation. 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 cognitive processes of ATC. Internal evaluation system which makes sure that action takes place as planned by the controllers.

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

Self-monitoring skills: Used to evaluate, monitor and regulate the self-performance, including attention allocation, workload management and recognition of problem areas in performance. Specific form of strategy.

Situational awareness (SA): The perception of the elements in the environment within a volume of time and space, comprehension of their meaning and 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 MP and the use of that picture in directing further perception and anticipating future events.

Skills: Goal-oriented actions, both cognitive and psychomotor, which are acquired through practice. Combination of aptitudes and knowledge after

training and practice which is required to perform a job-specific task. Skills can therefore be evaluated through performance. They are linked with one or more tasks. Some examples include gross motor, perceptual motor, perceptual, procedural, decision-making and representational skills.

Stress: State of the organism characterised by central and vegetative arousal, which is prolonged during a longer time period (H. Selye, 1981). Individuals depart from their normal homeostatic equilibrium. Stress will also change information processing.

Sub-task: 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: Group or combination of interrelated, interdependent or interacting elements forming a collective entity. The fundamental feature of a system is the interdependence of its parts or variables.

Task: Basic unit of work with a clear beginning and end point, a goal and one or more products. Basic unit of analysis for both CTA and traditional task analysis. Task activities may be observable or non-observable.

Task element: Step required to complete a sub-task, normally used when a very detailed analysis is required.

Time horizon: The time window in which workers anticipate and plan into the future, allowing them to stay ahead of a situation.

Top-down process: The process of governing behaviour by plans, MMs, intentions and rules. Used to describe 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 (WM): Also known as the short-term memory. Stores information currently being used or attended to. Has 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 MMs are active in the WM when used to support task performance.

ABBREVIATIONS AND ACRONYMS

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

AAC loop	Anticipation-Action-Comparison loop
a/c	AirCraft
ACC	Area Control Centre
APP	Approach Control
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer / Air Traffic Controller (<i>UK/US</i>)
ATM	Air Traffic Management
CTA	Cognitive Task Analysis
DED	EATCHIP Development Directorate (<i>no longer exists</i>)
DED5	Human Resources Bureau (<i>now HUM Unit or DIS/HUM</i>)
DEL	Deliverable
DIS	Directorate Infrastructure, ATC Systems and Support (<i>EUROCONTROL</i>)
DIS/HUM	See HUM Unit
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme (<i>now EATMP</i>)
EATMP	European Air Traffic Management Programme (<i>formerly EATCHIP</i>)
ECAC	European Civil Aviation Conference
ET	Executive Task
EWPD	EATCHIP/EATMP Work Programme Document
FPL	Flight Plan
FPS	Flight Progress Strip

HMI	Human-Machine Interface
HRT	Human Resources Team (<i>EATMP</i>)
HUM	Human Resources (Domain)
HUM Unit	<i>Also known as DIS/HUM (EUROCONTROL)</i> ATM Human Resources Unit (<i>formerly DED5 Human Resources Bureau</i>)
IANS	EUROCONTROL Institute of Air Navigation Services
I/O	Input/Output (system, unit, device, loop, etc.)
IfB	Institute for Evaluation Research (<i>Germany</i>) <i>Institut für Begleitforschung</i>
ITA	Integrated Task Analysis
ITAM	Integrated Task Analysis Methodology
LTM	Long-term Memory
MM	Mental Model
MP	Mental Picture
NLR	National Aerospace Laboratory (<i>The Netherlands</i>) <i>Nationaal Lucht- en Ruimtevaartlaboratorium</i>
PCS	Process Control System
R/T	RadioTelephony
REP	Report
RESTQ	REcovery STress Questionnaire
SA	Situational Awareness
SDE	Senior Director(ate) EATMP (<i>EUROCONTROL - formerly SDOE</i>)
SDOE	Senior Director(ate) Operations and EATCHIP (<i>now SDE</i>)
ST	Specialist Task

SYNBA	Synthetic Strain and Task Analysis <i>SYNthetische Beanspruchungs- und Arbeitsanalyse</i>
TDH Unit	Training Development and Harmonisation Unit (<i>IANS</i>)
TV	TeleVision
TWR	Aerodrome Control Tower
WM	Working Memory

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