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FOR THE SAFETY OF AIR NAVIGATION

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Team Co-ordination Study

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Abstract

This study carried out a literature review to get a better understanding of how ATCO-teams co-ordinate and share information. This is an important baseline to establish prior to embarking or considering other staffing options such as Multi Sector Planning (MSP), Single Person Operations (SPO) or removing or automating a task. In addition, this study proposes a framework to guide the assessment of the expected impact on teamwork when considering different staffing options.

Keywords

Team; Team work; Team co-ordination; Team tasks; En-route control

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Contents

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EXECUTIVE SUMMARY

This study carried out a literature review to understand better how ATCO teams co-ordinate and share information. This is an important baseline to establish prior to embarking or considering other staffing options such as Multi Sector Planning (MSP), Single Person Operations (SPO) or removing or automating a task.

This report describes teamwork / team co-ordination aspects based on the findings from literature relevant when considering changing staffing options. In addition, a framework is proposed to guide the assessment of the expected impact on teamwork when considering different staffing options. The scope of the current framework is limited in its application to the en-route environment.

For the purpose of this study, the focus has been predominantly on the 'standard' sector team i.e. consisting of Planning Controller (PC) and Tactical Controller (TC).

Chapter 1,'Introduction', describes the background, objectives, scope, purpose, benefits and approach of this team co-ordination study.

Chapter 2, 'Team concepts', describes three key factors to create successful teams for its sector manning, - team selection, task design and team training.

Chapter 3, 'Team structure and tasks', the important teamwork tasks are described for ATCOs i.e. team-co-ordination, team decision-making, cross-monitoring and hand-over tasks.

Chapter 4, 'Factors impacting teamwork and team performance', the teamwork tasks are further detailed for normal and non-normal operations, including degraded modes of operation. The most important factors affecting teamwork, such as the level of task automation, workload, attitudes, working style and team culture are also explained.

Chapter 5, 'Staffing options and teamwork', The impact of the above mentioned factors on four staffing concepts are discussed. These four staffing concepts are:

- MSP, with a PC supplying either two or three TCs with planned traffic;
- SPO, i.e. one ATCO manning the sector;
- collapsing (merging) and de-collapsing (splitting) of sectors;
- dynamic re-sectorisation, either with a limited number of sectorisations, or unlimited.

Chapter 6, 'Staffing options assessment framework', a framework is proposed to help guide the assessment of the expected impact of team changes when considering different staffing options. This framework details four steps to be taken to make the transition to a new staffing concept.

Chapter 7 ' Existing team assessment methodologies', details the existing techniques of measuring and assessing teamwork together with guidelines for selecting these techniques during the application of the framework.

Chapter 8, 'Conclusions', summarises the main conclusions from this study.

A list of references, a glossary of terms and a list of the abbreviations and acronyms used in this document together with a list of contributors.

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1. Introduction

1.1 Background

The growing traffic, technological changes and commercial pressures makes safely staffing the Air Traffic Control (ATC) operations complex and challenging. To maintain a safe, orderly and expeditious flow of traffic it is important to staff positions safely and to withstand commercial pressure avoiding unnecessary risks.

Within the context of the European Safety Programme (ESP) during 2005/2006, there are three published EUROCONTROL deliverables, which form the basis for the current study i.e.:

- Shift work Practices Study - ATM and Related Industries (EATMP, 2006a);
- Study Report on Selected Safety Issues for Staffing ATC Operations (EATMP, 2006b);
- Managing Shift work in European ATM: Literature Review (EATMP, 2006c).

As a result of a study in 2006 on ‘Safe Staffing in ATC Operations’ there is an interest to understand how a team of Air Traffic Controllers (ATCOs), e.g. two persons in a sector team, communicate and co-ordinate tasks. It is considered that getting a better understanding of how ATCO teams co-ordinate and share information is an important baseline to establish prior to embarking or considering other staffing options such as Multi Sector Planning (MSP), Single Person Operations (SPO) or removing or automating a task.

Consequently, EUROCONTROL initiated a ‘team co-ordination study’ with the objective to gain insight from literature and previous research on how ATCO teams co-ordinate and share information and what team factors need to be considered when changing staffing options. Also to develop a ‘framework’ that could be used at the level of the ATC unit, to guide the assessment of expected impact on teamwork when considering different staffing options.

1.2 Objectives

The objectives of the study are:

- To understand the impact of team changes on team co-ordination tasks;
- To develop a framework to assess staffing options;
- To learn from ATM and related industry.

1.3 Scope

The focus of the current study is on Human Factors (HF), particularly on teamwork aspects, such as the composition of the team, co-ordination between different sector teams, shift hand-overs and team training aspects. Such aspects are interwoven with safety and capacity of the ATC system. Central to this study are the changes in teamwork as a result of staffing changes or the introduction of new systems. The implications for safety and capacity are discussed where appropriate, but not exhaustively.

The scope of the framework is limited in its application to the en-route environment. The possible team compositions and working practices will increase/vary when considering all possible ATC environments (terminal, approach and aerodrome control). However, this study made use of literature with respect to teamwork in other ATC environments.

In this study, the ‘standard’ sector-team in the en-route environment is supposed to consist of a Planning Controller (PC) and Tactical Controller (TC). The role of the assistant is not taken into account in this study, although it is acknowledged that in some centres the assistant plays a significant role in supporting the PC/TC, particularly in high-workload situations. Moreover, the current report focuses predominantly on the sector-teams consisting of PCs and TCs, including the PCs and TCs of previous and subsequent shifts and possibly the multi-sector team. To avoid complicating unnecessarily the applicability of the framework, teamwork of the ‘macro-team’, possibly consisting of other ATM personnel, flight crew, system engineers, etc. was not considered in detail in this study.

For practical purposes, a philosophical question is whether ‘the automation’ can be considered as an additional team member, and hence part of the team. Although it is acknowledged that automation can be viewed as part of the team, it was decided during a first workshop for this study, to not further detail this approach.

The literature review is based on open sources, i.e. articles from (applied) scientific journals, conference proceedings, EUROCONTROL studies and technical reports.
Note: when general reference is made to an ATCO or other (male or female) operator, the pronouns he, him or his are used for brevity. The reader should read these pronouns as s / he him / her, and his / her, respectively.

1.4 Purpose

The purpose of the study is to provide:

- An overview of current practices of assessing teamwork options in Air Traffic Management (ATM) operations, and in other domains if applicable;
- An overview of existing tools and methodologies and their status for understanding team co-ordination tasks;
- Issues/concerns regarding team co-ordination when changing the team or when introducing new automation in the ATC system;
- A framework, including criteria, with which team co-ordination aspects in an ATC environment can be assessed.

1.5 Benefits

The team co-ordination study aims at the following benefits for ANSPs:

- Increased clarity and understanding of criteria to assess staffing options;
- Key references material and checklists at hand for ANSPs;
- Awareness of lessons learned from ATM and related industry can be fully exploited;
- Mitigation of project risks when changing staffing options.

1.6 Approach

Table 1 lists the questions to be addressed in this study following from the relationship between the management instruments ‘team design’, ‘task design’ and ‘training’ and the performance of the centre/unit in terms of safety, capacity and efficiency.

Table 1: Approach in terms of questions to be addressed

<table>
<tr><th></th><th>Team design</th><th>Task design</th><th>Team training</th></tr>
<tr><td>Safety</td><td>What are the safety implications of particular team compositions?</td><td rowspan="3">Task design variables:
– Airspace Sectorisation,
– configuration of CWPs,
– System automation,
– Procedures, regulations, etc.</td><td rowspan="2">Which teamwork competencies are central to safety?
Can the safety culture be improved through training?
Which teamwork competencies influence capacity? Can these be trained?</td></tr>
<tr><td>Capacity</td><td>Which staffing options provide the highest sector capacity?</td></tr>
<tr><td>Efficiency</td><td>Which staffing options minimize the cost per controlled flight-hour?</td><td>Which teamwork competencies influence the cost per controlled flight hour? Can these be trained?</td></tr>
</table>

To address the questions in Table 1, a four step approach has been taken i.e:

1. **Information Source Identification and Data Collection**
   Data collection involved the following activities:
   - Literature- and web search
   - Collecting experts’ viewpoints (during a workshop on 11 July 2007). Existing reports and articles on practices and trends in assessing teamwork options in ATM and related industries have been reviewed. Expert viewpoints (from EUROCONTROL and ANSPs), discussed during the workshop, indicated potential useful directions, present research and keywords for literature and web search.

2. **Data analysis**
   Relevant methodologies and tools that result from the previous step have been categorised and connected to team co-ordination tasks that may exist in teams of ATCOs.

3. **Framework development**
   A framework has been outlined and was discussed with experts during a second workshop on 11 December 2007.

4. **Reporting**
   The current report summarizes the key findings of the previous three steps.

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2. Team concepts

2.1 Introduction

This chapter outlines general concepts and terminology in relation to teams, teamwork and team co-ordination together with their applicability in the ATC context. Three basic elements underlie the creation of a successful team. These three elements, which are (1) team design, (2) task design and (3) training, will be detailed in this chapter.

When introducing changes to teamwork (e.g. in staffing, adding automation, or changing shift-work practices), one needs to understand the essential qualities or competencies of the team that need to be preserved. These teamwork competencies, which can be categorized as (1) teamwork skills, (2) teamwork knowledge, and (3) teamwork attitudes are explained in the context of an ATC teamwork task.

2.2 What is a team?

In ATC, a team is defined as a group of two or more persons who interact dynamically and interdependently with assigned specific roles, functions and responsibilities. They have to adapt continuously to each other to ensure the establishment of a safe, orderly and expeditious flow of air traffic (EATMP, 1996b).

At the behavioural level, team-based activity comprises two components (Stanton et al, 2005):

- **Teamwork** refers to those instances where actors within a team or network co-ordinate their behaviour in order to achieve tasks related to the team's goals.
- **Taskwork** refers to those tasks that are conducted by team-members individually or in isolation from another.

Obviously, co-ordination between team-members in a team of ATCOs is central in achieving the aforementioned safe, orderly and expeditious flow of traffic. As well as understanding team co-ordination at a behavioural level, it is important to be aware of the level of underlying cognitive processes, of which, according to Klein (2000), the most important are:

- Control of attention
- Shared situation awareness
- Shared mental models
- Application of strategies and heuristics to make decisions, solve problems, and plan
- Metacognition[1]

Klein (2000) distinguishes planning teams and action teams. The cognitive processes are different.

- The job of a planning team is to produce a plan.
- The job of an action team is to accomplish a task

[1] Thinking about (other team members') thinking

Klein mentions an ATC team as an example of **a typical action team**, in which the task is moving airplanes across a sector. It may seem contradictory to define an ATC team as an action team rather than a planning team, since some team members are even called planners. However, the output of a team in ATC is the sequence of actions that implement a safe and expeditious flow of air traffic. In generating this output, the team takes into account different plans at different levels, some of these plans (i.e. the flight plans of individual aircraft) need modification by a PC. Thus, the job of a team in ATC is not to produce a plan, such as a planning team, e.g. for a military air campaign at an Air Operations Centre (AOC), need to do.

According to Klein, there are often differences in cognitive processes between action teams and planning teams. Klein found that:

– **Information management** (control of attention, including information seeking) **is critical** for action teams in all of the professional settings he encountered;
– Action teams **struggle less with shared mental models** (of the roles and functions and the ways the task is to be performed) than planning teams. For ATCOs, this is due to their high level of expertise and the structure of their work.

2.3 Elements to create a successful team

At the managerial level, one may distinguish three different avenues to creating successful teams (Paris et al., 2000):

– Team Selection
– Task Design
– Team Training

These three different avenues are depicted as elements of the pie-chart in Figure 1. Examples are given of important aspects to be taken into account when following each of these avenues.

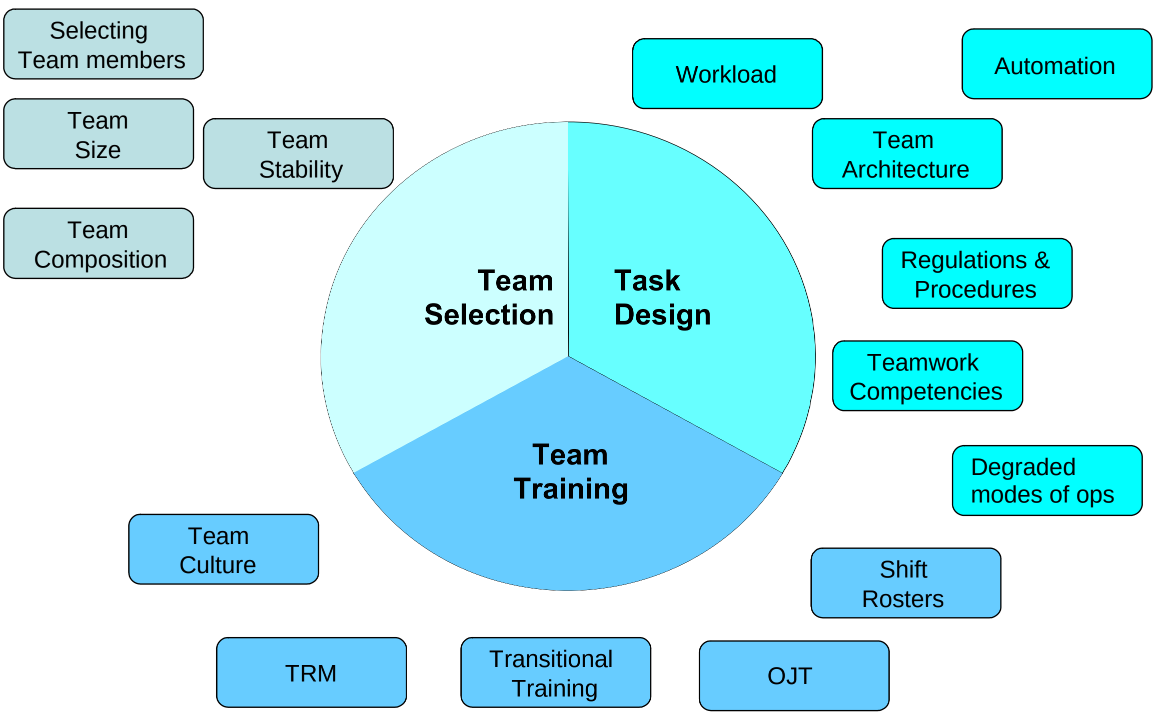

Figure 1: Elements to creating a successful team

2.3.1 Team selection

- **Selecting the right team members**
  For teamwork one should select team members with the appropriate traits, i.e. not only with the taskwork-related knowledge, skills and attitudes, but also individual traits that may facilitate team-processes, such as learning ability, initiative and leadership. When it is mainly individual performance, i.e. taskwork, that determines team output, then team processes are less important. Hence, in such a case it would not be overly important to select team members on the basis of traits that facilitate team processes.

- **Defining the appropriate team-size**
  If the team is too small, then team members will be overloaded, if the team is too large, resources are wasted. Team size is largely fixed by the nature of the tasks to be performed. Unfortunately, task-load in ATC is not always stable and can often be unpredictable. Larger teams tend to be detrimental to effectiveness, typically as a result of heightened co-ordination needs. As a general rule, **teams should be staffed to the smallest number needed to do the work** (Hackman, 1987, Sundstrom et al, 1990). Within an en-route environment teams will already be small, only existing of a PC and TC.

- **Defining the appropriate team-composition**
  In terms of differences in attributes, personal ability, skills, experience, age, etc, it is important to establish the mix of competencies and team characteristics that may be appropriate for the team.

- **Team stability**
  Team stability refers to the time-span during which a team has the same members. A team in an en-route centre may have a relatively **low stability** over time due to rostering-constraints and position-handover. However, it has been observed that team stability increases when ATCOs have flexibility in choosing a shift (‘personal roster’). In a somewhat wider team interpretation, team stability is also affected by the hiring of new staff, i.e. when ATCOs suddenly have to work with a new colleague.

2.3.2 Task design

Task design variables include such things as (Paris et al, 2000):

- workload,
- team architecture (refers to task variables that influence how team members interact, such as proximity, available communication means, and allocation of functions),
- using automated technologies effectively,
- governmental regulations and established procedures (Standard Operating Procedures (SOPs)).

In this context, it is useful to consider the distinction between different types of competencies (i.e. knowledge, skills and attitudes) relevant for teamwork (Cannon-Bowers, et al, 1996), namely:

- *Task specific* competencies (for a specific task or situation, i.e. knowledge of specific co-ordination procedures in the sector or unit, pointing out specific problems in the sector, co-ordinating a solution)
- *Task generic* competencies (transportable, can be used for other tasks, for example managerial skills)
- *Team specific competencies* (influence the performance of a specific team, for example, knowing how a specific team mate will function or react)

– *Team generic competencies* (influence the performance of any team the individual serves on, for example leadership or communication skills)

One can subsequently characterize a task environment through a combination of competency requirements ('competency alignment') for the type of teamwork. These combinations are:

– Task specific / team specific
– Task specific / team generic
– Task generic / team specific
– Task generic / team generic

This concept is depicted in Figure 2.

Task specific/ Team generic Alignment Needed when tasks are well-defined, and team membership is unstable. *E.g.:* *For a team in large ATC unit, under standard operating conditions.*	***Generic*** ← **Competencies related to teams** →	**Task generic/ Team generic alignment** Needed when tasks are not well defined, and team membership is unstable. *E.g.:* *For a team in large ATC unit under non-standard operating conditions.*
Specific **Task specific/ Team specific Alignment** Needed when tasks are well-defined, and team-membership is stable *E.g.:* *For a team in small ATC unit, under standard operating conditions.*	← **Competencies related to tasks** → ***Specific***	***Generic*** **Task generic/ Team specific alignment** Needed when tasks are not well-defined, and team membership is stable *E.g.:* *For a team in small ATC unit under non-standard operating conditions.*

Figure 2: Competency alignments required in different environments

For example, the competency alignment "task specific / team specific" is applicable when team membership is stable and the number of different tasks is relatively small and well defined. For ATCO-teams with stable team membership (e.g. at smaller units) this characterization may be applicable. At a large en-route centre where team composition changes more frequently, such that ATCOs may work with relatively unfamiliar team-mates, the competency alignment "task specific / team generic" may be more applicable. For members of project-teams at organisations such as EUROCONTROL, the competency alignment "task generic / team generic" may be more applicable. These characterisations of teamwork competencies by means of competency alignments may be a good starting point when identifying competencies for team training.

2.3.3 Team Training

Once the competencies that improve team-co-ordination have been identified, teams can be trained. Team training has been greatly improved since the mid-eighties, when team training suffered many deficiencies. Standards have been developed e.g. training methods, team performance criteria, performance assessment, and provision of feedback to the team and the individual (Paris et al, 2000).

For ATCOs, team training elements are nowadays integrated in initial, rating and unit training. On-the-Job Training (OJT), which forms a substantial part of unit training, when ATCOs work towards their unit endorsement, takes place in the context of a team, and can therefore be considered a form of team training. Whenever transition training is required (e.g. with system changes, or changes in the operation concept), training objectives with respect to team competencies should be formulated and addressed in the training programme, using the appropriate instructional strategies and tools (EATMP, 1996b, guidelines for transition training).

Team Resource Management (TRM) is a concept and training that is designed to improve the functioning of ATC teams. It does this by increasing the awareness and understanding of interpersonal behaviour and HF capabilities, with the goal of increasing flight safety (from the EUROCONTROL website). The components of the training are shown in Figure 3.

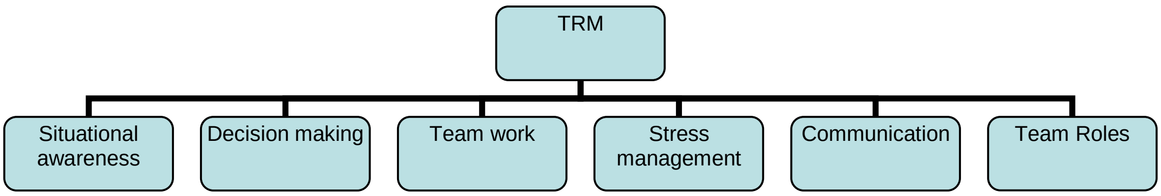

Figure 3: Components of TRM Training as offered by EURCONTROL IANS (copied from the EUROCONTROL website)

In addition to the modules depicted in Figure 3, New TRM modules, have been added, covering 'automation and teamwork' and 'human error and teamwork'. For example, Behavioural Oriented Observation Method (BOOM) Training is a method for training TRM facilitators to observe non-technical skills of ATCOs during simulations.

A related issue to TRM is the 'team culture' that develops in larger teams. For example, in one large en-route centre, a difference in culture developed with time and experience between teams responsible for North and South sectors. As a result, mixing members from these two different teams, sometimes lead to misunderstandings about co-ordination issues not explicitly communicated. Those issues were obviously handled differently and implicitly by both teams. This illustrates the influence of team culture on teamwork, particularly the large grey area of teamwork not explicitly mentioned in the procedures. The development of 'cultural' habits in an organisation can be influenced by TRM training. Cultural habits are discussed in Chapter 4.

2.4 Team competencies and team qualities

Competencies are the knowledge, skills and attitudes required to perform a task or a job, e.g. en-route ATC. Specific competencies are required to perform this task or job in a team-context, which depend on the nature of team (team size, composition, team stability, etc.) and task (e.g. specificity of the task). In a general sense, i.e. for a wide range of professional settings, Paris et al (2000) provide examples of competencies in each category (i.e. team skills, team knowledge and team attitudes), which are listed in Table 2.

Table 2: Examples of team competencies, categorized in skills, knowledge and attitudes (Paris et al, 2000)

Team Competencies Categories	Team Competencies
Team skills (behaviours)	Adaptability, Shared Situation Awareness (SSA), mutual performance monitoring, motivating team members, leadership, mission analysis, communication, decision making, assertiveness, interpersonal co-ordination, conflict resolution.
Team knowledge (cognitions)	Cue strategy associations, task-specific team-mate characteristics, shared task models, team mission, objectives, norms, resources, task sequencing, accurate task models, problem models, team role interaction patterns, knowledge of teamwork skills.
Team attitudes	Motivation, shared vision, team cohesion, mutual trust, collective orientation and (believe in the) importance of teamwork.

To understand the value of these competencies for en-route ATC tasks, it is useful to consider:

- *Which team-tasks have to be performed in en-route control?*

  A list of team-tasks is included in **Appendix 1**. However these tasks must still be considered as *general* ATC en-route team tasks since the specific tasks may vary from country to country and from unit to unit.

- *Under what conditions have these tasks to be performed?*

  Consider for example, conditions with respect to task-load, weather and serviceability of equipment.

- *Does the task require task- or team- specific competencies?*

2.5 Summary

This chapter highlighted key elements of teamwork, in particular:

- Three elements are important for the creation of a successful team i.e. team selection, task design and training.
- The competencies (skills, knowledge and attitudes) required for teamwork in an en-route centre are mostly task-specific under normal operating conditions, however some task-generic competencies are required under non-normal operating conditions. At en-route centres with many operational ATCOs, fellow team-members may change frequently (from shift to shift). This requires team-generic competencies.

- In present-day en-route ATC a large number of different team tasks can be distinguished (Appendix 1), for which specific team competencies are required. According to Klein (2000), only a limited number of team cognitive processes (control of attention, SSA, etc.) underlie these competencies.

When considering specific changes in teamwork, it is important to understand for the existing team:

- What are the specific team qualities in a team? Therefore, it is necessary to consider:
  - Which team-tasks have to be performed?
  - Under what conditions have these tasks to be performed?
  - Which team competencies does the task require?
  - What are the important team qualities to maintain and preserve?
- Are there already ‘good practices’ with respect to teamwork at the ANSP, e.g. for OJT, shift-work, TRM, position hand-over, etc.?

For the proposed changes in teamwork it is important to understand:

- Which options for maintaining/ creating a successful team are possible?
  – Which changes in team-size/ composition/ shift-work are viable?
  – Is it possible to improve teamwork through task-design?
  – Is it possible to improve teamwork through training?
- Which tasks will change and consequently which competencies are affected?

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3. Team structure and tasks

3.1 Introduction

In the previous chapter, the basic concepts of teamwork were explained. This chapter deals in more detail with the interplay between the ATC en-route environment and the team of ATCOs. First, the sector team in en-route control is introduced, second the structure of teamwork, tasks and competencies are described.

3.2 Structure of the sector team (PC/TC)

Several different en-route control positions are in operational use. Typically, the control position is designed for two ATCOs with specific activities and roles, i.e. the Tactical (or radar) Controller (TC) and the Planner Controller (PC).

The TC is typically in charge of contacting aircraft, giving clearances, providing aircraft navigational guidance and separations, resolving conflicts and transferring aircraft to other sectors. The PC is typically in charge of inter-sector co-ordinations, updating flight information of flights in the sector (integration of new strips on the strip board) and performing pre-analysis to help the TC.

It must be noted that responsibilities of different team members in en-route control may vary across countries and centres. Also, roles, or aspects thereof, may be implicitly developed with experience. At the European level, no separate ratings or endorsements for PCs and TCs are distinguished. The European Manual of Personnel Licensing (EATMP, 2004) is the main reference for both ESARR-5 (EUROCONTROL, 2002) and the EC directive on ATCO licenses (EC, 2006). According to this manual, an Area Control Surveillance (ACS) rating with a ‘Radar’ endorsement or an ‘Automatic Dependent Surveillance’ endorsement is required for en-route control. It is assumed here that for control of airspace in which surveillance radar equipment is used, both PC and TC have an ACS-rating with at least a Radar endorsement.

A variety of tools have been developed to aid the PC, TC or both. Some of these tools have been implemented, some of these tools are still in the test-phase, and some systems have none of these tools. Examples are:

- Electronic Flight Strips (EFS) / Lists, with additional features such as automatic sorting, preview of strips to be received from other sectors, colour coding for in- and outbound traffic, automatic updates of flight-data, etc.
- Controller Pilot Data Link Communication (CPDLC), in which flight information and route clearances are exchanged in digital form via radio, such that conventional (analogue) R/T is required for back-up purposes only (in case of communication with non-equipped aircraft and in case of emergencies).
- Several tools based on trajectory prediction, such as
  - Medium Term Conflict Detection (MTCD), an aid for the PC that predicts future conflicts up to 20 minutes ahead.
  - Aids to monitor the progress of flights in the sector, including flight plan deviations.
- System-Supported Co-ordination (SYSCO) provides a screen-to-screen dialogue in co-ordination and transfer of control of a flight to / from a neighbouring unit or sector (EUROCONTROL, 2007a).

The Integrated Task and Job Analysis (ITA) of en-route ATCOs (ITA, see EATMP, 1999) observed that few tasks of ATCOs are executed independently and that much of the **teamwork is serially structured** (i.e. between different ATCOs in the same sector and between ATCOs in different sectors). This is most prominently apparent from the sequential handling of (paper) flight strips by the two ATCOs in the sector. Paris et al (2000) note that serially structuring a team will expose it to the distinct possibility of system overload, since its performance is determined by the weakest link in the chain. However, teams in en-route control are often flexible enough to abandon the seriality in favour of working concurrently on 'each others' tasks in order to relief each other when task load requires.

3.3 Temporarily changes in team structure

In en-route control units where PCs are present only in high traffic load situations, one of the first steps for the TC when traffic load increases is to call for a PC. They take over part of the work, e.g. the PC takes over the pre-planning of the traffic to avoid conflicts based on proper long-term traffic planning, so that the TC can concentrate on the actual situation in the sector. Also, the TC may delegate the writing on strips to the PC and monitor integrity of RTF communication conducted by the TC when phone calls for the TC arrive simultaneously. In more difficult situations (e.g. cumulonimbi in the sector), the TC barely uses the strip board and concentrates on the radar display. The PC then assists in checking the radio clearances, the global traffic situation, and the acknowledgements of the pilots over R/T (EUROCONTROL, 2006, Intuilab, 2007).

Mutual monitoring is both auditory (telephone calls, R/T) and visual (radar display, strip board). This improves the PC's and TC's ability to detect inconsistencies or errors. Both ATCOs use their down time to compare data on the strip board and data on the radar display to detect discrepancies. This may however in real life not always be feasible due to high workloads for both ATCOs.

Some staffing concepts allow that in extreme situations a third ATCO comes to support the TC and PC (on a position not designed for that purpose). In the first minutes he has to build his own representation of the traffic and manages simple and well defined tasks, such as pointing out aircraft that can be transferred, or calling another sector (by own initiative or on demand). After that, he will assist on more complex activities on the basis of a strategy to be established in collaboration, e.g. building solutions, managing separations in a specific area of the sector, transferring outgoing aircraft, managing the co-ordination with other sectors. The strip board may be divided in two parts (between the PC and the third ATCO). Co-ordination load (as apparent by the amount of verbal communication) is increasing in such case (EUROCONTROL, 2006). Another step in some centres may be to split the sector when traffic load increases. Larger centres may have a large number of possibilities for merging and splitting (collapsing, de-collapsing) of sectors (positions).

3.4 Team tasks and competencies

Appendix 1 details the team tasks which have been identified. The list is fairly general, in the sense that it doesn't take into account specific systems or system features such as electronic flight strips/lists. Some of the team-tasks are mentioned by the Integrated Task Analysis (EATMP, 1999), EUROCONTROL (2006), Intuilab (2007), NRC (1998), the SHAPE teamwork report (EATMP, 2004), EUROCONTROL's review of shiftwork practices (EATMP, 2006a) and Paterno (1998). The main team tasks in ATC en route context are summarized in Figure 4.

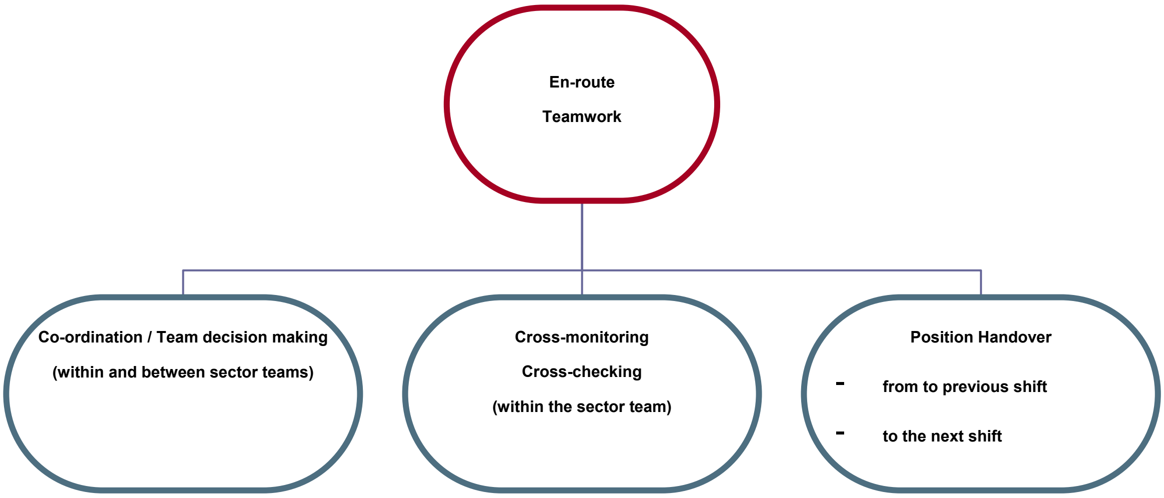

Figure 4: Main tasks in the ATC en-route context

3.4.1 Co-ordination and Team decision making (within / between ATC teams)

3.4.1.1 Co-ordination

Inter-sector co-ordination requires implicit understanding of tasks and mutual awareness for conflicts between TC and PC. In the ITA (EATMP, 1999) it has been noted that conflict detection in en-route control depends partly on the PC. When the traffic load requires that a PC is present, he performs the pre-screening for conflicts. Then, he takes either action by himself, e.g. he co-ordinates a solution with the previous sector (telling or showing the TC afterwards), or he makes the TC aware of the problem. They discuss together to try and find a solution, or the problem is left to the TC and he decides what to do. Smooth and efficient teamwork requires the TC and PC to have a tacit (implicit) understanding.

It has been noted that mutual awareness and monitoring between two adjacent sectors enables non-vocal or implicit co-ordinations between the two PCs (EUROCONTROL, 2006, Intuilab, 2007). This requires 'awareness validation' (an indication) by the TC of the receiving sector, to ensure that he is aware of the co-ordination.

It has been identified that inter-sector co-ordination is a key element for mutual awareness, having consequences for the PC/TC collaboration. This becomes apparent considering CPDLC, where this mutual awareness may be at risk when no proper design measures are taken. The PC should therefore point out any revisions to the TC when using CPDLC. The non-vocal aspect of CPDLC may create some conflicts due to unsynchronized actions between TC and PC. For example, the PC may accept a co-ordination request through OLDI/SYSCO for an aircraft to FL300, whereas the TC sends a CLIMB TO FL300 message to another aircraft. This could create a conflict between these two aircraft. As all these actions were non-vocal, the two ATCOs could not prevent this conflict.

3.4.1.2 *Team decision-making*

Decision-making is the cognitive process leading to the selection of a course of action among multiple options. EUROCONTROL (EATMP, 1996b) defines decision-making as the mental process by which operators recognise, analyse, and evaluate information about themselves, the air traffic, and the operational environment, leading to a decision. In more formal and general terms, one may break down the decision making process in the following sub-tasks or sub-goals: option generation, option prioritisation, evaluation of options, and option choice.

The aforementioned EUROCONTROL definition clearly aims at individual decision-making and not at 'team decision-making' (also called 'distributed decision-making') in which the team needs to agree on the actions to be taken. This type of decision-making is distributed because none of the team-members possesses all the information relevant to the decision, in other words, this information needs to be communicated.

Individual decision-making is poorly understood and there is a vast amount of literature on the subject. Team decision-making is less understood. It is complex matter and a detailed treatment of team decision-making is outside the scope of this team co-ordination study. However, a few lines are needed to explain the dilemmas and the current practices.

Different individual decision-making mechanisms can be assumed. A quick decision-making mechanism is called 'recognition-primed decision making' (Klein, 1998), presumably based on pattern matching between an activated 'mental solution' and the real-world situation or problem. A large part of this recognition-primed decision-making process proceeds 'automatically', subconsciously, without explicitly activating the separate elements. In formal problem solving, these elements would be the givens, constraints, operators, methods and sub-goals of the problem (see e.g. Wickelgren, 1974). The recognition primed decision making process is quick, relatively immune for workload demands and effortless, such that multi-tasking is possible.

A much slower individual decision-making process comes into place when novel, unfamiliar problems are presented to the operator. Such problems, often with incomplete information, require so-called inductive strategies, such as backward-reasoning, sub-goal-setting etc. Such conscious cognitive processes are sensitive to stress, effortful (no spare capacity for other tasks) and more prone to error.

ATCOs typically make many decisions in a short period of time. Through years of training and experience (i.e. development of expertise) the vast majority of ATCO-decisions can be classified as **recognition-primed decisions**. One would not like to expose ATCOs to unfamiliar problems that require inductive strategies. Hence, recognition-primed decision making seems to be the preferable type of decision making. This type of "automatic" decision making is highly preferable and develops with experience.

In team decision-making none of the team-members has the whole plan, it is shared. Therefore, team decision-making implies that recognition-primed decision-making is always hampered to some extent. **After all, information that is missing at one individual is present at another individual and needs to be made explicit through communication. This is what is called team-co-ordination**. Through team-co-ordination, a potentially quick process (recognition-primed decision-making) thus becomes a slower process. One or more elements of the solution (a given, a constraint, an operator, a method, or a sub-goal) need to be communicated. It seems therefore straightforward to design tasks in such a way that the amount of team-co-ordination is minimized, for example by presenting all team-members with all possibly required information. This could in turn lead to information overload. Hence, a proper balance needs to be set between team co-ordination and information-load / management.

Team-decision making is integrated in TRM training (EATMP, 1998) in which trainees have to understand factors which contribute to effective team decision-making and have to understand a structured process of decision-making in special situations, e.g. as given by some model such as the FOR-DEC (Facts, Options, Risks and benefits, Decision, Execution, Check) model (Hoermann, 1995) or DODAR model (Diagnosis, Options, Decision, Assessment, Revision).

3.4.2 Cross-monitoring and cross-checking

One of the functions of the team members in a team of en-route ATCOs that is often mentioned (EATMP, 1999, Intuilab, 2007) is to monitor each other to prevent for cognitive overload and to cross-check each other for errors. Such cross-checking can be done, for example, by checking the information on the paper flight strips, which is the primary tool of the PC, against the information on the radar display, which is the primary tool of the TC. There are many tasks in which the PC supports the TC (and vice versa) when the situation requires to do so.

3.4.4 Position hand-over

Another important team task is taking over the working position from another ATCO. Under normal working conditions the mental picture is built up when taking over the position during a period of overlap. Maintaining Situational Awareness (SA) is only possible if a mental picture has adequately been built up. When SA is maintained, a continuous anticipation of future situations is possible (EATMP, 1999).

EUROCONTROL’s study into shiftwork (EATMP, 2006a) concludes that hand-over of ATCO positions are typically “risk times” in ATM. As a general rule it has been stated that there is little disruption of team performance from position-handover, as long as only one team member is replaced at a time and that the replacement is as skilled as the person he replaces. Moreover, disruption is increased if additional team members are replaced (Naylor and Briggs, 1965, Meister, 1985). In line with this notion EUROCONTROL advises that simultaneous takeover of all sector positions (both TC and PC) should be avoided (documentation on “best practice”, see EATMP, 2006b).

3.5 Summary

This chapter highlighted key elements of general teamwork practices in a sector team in an en-route control centre, in particular:

- Teamwork in en-route control is largely serially structured by nature. If there would be little flexibility between the team-members (in terms of assisting each other whenever required) the team would be more susceptible to overload.

- Important team tasks in en-route control (which are further detailed in the task list of Appendix 1) are:
  - Co-ordination within the sector team and between sector teams, as well as the associated *team decision-making*. The latter process is characterized by the distribution of different 'pieces' of information over team members.
  - Cross-monitoring and cross-checking between team-members
  - Position hand-over

When considering specific changes in teamwork, it is important to understand for the existing team:

- Which team tasks may occur in this specific unit, in normal and non-normal situations?
- How is it ensured that, despite the serial structure of many team-tasks, the team is prevented from system overload?

For the proposed changes in teamwork it is important to understand:

- Does the change in teamwork introduce new (previously unnecessary) team-co-ordination tasks?
- Is, after changing the team concept, all information necessary for making decisions available for the team-members?

4. Factors impacting teamwork and team performance

4.1 Introduction

This chapter aims at capturing and explaining the most important 'on-the-spot' factors (observable, and with measurable changes, in the working environment) influencing team co-ordination in en-route ATC as described in the literature.

- Automation
- Degraded operation of equipment
- Workload
- Attitudes towards teamwork and working styles

In addition the influence of organisational culture on teamwork is briefly described.

4.2 Automation

In this paragraph, the question is posed which functions can be automated and at what level of automation. Specific attention is given to team decision making, and the extent to which this process can be automated. Automation of parts of the decision making process may increase, e.g. starting with automatic option generation, subsequently automatic option prioritisation, automatic evaluation of options, and eventually automation of option choice.

Automation tools developed for ATCOs are primarily focused on supporting the individual ATCO, while many, if not all of ATC functions are a team effort (Maynard and Rantanen, 2005). For most team tasks some level of automation assistance is possible. However, tasks involving complex judgements and other higher cognitive functions are extremely difficult to automate. This is, for example, the case with the following high-level team tasks:

- monitor fellow team members for performance, SA and workload;
- engage in the splitting and merging of functions, sectors or areas to cope with team task load;
- anticipate each other's reactions, capabilities and acceptance levels.

Particularly, tasks that need to be exercised in non-normal situations are rare and many non-normal situations simply cannot be anticipated, let alone automated. For example, the general team task 'manage a degraded system and ask for human support for tasks normally accomplished by a single ATCO' must usually be resolved by the team (EATMP, 2004).

To classify the functionality of automation in terms of the tasks that automation takes over from (teams of) human operators, levels of automation have been defined. The US National Research Council (NRC, 1998) recommends that future automation developments should focus on information automation rather than automatic action implementation.

<u>Decision Making using automated technology</u>

Parasuraman, Sheridan and Wickens (2000) proposed a set of ten levels of allocation of decision-making tasks between humans and computers.

1. The computer offers no assistance; the human must make all the decisions and actions;
2. The computer offers a complete set of decision alternatives;
3. The computer narrows the selection down to a few;

4. The computer suggests an alternative;
5. The computer executes the suggestion if the human approves;
6. The computer allows the human a restricted time before automatic execution;
7. The computer executes automatically, then necessarily informs the human;
8. The computer informs the human only if asked;
9. The computer informs the human only if it (the computer) decides to;
10. The computer decides everything and acts autonomously, ignoring the human.

In the US, the National Research Council (NRC,1998) recommended that for system functions with relatively little uncertainty and risk a high level of automation is appropriate. However, when the system function is associated with greater uncertainty and risk, the level of automation should not be more than ‘the computer suggests an alternative’ (i.e. level 4, the fourth level in the list above). Here, it is assumed that ATC system functions, implemented to assist the sector team, must indeed be associated with greater uncertainty and risk.

The panel adds to this recommendation of the NRC

Any consideration for automation at or above this level must be designed to prevent: loss of vigilance, loss of situation awareness, degradation of operational skills, and degradation of teamwork and communication. Such designs should also ensure the capabilities to overcome or counteract complacency, recover from failure, and provide a means of conflict resolution if loss of separation occurs.

Experts expect that in the coming five years, the actual implemented decision-making automation in Europe will not exceed level two.

<u>Information automation</u>

An important aspect of decision making is the automatic presentation of relevant information to the team members. This aspect is thought to have more potential for being of use to ATCOs and to have more relevance to teamwork than other aspects of decision making and team co-ordination (e.g. automation of evaluation of options, option choice and action implementation).

Information automation may include the following:

- Filtering out of irrelevant information;
- Automatic distribution of relevant information to relevant team members;
- Automatic transformation of information;
- Providing confidence estimates on measurements/predictions;
- Providing integrity checks on information;
- Team members have the flexibility to request information.

<u>Autonomy</u>

A notion related to advanced automation is that of autonomy. The term autonomy has been introduced to describe the boundaries of decision authority of advanced automation and intelligent decision systems. Autonomy can be defined simply as the capability to make decisions. Thus, autonomy can be considered in terms of freedom to make decisions, considering:

- constraints on decision-making (limitations, rules and regulations);
- decision-making abilities (authority, responsibility, competency);
- capabilities to make different types of decisions (e.g. from resolutions requiring simple choice to resolutions requiring inductive reasoning).

The role of the controller will change in the future. In the longer term we may find more autonomous automation, for example controlling a holding stack. Higher levels of automation may replace a team-member.

Relationship between automation and age

Automated technologies change the required competencies of ATCOs, i.e. the skill-set, including team skills and the attitude towards teamwork. Both team skills and attitudes should be re-calibrated, e.g. through calibrating the team-composition or through training.

It is generally thought that young ATCOs deal with automation differently than old ATCOs. In the SHAPE project (EATMP, 2003) the relationship between age and automation is summarised as follows:

- The issue of age of employees and new technology has attracted little research so far. It appears that older employees have a higher reluctance to use computers. However, if they get a chance to gain experience the negative attitude becomes more positive;
- HF problems associated with the introduction of new equipment can be expected to be even more pronounced for older users;
- Interface issues and workload impacts should be carefully considered;
- Technological change bears the danger of out-dating expertise. The design of new systems should facilitate the transfer of expertise form the old to the new system.

4.3 Degraded operation of equipment

Johnson et al (2008) distinguish four different modes of operation at ANSPs:

- Normal operation;
- Degraded modes of operation (of equipment);
- Crisis;
- Contingency.

The degraded mode of operation, i.e. the second bullet above, can be further subcategorised into predictable and unpredictable conditions (EATMP, 2006b). Predictable conditions include routine maintenance and degraded modes of operations for which a contingency plan is foreseen. Unpredictable conditions are those system malfunctions for which there is no contingency plan.

Furthermore, the degraded mode can be characterised by its severity, which depends on the components of the system that fail; *primary systems* are systems that are normally used by the ATCOs in order to perform their tasks. The most critical of these systems have been implemented *redundantly*, so that if one system fails the ATCO can quickly switch to a replacement with the same functionality as the old one. Redundant in this sense means that if the first system is working there is a redundant system that serves as a back-up system if it should happen that the first system is no longer operational for some reason. In addition, there are *fall-back systems* when both primary and redundant systems fail. These are substantially different systems with less functionality. Although, ATCOs are proficient to use these fallback systems to perform their work, working with the fallback systems is usually not as efficient as working with the normal systems and often involves additional effort from the ATCOs as they are not used to work frequently with such systems.Teamwork implications are:

- That the team must remember how to work with the fall-back system;
- That the right number and mix of staff must be available to work on the positions;
- Co-ordination requirements and team workload may increase.

Failure of equipment, or software, may have additional team related aspects. Johnson et al (2008) discuss a number of these aspects.

- Conflict detection tools serve as an extra set of eyes for the team. With the failure of such tools, spare capacity is required to intensify conflict detection.
- Technical specialists, and possibly specialists/suppliers from outside the ANSP, are involved in the resolution of a degraded mode of operation. It is important that these 'members of the macro-team' resolve the problem in a fashion expected by the operational users of the system, i.e. that at any stage the system behaves exactly as expected by its users.
- Some ANSPs claim that traffic-flow prediction systems are low-risk and that ATCOs don't need redundant or fallback systems. However, these systems are often installed in order to increase capacity. For example, decisions related to collapsing and de-collapsing of sectors are made on the basis of traffic-flow predictions. When there is no technological fall-back for such systems, larger staffing volumes are needed in order to maintain capacity.
- Larger ANSPs have a number of very characteristic sectors (typical terrain or traffic patterns for that environment / sector) in their airspace. Extensive experience with these sectors is essential for efficient control. This makes it impractical to move controllers from one sector to another in order to assist colleagues in case of degraded mode of operation.
- When services related to degraded operation (such as maintenance, repair) are outsourced, care needs to be taken that safety-culture standards of these companies meet the standards of the ANSP.
- When operating in watches, it may be difficult to temporarily move ATCOs from one watch to another, to assist during degraded modes of operation. ATCOs operating at different watches may have been trained differently or are used to a different working culture.
- Older staff may be more familiar with operating under degraded modes because these modes are in a way more comparable to how they were trained initially.
- In some centres, technology is managed so well that equipment seldom fails. When staff is exposed to unexpected equipment failures that have not been part of exercises and drills, they are unfamiliar with the degraded mode of operation.
- A number of ANSPs have agreements with neighbouring countries that traffic is taken over in case of degraded modes. These procedures and protocols are largely untested.

In general Johnson et al (2008) state that organisational and cultural aspects in ATC are more and more acknowledged as very relevant aspects when it comes to safety. By focussing on degraded modes of operation they made this statement more insightful and tangible.

4.4 Workload

EATMP (2006a) notes that workload varies substantially in ATM. Variations occur during the day (inbound - outbound rush), during the week (workday - weekend) and during the year (holiday - fare season, summer - winter traffic). On the employer side, these fluctuations challenge cost-effectiveness. The slopes down of traffic peaks can be critical due to 'overshooting relax' responses. Overshooting relax refers to a too large decrease in attention by ATCOs during the fade-off period of traffic peaks.

Workload is the subjective experience of a certain *task load.* Task load can be measured objectively, for example by measuring the number of clearances an ATCO has to give. The difficulty or complexity of the sector may contribute to workload as well. Individual differences influence the experienced *workload* (Lee et al, 2005). Since these individual factors are often weakly specified, it can sometimes be difficult to explain or predict the workload that an ATCO is experiencing in a given situation.

Workload in this context (ATC and more particularly en-route control) refers to *mental workload*, not to physical workload. The job of an ATCO is more relevantly characterized by tasks that involve information processing and information exchange than by tasks that involve physical activities (Wickens, Mavor, and McGee, 1997). Shift-rosters are usually based on limits to sustained mental load rather than on physical load, although working positions that are not properly adapted to the actual operational concept (including team size/composition) may negatively impact the (physical) interaction with the equipment, and create physical overload. This, in turn, may contribute indirectly to mental workload, because the physical conditions interfere with the cognitive tasks of the ATCO.

Appendix 2 provides further details on workload variations and stress. Elements to consider regarding impact of workload on team performance are:

- **Effect of high workload on team performance:** High workload may occur in individuals and teams. In general, teams have more flexibility to deal with workload than individuals, since there are more opportunities to redistribute task-load between team members. As such, teams are better in regulating workload than individuals.

- **Monitoring of each other's workload by team members:** When team members are able to monitor each other they are better able to assess each other's workload. Hence, they better able to take each other's workload into account during co-ordination, communication and sharing of tasks.

  To some extent, technological solutions are available to improve cross-monitoring of team members, e.g. EFSs (Carotenuto and Teutsch, 2007). By using EFSs, or electronic strip lists, ATCOs can assess the number of aircraft under control of their team-members by viewing each other's strip bay remotely. This allows more careful time of handing over flight strips when the colleague is ready for it. When cross-monitoring is hampered, regulating workload becomes more difficult, eventually resulting in less effective team performance.

- **Verbal and non-verbal signals:** Workload may become clearly apparent to other team members when verbal communication is used, i.e. one team member can say to the other "please wait, I'm too busy right now". But there are also a large number of non-verbal signals, that team members use, as indications of each others workload. Examples are higher pitched tone of voice, going tense, the taskload itself (i.e. number of a/c under control), number of clearances given within a certain timeframe, etcetera.

4.5 Attitudes and working style

Teamwork attitudes are defined as an internal state that influences a team member's choices or decisions to act in a particular way (Cannon-Bowers et al., 1995). Two examples of teamwork attitudes are (1) belief in the importance of teamwork and (2) belief in continuous learning as one of the main functions of the team.

Positive attitudes toward teamwork and an attraction to being part of a team ('collective orientation') have been found to enhance team processes and team performance. Also, attitudes towards teamwork depend on culture (JAR-TEL, 2001). A significant body of work exists on the assessment of attitudes toward teamwork in aviation (see for instance Helmreich et al., 1986), mostly focusing on commercial pilot attitudes toward teamwork in the cockpit. Some important attitudes found in the general literature are included in Table 2 (see Chapter 2). Appendix 3 highlights some studies on the measurement of attitudes.

With respect to attitude / working style, the ITA (EATMP, 1999) reports that en-route ATCOs prefer to work with colleagues who have a similar working style and similar attitudes towards providing service and who prefer similar solutions to give problems. Tacit understanding is linked with a shared mental model and shared anticipations. Teamwork goes more smoothly if ATCOs are able to anticipate each others' reactions and what the others accept or are capable of.

4.6 Team culture

A culture has impact on all sorts of interactions, values or communication within a team. However persons (team members) normally do not belong to one single culture (Helmreich, 1999). Besides national culture there is the professional culture of trained ATCOs and thirdly the specific organisational cultures that all shape the cultural background, behaviour and attitudes of a person. For most people, the national culture is the culture that they have been exposed to for most of their lives. Therefore the impact of this culture is stronger, and less likely to change, compared to professional or organizational culture.

Within ANSPs, not just the operational culture may influence team members, but also the safety culture (Smoker, 2003). In ATC, the organisations are usually highly reliable and sustain their performance level during a range of different operational conditions. This organisational culture results in a certain safety culture. However, this organisational climate is not the only factor that shapes the safety culture. Trust of ATCOs in equipment, management, procedures and the organisation in general influences on the safety culture as well, and the same is true for all kinds of resource limitations.

The above illustrates the potential impact of culture on team performance and as such the relevance of assessing cultural aspects if one wants to describe the foreseen impact of team changes on team performance. Also with the right conditions i.e.: a cohesive team, insulation from outside information, no search of alternative information, urgent decision deadlines and a directive leader, groupthink leading to bad decision making may occur (Janis, 1982).

4.7 Summary

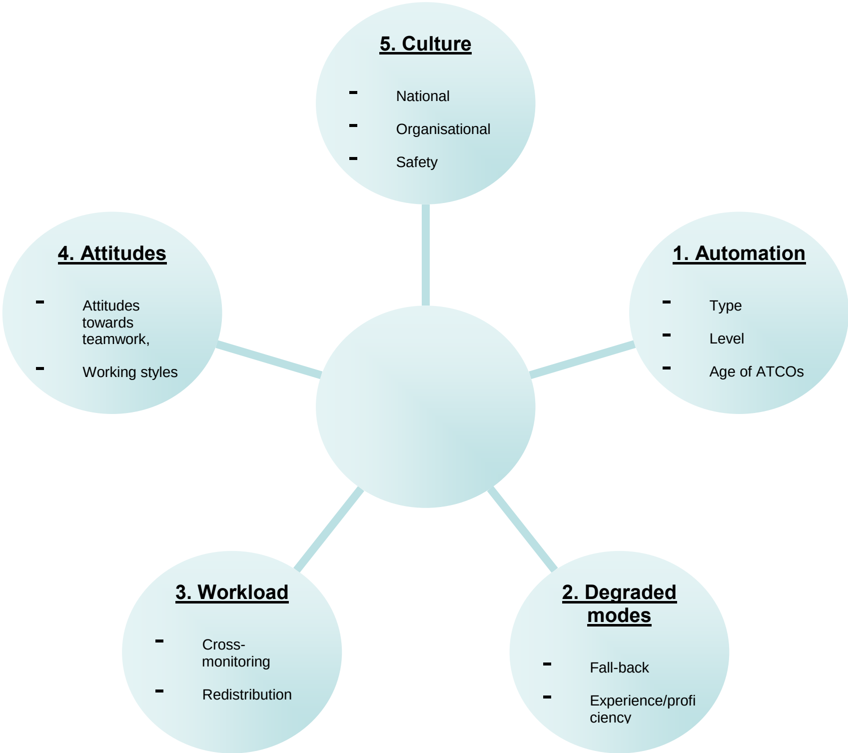

Figure 5: Main factors impacting teamwork in the ATC en-route context

This chapter highlights the factors impacting on team performance as depicted in Figure 5.

- With respect to automation ① a distinction should be made between decision making automation, information automation and action implementation. With respect to improving teamwork, a focus on information automation appears to be most relevant. Introduction of automated technologies changes the required competencies of ATCOs. The age of ATCOs may mediate the effect of automation on teamwork.
- For unpredicted degraded modes of operation ②, the team must be able to cope with the fall-back system, which depends on experience and proficiency with the system and the potential assistance from other ATCOs.
- Teamwork should enable monitoring of workload ③ across team members, i.e. team members should be able to pick-up verbal and non-verbal signals of extremes in workload of team-members, including the so-called overshooting relax response. Preferably, staffing is organised to allow for flexible redistribution of workload over the team members.
- One of the team-competencies is an appropriate attitude ④ towards teamwork, such as trust in the team. Team-members have preference for similar working styles, which promotes tacit understanding between them and the development of a shared mental model.
- Finally, teamwork is affected by cultural aspects ⑤, particular the safety culture, which in its turn is affected by organisational climate and trust in equipment, management and procedures.

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5. Staffing options and teamwork

5.1 Introduction

In this chapter, different (general) staffing options for ATCO teams are described, with annotations from the literature, where available. This review is restricted to the following general staffing options listed in Table 3, although more subtle staffing options are possible.

Table 3: General staffing options discussed in this review

Option	***Personnel at the sector level***	***Description***
Standard	1 PC and 1 TC for 1 sector	the assumed standard staffing of one PC and one TC per sector
[2]MSP-1	1 PC and 2 TCs for 2 sectors	one PC plans for two sectors.
MSP-2	1 PC and 3 TCs for 3 sectors	MSP-2, one PC plans for three sectors.
SPO	No PC and 1 TC for 1 sector	a sector is staffed by a single person, i.e. a TC who also performs the task of a PC, rather than by two persons, i.e. a PC and TC.
Collapsing/De-collapsing of sectors[3]	1 PC and 1 TC for 2 sectors	The collapsing of two sectors into one new sector, such that only the standard personnel for one sector (one PC and one TC) is responsible for the two sectors merged into one larger sector.
Dynamic re-sectorisation	1 PC and 1 TC for each 'new' sector	A number of 'old' sectors can be dynamically re-sectorized into a number of 'new' sectors by shifting the sector boundaries. Multiple sectors can be merged or larger sectors can be de-collapsed as required.

Notes:

- In theory, each of these staffing options can be either a temporary situation (e.g. dynamically dependent on traffic load) or a permanent situation (e.g. when important parts of the planning process have been automated).
- In theory, many different temporary combinations of staffing are possible, e.g.:
  – From the standard situation, via MSP to SPO, or;
  – From the standard situation, via MSP, to a merging of sectors, to SPOs.

In the next sections the general staffing options will be discussed in terms of benefits and drawbacks relative to the assumed standard situation, in which en-route sectors are controlled by a team of two ATCOs, a TC and a PC. As mentioned in Chapter 3, the TC is typically charged with maintaining separation of the airplanes in the sector, and is the one who communicates verbally with aircraft over the radio. The PC is responsible for coordinating the transfer of control of aircraft to other sectors, as well as providing a second opinion and safety mechanism for the TC.

[2] MSP is considered here as a permanent staffing concept, i.e. its application is not temporarily depending on traffic-load. Obviously, MSP-1 and MSP-2 are simplified representations of possibly much more complicated MSP configurations at actual units.

[3] Collapsing and de-collapsing of sectors is a dynamical method, in the sense that it will be applied temporarily on the basis of traffic demand. At actual units, merging of sectors can take multiple forms: i.e. merging of lateral sectors, merging of vertical sectors, merging of more than two sectors, etc.

The benefits and drawbacks of the different staffing options will be discussed on the basis of the concepts identified in chapters 2-4:
- Teamwork implications;
- Factors impacting team performance;
- Creating successful teams;
- Operational Considerations

5.2 Multi Sector Planning

5.2.1 Introduction

European research studies (EUROCONTROL, 2007e, Pember, 2007, see also Appendix 4) indicate that MSP would benefit from the following technological advancements:
- A (conflict) probing function
- MTCD, which identifies problems that require PC resolution. Otherwise the co-ordination between sectors proceeds automatically (offering / accepting), i.e. system co-ordination between sectors.
- CPDLC

Specialized training and very clear procedures are essential to the concept of MSP.

In the US, two MSP-concepts have been investigated by Corker et al (2006), entitled ‘multi-D’ and ‘Area Flow Planning’ (AFP) respectively. In both concepts three sectors were manned by three TCs and one PC.
- In the AFP concept, the PCs job is focused on re-routing traffic throughout the combined sectors, such that task-load for the TC in each sector is manageable.
- In the Multi-D concept, the PCs job is focused on assisting the TC with Medium Term Conflicts.

5.2.2 Teamwork implications

Co-ordination / decision-making

- In a qualitative sense, co-ordination between PC and the TCs becomes more problematic relative to the standard situation:
    - Physical distance between PC and the TCs will generally increase (the more TCs the PC has to plan for, the larger the physical distance between PC and TC may become).
    - The PC has a stronger focus on longer term planning and a diminished focus to assist any of the TCs.
- In a quantitative sense, the co-ordination of the PC with other sectors may increase, since he has to deal with more adjacent sectors, unless the adjacent sectors will also be subjected to MSP, providing more opportunities for direct routing. However, this is a matter of airspace management and flow control, and as such outside the scope of this work.
- The co-ordination within the sector, including (implicit) co-ordination between PC and any of the TCs will decrease, since there are less transfers via sector-boundaries per unit time (from a TC perspective). The PC has more autonomy with respect to the standard situation, i.e. can make more autonomous, hence quicker, decisions.

Cross-monitoring / cross-checking

- Cross-monitoring for task-load of the TCs by the PC will generally improve, since the PC has a broader picture of the overall traffic situation and some authority to divide the task-load over the different TCs.
- Cross-monitoring for physiological non-verbal signals of workload/stress may degrade due to physical distance between PC and TCs and the increased number of TC's that are to be monitored.
- Cross-checking for threats and errors of the TC by the PC will generally degrade, because of the physical characteristics of MSP and the larger airspace in which the PC has to work.

Position hand-over

- Position hand-over of the PC, relative to the standard-situation, becomes more critical since relieving the PC is equivalent to relieving multiple PCs at the same time.

Impact on other teams / the macro team

- The PC generally deals with a larger number of adjacent sectors. The number of inter-sector co-ordinations of the PC that is tasked with MSP increases. This may have some impact in the response time of this PC (e.g. in accepting inbound traffic or releasing outbound traffic).

5.2.3 Factors impacting team performance

Automation

- MSP is possible only with sufficient support of automated tools for the PC. Overall team performance (PC and multiple TCs) will critically depend on the PC's performance, since the serial nature of ATC in MSP becomes more outspoken. There is less flexibility in the team to back-up for each-other.

Digital Communication

- The use of CPDLC could lead to a diminished understanding of where the (potential) conflicts are. With traditional R/T, at least one of the team-members (i.e. the TC) 'hears' the instruction that is uttered, and by uttering this instruction, it is firmly encoded in memory when issuing the next instruction. When using CPDLC, this effect might be diminished.

System degradation

- The strong dependence of the PC on automated tools causes MSP to be more vulnerable to system degradation.

Workload and stress

- At the multi-sector level, task-load can be better regulated. However, at the sector level, TC and PC cannot monitor each other for workload and no longer support each-other.
- In the context of monitoring for workload, SA, stress, etc., it is unclear who takes care of the PC in the MSP-concept.

Attitudes and working style

- In the standard situation, the PC may be sometimes considered as the assistant of the TC, or at best, the TC can be considered as the Primus Interpares of the team. However, in the MSP-concept the PC gets a more specialised profile. This may impact attitude and working style of both PC and TC.

- Both PC and TC work more on their own, i.e. their roles in the core team become less teamwork oriented.

5.2.4 Creating successful teams

Team selection

- The job and competencies of the PC become more specialised. Also team size increases. However, little impact on selection requirements is expected on the basis of just MSP.

Task design

- Assistance by automated tools and longer term planning imply task redesign for the PC.

Training the team-members

- MSP will generally coincide with system changes. Therefore, a system conversion (transition) training will be required. New working methods need to be implemented in unit training and the Unit Training Plan (UTP).

5.2.5 Operational Considerations

Characteristics of airspace, centre and working positions

- Physical distance between PC and TCs may impact communication, both verbal and non-verbal. For example:
    - Indications that an ATCO is available for communication (approachable) may be less clear;
    - There will be less opportunity to refer in communication to features on the radar display or strip-board by finger-pointing.
- In some physical configurations, TCs controlling adjacent sectors may be positioned next to each other. This may lead to different communication patterns in the team.

Organisation of staffing / shift-work

- Team composition will change, i.e. less PCs are required and the job of the PC becomes more specialised. This causes exchange between the pool of PCs and TCs to become more difficult, which hinders flexibility in rostering.

Organisation of On-the-Job Training

- The job of the PC becomes more specialised. The question arises whether trainees can still be trained to do both PC and TC work. This may impact unit training and licensing.

5.3 Single Person Operations

5.3.1 Introduction

Some en-route units have now adopted, or are at least considering, SPOs in their operation (EATM, 2006b), which means that only one person fulfils both the PC and the TC role for one sector. With SPO, the PC is abandoned from the team. Sector planning, including coordinating the transfer of control of aircraft to other sectors, is then either automated or part of the job of the TC. It is assumed here that SPO is only a temporary operation, e.g. only at night while during the day, the operation reverts to the standard staffing of a PC and a TC per sector.

5.3.2 Teamwork implications

<u>Co-ordination / decision-making</u>

- Within the sector, team co-ordination or team decision making is no longer necessary. The extent of inter-sector co-ordination depends on (extra) system features (e.g. OLDI/ SYSCO) that have been installed to facilitate SPOs.

<u>Cross monitoring / cross-checking</u>

- The aforementioned cross-monitoring, cross-checking and back-up/support functions do not exist in SPOs. There is no ‘second pair of eyes’. When the single operator gets distracted, no one will notice what is going on. This will result in a decreased probability of detecting threats and errors, when no other measures are being taken. Overall team performance will critically depend on the single ATCO’s performance. There is no back-up for the single ATCO.

<u>Position hand-over</u>

- Position hand-over becomes more critical since relieving the single ATCO is comparable to relieving a PC and TC at the same time.

<u>Impact on other teams / the macro team</u>

- Since the ATCO is on his own, he may have no capacity for co-ordination/communication with other sectors/centres when he is talking to aircraft.

5.3.3 Factors impacting team performance

<u>Automation</u>

- SPO needs appropriate (dependent on the situation) support of automated tools for the single ATCO. Such automation support could aim at increasing the probability to detect safety-threats and to detect errors of the single ATCO, in order to compensate for the absence of a second pair of eyes during SPOs. The amount of support is dependant on the specific situation.

<u>System degradation</u>

- The presence of a single ATCO only, causes the ATC system to be more vulnerable to equipment/software degradation. Because a single ATCO relies more on that equipment since it, in a way, replaces other staff. He cannot do the job at the same level any more when these systems fail.

<u>Workload and stress</u>

- Task-load is more difficult to regulate.
- Underload (boredom) is an issue as most units deal with low volumes of night time traffic. Boredom may impact SA and cause complacency.

- In the context of monitoring for workload, SA, stress, etc., it is unclear who monitors the single ATCO in the SPO-concept.

Attitudes and working style

- A different set of attitudes is required for SPOs. See Kern (1998) for a description of relevant attitudes in aviation, in which field the issue of SPOs is also relevant.

5.3.4 Creating successful teams

Team selection

- The single ATCO must be able to fulfil the role of both PC and TC.

Task design

- All aspects of the tasks (HMI, SOPs, regulations) must be tailored to the single ATCO.

Training the team-members

- SPO must be integrated in the UTP.

5.3.5 Operational Considerations

Characteristics of airspace, centre and working positions

- Physical working space must be tailored to a single person.
- Supervisory responsibility need to be clear.

Organisation of shift-work

- Organisation of shift-work will become easier with SPOs.

Organisation of On-the-Job Training

- On-the-Job Training should take into account that a single person needs to fulfil the tasks of a PC and TC at the same time (cross monitoring) and needs to be trained to handle additional stress and or workload.

5.4 Collapsing/Decollapsing Sectors

5.4.1 Introduction

Sector collapsing and de-collapsing with decreasing and increasing traffic-load is common practice among many centres in Europe nowadays. Although this practice is described in OPS manuals in a technical sense, there is little research literature on the implications for (team-) work of this practice.

In some centres, the actual (de-)collapsing of sectors is a supervisory decision that must be taken well in advance, in the order of half an hour. In other centres the collapsing of sectors can also be an ATCO decision that can be taken on shorter notice. In the latter case, the supervisor is still the person with best knowledge of overall traffic flows, as he monitors the FMP continuously.

Collapsing doesn't need to be co-ordinated with the aircraft in the sector, since the communication frequencies for all traffic in the collapsed sector will be combined automatically in one R/T channel. Collapsing of sectors is done during periods of decreasing traffic-load to keep workload at a sufficient high level, while de-collapsing is done during periods of increasing traffic-load, to keep workload at a sufficient low level. Moreover, de-collapsing requires transferring a number of aircraft in the sector to a new sector, including assigning a new frequency to these aircraft. Therefore de-collapsing seems to be the more critical process.

After initiating a de-collapsing process by the supervisor, a team of PC and TC will split their sector in two (or possibly more) sectors, according to standard operating procedures. An additional PC and TC are needed to control the newly created sector. In some centres, technical staff are needed to actually implement the required settings in the system, such that radar displays have the appropriate centre and scale factor. In other centres, this is the task of the supervisor.

5.4.2 Teamwork implications

Co-ordination / decision-making

Both collapsing and de-collapsing require some kind of hand-over, i.e. multiple aircraft are transferred to a different sector. The conflict-free accomplishment of this task requires additional co-ordination between PC/TC teams (relative to the standard situation).

The decision to collapse and to de-collapse is a team decision, with involvement of the supervisor. The decision is based on flow figures and personnel occupancy. Before implementation, an (daily) evaluation takes place of the current roster. Collapsing of sectors can thus be used to take away superfluous shifts. The involved ATCOs in these superfluous shifts will do other duties instead (such as administrative work) or will be offered leave or breaks.

Cross monitoring / cross-checking

With respect to intra-team monitoring (between PC and TC), the 4-eye principle is maintained, with no significant changes.

Position hand-over

- In addition to the standard position hand-over, when de-collapsing the sector, a new PC/TC team need to build up a traffic picture well beforehand. This process can proceed in different ways, depending on the standard operating procedures at the centre.
- The procedures for hand-over of traffic in the case of de-collapsing sectors need special attention. For example, it needs to be agreed who is responsible for the decision to 'press the button' (for reconfiguration of the system). Although the supervisor may implement the decision, the TC of the sector before it was de-collapsed may give the go-ahead as soon as he has transferred the relevant traffic to the TC of the opening sector.

Impact on other teams / the macro team

- The supervisor is involved in the (de-)collapsing decision.
- With collapsing, the number of adjacent sectors generally increases. When this is the case, the PC will deal with more different sector teams.

5.4.3 Factors impacting team performance

Automation

Dedicated automated tools are helpful in the following respects:

- Predicting traffic-load well in advance, to support the decision to merge or split.
- Aiding the actual and safe transfer of traffic to the new sector
- Standardizing the (de-)collapsing options within the system, such that the decision of which option to choose can be implemented by a ‘single mouse-click’.

System degradation

- Particularly during the de-collapsing phase, i.e. when capacity/manpower are most needed, the consequences of system degradation will be more severe than in the standard situation (i.e. standard sectors).

Workload and stress

- (De-)collapsing can be considered as a tool to regulate workload, i.e. less peaks and dips in workload. Since the process of de-collapsing itself may cause higher workload, it needs to be carefully planned.

Attitudes and working style

- Basics of teamwork are not affected, with the exception of more inter-team co-ordination. Hence the required attitudes and working styles within the team are hardly affected.

5.4.4 Creating successful teams

Team selection

- Traditional roles of PC and TC are preserved.

Task design

- Automated system functions for merging / splitting of sectors need to have appropriate interfaces to all staff involved (all PC/TC teams, supervisor and the technician implementing the appropriate sector configuration).

Training the team-members

- All knowledge and skills associated with all possible sector configurations need to be trained during unit training.

5.4.5 Operational Considerations

Characteristics of airspace, centre and working positions

- A gamut of different airspace / sector collapsing configurations requires memorization of many aspects of each of those configurations. This may cause confusion between configurations, forgetting, erroneous decision making and diminished orientation and SA. Therefore, it seems advisable to keep the number of possible configurations limited.

Organisation of shift-work

- In principle, rostering becomes more complex, since team composition is more dynamic in comparison with the standard manning of PC and TC per sector.

- It is undesirable to solve problems with the availability of personnel by means of collapsing and de-collapsing of sectors. However, (de-)collapsing can be used to regulate manning, i.e. to remove superfluous shifts from the roster, such that the ATCOs in these shifts can be offered leave or other duties. Some centres have potential problems of ATCOs saving too much leave (statutory or compensation) and collapsing of sectors can be used to offer these ATCOs leave.

Organisation of On-the-Job Training

- All issues associated with (de-)collapsing of sectors are implicitly part of OJT. Hence, no specific additional issues are associated with OJT.

5.5 Dynamic Re-sectorisation

5.5.1 Introduction

Dynamic re-sectorisation is a system that allows more flexibility regarding the borders of sectors. Stein, Della Rocco and Sollenberger (2005) discriminate between two kinds of dynamic re-sectorisation; “limited” and “unlimited”. Limited re-sectorisation is something that we know already from nowadays operations. Examples will be given below. It can even be extended further, without having major impact on today’s ways of operation. Unlimited re-sectorisation is a future scenario, with total freedom on how to rearrange sectors. The main reason why sectors may be rearranged is to (re)distribute task-load or workload evenly over the different ATCOs working on (adjacent) sectors.

Examples that are known from daily practice are:

1. Merging or splitting of sectors due to decreased or increased traffic load.
2. Hampered radar coverage in one of the sectors, such that the team of another sector takes over control.
3. When the winds in oceanic area change direction, it may save aircraft fuel when the sectors are adjusted according to these winds.
4. Sector boundaries around an airport with multiple runways, not all being in use at the same time, can be optimised for a particular RWY configuration that is being used.
5. Airspace with restricted use due to military operations can sometimes be made available for line traffic.
6. Weather conditions, especially thunderstorms, may make it more efficient to adjust the sector boundaries to the position and direction of the thunderclouds.

Obviously, the reason for the re-sectorisation (better traffic management/ regulating workload) should be accomplished. However, the safety levels need to be maintained, which implies that the SA of the sector teams should stay at the same level or improve. Sector boundaries and other features of the re-sectorisation should be clear to all ATCOs involved.

5.5.2 Teamwork implications

Co-ordination / decision-making

- All features of the re-sectorisation (sector boundaries, frequencies, entry- and exit waypoints, standing procedures, etc) should be clear to all operational staff involved, i.e. co-ordinated within the sector teams and between the sector teams.

Cross-monitoring / cross-checking

- PC and TC both need to be aware of the exact sector configuration that they are working on in order to effectively monitor each other. Since they are both working on that same sector that will usually work out well.

Position hand-over

- When handing over the position, not only the traffic situation as such needs to be communicated, but also the chosen sector configuration and consequences of possible changes of the sector configuration.

5.5.3 Factors impacting team performance

Automation

- It is assumed that re-sectorisation, particularly the unlimited form, must be supported by an advanced automation concept.
- When automation fails it is likely that the workload for the team (PC and TC, supervisor, but possibly also technical staff, ANSP manager, etc.) increases. A possible solution is to revert to the ‘standard’ configuration.

System degradation

- As was stated under the previous bullet, degradation of the system increases the team’s workload and may be a source of distraction. Reducing the sector size may be an effective way to manage/ redistribute workload over the available ATCOs.

Workload and stress

- The different sector teams together form one big team that together manages all sectors that are under the control of one particular ANSP. Dynamic re-sectorisation provides the ANSP-manager with an instrument to redistribute workload as required.

Attitudes and working style

- Depending on the dynamics of the re-sectorisation, a more flexible attitude/ working style may be required.

5.5.4 Creating successful teams

Team selection

- The more flexible the team is supposed to deal with sector boundaries the more flexibility from the team members is required. As such, flexibility may become a more prominent selection criterion for team members.

Task design

- When re-sectorisation takes place, multiple tasks need to be performed at the same time. Probably, a number of aircraft need to be transferred and need to change frequencies. The tasks associated with re-sectorisation need to be designed in such a way that these do not interfere with the normal ATC tasks. Possibly, the re-sectorisation can be supported with automated tools.

Training the team-members

- Specifically the moment of re-sectorisation itself needs to take place in a relatively short timeframe. The ATCOs needs to be trained to keep checking what he actual characteristics and borders of their sector are and adjust their strategies according to that situation. Operating in an environment with dynamic re-sectorisation imposes new training objectives, that need to be properly implemented in transition training and the different stages of unit training (including OJT).

5.5.5 Operational Considerations

Characteristics of airspace, centre and working positions

- Characteristic features of airspace may move from one sector to another when sector boundaries shift.

Organisation of staffing / shift-work

- Planning the staff rosters becomes more constrained, as the number of possible sector configurations increases. Staff rosters need to be reviewed with shorter time intervals. Moreover, to keep a sufficient number of ATCOs current with all or part of the sector configurations becomes more complicated.

Organisation of On-the-Job Training

Obviously, OJT requires a structured learning environment, particularly in the first stages. Since dynamic re-sectorisation requires more flexibility from the team, including the OJT-instructor, it may become harder to organize high quality OJT, in addition to the additional training objectives associated to dynamic re-sectorisation that need to be addressed in OJT.

5.7 Comparison of safety issues per staffing option

Safety may be expressed in qualitative and quantitative ways. Quantitative ways are very helpful to express whether the chance of safety hazards is increasing of decreasing as a result of certain (team) changes. Since incidents and accidents have a very low frequency of occurrence, a large number of data is needed in order to actually quantify safety.

The EUROCONTROL Safety Regulatory Requirement (ESARR) 4 is concerned with risk assessment, mitigation and hazard identification in ATM when introducing and / or planning changes to the ATM system. (EUROCONTROL, 2001). Since team changes can be considered as a change of the ATM system, this ESARR can also be used as a starting point to discuss, study or quantify safety aspects of team changes.

ESARR 4 divides safety in five severity classes. The classes of hazards that are used now are:

1. No immediate effect on safety
2. Significant incidents
3. major incidents
4. Serious incidents
5. Accidents

The severity and outcome of an hazard (qualitative part of the risk), combined with the (assessed/ estimated) frequency, that one of these hazards will occur quantative part of the risk, determines the risk.

In order to make such risk assessments, relevant scenarios need to be determined first. One of the ways to start risk assessment is that the new situation (team change) needs to be described to specialists. Hence, these specialists will describe scenarios in which these changes can be a causal of contributing factor to an incident or accident. For all four of the example team-changes that were discussed in this chapter, a number of safety aspects will be discussed.

5.7.1 MSP

Sector-team related safety aspects of MSP relate primarily to the increased physical separation between TC and PC, increased task-specialisation of the PC and an increased proportion of task-work.

When the four-eyes-principle is abandoned, in the case with MSP, there is the increased risk that a TC may not spot relevant information in time and that the PC will not bring that under his attention.

The task design, how the TCs and PCs share responsibilities and are able to look (via their own displays) at the work of other TCs may mitigate the loss of cross-monitoring capability.

In the standard staffing option, the TC and PC were working together, using the same displays. Therefore, it may be relevant to ensure that cross-checking/ cross-monitoring by PC and TC is maintained. This may require the PC to view the TC's sectors at its own working position and to call each other in case of irregularities.

5.7.2 SPOs

The same effects as with the MSP apply during SPO. The effects on safety that were mentioned in the previous section on MSP are likely to be stronger, since there is just one (single) ATCO monitoring what goes on in his own sector. Therefore, the likelihood that an error or threat goes unnoticed, prior to an incident, is higher than situations where there is at least one other person who has tasks in the same sector.

The single ATCO is responsible for all communication with the entire macro-team. This includes flight crew, ATCOs of adjacent sectors etc. In order to manage communication, care needs to be taken that the communication load does not suddenly increase, such that there will always be sufficient time to call for assistance.

5.7.3 Collapsing/De-collapsing Sectors

The main safety risks identified for merging or splitting sectors are that:

- It may not be clear what the boundaries and other characteristics of the new sector are (particularly when a multitude of configurations are possible);
- Aircraft that are flying in the area where splitting will take place are not handed over properly.
- De-collapsing of sectors (the more critical process) does not take place in a timely manner.

Protocols or checklists should be in place to mitigate these hazards. The protocols or checklists should be an integral part of the split or merge procedure. These must ensure that the new sector(s) are handled in a systematic way and that all relevant members of the macro-team are fully in-the-loop before the split or merge takes place.

5.7.4 Dynamic re-sectorisation

Dynamic re-sectorisation is more complex than splitting or merging two sectors. After all, there are more different options then just split or merge. As such, there are more hazards associated with it. Hence, procedures or checklists must deal with all possible variants.

5.8 Summary

This chapter discussed four advanced sector staffing options relative to the standard manning of one PC and one TC per sector. These options are:
- MSP;
- SPO;
- Collapsing/De-Collapsing Sectors;
- Dynamic re-sectorisation.

These options have been discussed with respect to the most important teamwork implications, the factors impacting team performance, the obstacles encountered in the creation of successful teams, and operational considerations, e.g. related to the layout of controller working positions.

Notes:
- Staffing options can be relatively permanent or steady in time (same staffing configuration throughout shifts/watches) or dynamically depending on situational variables.
- MSP, SPO and dynamic re-sectorisation, need to be supported by automated tools. Collapsing/de-collapsing of sectors may be aided by automation.
- Return to the ‘standard’ configuration, after having operated with one of the discussed staffing option, may often take place during a period with increasing traffic levels/ task load. Particularly de-collapsing/collapsing of sectors under these circumstances can be considered a time-critical process.
- Also, with all staffing options, position hand-over becomes a more complicated process

Obviously, each staffing option has its benefits and drawbacks, however the effects of these benefits and drawbacks depend on the actual implementation environment, for which, for example, the following questions can be posed:
- Does the new staffing concept improve ATM?
- Can the system be fitted to the new staffing option?
- Is the staffing option compatible with how the centre operates today and how it will operate in the future?
- Is the staffing option compatible with the organisational staffing?

Rather than giving the impression that there are large benefits or drawbacks associated with a particular staffing option, the purpose of this chapter was primarily to identify the potential benefits and drawbacks and think about mitigation means for the latter.

Potential benefits and problems are summarised in Table 5, in which it is assumed that the following are issues that need to be considered and examined:
- Co-ordination when more co-ordination within the sector team and between teams is needed in comparison to the standard staffing option.
- Cross-monitoring when cross-monitoring between team members diminishes.
- Position hand-over when position hand-over requires more complicated procedures.

- When additional automation is necessary to enable a specific staffing option.
- When system degradation is likely to have more negative consequences than in the standard staffing option.
- When, with the new staffing concept, workload is more difficult to regulate within the team.
- When different attitudes or working styles are required in comparison with the standard concept.
- When it is more difficult to select and compose the appropriate team for the staffing concept.
- When measures need to be taken to re-design ATC tasks to enable teamwork after implementation of the staffing concept.
- When new training-objectives need to be formulated and/or extra training is needed.
- When the working environment (position, centre, airspace) has a negative impact on teamwork or need to be changed.
- When OJT in its current form need to be changed.

Table 5: Summary of the benefits and drawbacks of the general staffing options (? = don't know, 0 = no effect / neutral, +/- = effect can be either way)

	Productivity	Co-ord. / DM	Cross-monitor	Hand-over	Automation	Degradation	WL/ Stress	Attitude / Style	Team selection	Task design	Training	Work environ.	Work organ.	OJT
Standard	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSP-1	+	0/-	-	-	-	-	-	?	0	-	-	-	-	0/-
MSP-2	++	0/-	-	-	--	-	-	?	0	-	-	-	-	0/-
SPO	+++	++	--	-	?	-	-	-	+	+	+	-	+	0
Collapse/De collapse	+++	-	0	-	?	--	++	0	0	+/-	-	-	-	0
Re-sector	?	-	0	-	--	--	++	+/-	0	+	-	+/-	-	0/-

6 Framework to assess staffing options

6.1 Introduction

Changing a staffing concept permanently can be a complex and challenging task for an ANSP, which will probably also include changes to the ATC system itself (e.g. the HMI). The aim of this study was to propose a framework to guide the assessment of the expected impact on teamwork when considering different staffing options. The scope of the current framework is limited in its application to the en-route environment. The objective is to provide a structure for resolving issues related to team co-ordination in an ATC environment when considering and implementing different staffing options.

It is envisaged that the application of the framework is embedded within an overall system change transition lifecycle. Thus applicable to projects in which changes in teamwork in en-route sector teams are foreseen.

The framework is based upon:

- A general model of the transition phases (steps) in ATM Projects. This model consists of five steps, i.e. (1) ‘Definition and feasibility’, (2) ‘Requirement Validation’, (3) ‘Procurement/Development’, (4) ‘Transition to Ops’, and (5) ‘Implementation’. For the current purposes, i.e. assessing staffing options, the step ‘Procurement’ is left out.
- The three main avenues to create a successful team: (1) team selection, (2) task design and (3) team training. These avenues were introduced in Chapter 2. The activities that are needed to resolve specific teamwork issues and that are comprised in each step of the aforementioned general model, can be grouped according to these three avenues.

6.2 Outline of the framework

Table 6: The four steps of the framework

1	Definition and feasibility
2	Requirement validation
3	Transition to Ops (Pre-implementation)
4	Implementation

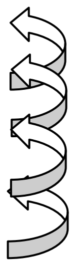


Table 6 lists the four steps of the framework. The arrows depict the re-iteration of previous steps when the output of any step does not fulfil pre-defined criteria.

1. In the definition and feasibility step a ‘concept of operations’, including team operations, is developed. In addition a set of operational requirements is identified, and its feasibility assessed.
2. In the requirement validation step, detailed ‘operational scenarios’ will be defined on the basis of the concept of operations from the previous step. These scenarios form the basis for the development of e.g. training materials, and the definition of (prototype) systems to be procured.

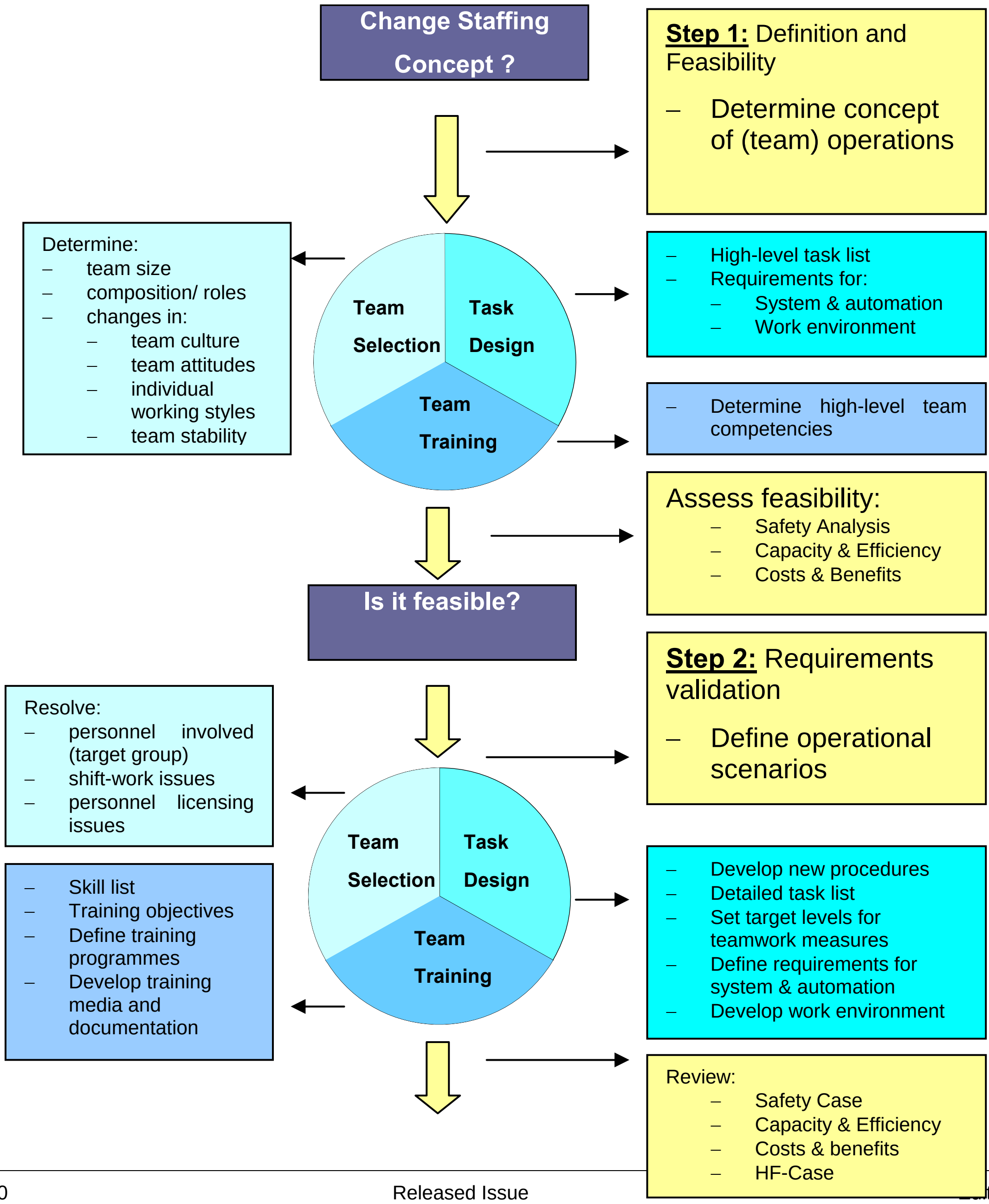
3. In the pre-implementation step, the operational scenarios will be tested using suitable techniques, e.g. elicitation of operational experts or simulation experiments. Experimental teams will be trained.

4. In the implementation step, the first actual trials with the new staffing concept will take place including installation of any hard and software system changes. Validation and training are performed. The new system will initially run in shadow mode, and when all possible issues, hick ups and problems are mitigated the old system will be dismantled.

6.3 *Framework Description*

Figure 6, below, depicts the subsequent steps and activities in the framework. Overall, the following questions need to be clarified:

1. Is it feasible to change the staffing concept?
2. What operational-, system-, HF- and safety requirements are necessary?
3. Are the requirements valid?
4. How can the staffing concept be implemented into operations?
5. How effective has the staffing change been?



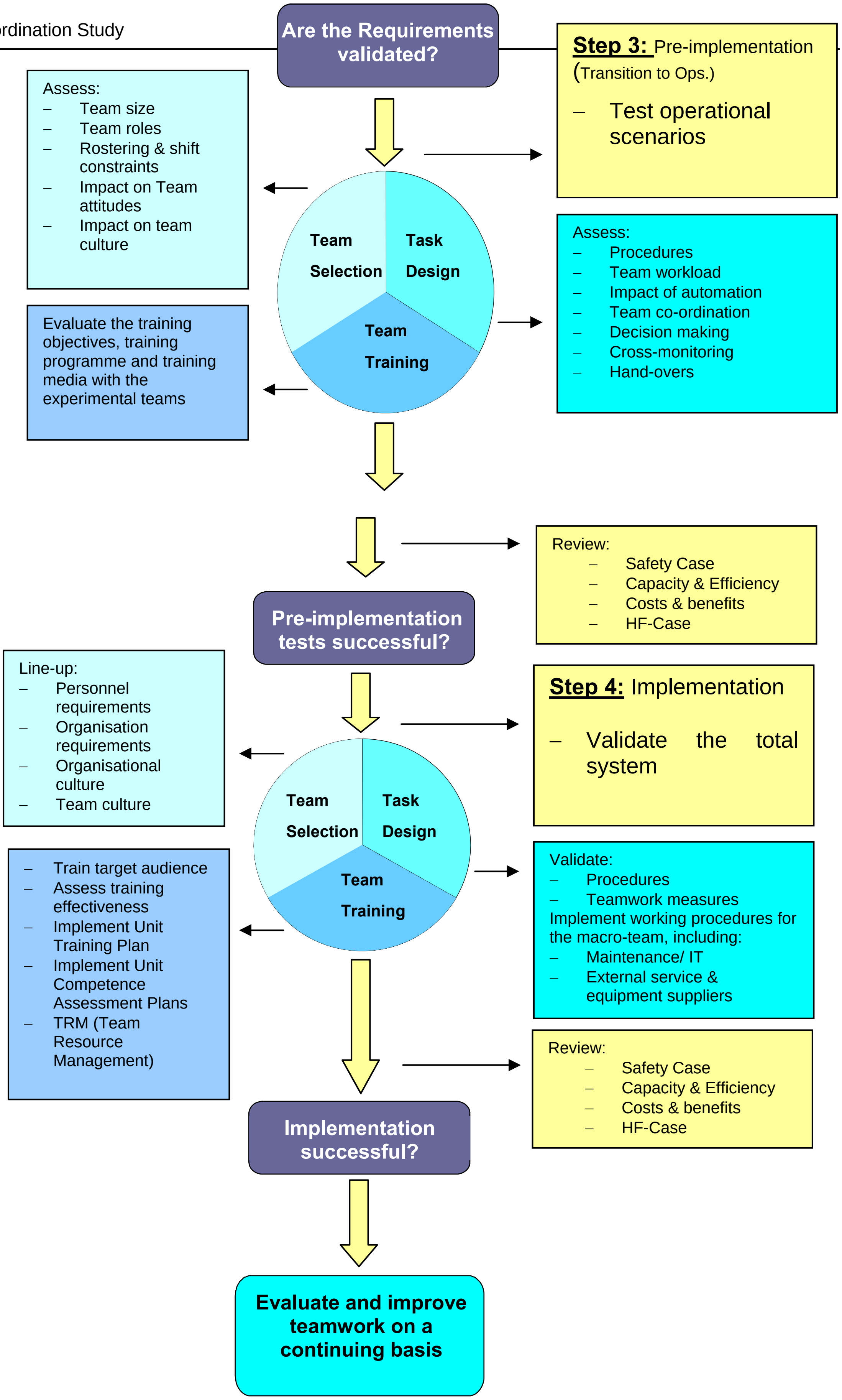


Figure 6: Diagram of the Framework

6.3.1 Step 1: Definition and Feasibility

General activities
- Definition of the concept for (team) operations (see chapter 5)

Activities concerning team selection
- Determine sector team size
- Determine composition of the sector team
- Define roles of each team-member

Activities concerning task design
- Define high-level tasks for the team
- Define operational requirements for the system, the automation and the working environment

Activities concerning training the team-members
- Define the high-level team competencies

Criteria to conclude step 1
- Estimated sector capacity
- Estimated operating costs
- Estimated safety level
- Estimates of HF-criteria for the new staffing concept, such as those used in Ch. 5:
  - Is less/more co-ordination within the sector team and between sectors needed in comparison to the current situation?
  - Will cross-monitoring between team members diminish/increase?
  - Will hand-over require more complicated/simpler procedures?
  - Are additional automation aids necessary to enable the staffing change?
  - Is system degradation likely to have more negative consequences?
  - Is, with the new staffing concept, workload more difficult/easier to regulate within the team?
  - Are different attitudes or working styles required?
  - Is it more difficult/easier to select and compose the appropriate team for the new staffing concept?
  - Is it needed to re-design ATC tasks to enable teamwork in the new concept?
  - Do new training-objectives need to be formulated or is extra training needed?
  - Does the working environment (position, centre, airspace) has a negative impact on teamwork or need to be changed?
  - Is it needed to change OJT practices?

6.3.2 Step 2: Validation of requirements

General activities
- Definition of the operational scenarios (using a task-analysis technique, e.g. cognitive walkthrough)

Activities concerning team selection
- Determine which personnel is involved in the new staffing concept
- Determine changes in shift-work
- Check the appropriateness of current licensing practices

Activities concerning task design
- Develop new procedures
- Describe team tasks at detailed level (on the basis of operational scenarios and the high-level tasks of step 1)
- Set target levels for teamwork measures
- Define requirements for systems and automation
- Define the working environment
- Procure, when necessary

<u>Activities concerning training the team-members</u>
- Identify new team competencies
- Set the training objectives
- Design or adapt the training programme
- Develop/procure training media and documentation

<u>Criteria to conclude step 2</u>
- Update of estimate for sector capacity
- Update of estimate for operating costs
- Update of estimate for safety level
- Fine-tune/ confirm the estimates for HF-criteria of the previous step.

6.3.3 Step 3: Pre-implementation

<u>General activities</u>
- Test operational scenarios, possibly in an experiment

<u>Activities concerning team selection</u>
- Assess required team size, team roles, rostering and shift constraints, impact on team attitudes and impact on team culture

<u>Activities concerning task design</u>
- Assess required procedures, team workload, impact of automation, team co-ordination, decision making, cross-monitoring, and hand-overs

<u>Activities concerning training the team-members</u>
- Evaluate the training objectives, training programme and training media with the experimental teams

<u>Criteria to conclude step 3</u>
- Sector capacity confirmed by tests
- Operating costs confirmed by tests
- Safety level confirmed by tests
- HF-criteria confirmed by tests

6.3.4 Step 4: Implementation

<u>General activities</u>
- Validate the total system, initially in shadow mode

<u>Activities concerning team selection</u>
- Line-up: personnel requirements, organisation requirements, organisational culture and team culture

<u>Activities concerning task design</u>
- validate procedures and teamwork measures
- Implement working procedures for the macro-team, including maintenance and IT department, external services, equipment suppliers and possibly flight crew

<u>Activities concerning training the team-members</u>
- Train target audience
- Assess training effectiveness
- Implement or update the unit training plan
- Implement or update the unit competence assessment schemes
- Possibly implement TRM (Team Resource Management) training

<u>Criteria to conclude step 4</u>
- Sector capacity
- Operating costs
- Safety level
- HF-criteria

6.4 Summary

The framework serves as a guide to ensure that all relevant issues related to team changes have been given attention. At each step teamwork-related questions can be posed.

By means of providing a summary, such questions are listed in Table 7 below. The questions pertain to (1) the current situation, (2) the proposed or future situation. This distinction may highlight unanticipated effects, and helps to find resolutions for undesirable effects.

Not necessarily all questions in Table 7 are applicable to each change. The questions do not need to be answered in the listed order. Answers to these questions may be found using different methods, e.g. through discussions with team members / experts, through experimental data collection, modelling, or team task–analysis. See also chapter 7 for more details on methodologies for obtaining answers concerning team change related questions.

Table 7: Questions to be posed at each step of the framework

Factors to consider	Element	Existing team	Proposed team

Definition		- What are the specific team qualities in a team?
		  - Which team-tasks have to be performed?
		  - Under what conditions have these tasks to be performed?
		  - Which team competencies does the task require?
		  - What are the important team qualities to maintain and preserve?
		- Are there already 'good practices' with respect to teamwork at the ANSP, e.g. for OJT, shift-work, TRM, position hand-over, etc.?
			- Which tasks will change and consequently which competencies are affected?

Creating Successful teams	Team Selection
	Task Design
	Team Training
		- What are the aspects now of :
		  - selecting team members
		  - team size
		  - team composition
		  - team stability
			- Is it more difficult/easier to select and compose the appropriate team for the new staffing concept?
			- Which changes in team-size/ composition are viable?
			  - selecting team members
			  - team size
			  - team composition
			  - team stability
			- Which changes in team-size/ composition are viable?
			- Is it needed to re-design ATC tasks to enable teamwork in the new concept?
			- Do new training-objectives need to be formulated or is extra training needed?

Table 7: Questions to be posed at each step of the framework (continued)

Factors to consider	Element	Existing team	Proposed team
Teamwork implications	Co-ordinating and decision making Cross monitoring and cross checking Position handover Other teams and macro team	- Which team tasks may occur in this specific unit, in normal and non-normal situations? - How is it ensured that, despite the serial structure of many team-tasks, the team is prevented from system overload? - How is safe co-ordination between teams ensured?	- Is less/more co-ordination within the sector team and between sectors needed in comparison to the current situation? - Will cross-monitoring between team members diminish/increase? - Will hand-over require more complicated/simpler procedures? - Does the change in teamwork introduce new (previously unnecessary) team-coordination tasks? - Is, after changing the team concept, all information necessary for making decisions available for the team-members? - Is co-ordination between teams still ensured in new composition? What are the differences with the current situation?

Factors affecting team Performance	Automation	- What is the current level of automation concerning:
		  - decision making,
		  - information
		  - action implementation
		- What are the required competencies of ATCOs that result from the current level of automation?
		- Is there a relationship between the age of ATCOs and the ability to handle the system in the current situation?
			- Are additional automation aids necessary to enable the staffing change?
			- Will the proposed automation support affect:
			  - decision making
			  - available information
			  - action implementation.
			- Will there be a relationship between the age of ATCOs and the ability to handle the system in the future situation?

	Degraded modes	- What happens in unpredicted degraded modes of operation? - How does the team cope with the fall-back system, which depends on proficiency with the system and the potential assistance from other ATCOs?	- Is system degradation likely to have more negative consequences? - How will the team cope with the fall-back system, which depends on proficiency with the system and the potential assistance from other ATCOs?
	Workload	- How do team members monitor workload within the team? - How do team members pick-up verbal and non-verbal signals of extremes in workload of team-members, including the so-called overshooting relax response? - How is staffing organised to allow for flexible redistribution of workload over the team members? - What are the typical chokepoints with respect to team workload?	- Is, with the new staffing concept, workload more difficult/easier to regulate within the team? - How will team members monitor workload within the team? - How are team members able to pick-up verbal and non-verbal signals of extremes in workload of team-members, including the so-called overshooting relax response? - How will staffing be organised to allow for flexible redistribution of workload over the team members - Will current chokepoints change after the team change? Are there new chokepoints? And are there ways to mitigate extreme workload levels?

Table 7: Questions to be posed at each step of the framework (continued)

Factors to consider	Element	Existing team	Proposed team

	Attitude	- What is opinion of team members about the current workshare?	Are different attitudes or working styles required?
			- How could the attitude of team members towards teamwork be impacted by the proposed change?
			  - level of trust in the team
			  - preferred team working styles which promotes tacit understanding between them and the development of a shared mental model.
			- How do team members feel about the proposed changes?

	Culture		- Describe (foreseen) changes in team culture concerning safety and the organisation. - How would that culture change influence team performance?
Operational Considerations	Airspace, capacity and working positions	- How many working positions are there now, and where are they located (in relation to each other)? - How are sector- and macro teams related to the physical layout of working positions?	- Does the new staffing concept improve ATM? - Can the system be fitted to the new staffing option? - Is the staffing option compatible with how the centre operates today? - Is the staffing option compatible with the personnel organisation? etc. - What will be the number and layout of working positions in the new concept?
	Staffing and shift work	– What are the rostering / shift work constraints in the current concept?	What will be the rostering / shift work constraints in the future concept?

	OJT		- Is it needed to change OJT practices?
			- How does the future team composition influence OJT opportunities? Think of:
			  - Experienced ATCOs with less experienced ATCO working in one team
			  - Moments of low workload that enable less experienced ATCOs to familiarise with new sectors or working concepts.

7. Existing team assessment methodologies

7.1 Introduction

This chapter lists a number of methodologies that are designed to assess team aspects and contains some hints to take into account when choosing a methodology to apply.

When applying the framework, there are variables that need to be measured. A number of the methodologies that are listed here may be good candidates for measuring these factors.

7.2 Methodologies that were identified

A great number of methodologies for assessment of (team) behaviour were identified and detailed in Appendices 5 and 6. Table 8 lists a subset of methodologies to assess team behaviour.

Table 8: A subset of methodologies for assessment of team behaviour

Team assessment methodology	Primary references	Brief description of tool
SHAPE toolkit	EUROCONTROL (2005)	A set of questionnaires and rating scales to measure: trust, SA, consequences for teamwork, age required skills and workload of teams.
NLR Norway towers	Zon (2005) Roerdink (2005) Jong (2004)	A method that was successfully applied during a study of ATC teams in towers at small airports in Norway. It comprises a hierarchical task analysis, structured interviews, workload assessment and observations during execution of tasks. This approach is explained in more detail Appendix 5.
Hierarchical task Analysis for Teams (HTA(T))	Annet et al. (2000)	A dedicated Hierarchical Task Analysis for Teams (HTA(T)). It describes order of tasks that are performed within a team. It does not describe the (cognitive) load that the team members experience during execution of the tasks.
Behavioural Observation Scales (BOS)	See Stanton (2005)	Behavioural Observation Scales (BOS) trained domain experts rate the behaviour of team members on a number of dedicated scales during observations of those team members while they are performing their tasks.
Co-ordination Demands Analysis (CDA)	See Stanton (2005)	Co-ordination Demands Analysis (CDA) describes the co-ordination of actors within teams. It is based upon teamwork related behaviours like: SA, decision making, mission analysis, leadership, adaptability, assertiveness and total co-ordination.
Groupware Task Analysis (GTA)	Welie and van der Veer (2003)	GTA analyses team activity in such a way that its results can be input for design and analysis teams. Therefore GTA can prove very useful when designing new systems, processes or teams in an organisation.
Team Cognitive Task Analysis (TCTA)	Klein (2000)	TCTA describes cognitive skills and processed of teams during task performance. It is primarily based upon interviews and its output comprises: control of attention, shared SA, shared mental models, application of strategies and metacognition.
Team Workload Assessment (TWA)	Jentsch and Bowers (2004)	TWA Measure team and team member workload. It is based upon a modified version of the NASA-TLX.
Task and Training Requirements Analysis Methodology (TTRAM)	Swezey et al. (2000)	TTRAM identifies team based training requirements. As such the technique may be relevant when a proposed change is expected to require additional training.

7.3 Applying methodologies

When applying the methodologies listed in Table 8 the following factors should be taken into consideration:

- Does the methodology measure what is required? Does it not measure more, or less, than that? When a methodology measures less than what is required the answers that one is looking for may not be found. When it measures more it is likely that the methodology is more complex, effortful, costly or troublesome to apply.
- The validity of the methodology may be an issue. Is the methodology validated in such a way that one can assume that the methodology indeed measures what it claims to do?
- Does the methodology interfere in an unacceptable way with the tasks that the team is performing? When a team is hindered by the measurements and therefore are not able to perform their task appropriately it needs to be established whether that is acceptable, or whether the undesired side effect of the methodology is worth the output that the methodology gives.
- Are the resources that are needed to apply the measurement available? “Resources” refers in this context to a number of factors. Examples are: is the experience that needed to perform the measures available? Is the effort that is required (from team as well as research staff) available and acceptable?

7.4 Summary

This chapter highlighted key elements of methodologies that were identified as useful ways for measuring aspects of teamwork/team co-ordination when changing staffing options, in particular:

- Hierarchical or cognitive task analyses to get clear descriptions of what the team tasks are, how they relate to each other, and for the latter one the cognitive demands of the tasks.
- Rating scales to measure different aspects of (team) behaviour. Examples are workload, SA or trust.
- Methods that are designed for special purposes that are related to changes in team activity. Examples are training requirements or for design of new systems, processes or teams.

When choosing methodologies to apply, it is recommended to verify its:

- Validity
- Unacceptable interferences with the task
- The practical feasibility to apply the method

When considering specific changes in teamwork, it is important to understand for the existing team:

- That HF aspects of teamwork need to be assessed in the current and future situation and that looking at the differences between those two is the core of the analysis.

For the proposed changes in teamwork it is important to understand:

- The different concepts that are measurable and to find the optimal match between the changes that need to be measured and the methodologies that are available.

8. Conclusions

There is large interest among ANSP in the introduction of new staffing concepts due to trends in automation support, the potential increase in efficiency and capacity of more advanced concepts of airspace management, e.g. in the context of SESAR, and the potential economical advantages thereof.

This study carried out a literature review to get a better understanding of how ATCO-teams co-ordinate and share information. This is an important baseline to establish prior to embarking or considering other staffing options such as MSP, SPO or removing or automating a task. In addition, this study proposes a framework to guide the assessment of the expected impact on teamwork when considering different staffing options.

The main conclusions/findings from the study are:

- An ANSP has basically three instruments to create successful teams to staff their ATC units: selecting the appropriate teams, designing the appropriate ATC tasks to be performed by these teams, and providing the appropriate training such that these teams have the suitable competencies (skills, knowledge and attitudes) to perform those tasks.

- When making the transition to a new staffing concept, essential competencies of the team need to be preserved and the team needs new competencies to cope with new tasks, such as more complicated forms of hand-over, back-transitions to the standard staffing concept in operations with degraded system modes, etc.

- The competencies required for teamwork in an en-route centre are mostly task-specific under normal operating conditions, however some task-generic competencies are required under non-normal operating conditions. At en-route centres with many operational ATCOs, fellow team-members may change frequently (from shift to shift). This requires team-generic competencies.

- Teamwork in en-route control is largely serially structured by nature. With little flexibility between the team-members (in terms of assisting each other whenever required) the team would be more susceptible to overload.

- The most important factors influencing teamwork and team performance when considering staffing concepts are:
  - automation support,
  - system degradation,
  - team workload,
  - attitude of team-members towards teamwork,
  - working style, and
  - team culture.

- The following four staffing concepts have been analysed: (1) MSP, (2) SPO (3) collapsing/de-collapsing of sectors, and (4) dynamic re-sectorisation. The flaws and benefits of each are discussed with respect to the following :
  - teamwork implications,
  - factors impacting team performance,
  - creating successful teams,
  - operational considerations e.g. characteristics of ops room, organisation of shift-work, staffing and OJT.

- Obviously each staffing option has its benefits and drawbacks, however the effects of these benefits and drawbacks depend on the actual implementation environment and the following questions concerning teamwork should be addressed:
  - Is less/more co-ordination within the sector team and between sectors needed in comparison to the current situation?
  - Will cross-monitoring between team members diminish/increase?
  - Will hand-over require more complicated/simpler procedures?
  - Are additional automation aids necessary to enable the staffing change?
  - Is system degradation likely to have more negative consequences?
  - Is, with the new staffing concept, workload more difficult/easier to regulate within the team?
  - Are different attitudes or working styles required?
  - Is it more difficult/easier to select and compose the appropriate team for the new staffing concept?
  - Is it needed to re-design ATC tasks to enable teamwork in the new concept?
  - Do new training-objectives need to be formulated or is extra training needed?
  - Does the working environment (position, centre, airspace) have a negative impact on teamwork or need to be changed?
  - Is it needed to change OJT practices?

- The framework proposed aims to facilitate how to assess the expected impact on teamwork when considering different staffing options. The objective of the framework is to provide a structure and focus on key team co-ordination criteria in an ATC environment when considering different staffing options. It is envisaged that the application of the framework is embedded within an overall system change, consisting of four general steps:
  - Definition and feasibility;
  - Requirement validation;
  - Transition to Ops (Pre-implementation);
  - Implementation.

- Since each step is concluded with a check against teamwork-criteria, assessment of teamwork is central to the framework. To this end, an important part of the literature-review has been dedicated to identifying and describing appropriate team assessment techniques in experiments, expert-elicitation and team-task-analysis.

- The framework that results from this team-co-ordination study should be considered as a starting point for understanding the challenges and complexities impacting teamwork when changing the ATC-team. To build forth on findings and conclusions from this study during 2008, it is recommended to build synergy within EATM Programmes (e.g. FASTI, see EURCONTROL, 2007d) that may envisage simulations on staffing changes and automated tools for controllers and encourage the sharing of lessons learned from projects carried out by ANSPs. This would help to establish and validate the findings from this study.

Appendix 1 - Team Tasks

1	Call for an (extra) PC
2	Delegate writing on strips
3	Give flightstrip to other controller
4	PC cross-checks TC via radarscreen
5	PC cross-checks TC by listening to R/T
6	TC cross-checks PC via stripboard
7	TC cross-checks PC by listening telephone calls
8	Share observations and predictions (inconsistencies, errors, separation, deviations, weather, capacity problems, etc.)
9	PC and TC actively compare data
10	PC and TC (tacitly, implicitly) reassign tasks based on traffic situation
11	Point out (to TC) aircraft that can be transferred
12	Point out weather features, aircraft parameters, designation, etc., where appropriate
13	Share plans with respect to traffic flows
14	Share plan in response to weather situation
15	Share plan with respect to special use of airspace
16	Share plans with respect to lost aircraft
17	Call another sector on demand
18	Assist in building a solution for potential problem
19	Delegate responsibility for separation in specific area of the sector
20	Accept responsibility for separation in specific area of the sector
21	Divide the strip-board / planning task between two ATCOs
22	Engage in the splitting and merging of functions, sectors or areas to cope with team task load
23	Monitor other team members for workload
24	Prevent other team-members of attention decrease
25	Prevent other team-members from decrease in SA
26	Controller builds-up traffic picture before taking over position
27	PC hands-over position to PC of next shift
28	PC takes-over position of PC from previous shift
29	TC hands-over position to TC of next shift
30	TC takes-over position of TC from previous shift
31	PC co-ordinates a solution with previous sector
32	PC co-ordinates a solution with next sector

33 PC tells/shows TC solution of a co-ordinated problem

34 PC makes TC aware of an unresolved co-ordination problem

35 PC co-ordinates with military ATC concerning military flights

36 Engage in a controlled transition to different working strategy / procedures

37 Engage in an emergency transition to different working strategy / procedures

38 Notify adjacent units of a non-normal situation

39 Monitor availability and serviceability states

40 Manage degraded systems – ask for human support in tasks normally accomplished by a single controller.

41 Call for assistance / notify in case of system problems

42 Anticipate each other’s reactions, capabilities and acceptance-levels.

43 Engage in (de-)briefing

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Appendix 2 – Workload in ATC

1 Workload peaks

Fluctuation between low workload and high workload are common in teams of ATCOs, mainly due to fluctuations in traffic-load, although adverse weather, degraded equipment, loss of aircraft and other non-normal situations may also be causal to workload peaks.

The team is trained to cope with such fluctuations and can handle different levels of traffic up to a certain limit. However, a sudden peak of workload, i.e. a relatively large increase in workload compared to the average level, requires different working strategies.

A study performed by Sperandio (1971, quoted by Wickens et al., 1997) demonstrated that ATCOs adapted their way of working to a sudden increase of traffic by decreasing the amount of time devoted to each aircraft. The highest priority is given to ATC related tasks, while less important tasks are postponed and/or discarded. Another way of coping with such a situation is by delegating tasks to a colleague of the team, or by temporarily assistance of ATCOs not belonging to the core team, i.e. the sector team (see e.g. EATMP, 1999, Intuilab, 2007).

Whether a sudden increase in task load has an effect on performance, is determined by several factors. An increased task load can be compensated by additional attentional resources from the ATCO, which creates the feeling of increased mental workload, but can also be compensated by changes the in working strategies mentioned above.

The relationship between task load and ATCO workload is however not linear. Lee et al. (2005) report that ATCOs often report a low to moderate level of workload for a seemingly busy traffic-situation but report much higher workload with few added tasks and/or minor off-nominal events once a certain traffic level is reached. In general, there seems to be a non-linear relationship between experienced workload and objective metrics. An ATCO may *perceive* the workload to be low until the traffic and associated task load reach a critical point, after which s/he perceives the workload to be high.

When this critical point is reached and high workload is experienced, and compensation (see above) measures are not sufficient or not possible, the high workload can impact the team's ability to handle traffic, and set a limit on the number of aircraft that can be controlled. Obviously, the latter situation is prone to operational errors and implies a safety risk.

One of the recommendations of EATMP (2006a) is that ATCOs should be informed, sensitized and trained with respect to the typical human 'overshooting relax' response after high workload / stress peaks.

2 Workload dips

Although overload can negatively impact performance, underload can also have an adverse effect on performance. Wickens et al. (1997) mention that low traffic load can result in boredom and a reduced level of alertness. For a task like en-route control, a certain level of sustained attention is needed, for which the term *vigilance* is used. This refers to the ability to detect, interpret and respond on certain changes in the environment. Wickens et al. (1997) state that maintaining vigilance for critical (and infrequent) events such as loss of separation, altitude deviations and incorrect pilot readbacks is an important component of the ATCO's task.

Many studies have indicated that vigilance decreases after time, when no changes in the environment were present. This means that the ability to act correctly and rapidly on the occurrence of events decreases over time (which is stronger when the occurrence of the event has a low probability). In the context of ATC, this means that it will be more difficult to detect and react on an event (e.g. traffic flying into the sector) when it occurred after a long period of low task load and when the event was unexpected. Such a situation of low task load can easily lead to the experience of low workload. However, if one is trying hard to maintain attention at a sufficient level under low task load conditions, this may create the experience of high workload.

Although maintaining vigilance is one of the core features of the team's job, few studies have been performed in operational team settings. Such studies still have to be performed to identify more closely what the influence will be on the team's performance.

3 Stress

In addition to workload, stress may impact the individual worker. Cartwright and Cooper (2005) define stress as any force that puts a psychological or physical function beyond its range of stability, producing a strain within the individual. Knowledge that stress is likely to occur constitutes a threat. A threat can cause a strain because of what it signifies to the individual. However, there is no single universally agreed to definition of stress and consequently no single measure that will tell us when a person is stressed or operating under stressful conditions (Hancock and Desmond, 2001, Bourne and Yaroush, 2003).

Some conditions have generally been accepted as stressful. For ATCOs these include, but are not limited to, sleep deprivation, extreme heavy or prolonged workloads, time pressures, social pressures, and intense negatively-toned emotions. Stressors are events that, among other things, challenge or threaten the well-being of an organism, increase its activation level, and deplete its resources (see, e.g., Hobfoll, 1991 in Bourne and Yaroush, 2003).

With respect to activation levels of the human operators, EATMP (2006a) provides a guideline that the optimal level of arousal is:

- Lower for more difficult or intellectual (cognitive) tasks (the human needs to concentrate on the material)
- Higher for tasks requiring endurance and persistence (the human needs more motivation)

It has been widely reported that stress is detrimental to complex cognitive activities, such as problem solving.

Stressors can be extraneous (non-work stress) or indigenous (stress created by the task). They can arise from endogenous or exogenous sources. The resulting stress states can be time limited (acute stress), as in responses to a single transitory event, or they can persists in time (chronic stress). Normally, human beings respond to stressors either through extraordinary mental or physical effort or by exhibiting degraded performance. Extreme effort over time in response to chronic stress can result in either mental or physical exhaustion or injury (see, e.g., Kolich & Wong-Reiger, 1999 in Bourne and Yaroush, 2003)."

For the current study we consider workload as one of the sources of stress (Cooper, Cooper & Eaker, 1988). Stress, in the same sense as overload, is detrimental to performance. Redefinition of teamwork should take into account the dangers of overload and stress.

Specific areas of stress, highlighted by Austrian ATCOs, as reported by EUROCONTROL researchers (in EATMP, 2006a) were:

- Decisions that ATCOs have to make are complicated
- Difficult situations occur fairly often
- Quick reaction and decision requirements cause enormous time pressure
- Other stress factors are monotony, mental fatigue and mental saturation in periods with less traffic or fewer problems. ATCOs find it problematic during these phases to react quickly to an incident which occurs suddenly and threatens safety.

The same study reports that separation losses are the most stressful situations for ATCOs. For the majority of ATCOs the following situations are stressful:

- complex traffic mixes (large numbers of aircraft with different specifications);
- short radio outages;
- high-density traffic;
- emergency situations shortly before the end of a shift;
- radar image disruptions or otages;
- bad weather;
- slow colleagues;
- realising that not the best decision had been taken;
- radio interference;
- unjustified criticism from their superior;
- noise, heat.

As far as burnout is concerned, being the result of prolonged (chronic stress), the EUROCONTROL study (EATMP, 2006a) under Austrian ATCOs revealed that ATCOs proved to be at little risk of burnout. Further the study revealed that ATCOs often have traumatic experiences (which are not properly dealt with, e.g. through psychological counselling, which affect their working methods for a long period (years).

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Appendix 3 – Attitudes and Working Styles

For the measurement of attitudes towards teamwork some form of Likert scaling is usually favoured. Likert-type scales include a series of positive and negative statements about teamwork, and respondents endorse one of a series of graded response options (e.g. strongly disagree, slightly disagree, neutral, slightly agree, strongly agree, respectively). Points are allocated to each response option (e.g. 1, 2, 3, 4 or 5 points). The sum of these values represents ‘attitude strength’.

Motamedzade et al. (2002) designed a questionnaire that measured (among other things) attitudes towards teamwork in an industrial environment. Questions, using a five-point scale, referred to topics such as:

– size adequacy of the team;
– ability of team members including technical expertise, problem solving and decision-making;
– personal and interpersonal skills;
– clarity of roles in team;
– having a vision and commitment to it;
– establishment of goals at the team level;
– leadership and structure at the team level;
– accountability of team members at both individual and team level;
– evaluation and reward system in team;
– developing high mutual trust in the team;
– continuous learning process as one of the main functions of team;
– willingness to protect each other and maintain identity of the team;
– conflict resolution in team;
– changing attitude towards the organisation;
– behavioural changes at both personal and team level;
– sense of ownership toward work done by team members.

Sherman and Helmreich (1995) used the Flight Management Attitude Questionnaire to measure the attitudes of pilots towards automation in the cockpit. They report that three main factors affect this attitude:

– National culture,
– time spent flying automated aircraft,
– seniority of crew member.

EATMP (1999) reports on the Air Traffic Control Safety Questionnaire (ATCSQ), which was developed to enable the evaluation of the EUROCONTROL TRM Programme. The questionnaire includes a section that measures the attitudes of ATCOs. The results, based on a response sample of 29 ATCOs - which was considered rather small, reveal that the course changes attitudes in favour of better and more cooperative teamwork and more sympathetic team roles.

In one section of the questionnaire (consisting of forty items) responses are given on a five-point Likert scale (from ‘strongly disagree’ to ‘strongly agree’). Items relating both to attitudes towards automation and attitudes towards teamwork among others include:

- ‘automation reduces the requirement for team members to monitor the traffic situation closely’;
- ‘team members share responsibility for prioritising activities in high workload situations’;
- ‘asking for assistance makes one appear incompetent’;
- ‘to resolve conflicts, ATCOs should openly discuss their strategies with each other’;
- ‘during periods of low work activity I would rather relax than keep busy with small tasks’;
- ‘increased automation reduces the need for team communication’.
- understandings and slips / error that need to be mitigated.

Appendix 4 – MSP Concept Study – NATS

1 Background

iFACTS (interim Future Area Control Tools Support) is a set of Tactical Tools (MTCD and Conformance Monitoring) for en route airspace. The O' date for London Area Control Centre (LACC) – 2009/10. During R&D Phase, also developed Planner Tools which similar tools, but driven by different trajectory data

The aim of future FACTS Development is:

- to apply tools to TMA airspace
- Develop planner tools further, leading to MSP
- Integrate datalink for Comms and Clearances
- Develop trajectory-based concepts alongside systemisations (PBN) i.e. 2D, 3D and 4D concepts as per SESAR (4D contracts)

The development of the FACTS tools will enable an operation of 1 Planner Controller to 'n' Tactical Controllers. There are expected early benefits in En Route in terms of efficiency (fewer controllers) or capacity (can open more sectors). However to achieve this MSP concepts there are three requirements that need to be fulfilled:

- Require MSP framework for TMA FACTS (1 Co-ordinator for 'n' Radar controllers)
- Baseline on which to develop the 4D trajectory and separation management concepts for SESAR
- Need to understand the architectural requirements for the underlying FDP system as early as possible.

2 MSP Concept

iFACTS provides tactical tools only in 1P1T environment. MSP role will be

- responsible for Super-Sector comprising 1 or more Tactical-Sectors. Co-ordinates entry and exit boundaries to Super-Sector
- Integrated Co-ordination (iTEC) – MTCD identifies problems that require Planner resolution, otherwise automatic offer / accept

MSP will use FACTS TP/MTCD Planner tools to identify suitable co-ordinations

Tactical Controllers work together to achieve overall MSP goal

- Tactical tools differentiate traffic by "responsibility"
- Transfer of control coincident with transfer of comms

MSP Concept

- support to Planner
- support to 'n' Tacticals

3 Benefits

- Allows evolutionary transition from 1P1T to 1PnT
- Enabler for FACTS Tools in TC (TMA airspace) (supports Co-ordinator concept in electronic environment)
- Support to two-centre strategy (commonality of co-ordination concept at Prestwick and Swanwick through Integrated Co-ordination)
- Fewer controllers needed to run given number of sectors allowing combination of:
  - Capacity increase – opening more sectors more often
  - Manpower efficiency – better use of controllers in Ops Room, fewer AAVAs, reduced "spinning", potential reduction in future recruitment needs, night-time bandboxing of ACCs(?)
  - Potential early implementation of 1P2T on LACC/iFACTS?
- Controlling efficiency:
  - Fewer clearances issued due to fewer boundary co-ordinations
  - Potentially fewer frequency transfers
  - Reduced need for standing agreements – more efficient level selection "tailored" to aircraft performance (also fewer reco-ordinations)
  - Planner manages complexity and balances workload
  - Easier / more efficient bandboxing and splitting – may only need to split Tacticals for short traffic peaks / OJTI
- Environmental benefits
  - Facilitates direct routings (potentially from FIR entry to exit)

4 Progress to date

- Project initiated in April 2005
- Development of Concept which involved a 'User Group' every 6 – 8 wks (controllers from each unit)
- First simulation workshop – December 06
  - Aim: is the concept viable?
  - up to and including 1P for 3Ts
  - using MACC (Manchester) airspace3 Sectors arranged into 5 organization configurations
    1. 1P 1T
    2. 1P 2T (S29 and North sector combined)
    3. 1P 2T (North and East sector combined)
    4. 1P 2T (S29 and East combined)
    5. 1P 3T (all three sectors combined)
  - encouraging feedback as to the viability of the concept

5. Key Findings of the Dec 2006 Simulation

- Overall view that MSP concept was viable but Tactical concept and support needed some refining

- Planner Issues:
  - Planner situational awareness (reduced? changed?) (who's working the aircraft?)
  - Planner to Tactical communication
  - vertical co-ordination – into the receiving sector?
- Tactical Issues
  - "active collaboration" versus "passive collaboration"
  - shared responsibility to separate, who initiates?
  - resolution of problems near (tactical) boundaries
  - Tactical to Tactical communication
- Internal (T-T) co-ordinations? Internal SAs

6. Current Plans

Technical areas are being worked on, including implementing recommendations from workshop and new functionality. A second MSP simulation is planned for May 2008 which will focus on the development of Tactical MOps concept to address issues from the first simulation and measurements to demonstrate benefit. A third MSP simulation is tentatively planned for Dec 2009 which will focus on advanced planning concept and integration of AMAN / P-RNAV technologies.

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Appendix 5 –NLR's Norway towers approach

NLR developed a methodology to study staffing changes and introduction of new technologies in ATC towers at Norwegian airports. The reason for this development was that both a Safety Assessment (S-A) and a Human Factors (HF) study had to be applied at a number of ATC towers on relatively small Norwegian airports. For reasons of efficiency and costs it was decided to combine both the S-A and the HF methodology in one procedure. The original S-A method (de Jong, 2004) was too extensive for the Norway study, as were the HF assessments usually performed by NLR. For the current study it is suggested to use an even simpler version of a method to study teamwork changes, with a stronger emphasis on the HF approach.

Prior to visiting the towers, the customer provided information on the type and frequency of traffic, weather conditions around the year, and procedural information on SIDS, STARS, poor visibility and missed approaches.

All towers were visited two times. During the first visit of each tower, the safety and HF researchers interviewed a number of ATCOs and assistants who were operational at that tower. The specific situation of the proposed changes (concerning staffing and the introduction of new technology), the ATC environment and characteristics of that particular airport were discussed. Safety as well as HF related items were included in those discussions. The HF specialist observed the ATCOs while they were at work in the tower. Hierarchical task analyses were performed and verified with the ATCOs and assistants.

After a first visit the researchers categorised the different issues that were mentioned, and wrote them on separate cards. These cards were used during the second visit. Examples of different categories are: inbound / outbound traffic, tasks and responsibilities, traffic mix, procedures, technical systems, seasonal influences and proposed changes.

During the second visit, sessions were scheduled during which a number of ATCOs and assistants individually sorted cards about potential risks that might result from the proposed changes. These were sorted according to severity and likelihood that particular events would happen. These sessions eventually resulted in assessments of risks and possible means of mitigation. Subsequently, the HF specialist participated in those sessions and visited the towers for additional observations. These observations comprised mental workload ratings at regular time intervals and ratings of communication frequencies between ATCO and assistant. Next, the observations gave the HF researchers opportunities to identify 'peculiarities' for that particular tower. Finally, discussions about possible mitigations for the issues that were raised during the previous sessions were performed.

The Norway studies resulted in recommendations for staffing and technological changes. Some examples with respect to a proposed staffing reduction were:

- Some tasks need to be refrained of, such as services to the outside world that do not necessarily have to be performed from the tower;
- Certain operations will take more time;
- The number and mix of traffic at rush hours need to be limited in order to avoid ATCO overload;
- The flexibility when having to respond to emergencies will be reduced.

More detail is provided in Zon (2005), Roerdink (2005) and Baren et al (2005). For each conclusion/ recommendation, arguments and data were included in the final reports. Special attention was given to potential risk and the options to mitigate these risks.

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Appendix 6 – Team Assessment Methodologies

1 Introduction

Different descriptions of team behaviour assessment and analysis methods have been reviewed. Some of these methods produce very detailed output but require a relatively large effort in their application. Quicker approaches measure only a limited set of variables. In this chapter, different ways to measure and present models are described. First, methods to represent shared mental models are described, subsequently an overview is given of methods that measure single aspects of team performance and finally an overview is given of methodologies that measure multiple aspects of team performance. See also Table 9.1 in Stanton et al. (2005) and Table 1 in Langan-Fox et al. (2000) for a comparable overview of some of these techniques.

2 Representing and Measuring Shared Mental Models

There are different ways of representing and measuring team (shared) mental models. Langan-Fox et al (2000) describe a number of these methodologies. The focus here, contrary to most of the other descriptions that have been reviewed, is not so much on the measurement aspects but on representation aspects. This is potentially useful for the current study since it provides an understanding of the consequences of changes in teamwork for team processes and productivity.

Team mental models can be measured and represented with a wide range of techniques, which are categorized below as either “Expert elicitation methods” or “Analysis and representation methods”. Expert elicitation is the synthesis of opinions of experts, i.c. ATC experts, ATCOs or unit managers, of a topic, i.c. teamwork, where there is uncertainty due to insufficient data.

Possibly such data is unattainable because of physical constraints or lack of resources. Expert elicitation is essentially a scientific consensus methodology. It is often used in the study of rare events. Expert elicitation allows for parameterization, an ‘educated guess’, for the respective topic under study. Expert elicitation generally quantifies uncertainty.

2.1 Analysis and representation methods

- Multidimensional scaling (MDS) – By visually representing those items that have more in common closer together in a graphical representation of all items. As a result, the correlations between items and the entire concept can be grasped in an eye blink.
- Distance ratio formula (DR) – The goal is to provide a metric (between 0 and 100%) that indicates the overlap between two mental models. Using this technique, the mental models of two team members can be compared.
- Pathfinder – a computerised networking technique, able to compare mental models.

Langan-Fox et al. (2000) provide an overview with advantages and disadvantages and recommendations for the area of application of each technique.

Paternò et al (1998) specify task models for cooperative applications to aid designers to create interfaces for multi user environments. ConcurTaskTrees is an existing tool, created by the authors. It is intended for the description of task models, which was originally limited to single user situations. Paternò et al. provide a new model for multi users (teams). It takes the teamwork of TC and PC in the en-route environment as a starting point. The authors describe three different tree structures for Hierarchical Task Analyses (HTAs), with a more extensive explanation of a specific HTA that comprises different structures for the tasks of each individual involved and additional trees for different interactions between individuals. This technique provides more manageable output when dealing with complex HTAs involving many individuals. As an illustration of the technique, an example for a TC/PC team is provided at the end.

The design methodology described in this article is not directly applicable when applying the Framework. However, when, as a spin-off of this work, a measurement methodology has to be created to represent team behaviour at a detailed level, the ConcurTaskTrees tool may be of value.

3 Measurement tools for aspects of team performance

Some tools don't claim to provide a complete assessment of team performance, but measure variables a limited number of variables that may contribute to assessment of team performance. These variables may be of relevance for the Framework. Therefore, this section provides descriptions of such variables.

3.1 Communication time as indicator of mental workload

Mental workload can be assessed in numerous ways. Porterfield (1997) reports that ATCO communication time can be considered as a measure of workload. In his study a strong correlation was found between "en-route ATCO ground-to-air communication" and subjective workload rated by the same ATCOs. Communication duration can thus be used as a (validated) measure of ATCO workload. Since workload is a relevant aspect of teamwork, and as such may be included in the TCF, this methodology itself could be part of it. The methodology is not intrusive for ATCOs, and relatively easy to record. Mental workload indications that are not intrusive and validated as well are the Air Traffic Workload Input Technique ATWIT (Stein, 1985 in Porterfield, 1997). Workload measures from ATWIT are:

- No. of a/c
- No. of altitude transitioning a/c
- No. of ATCO – pilot contacts
- No. of route or speed changes

3.2 Assessing the impact of automation: the SHAPE toolkit

EUROCONTROL's 'Solutions for Human-Automation Partnerships in European ATM' (SHAPE) Project deals with the impact of new automation on the ATCO. Seven factors need to be addressed for harmonization between automation (automated support) and ATCO:

- Trust in automated support
- Situational Awareness (SA)
- Teamwork consequences
- Age of ATCOs
- Skill set requirements
- Workload
- Managing system disturbances (how to deal with system failures)

Within the SHAPE project, questionnaires have been developed that serve to assess the impact of automation on workload, situational awareness, teamwork, and trust. With the exception of the teamwork questionnaire, the SHAPE tools are meant for assessment of impact of automation on a single operator, not a team of operators. In brief, the following questionnaires have been developed:

- *Assessing the Impact of Automation on Mental Workload (AIM)*. The AIM exists in a short and in a long version, referred to as AIM-s and AIM-l respectively. The AIM-l questionnaire comprises 32 items, divided into eight subtests with four items each. The AIM-s questionnaire consists of sixteen items, which are not further divided into subtests.
- *SHAPE Teamwork Questionnaire (STQ).* The STQ exists in a short and in a long version, referred to as STQ-s and STQ-l. The STQ-l questionnaire comprises 24 items, divided into six subtests with four items each. The STQ-s questionnaire consists of twelve items which are not further divided into subtests.
- *Situational Awareness for SHAPE (SASHA).* The SASHA questionnaire is available as short version only with a total of six items. SASHA delivers an overall score for situational awareness.
- *SHAPE Automation Trust Index (SATI).* The SATI questionnaire is available as short version only (six items). SATI delivers an overall score for trust in an automated system.

The SHAPE User Guide describes the questionnaire construction process and provides recommendations on the use of the questionnaires. The questionnaires, scoring keys, and a user manual are available from EUROCONTROL (2007b).

4 Team analysis methodologies

Stanton et al. (2005) found that during the last decades more and more work is done in teams and that as such more and more methodologies are created to measure team performance and team behaviour. They summarised twelve team assessment methods in a very structured way. In their book, they provided background information, domain of application, a step-by-step procedure about how to apply the method and advantages and disadvantages of each method. In the next paragraphs, the items about each method mentioned by Stanton et al. (2005) that were considered relevant for the current project are described.

Stanton et al. (2005) discriminate between five different categories of team performance methods:

1. Team task analysis (TTA)
    - Team requirements (skills, knowledge, attitudes) and whether tasks require teamwork or individual (task-work) performance
2. Team cognitive task analyses
    - Describe cognitive processes associated with team decision making and performance
3. Team communication assessment methods
    - Teams need to communicate these methods measure content, frequency, efficiency, technology and nature of communication.
4. Team behavioural assessment
    - Assess performance or behaviour during particular tasks or scenarios.
5. Team mental workload assessment
    - with NASA-TLX.

Category number 4 is probably of less importance for the Framework since it used to be applied as a measure of effectiveness of team training and crew resource management programmes.

Category number 5 focuses on only one aspect of teamwork. The authors of this document consider that a class that should normally be combined with one of the other classes in one study, like the methodologies that are described in Section 0.

There are several ways to perform, or to visualise and present, task analyses. Paper and pencil method always impose limitations on the flexibility with which new information can be added or different kinds of visualisations can be made. Computerised methodologies, that do not have these limitations, such as those that were developed at Brunel University (Stanton, 2007), are:

- Cognitive Work Analysis (CWA),
  - Inspired upon Rasmussen's work
  - Also called Work Domain Analysis.
  - Output may be exported to MS Word
- Workload, Error, Situation Awareness, Time & Teamwork (WESTT), and
  - Many different kinds of data can be imported
  - It represents the data
  - It provides a propositional network to visualise and study all relationships between the different variables.
- Hierarchical task Analysis (HTA)
  - Information that was gathered in the context of classical hierarchical task analysis can be entered into the tool
  - Additional information such as questionnaire ratings (NASA-TLX, SWAT) may be added.
  - It delivers lists with remedies and probabilities.

These three tools (CWA, WESTT and HTA) are, according to their designers, supposed to be used in a specific order, i.e. first the CWA, then the WESTT and finally the HTA.

4.1 Hierarchical task Analysis for Teams HTA(T)

4.1.1 Method description

Annet et al. (2000) measured team skills in command & control (C2)-teams in the maritime domain. The authors chose a theoretical model for team performance and adapted a Hierarchical task Analysis for Teams HTA(T) for measurement and analysis purposes. The methodology should eventually provide:

- A device for identifying team skills
- To develop an objective method for measuring team performance.

The model comes down to a description of relationships between team processes and how these together lead to the team product. The team processes that are described are:

- Affective processes
- Moral
- Cohesion
- Cognitive processes
- World mental model

- People model
- Team plans
- Behavioural processes
- Communication
- Send information
- Receive information
- Discuss
- Co-ordination
- Collaborate
- Synchronise
- Discuss

The HTA(T) may be described as decomposing team goals into subgoals and then identifying whether these can be achieved by teamwork, and how.

The method is limited to those aspects of teamwork that are observable. Hence, it doesn't deal with inferred team constructs or cognitive processes that lie beneath team co-ordination. As such, the method relies / builds upon so called trigger events (objectively identifiable events).

4.1.2 Practical use

In a simulated scenario, a number of triggers are built-in after which a specific series of responses from the subjects (participants) is expected. The observations focus on these series of responses. They are transcribed in forms (a kind of checklists) and the observer / SME can rate whether each step was completed. Further processing results in tables reporting observable behaviour such as: time, event and description of the reaction of the team. The tables are later converted into frequency tables, and, together with information on criterion performance, these tables provide a team performance score (expressed as a percentage).

When the SMEs used paper and pencil for the ratings, it was difficult for them to keep up with the actual behaviour of the team members. With an electronic rating form they were actually able to rate all the observable behaviour which they considered relevant.

4.2 Behavioural Observation Scales (BOS)

BOS are a general class of observer-rating techniques to access different aspects of team performance in complex systems. The procedure to apply BOS comes down to selecting tasks to observe, find matching rating scales and SMEs perform training of raters, observe behaviour en eventually calculate the BOS scores. It can measure, amongst others, communication, information exchange, leadership, and it accesses both teamwork and taskwork (individual) performance. The approach is simple, low cost, can be applied during task execution. However some preparation needs to be done, like adjusting pre-existing scales to the demands of the study, some (not observable) behaviour is not accurately available. Examples of such behaviour are SA and MWL. It costs time and reliability and validity are still a matter of concern. Stanton et al. (2005) refer to Baker (2004) as an important author about this methodology.

4.3 Comms Usage Diagram (CUD)

CUD is meant to describe collaborative activity between teams, or individuals, in different geographical locations. It is a simple technique that requires minimal training. Especially regarding communication it provides a detailed output. It is more often used in C4 studies.

The authors of this document consider this methodology simpler than BOS but the "different geographical locations" are probably not the highest priority issue that we have to deal with in our study. Stanton et al. (2005) refer to Watts and Monk (2000) as important authors about this method.

4.4 Co-ordination Demands Analysis (CDA)

CDA focuses upon seven measurable entities:

- Situation Awareness
- Decision making
- Mission analysis
- Leadership
- Adaptability
- Assertiveness
- Team Co-ordination

It is not fully clear how these entities together are combined into an indicator of team performance.

4.5 Decision Requirements Exercise (DRX)

Focuses strongly upon "critical decisions" and is as such a bit too limited for our purposes.

Stanton et al. (2005) refer to Klinger and Hahn (2004) and to Klein and Armstrong (2004) as important authors about this method.

4.6 Groupware Task Analysis (GTA)

The method performs team analyses in order to give input to design and analysis teams. GTA answers, amongst other, questions like:

- What are the critical tasks?
- How frequently are those tasks performed?
- Are they always performed by the same user?
- Which types of user are there?
- Which roles do they have?
- Which tasks belong to which roles?
- Which tasks should be possible to undo?
- Which tasks have effects that can't be undone?
- Which errors can be expected?
- What are the error consequences for users?
- How can prevention be effective?

It comprises five steps, which come down to definition of the system to be studied, collecting data and in an iterative way constructing task models. Eventually the system can be redesigned.

The output of a GTA is very detailed and highlights issues that require attention in a new design. But it is recourse and time consuming and requires a large team of analysts. Further there is little availability of literature reviews and limited guidance for the application

This method definitely answers a number of relevant questions for our teamwork studies. However, it is extremely resource and time consuming. That is a difficult trade off.

Stanton et al. (2005) refer to Welie and Van der Veer (2003) as important authors about this method. More information about this technique may be obtained from their website: http://www.cs.vu.nl/~mmc/gta/.

The FASTI (2007a) study is a very useful example of how a Cognitive Task Analysis (CTA) is applied in order to identify the impact of automation (three different new tools) on performance and mental demands of ATCOs. In the current review these tools themselves will not be discussed in detail. The reason why this study is included in this report is the fact that a CTA was used as a means to evaluate the impact of the FASTI support tools. The process described in the FASTI (2007a) report is potentially very valuable for creating the TCF. This is especially true since the FASTI (2007a) report explains the used methodology with a great level of detail.

4.7 Cognitive Task Analysis (CTA)

In EUROCONTROL (2007a) two task analyses were performed one before and one after implementation. The differences in outcomes between the two CTAs were studied.

The methodology comprised seven steps:

- Establish the CTA approach
- Review descriptions and relevant literature about the changed situation (in this case the FASTI tools)
- Construct initial Hierarchical Task Analysis (HTA) of observable tasks
- Use cognitive walkthrough interviews and perform observations at a demonstrator of the changed situation (the FASTI tools) to identify cognitive strategies
- Identify the information processing demands and performance shaping factors
- Identify potential human error modes
- Collate Human Factors issues and benefits

The FASTI researchers report that CTA is a method for identifying the strategies and information processing demands associated with skilled behaviour. The purpose of the FASTI study is to develop a CTA which describes:

- How ATCO tasks will be performed following the implementation of the FASTI tools, and
- The mental demands that are associated with these tasks.

Important questions that CTAs can help to answer are:

- Do the tools cause any change in information processing?
- What are potential error modes resulting from the changes?
- What information processing and performance shaping factors are associated with the potential error modes?

The CTA report gave recommendations with respect to the FASTI tools concerning: training, Human Machine Interface (HMI), working methods, and allocation of tasks / functions.

One of the results of the study is that the CTA is at a conceptually sufficient level for application to other implementations of FASTI-like tools. As such this CTA is a good candidate to become part of the measurement methodology of the TCF.

4.8 Team Cognitive Task Analysis (TCTA)

This method describes cognitive processes of a team or group. It uses interview techniques and probes. The method reports about five team cognitive processes

- Control of attention:
  - Management of information / seeking form information (coping with the team's resource limited working memory)
- Shared situation awareness:
  - Teams can also benefit from having different team members hold different interpretations of the situation
- Shared mental models:
  - Team members may be more or less congruent in their understanding of their roles and responsibilities, the operation of equipment, etc.
- Application of strategies and heuristics to make decisions, solve problems, and plan:
  - A skilful team has learned the shortcuts – the workarounds- that are not codified in procedures.
- Metacognition:
  - Self-monitoring of the team, observe when running into difficulties, shift strategies

The method is executed in seven steps. These are not simply connected in a serial way but there are also decision moments and feed back loops included. It starts with specifying the 'desired' outcome, so underlining the areas on which the study should focus. Then the individual tasks that have to do with it are identified. Perform (Critical Decision Method) CDM interviews take place and after processing of the results that should result in a decision requirements table.

After training the method is easy to apply. It is not domain specific, so will work for ATC as well. The analysis and output are very comprehensive. And the CDM probes, that are used in the methodology are already in use for a number of years and have proven to be useful. However, it needs to be noted that the reliability is questionable. That is because the information quality relies on interviewees' memory and because the interviewer skill has great impact on quality. For maximum effect highly skilled interviewers are recommended. Further the method is characterised as resource intensive. Stanton et al. (2005) refer to Klein (2007) as an important author about this method.

4.9 Social Network Analysis (SNA)

SNA represents relationships between groups of agents or teams. It may provide information about:

- Frequency and direction of communication
- Agent centrality
- Sociometric status
- Network density
- Network type

It is difficult to access whether this method is good or bad for studying ATCos in all kinds of team relationships. For the planner plus tactical and their relations with the outside world this method may be especially relevant for the relationship with the outside world. Stanton et al. provide an example about C4i (Command, Control, Communications, Computing and Intelligence) which might be comparable to the relationships between the planner plus tactical and the 'rest of the world'. It is possibly of less relevance when the focus is not on that 'rest of the world'. On the other hand Stanton et al. indicate that large complex networks may be too difficult to analyse with this methodology.

4.10 Questionnaires for Distributed Assessment of team Mutual Awareness

Is a set of three self rating questionnaire for team member to assess team member mutual awareness. It measures mutual awareness, workload awareness and teamwork awareness. The questionnaire are all administered afterwards (post trial).

It is a quick, easy and low cost method, with not much training needed. But it is subjective and post trial so possibly not always accurate. It is not frequently used and there is not much information about its validity available.

Stanton et al. (2005) refer to Salmon, Walker and Baber (all of them wrote a publication in 2004 about this) as important authors about this method.

4.11 Team Task Analysis (TTA)

TTA analyses team tasks as well as team knowledge, skills and abilities that are needed for that task. It is typically used for design of training. It looks at teamwork as well as (individual) taskwork. The analysis investigates, amongst others, situational awareness, decision making, mission analysis, leadership, adaptability, assertiveness, and total co-ordination.

The method goes deeper than normal task analyses because of the detailed statements about skills and knowledge needed for every single step. Further it includes differences between team and individual tasks in the analysis. But it is time consuming, requires specialists to administer, the procedure is not very strict so output quality may differ.

Stanton et al. (2005) refer to Baker, Salas and Bowers (1998) as important authors about this method.

4.12 Team Workload Assessment (TWA)

Is actually a modified version of NASA TLX. It is inexpensive and easy to apply, but does nothing but measuring (team and individual) workload.

Stanton et al. (2005) refer to Bowers and Jentsch (2004) as important authors about this method.

4.13 Task and Training Requirements Analysis Methodology (TTRAM)

TTRAM identifies the training requirements for teams. It is typically designed for military aviation and as such not very relevant for application in the ATC domain.

Stanton et al. (2005) refer to Swezey, Ownes, Burgondy and Salas (2000) as important authors about this method.

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GLOSSARY OF TERMS

Action Team	A general term for a team which job it is to accomplish a task
Arousal	The level of activation of the operator / ATCO
Assessment of Training Effectiveness	A general term for the processes of determining to what extent training has enabled an individual to carry out his job satisfactorily.
Attention	Allocation of mental resources and sensory-perceptual functions to a subset of possible tasks and input.
Autonomy	The capability to make decisions
Coach	A person monitoring the trainee in order to provide advice, guidance, help and encouragement towards the final achievement of the required goals or operational functions.
Coaching	Systematically increasing the ability and experience of the trainee by giving him planned tasks, coupled with continuous appraisal and counselling by the trainee's supervisor.
Cognition	A general term covering higher mental activities involved in the perception, storage, judging, reasoning and output of information.
Cognitive skill	Thinking: decision making, problem solving, logical thinking etc. In case of ATC, a cognitive skill is prioritising between problems, solving a conflict, planning, prediction, etc.
Competence	Ability to perform a particular skill or range of skills to a prescribed standard.
Conflict	Predicted converging in space and time leading to a violation of separation minimum.
Conflict resolution	To take action when a conflict has been detected to prevent any risk of collision.
Decision Making	Ability to evaluate information in order to timely choose the optimal course of action, does not include the initiation of standard procedures, (e.g. in situations never before encountered). EUROCONTROL (EATMP, 1996) defines decision-making as the mental process by which operators recognise, analyse, and evaluate information about themselves, the air traffic, and the operational environment, leading to a decision.
Deductive reasoning	Ability to reach a conclusion that follows logically from own facts or data.
Information management	Control of attention, including information seeking
Inter sector co-ordination	The safe transition and the safe transfer of control responsibility from a control sector to another sector.
Meta-cognition	Thinking about (other team members') thinking
On-the-job-Training (OJT)	Training given at the normal place of work in the attitudes, knowledge and skills appropriate to a task or job under the supervision of a coach in a live situation. It is an integral part of the overall training programme. Also known as On-job-

	Training.
Operational concept	Broad outline of an operational structure able to meet a given set of high level user requirements.
Planning Controller	En-route controller typically responsible for inter-sector co-ordinations, updating flight information of flights in the sector and performing pre-analysis to help the Tactical Controller.
Planning team	A general term for a team which job it is to produce a plan.
Role	The set of tasks performed by a human controller/operator which constitute his/her purpose in the system. Thus, recent descriptions of air traffic controllers (and aircraft pilots) as "system managers" or "supervisors" reflect their changing roles because of the introduction of certain types of automation.
Scenario	Script describing a possible sequence of events and circumstances.
Selection	The process of accepting or rejecting job applicants by assessing their potential and/or ability to meet the requirements of the job role.
Shadowing / Shadow mode	Used to refer to a period where the new equipment is operated in parallel with the existing equipment. During this period live control is not carried out but all the control functions are followed.
Tactical Control	Whenever an ATCO or system is monitoring an aircraft and is using authority to issue commands for immediate response by the aircraft, the aircraft is said to be under the tactical control of the ATCO or system.
Tactical controller	En-route controller typically in charge of contacting aircraft, giving clearances, managing guidance and separations, resolving conflicts and transferring aircraft to other sectors.
Tactical Intervention	Commands that cause an aircraft to manoeuvre in a way which was not prescribed by its active system plan and which do not in themselves imply renegotiation of the active system plan.
Task	A set of related human activities, performed for an immediate purpose, i.e. in response to a specified input and yielding a specified output. For example, the task of monitoring aircraft positions may consist of the activities of: look at radar display, look at flight strip data, listen to R/T. Tasks are performed by one or more individuals and directed towards accomplishing a specific functional objective (e.g. ensure aircraft separation), and ultimately towards the goal of a system. The following features are characteristic to a task: existence of an operational goal, possibility of determining quantitative task-performance indices, clearly distinguishable start and end (representation of the sequence in which (sub)tasks has to be carried out must be possible), meaningful without another task, independent of context,

	presence of an observable action, and the state of the system has to change.
Taskwork	Taskwork (in contrast with teamwork) refers to those tasks that are conducted by team-members individually or in isolation from another.
Team	A distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span membership (Salas, Dickinson, Converse & Tannenbaum, 1992). A group of two or more persons who interact dynamically and interdependently with assigned specific roles, functions and responsibilities. They have to adapt continuously to each other to ensure the establishment of a safe, orderly and expeditious flow of air traffic (EATMP, 1996).
Team Resource Management	A concept and training that is designed to improve the functioning of ATC teams. It does this by increasing the awareness and understanding of interpersonal behaviour and human factor capabilities, with the goal of increasing flight safety
Team stability	Refers to the time-span during which a team has the same members.
Teamwork:	The seamless integration of specific cognitive, behavioural and affective skills that allow team members to adapt and optimise their performance (Paris et al., 2000). Teamwork refers to those instances where actors within a team or network co-ordinate their behaviour in order to achieve tasks related to the team's goals.
Teamwork attitudes	Defined as an internal state that influences a team member's choices or decisions to act in a particular way (Cannon-Bowers et al., 1995)
Training Objectives	Statements which detail as precisely as precisely as possible the skills and knowledge to be acquired and the attitudes to be developed during the conduct of training. A training objective may be broken down into a set of lower level objectives (enabling objectives), the attainment of which implies the attainment of the training objective. (Training objectives and the procedures for assessing their attainment will usually include a subjective element, for example in the assessment of attitudes and the performance of complex skills).
Workload	The subjective experience of a certain task load. It can be measured objectively, for example by measuring the number of clearances an ATCO has to give.

ABBREVIATIONS

AFP	Area Flow Planning
AIM	Assessing the Impact of Automation on Mental Workload
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
AOC	Air Operations Centre
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATWIT	Air Traffic Workload Input Technique
BOS	Behavioural Observation Scales
C2	Command & Control
C4i	Command, Control, Communications, Computing and Intelligence
CDA	Co-ordination Demands Analysis
CPDLC	Controller Pilot DataLink Communication
CTA	Cognitive Task Analysis
CUD	Comms Usage Diagram
CWA	Cognitive Work Analysis
CWP	Controller Working Position
DODAR	Diagnosis, Options, Decision, Assessment, Revision
DR	Distance ratio
DRX	Decision Requirements Exercise
EATMP	European Air Traffic Management Programme
EFS	Electronic Flight Strips
ESARR	EUROCONTROL Safety Regulatory Requirement
ESP	European Safety Programme
FASTI	First ATC Support tools Implementation
FMP	Flow Management Position
FOR-DEC	Facts, Options, Risks and benefits, Decision, Execution, Check
GTA	Groupware task Analysis
HF	Human Factors
HMI	Human Machine Interface
HTA	Hierarchical task Analysis
HTA(T)	Hierarchical task Analysis for Teams
iFACTS	interim Future Area Control Tools Support
ITA	Integrated Task and job Analysis
JAR-TEL	Joint Aviation Regulations - Translation and Elaboration of Legislation
LACC	London Area Control Centre

LOA	Level Of Automation
MAMMI	Multi Actor Man Machine Interface
MDS	Multidimensional scaling
MSP	Multi Sector Planning
MTCD	Medium Term Conflict Detection
MWL	Mental Work Load
NASA-TLX	NASA's Task Load Index
NATS	National Air Traffic Services
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NRC	National Research Council
OJT	On-the-Job Training
OLDI	On-Line Data Interchange
Ops	Operations
P- RNAV	Precision Area Navigation
PC	Planner Controller
R&D	Research & Development
R/T	Radio Telephony
RWY	Runway
SA	Situational Awareness
SA	Situational Awareness
S-A	Safety Assessment
SACHA	Situational Awareness for SHAPE
SATI	SHAPE Automation Trust Index
SESAR	Single European Sky ATM Research
SHAPE	Solution of Human-Automation partnerships in European ATM
SHAPE	Solutions for Human-Automation Partnerships in European ATM
SID	Standard Instrument Departure
SME	Subject Matter Expert
SNA	Social Network Analysis
SOP	Standard Operating Procedure
SPO	Single Person Operation
SSA	Shared Situational Awareness
STAR	Standard Arrival
STQ	SHAPE Teamwork Questionnaire
SWAT	Subjective Workload Assessment Techniques
SYSCO	System-Supported Co-ordination
TCF	Team Co-ordination Framework
TCTA	Team Cognitive Task Analysis
TMA	Terminal Manoeuvring Area

TRM	Team Resource Management
T-T	Tactical to Tactical
TTA	Team Task Analysis
TTRAM	Task and Training Requirements Analysis Methodology
TWA	Team Workload Assessment
US	United States
UTP	Unit Training Plan
WESTT	Workload, Error, Situation Awareness, Time & Teamwork
WL	Work Load

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