# EPISODE 3

## Single European Sky Implementation support through Validation

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# EXECUTIVE SUMMARY

In anticipation of en-route validation activities for SESAR (Single European Sky ATM Research), and within the context of the European Commission Episode 3 Project (EP3), the EUROCONTROL Experimental Centre has conducted a series of prototyping sessions whose main aims were to:

- Start to build the SESAR en-route operational environment (e.g. airspace and support tools)
- Assess the Operability, from the controller perspective, of the introduction of the SESAR Reference Business Trajectories (RBT)
- Provide initial trends regarding expected benefits in terms of:
    - efficiency (optimised flight profile, better delivery conditions to TMA)
    - predictability (adherence to pre-defined trajectory)
    - capacity (optimised airspace usage and reduced controller workload)

This document is the consolidated validation exercise report for the prototyping sessions of the Episode 3 En-Route WP4.3.4 Prototyping on Queue, Trajectory, and Separation Management. The work covers step 4 of the European Operational Concept Validation Methodology (E-OCVM). It reports the work carried out to assess the operability of the 4D trajectory management, from the controllers' perspective.

The methodology consisted of a series of prototyping sessions. From session to session the scope of the en-route SESAR concept elements deployed was gradually increased. Three prototyping sessions of one week each were performed in a SESAR Intermediate Timeframe En-Route Environment. The content and focus of the sessions were defined by the EP3 WP4 Separation Management Expert Group. The sessions started by refining possible options (e.g. airspace, routes, and scenario), then assessed the operability and acceptability of both the Reference Business Trajectory (RBT) and the Controlled Time of Arrival (CTA) in the En-Route environment.

The prototyping sessions took place between October 2008 and February 2009 at the EUROCONTROL Experimental Centre and involved a total of fourteen controllers from MUAC, DFS, NATS, AENA and DSNA. The airspace was derived from MUAC sectors (new route structure) and traffic flows based on SESAR 2015 forecasts. All aircraft were 100% ADS-B equipped and 4D capable.

Overall the controllers did not reject the concept. However there were important caveats that they wished to be noted.

In a high workload situation the CTA/RTA goals “go out the window”. The controllers concentrated on the higher priority separation tasks. As the aircraft are flying to target times by using speed control and controllers were, therefore, discouraged from using speed control. A consequence of this is that they felt that one element of the currently available Controller toolset had been removed.

In the prototyping sessions every flight is flying a unique preferred trajectory this had consequences for the controllers as potential conflicts are now distributed across sectors rather than at defined crossing points. In order to mitigate this it was reported that:

- Information exchange from cockpit to controller is required to help the controller to make an overall assessment of how aircraft will be flown

- The airspace and route structure need to be addressed. There needs to be optimisation of the shape of the airspace and structures within it particularly for complex traffic

The agreed RBTs must consider vertical profile

The agreed RBT profiles should segregate traffic

The concept allows for the deployment of structure in complex sectors. In sessions two and three route structures were used (particularly for arrival/departure flows to be segregated from over flights). For the full potential benefits of 4D trajectory management to be achieved all controllers strongly felt that the current route structure should be examined and possibly modified, and larger sectors respecting traffic flows be introduced.

Enhanced and new tools are required to support the controllers in the 4D trajectory management:

- Conflict detection tools
- A tool to issue closed loop headings for planning and tactical use
- A tool displaying the required delivery sequence to TMAs
- A tool providing information on the time status of the aircraft (in relation to the RBT/CTA time)

The addition of active military areas had no real impact.

# 1 INTRODUCTION

## 1.1 PURPOSE OF THE DOCUMENT

This document provides the consolidated validation exercise report for the series of prototyping sessions performed in Episode 3 WP 4.3.4 “Prototyping Session on Queue, Trajectory and Separation Management in En-Route”. It will contribute to the Validation activities of Work Package 4.

A series of three prototyping sessions was carried out between October 2008 and February 2009 at the EUROCONTROL Experimental Centre (EEC) to evaluate the potential for new functionality and techniques needed to accommodate predicted traffic levels in ECAC En-Route, in the intermediate timeframe, typically from 2015.

Complementing the validation exercise plan [3], the validation report addresses the step 4 of the European Operational Concept Validation Methodology (E-OCVM) [1]. It includes all information necessary to understand the conduct and outcomes of the three prototyping sessions of Episode 3 En-Route (Episode 3 WP 4). It is developed from the Episode 3 WP 4 validation strategy which covers step 1 of the E-OCVM [2].

## 1.2 INTENDED AUDIENCE

This document is intended for use by the exercise leaders in EP3 WP 4 and in EP3 WP 2.3 Validation Process Management as input for the consolidated validation strategy. It forms the basis for further elaboration of the detailed WP 4 validation and exercise reporting (E-OCVM steps 4 and 5).

The intended audience includes:

- EP3 WP 2 System Consistency leader;
- EP3 WP 2 Reporting and Dissemination;
- EP3 WP 4 En Route and Traffic Management:
    - EP3 WP 4 Leader;
    - EP3 WP 4.2 En-Route validation strategy;
    - EP3 WP 4.3.1 En Route Queue, trajectory and Separation management Expert Group Leader;
    - EP3 WP 4.3.2 FTS on 4D trajectory Management and Complexity Reduction Exercise Leader;
    - EP3 WP 4.3.3 Queue, trajectory and Separation management Gaming Exercise Leader.
    - EP3 WP WP 4.4 En-route results Analysis and Report.

## 1.3 EXPERIMENT BACKGROUND AND CONTEXT

Based on the corresponding exercise plan, validation exercises are performed to provide evidence -preferably measured- about the ability (of some aspect) of the concept to deliver on (some aspect) of the performance targets. According to step 4 of the E-OCVM, an exercise report should be produced to lay down the evidence of qualities and shortcomings together with issues and recommendations. The document reports on the validation exercise WP 4.3.4

Prototyping Session on Queue, Trajectory and Separation Management in En-Route, which was done within WP 4: En Route and Traffic Management.

The main limitations of the ATM system, with respect to the airspace environment, are identified in SESAR ATM Target Concept [4]. The two main factors are:

- European airspace is, in the main, organised around the use of fixed volumes and rigid route structures which are organised and managed in a fragmented manner. This results in aircraft being unable to fly their most efficient trajectory and creates unnecessary additional task load for air traffic control.
- Most aircraft have the capability to fly with much greater precision in terms of position and time than is accommodated in the design of, and supported by, many of the systems in operational service to manage and control air traffic. This capability is currently not exploited.

According to Sections 4 and 5 of SESAR Task 3.2.1, ''Identification of Limits/Blocking Points for Airspace Environment'' [5] the most relevant blocking points from an En-Route perspective, are as follows:

- Longer routes or non-optimum operations (non-economic speed, flight level) result in extra fuel burn.
- In many cases ATC sectors and associated procedures continue to be based upon State boundaries. An increased use of delegation of ATS across borders can enhance efficiency and capacity. A common goal must be the achievement of airspace structures appropriate to intended use with sufficient flexibility to provide capacity for all users at the required time. A pan European view of network design is essential to the effective management and use of our limited airspace asset.
- European airspace design and management is too fragmented.
- Air traffic flow and capacity management is insufficiently integrated.
    - There is a constant need for the optimisation of the network capacity through the capacity enhancement plans at local and regional level to which all actors must be fully committed;
    - The consolidated plans at network level should result in a Medium/Short Term Network Operations Plan updated constantly, that reflect changes made before the execution phase of flight and including the results of demand/capacity balancing. The Network Operations Plan should be shared by all ATM actors.

Episode 3 was tasked with beginning the validation of the operational concept described by SESAR Task 2.2 and consolidated in SESAR D3 [4]. The validation process as applied in Episode 3 is based on the E-OCVM [1], which describes an approach to ATM Concept validation. However, to date the E-OCVM has not been applied to validation of a concept on the scale and complexity of SESAR. Such a system level validation assessment must be constructed from data derived from a wide range of different validation activities, integrating many different levels of system description, different operational segments and contexts and different planning horizons. The data are collected through a variety of methods and tools and vary in its quality and reliability.

The process of performing systematic validation and the integration of results must be actively planned and managed from the beginning of the whole validation activity. This validation management is coordinated by EP3/WP 2.3, which is responsible for ensuring the effective application of the E-OCVM and the consolidation of the Episode 3 Validation Strategy.

Following the Episode 3 resumption on 1st August 2008 and acknowledging that a large part of the SESAR ConOps [6] is at a relatively early stage in the Concept Validation Lifecycle (late V1, early V2) there has been a shift in focus, with emphasis now increased in three main areas:

- Clarification of the concept; recognising that the concept is large and that Episode 3 does not have the resources to address all areas and OIs;
- Expanding the repertoire of cost-effective validation techniques (e.g. gaming variants) suited to these early stages of concept validation;
- Consolidating our learning on the application of the E-OCVM to SESAR-scale ConOps.

From this perspective, even though validation exercises should produce evidence (preferably measured) about the ability (of some aspect) of the concept to deliver on (some aspect) of the performance targets, it should be noted that human in the loop prototyping sessions actually focused on operability aspects – and provided initial trends on performance aspects. In addition, in order to be able to conduct Validation Exercises, there was a need for concept clarification, requirements development or elaboration activities in preparation for subsequent validation activities.

## 1.4 DOCUMENT STRUCTURE

The document is structured as follows:

- Section 2 introduces the scope and justification of the validation exercise (composed of the series of three prototyping sessions);
- Sections 3 describes respectively the validation methodology used to progressively validate the concept;
- Section 4 summarises the experimental plan (objectives, methods, settings and design);
- Sections 5 and 6 describe the experiment conduct and results according to the objectives;
- Section 7 provides recommendations;
- In addition, an overview of the three prototyping sessions and sessions' schedules are provided in annexes.

## 1.5 GLOSSARY OF TERMS

| Term | Definition |
|---|---|
| 4D | 4 Dimensions (i.e. Longitude, Latitude, Altitude and Time) |
| 4D TM | 4 Dimension Trajectory Management |
| A/C | Aircraft |
| ADS-B | Automatic Dependant Surveillance Broadcast |
| AENA | Aeropuertos Españoles Navegación Area (Spanish ATC Corporation) |
| AFAS | Aircraft in the Future Air traffic management System |
| AMAN | Arrival Manager (Tool) |
| ANSP | Air Navigation Service Provider |
| APW | Area Proximity Warning |
| ASAS | Airborne Separation Assistance System |
| ATC | Air Traffic Control |
| ATCo | Air Traffic Control Officer |
| ATFM | Air Traffic Flow Management |
| ATM | Air Traffic Management |
| ATS | Air Traffic Services |
| APW | Area Proximity Warning |
| CAP | Controller Access Parameters |
| CATS | Contract-based Air Transportation System |
| CBT | Computer Based Training |
| CPDLC | Cockpit Pilot Data-Link Communication |
| CONOPS | Concept Of Operations |
| CTA | Controlled Time of Arrival |
| CWP | Controller Working Position |
| DCB | Demand-Capacity Balancing |
| DDL | DELTA Lower sector |
| DDU | DELTA Upper sector |
| DFS | Deutschen Flugsicherung (German ATC Corporation) |
| DOD | Detailed Operational Description |
| DOW | Description Of Work |
| DSNA | Direction des Services de la Navigation Aérienne (French ATC Corporation) |
| EC | European Commission |
| ECAC | European Civil Aviation Conference |
| ECHOES | EUROCONTROL Consolidated HMI for Operations, Evaluations and Simulations |
| ECIP | European Convergence and Implementation Plan |

| Term | Definition |
|---|---|
| EEC | EUROCONTROL Experimental Centre |
| E-OCVM | EUROPEAN – Operational Concept Validation Methodology |
| EP3 | Episode 3 Project |
| ETA | Estimated Time of Arrival |
| EXC | Executive Controller |
| FIR | Flight Information Region |
| FL | Flight Level |
| FMS | Flight Management System |
| FT | Feet |
| G-DOD | General purpose Detailed Operational Description |
| GND | Ground |
| HM | MUNSTER sector |
| HMI | Human Machine Interface |
| HR | RUHR sector |
| IAF | Initial Approach Fix |
| ICAO | International Civil Aviation Organization |
| ID | Identifier |
| IP | Implementation Package |
| ISA | Instantaneous Self Assessment (*A workload assessment method)* |
| KPA | Key Performance Area |
| KPI | Key Performance Indicator |
| KT | Knot |
| LCIP | Local Convergence and Implementation Plan |
| LOA | Letter Of Agreement |
| MONA | Monitoring Aids |
| MTCD | Medium Term Conflict Detection |
| MUAC | Maastricht Upper Airspace Control Centre |
| MUDPIE | Multiple User Data Processing Interactive Environment |
| NASA | National Aeronautics and Space Administration |
| NASA-TLX | NASA Task Load index (workload assessment index) |
| NATS | National Air Traffic Services (UK ATC Corporation) |
| NM | Nautical Miles |
| OIs | Operational Improvement Step |
| OLDI | Standard On Line Data Interchange |
| PHARE | Programme for Harmonised ATM Research in Europe |
| PLC | Planning Controller |

| Term | Definition |
|---|---|
| PPD | Pilot Preference Downlink |
| PTC | Precision Trajectory Clearances |
| QNH | Atmospheric Pressure at Nautical Height |
| RBT | Reference Business Trajectory |
| ROI | Return On Investment |
| R/T | Radio Telephony |
| RTA | Required Time of Arrival |
| SAAM | System for Airspace Analysis at Macroscopic Level |
| SEL | Sector Exit List |
| SESAR | Single European Sky ATM Research in Air Transportation |
| SID | Standard Instrument Departure |
| STAR | Standard Terminal Arrival Route |
| STCA | Short Term Conflict Alert |
| SYSCO | System Supported Co-ordination |
| TCT | Tactical Controller Tool |
| TED | Trajectory Editor |
| TMA | Terminal Manoeuvring Area |
| TTA | Target Time of Arrival |
| UIR | Upper Flight Information Region |
| UNL | Unlimited |
| VERA | Verification and Resolution Advisory (Tool) |
| WP | Work Package |

# 2 EXERCISE SCOPE AND JUSTIFICATION

## 2.1 SESAR 2020 CONCEPT OVERVIEW

### 2.1.1 The SESAR 2020 concept

The SESAR concept, described in the D3 "ATM Target Concept" deliverable [4], states that the achievement of the capacity targets is supported by:

- 4D Trajectory Management (4D TM);
- Wide availability of controller support tools;
- New separation modes;
- Collaborative planning and balancing of traffic demand and capacity;
- Reduction in trajectory uncertainty;
- Improved airport processes.

The prototyping sessions have been scoped by analysis of the SESAR Concept and the initial focus for the three sessions that are to be conducted as part of the Episode 3 project was decided by the Episode 3 Separation Management Expert Group conducted in Toulouse in April 2008. The outcome of this meeting is summarised in section 2.3 of the validation exercise plan [3].

As described in [10], the prototyping sessions are concerned with the management of En-Route queues and En-Route separation management.

According to the SESAR concept [4], "queue management is the tactical establishment and maintenance of a safe, orderly and efficient flow of traffic." En-route queue management in the execution phase is concerned with the management of queues generated by:

- Network Queues from the Network Operations Plan;
- AMAN horizons extending into En-Route airspace.

The SESAR concept states that new separation modes will be deployed to allow for increased aircraft capacity. It states that new separation modes gradually being implemented over time, supported by controller and airborne tools, will use trajectory control and airborne separation systems to minimize potential conflicts and controller interventions. 4D-trajectory management is one of the key concept elements in this environment.

4D trajectory management is expected to improve air traffic operations, in particular to increase the overall predictability of traffic, with benefits to airlines and air traffic management [4].

The concept supposes the adherence to an agreed 4D trajectory for all aircraft, and is comprised of the following stages: planning, agreement, execution and revision (including renegotiation) as shown in Figure 1.

The concept relies on a Reference Business Trajectory (RBT) which the airspace user agrees to fly and the service provider agrees to facilitate (subject to separation provision). As roles and task repartition between actors are not clearly defined, outputs from both the Episode 3 Expert Groups and previous air and ground validation exercises led us to propose a repartition consistent with SESAR 2020 concept. This repartition is as follows: the time achievement of the 4D trajectory is under the pilots' responsibility and the controller has to facilitate the 4D trajectory by adhering as far as possible to the agreed trajectory (RBT).

In busy airports during peak periods, the RBT time window tolerance may not be accurate enough to ensure an efficient pre-regulation of traffic and to optimise the runway capacity. In that case, once the aircraft enters the arrival manager (AMAN) horizon (e.g. 30 minutes before landing) of its airport of destination, the aircraft could be tasked to achieve a Controlled Time of Arrival (CTA) at the IAF with a refined time window tolerance (±30s). It should be noted that not all airfields associated with any given En-Route airspace will have an AMAN, this means that for aircraft in a given same-direction traffic flow some may have, or be expecting to receive, a CTA and others will not.

The use of 4D TM in En-Route is expected to provide benefits in terms of predictability (reduced variability), efficiency (reduced deviation, reduced route extension and flight predictability), capacity and safety (better traffic delivery to next sector, better entry conditions, reduced bunching, reduced variability and smoother workload level (no ups and downs)).

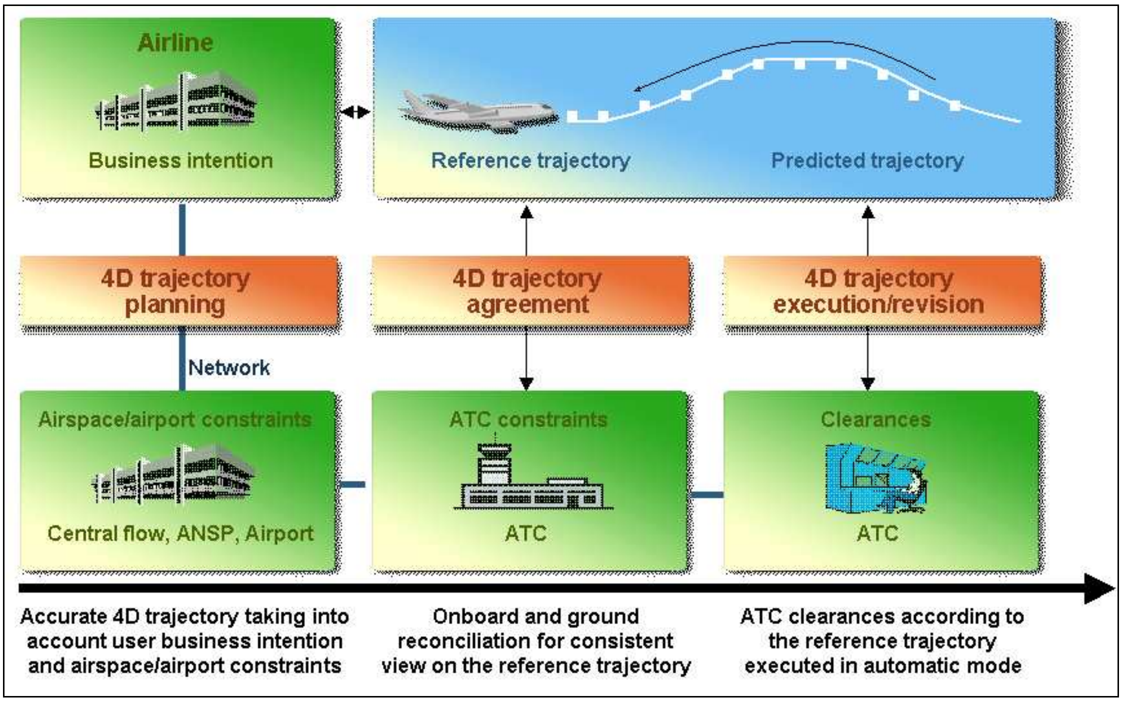

**Figure 1. Overall 4D trajectory management**

### 2.1.2 Related studies

Several projects (PHARE, AFAS) were conducted to assess 4D trajectory concepts and capabilities from both air and ground perspectives [11] [12]. Some flight trials were also conducted to evaluate the use of the FMS [13]. The ongoing CATS project also addresses 4D trajectory management [14].

Two real-time simulations (ground and air experiments) were conducted at the EUROCONTROL Experimental Centre to investigate 4D trajectory management in an En-Route environment respectively from controllers and pilots perspectives ([15] [16]). They examined the limitations of 4D TM in terms of airspace and route design, traffic characteristics and operational procedures. This work, in addition to the Episode 3 Separation Management Expert Group helped scoping and underpinning the prototyping sessions described here.

### 2.1.3 Stakeholders and their expectations

According to SESAR D1 [7], Air Transport is defined as the full set of activities required to satisfy mobility needs by air. The principal direct stakeholder groups in today's air transport industry are the following:

- End-user customers, principally passengers and freight;
- Airspace users, principally scheduled and non-scheduled airlines, military, business and general aviation;
- Aerodrome community;
- Air navigation service providers (ANSPs);
- Supply industry, principally aircraft manufacturers, suppliers of systems used for air traffic management and airport purposes, suppliers of other supporting systems.

The airspace users were the main ATM stakeholders driving the requirement for the SESAR concept. Their requirements were captured in the development of the SESAR documentation [8].

From an Episode 3 internal stakeholder point of view, active controllers from ANSPs are involved in the preparation and execution of the En-Route prototyping sessions. This secures a realistic operational feedback and evaluation of the results. In other words, as this series of prototyping sessions has been developed with major core area ANSPs (MUAC, NATS, DSNA, AENA and DFS) it is expected to have wide stakeholder buy-in.

### 2.1.4 Relevant Areas of research from SESAR

The main validation focus of the three prototyping sessions was on operability and concept clarification. OI steps and topics from the SESAR research framework have been identified as relevant ([3] Table 2). Only OIs of major focus are described in Table 1. Detailed coverage of the OI steps (IP2/SL2) in each session is provided in Table 2.

**Table 1. Mapping Episode 3 En-Route prototyping sessions to SESAR Operational Improvements**

| | |
|---|---|
| **OIs (Major Focus)** | IP2/CM-0104 Automated Controller Support for Trajectory Management (e.g. MTCD).<br>IP2/CM -0204 Automated Support for Near Term Conflict Detection & Resolution and Trajectory Conformance Monitoring.<br>IP1/CM-0202 Automated Assistance to ATC Planning for Preventing Conflicts in TMA and En-Route Airspace.<br>IP1/CM-0203 Automated Flight Conformance Monitoring.<br>IP2/CM-0404 Enhanced Tactical Conflict Detection/Resolution and Conformance & Intent Monitoring.<br>IP2/TS-0103 Controlled Time of Arrival (CTA) through use of Data Link.<br>IP1/TS-0305 Arrival Management Extended to En-Route Airspace. |

| | |
|---|---|
| **SESAR performance solution** | Capacity: Reducing controller workload by reduced requirement for tactical intervention, exploitation of a/c capability to fly precise trajectories.<br>Efficiency: User preferred trajectories wherever possible and new separation modes (also decreases environmental impact).<br>Cost Effectiveness: Introduction of automation and automated support, reducing controller training costs.<br>Safety: Pre-deconflicted trajectories and conformance monitoring tools enhancing safety.<br>Predictability: Through adherence to user preferred routing. |

**Table 2. Link between WP 4.3.4 Task and the SESAR OI steps (IP2/SL2)**

| IP | OI step | Covered by session | | | Assumed | Comments |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| 2 | L05-02 Managing Air Traffic Complexity. | - | - | ✓ | - | This was enabled using the TED tool. |
| | CM-0104 Automated Controller Support for Trajectory Management | - | - | - | - | |
| 2 | L06-01 Introducing Ground based Automated Assistance to Controller. | ✓ | ✓ | ✓ | - | The automation assistance deployed used the VERA, MONA and MTCD tools. |
| | CM-0202 Automated Assistance to ATC Planning for Preventing Conflicts in En Route Airspace. | - | - | - | - | |
| | CM-0203 Automated Flight Conformance Monitoring. | - | - | - | - | |
| | CM-0204 Automated Support for Near Term Conflict Detection & Resolution and Trajectory Conformance Monitoring. | - | - | - | - | |
| 2 | L06-02 ATC Automation in the Context of En Route Operations. | ✓ | ✓ | ✓ | - | The trajectories were available to the controllers. |
| | CM-0401 Use of Shared 4D Trajectory as a Mean to Detect and Reduce Potential Conflicts Number. | - | - | - | - | |
| 2 | L08-02 Precision Trajectory Operations. | ✓ | ✓ | ✓ | - | |
| | CM-0601 Precision Trajectory Clearances (PTC)-2D Based On Pre-defined 2D Routes. | - | - | - | - | |

| IP | OI step | Covered by session | | | Assumed | Comments |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| | CM-0602 Precision Trajectory Clearances (PTC)-3D Based On Pre-defined 3D Routes. | - | - | - | - | |
| | CM-0603 Precision Trajectory Clearances (PTC)-3D Based On Pre-defined 3D Routes. | - | - | - | - | |
| 2 | L05-03 Enlarging ATC Planning Horizon. | - | ✓ | ✓ | - | CTA being provided by a scripted AMAN (up-linked prior to entry in simulated airspace). |
| | CM-0302 Ground based Automated Support for Managing Traffic Complexity Across Several Sectors. | - | - | - | - | |
| 2 | L05-04 Moving to coordination-free environment. | ✓ | ✓ | ✓ | | There was a full data-link environment, including transfer function; it was coordination-lite. |
| | CM-0402 Coordination-free Transfer of Control through use of Shared Trajectory. | - | - | - | - | |
| 2 | L06-02 ATC Automation in the Context of En Route Operations. | - | - | - | ✓ | |
| | CM-0403 Conflict Dilution by Upstream Action on Speed. | - | - | - | - | |
| 2 | L05-01 Management / Revision of Reference Business Trajectory (RBT). | - | - | - | ✓ | The network-based revisions of RBT was assumed to be functional; trajectory uplinks, e.g. using TED can be made to the aircraft via Data Link |
| | AUO-0302 Successive Authorisation of Reference Business / Mission Trajectory (RBT) Segments using Data Link. | - | - | - | ✓ | |
| | AUO-0303 Revision of Reference Business / Mission Trajectory (RBT) using Data Link. | ✓ | ✓ | ✓ | | |

Note: S1, S2 and S3 refer to Prototyping Session 1, Session 2 and Session 3.

"✓" means "yes" "-" means "no".

### 2.1.5 Associated KPA and KPI

The present series of prototyping sessions aims mostly at concept clarification. Whereas the three prototyping sessions progressively focus on operability of both RBT concept and use of CTA, initial trends on KPAs such as safety, efficiency, predictability and capacity are examined (Table 3).

Table 3. KPA and KPI investigated during the three prototyping sessions

| Focus | KPA | KPI |
|---|---|---|
| Main | Operability | Subjective feedback on feasibility and acceptability of the 4D TM and on perceived benefits and limitations.<br>Objective measures of changes in working practices (instructions repartition, geographical distribution of manoeuvre instructions, controller workload level). |
| Secondary (trends) | Predictability | Temporal, lateral and vertical deviations from the planned flight paths.<br>Achieved delivery order to TMA. |
| | Capacity | Controller availability, through subjective and objective measures of controller workload, including number of tactical interventions.<br>Traffic load and delivery conditions. |
| | Efficiency | Temporal, lateral and vertical deviations from the planned flight paths.<br>Achieved delivery order to TMA. |
| | Safety | Subjective assessment of controller workload and situation awareness.<br>Objective measures of level of bunching, number of short term conflict alerts and of losses of separation. |

# 3 VALIDATION METHODOLOGY

## 3.1 PROTOTYPING APPROACH

The Episode 3 project uses a prototyping approach to the human-in-the-loop exercises that investigate the feasibility and operability of the en-route 4D TM concept elements. This approach is described in the project Description of Work [10], Validation Strategy [2] and Experimental Plan [3].

Prototyping sessions are considered as the most appropriate technique to assess the feasibility and acceptability of the different elements of the concept, within the new Episode 3 timescales, and at this level of concept maturity. Further they are a compromise between sufficient realism and flexible/iterative approach in close co-operation with WP 4 En-Route Expert Group.

Prototyping sessions address the concept clarification objectives in an efficient manner. They are an intermediate type of validation technique between expert groups, gaming exercises, and full scale fast-time and real-time simulations.

In addition prototyping sessions enable an iterative approach, in the sense that specific aspects of the concept may be assessed separately (possibly in a simplified environment), and then gradually integrated when sufficient maturity is reached.

According to the principle of iterative approach and as initial validation steps, the proposed series of prototyping sessions focus on the intermediate timeframe (Implementation Package 2, see Table 2) of the SESAR concept. It is anticipated that, beyond Episode 3, a full scale real-time simulation would have to be conducted.

## 3.2 LINKS WITH EXPERT GROUPS, DODS AND MODELLING ACTIVITIES

The prototyping activity is part of the global WP 4 validation strategy [2]. The three prototyping sessions were carried out in the SESAR En-Route Environment, in close co-operation with the Separation Management Expert Group (EP3 WP 4.3.1), taking advantage of the iterative nature of the sessions. After each prototyping session, an Expert Group meeting was convened by WP 4.3.1 so as to agree on the scope and content of the next session, based on a presentation of initial feedback on the one just conducted. Some scoping and direction for the sessions (in particular the first one) had already been addressed in the En Route Expert Group that took place on April 21st - 22nd 2008, before the project suspension [9].

In this sub-Work Package the support of Operational staff was essential for the validity and successful delivery of meaningful results. Two types of supports were provided: operational experts involved from the preparation of the experiment onwards and current operational controllers experienced in busy airspace participating in the sessions.

The EP3 WP 4 Expert Group and the WP 4.2 Concept Definition activities used the output of each prototyping session and the final consolidated validation report, where deemed appropriate, as inputs to the Scenario and Use Case development in the G-DOD [17] and in the E6 En-Route DOD document [18].

The links with Fast Time activities (EP3 WP 4.3.2) and Gaming activities (EP3 WP 4.3.3) were managed by the Separation Management Expert Group.

In addition, modelling activity was performed within EP3 WP 4.3.4 to provide de-complexified traffic samples for further use in WP 4.

# 4 EXPERIMENT PLANNING

## 4.1 MAIN OBJECTIVES

The aim of WP 4.3.4 was to provide evidence on the expected benefits of 4D Trajectory Management (adherence to the target times in the RBT, and the CTA where it exists). The three prototyping sessions were envisaged as complementary steps towards the assessment of 4D trajectory management. Their main objectives were:

1. Assess from controller's perspective the operational feasibility and acceptability of the RBT concept;
2. Assess from controller's perspective the operational feasibility and acceptability of the introduction of en-route CTA.

In other words, the sessions addressed the following questions:

- How does the 4D trajectory management impact the controller working method?
- How does the controller facilitate the RBT/CTA (procedures, roles, working method, conflict resolution…) in particular focusing on the use of CTA to deliver aircraft to TMA?

To meet these objectives, the controllers needed familiarisation to understand the RBT/CTA concept and provide relevant and adequate feedback.

In these experiments, although the concept allows for diversity, all aircraft have a TTA. This is to allow exploration of the operability of first managing aircraft TTA in a homogenous equipage environment and follows on from the preceding experiments en-route. Some of these target times that are subject to arrival management processes (e.g. AMAN tools) include a CTA.

In addition, the support required by the controllers in a 4D environment (e.g. airspace structure, tools, information - what/when/how) was also looked at as being closely linked to the controllers' tasks. The background arrival management processes described here refer to AMAN, but in the future concept this is not necessarily bound by the available tools of today.

## 4.2 STEPPED APPROACH

The step-wise approach introduced to address the operational feasibility of the 4D TM was guided by the following motivations:

- Progressive introduction to the 4DTM concept: first airspace and environment (feasibility), then RBT (acceptability) and finally CTA (acceptability);
- Progressive increase of complexity, with an initial focus on RBT (larger time constraint tolerance) before investigating CTA feasibility (time constraint reduced to a +/- 30s tolerance window);
- Progressive extension of scope: feasibility, acceptability including compatibility with other ATCO tasks before performance assessment.

The experiment was conducted over three separate but successive sessions with each session designed to introduce new elements of 4D trajectory management. At the end of the first session the results and comments from the controllers resulted in changes for the next session and the same was also true of the preparation of the final prototyping session. A brief summary of each prototyping session is as follows:

- Session 1
  - The airspace was based on 3 sectors within MUAC with all flights on direct tracks.
  - This session introduced one element of the 4D trajectory management (RBT). All aircraft flying an RBT thus allocated a RTA;
  - The aim was to get initial indications of the controllers' perception of 4D management (RBT).
- Session 2
  - Specific arrival and departure flows were segregated from overlying traffic by placing them on fixed routes during the initial climb or initial descent;
  - This session introduced an additional element of 4D management (CTA). All aircraft flew an RBT and some arrivals to specific airports under or adjacent to the simulated airspace were allocated a CTA;
  - The aim was to further assess RBT management and get initial indications of the controllers' perception of CTA management.
- Session 3
  - Revised sectorisation was developed with a vertical sector split of one sector and change to the geographical boundaries of another. Two segregated/reserved airspaces were introduced;
  - All aircraft flew an RBT and number of aircraft flying a CTA was increased compared to session 2;
  - This session introduced the availability of a tool to assist the controllers in managing the trajectories (TED);
  - The aim was to further assess RBT and CTA management in focusing on the delivery to TMA.

## 4.3 PROTOTYPING SESSIONS' OBJECTIVES

The assessment of 4D TM feasibility and acceptability was broken into three sub-objectives:

- Objective 1: Familiarise controllers with the 4D TM;
- Objective 2: Define and validate a suitable 4D environment (airspace, traffic flows);
- **Objective 3: Assess from controller's perspective the operational feasibility and acceptability of the 4D TM.**

Table 4 summarises the coverage of these objectives during each of the three prototyping sessions. Note that whereas the definition of a suitable environment was the focus of the first session, changes and improvements of the initial environment required additional assessment of the environment during sessions 2 and 3. In addition, the introduction of segregated areas in session 3 maintained the focus on environment design assessment. Similarly, due to the limited duration of each session, the familiarisation with concepts could not be limited to an initial session, and took place over all sessions, even though it became secondary.

**Table 4. Primary (X) and secondary (x) focus of the three prototyping sessions**

| Objectives | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| 1. Familiarise controllers with the 4D TM | X | X | X |
| 1a. Familiarise controllers with RBT | X | x | x |
| 1b. Familiarise controllers with CTA | | X | X |
| 2. Define suitable 4D environment | X | X | X |
| **3. Assess feasibility and operability of the 4D TM** | X | X | X |
| **3a. Assess feasibility and operability of RBT** | x | X | X |
| **3b. Assess feasibility and operability of CTA** | | x | X |

**(N.b. main objectives in bold type)**

The general aim of assessing acceptability and operational feasibility of both the RBT and CTA was broken down into the following set of objectives related to the Performance Areas of interest for the concept element under analysis (Table 5).

Table 5. Hypotheses per experiment objectives

| Objectives | Hypothesis | Metrics |
|---|---|---|
| 1: Familiarise controllers with 4D TM concept | HF1. Sufficient practice and training with the concept during the prototyping sessions will enable controllers to provide relevant and adequate feedback. | Questionnaire item and debriefing notes. |
| 2: Define suitable environment | HD1. Controllers' feedback will enable the identification of characteristics of a suitable environment (e.g. traffic flows, sectorisation, traffic load). | Questionnaire item and debriefing notes.<br>Number of aircraft on frequency.<br>Level of bunching |
| 3: Assess feasibility and operability of 4D TM (RBT and CTA) | | |
| 3.1: Operability | HO1. The 4D TM will be found difficult but feasible by the controllers due to the several changes implied: no route structure to support the task, no homogeneous speed between aircraft, speed variations due to the RTA function, less degree of freedom and aircraft time status to consider as much as possible.<br>HO2. The controller will need more tools (e.g. trajectory editor) to handle the 4D trajectory more efficiently.<br>HO3. The 4D TM will increase the level of controllers' workload compared to today's operation due to less anticipation of conflicts (facilitate aircraft adherence), consideration of aircraft status.<br>HO4. The 4D TM will increase monitoring tasks load and reduce planning tasks load.<br>HO5. RBT condition will lead the controller to "only" facilitate the trajectory whereas the CTA conditions will increase the level of cooperation between controllers and pilots (e.g. controllers considering the time status for conflict resolution). | Questionnaire item and debriefing notes.<br>Delivery conditions.<br>Deviation from sector exit list.<br>Evolution of time deviation throughout centre.<br>Instructions repartition.<br>ISA ratings.<br>Number of aircraft on frequency.<br>Time spent on open-loop vectors. |
| 3.2: Predictability | HP1. Aircraft will mostly respect their 4D agreed trajectory (respect of lateral profile, vertical constraint and be maintained within time tolerance windows) for RBT and CTA as far as they will start inside the tolerance window. | Questionnaire item and debriefing notes.<br>Delivery conditions. |

| Objectives | Hypothesis | Metrics |
|---|---|---|
| | HP2. The achievement of time constraint and achievement of the delivery order will be detrimental to other trajectory dimensions (first vertical profile and then lateral profile). | Deviation from sector exit list.<br>Evolution of time deviation throughout centre.<br>Track miles.<br>Time spent in open loop vectors.<br>Trajectory flown.<br>Vertical deviation. |
| 3.3: Efficiency | HE1. The 4D trajectory flown will be close to the reference trajectory planned as routes are already “direct” and controllers have to facilitate adherence to it. | Questionnaire item and debriefing notes.<br>Delivery conditions.<br>Deviation from sector exit list.<br>Evolution of time deviation throughout centre.<br>Track miles.<br>Time spent in open loop vectors.<br>Trajectory flown.<br>Vertical deviation. |
| 3.4: Safety | HS1. The 4D TM will increase the level of controllers’ situation awareness compared to today’s operation as all aircraft will follow as much as possible their planned trajectory, but the lack of route structure will impair the controllers’ picture of traffic (e.g. plan evolution of traffic).<br>HS2. The level of safety will be perceived lower than in today’s operation, as more dispersed aircraft trajectories will create more numerous, larger and less predictable bunching areas | Questionnaire item and debriefing notes.<br>Delivery conditions.<br>Instructions repartition. |

| Objectives | Hypothesis | Metrics |
|---|---|---|
|  | (compared to today's bunching waypoints).<br>HS3. With 4D TM the conflict resolution will be done later and with less resolution tools as controllers have to let the aircraft fly its reference trajectory as far as possible. | ISA rating.<br>Evolution of time deviation throughout centre.<br>Level of bunching.<br>Number and severity of losses of separation. |
| 3.5: Capacity | HC1. The increase in traffic load will be manageable by controllers using the 4D TM, due to the complexity management measures and adaptation of the airspace. | Questionnaire item and debriefing notes.<br>Delivery conditions.<br>Number of aircraft on frequency. |

## 4.4 MEASUREMENT METHODS AND TECHNIQUES

### *4.4.1.1 Subjective measurements*

The subjective measurement tools consist of questionnaire data and debriefings conducted with the controllers after each measured run. In addition, all spontaneous controller comments were recorded (i.e. noted down) by the observers.

#### 4.4.1.1.1 Questionnaires

#### *4.4.1.1.1.1 Entry questionnaire*

A questionnaire was filled in by the participating controllers at the beginning of the simulation to collect information on their ATC experience and their level of familiarity with the features and concept proposed for the session.

#### *4.4.1.1.1.2 Post run questionnaire*

The post run questionnaire was filled in by the controllers after each run. It included questions on the concept (e.g. RBT or CTA management), regarding strategy used for conflict resolution, delivery conditions to TMA, comparison with today's practices, EXC and PLC task sharing, workload, situation awareness and HMI usability/suitability/improvements.

#### *4.4.1.1.1.3 Final questionnaire*

The final questionnaire was filled out by all the controllers participating at the end of the simulation period. It consisted of high level questions on RBT and CTA management regarding, e.g. the feasibility, global workload, usability of the HMI, tools needed, benefits/limitations of the concept.

#### 4.4.1.1.2 Debriefings

At the end of each run, a short debriefing was conducted to collect feedback concerning the run. At the end of the prototyping session, a more complete debriefing was dedicated to collect feedback on the simulation conduct and the concept studied.

### *4.4.1.2 Objective measurements*

#### 4.4.1.2.1 General requirements

Several aspects were assessed by objective data, collected by means of system recordings during the runs. The recorded data include controller and pilot inputs, communications (R/T and telephone) and aircraft navigation data.

The MUDPIE (Multiple User Data Processing Interactive Environment) analysis tool was used both to retrieve the recorded data (AIR, TELECOM, CWP and ISA) from the simulation platform and to deliver them in a format that can be used for data analysis and exploration.

For objective data collection, the analysis period starts 15 minutes after the beginning of the exercise (allowing the traffic to build-up) and lasts 60 minutes.

The metrics used associated with KPAs are summarised in Table 6. Detailed description of the metrics is available in the WP 4.3.4 prototyping sessions validation plan [3].

Table 6. List of Episode 3 En-Route metrics, with associated performance areas and corresponding sessions

| Performance Areas / Metrics | Operability | Predictability | Efficiency | Safety | Capacity | Session | Performance Framework |
|---|---|---|---|---|---|---|---|
| Debriefing items | X | X | X | X | X | All | / |
| Delivery conditions | X | X | X | X | X | 3 | SAF.LOCAL.ER.PI1, SAF.LOCAL.ER.PI2. |
| Deviation from sector exit list | X | X | X | | | 2, 3 | / |
| Display of RBT information | X | | | | | 1 | / |
| Evolution of time deviation throughout centre | | X | X | | | All | / |
| (2D) Flown trajectory | | X | X | X | | All | / |
| Instruction repartition | X | | | X | X | All | CAP.LOCAL.ER.PI10 to 13,<br>SAF.LOCAL.TMA.PI1 to 3 and 11. |
| ISA (workload) ratings | X | | | X | X | All | SAF.LOCAL.ER.PI1, SAF.LOCAL.ER.PI2. |
| Level of bunching | X | | | X | X | 2, 3 | SAF.LOCAL.ER.PI7. |
| Number and severity of losses of separation | X | | | X | X | All | / |
| Number of aircraft on frequency | X | | | | X | All | CAP.LOCAL.ER.PI4; CAP.LOCAL.ER.PI8. |
| Questionnaire items | X | X | X | X | X | All | / |
| Time deviation achieved | X | X | X | | | 1 | PRED.ECAC.ER.PI2, EFF.ECAC.ER.PI2. |

| Performance Areas / Metrics | Operability | Predictability | Efficiency | Safety | Capacity | Session | Performance Framework |
|---|---|---|---|---|---|---|---|
| Time spent in open loop vectors | X | X | X | | | All | / |
| Track miles | | X | X | X | | 2, 3 | EFF.LOCAL.ENR.PI9. |
| Vertical deviation | X | X | X | | | 2, 3 | / |

## 4.5 VALIDATION SCENARIO SPECIFICATIONS

This section is related to step 2.5 of the E-OCVM. It reports more specifically the simulation environment (area, sectorisation…), traffic and working positions.

### 4.5.1 Airspace

The En-Route simulated airspace was based on a subset of the current Maastricht Upper Area Control Centre (MUAC). It comprises three high level en-route sectors from the core area of Europe processing flights to and from other core areas and busy TMAs (Figure 2). It includes portions of the Hanover UIR and the Amsterdam FIR above FL 245.

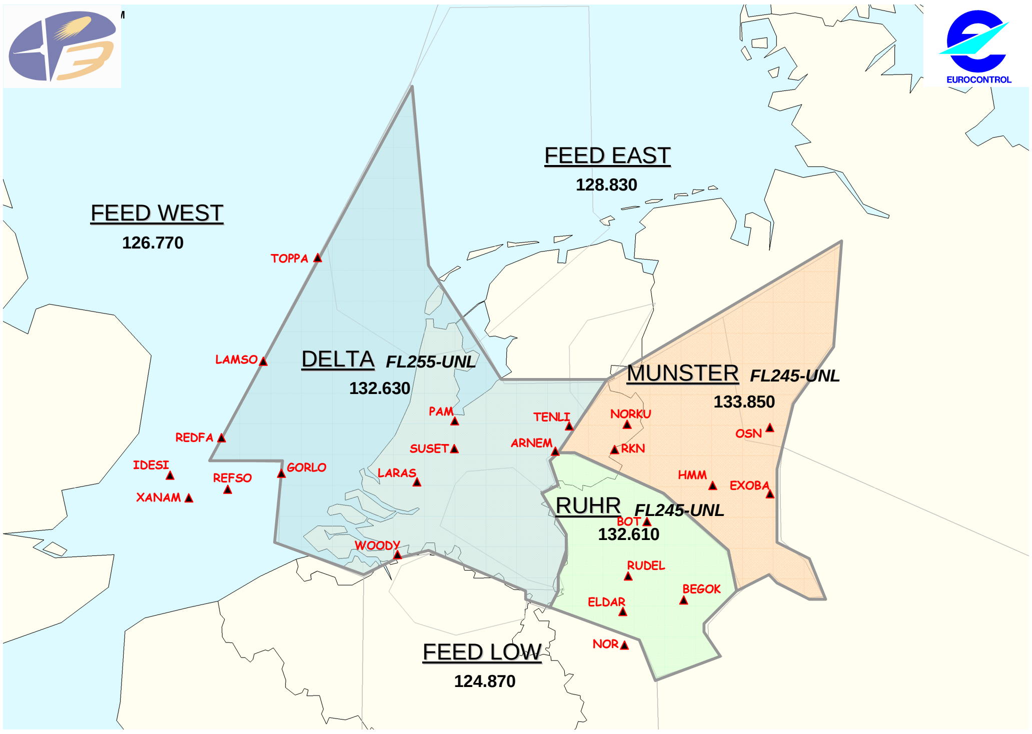

Figure 2. General map of airspace

#### 4.5.1.1 Sectors and traffic flows

The simulated airspace comprised three measured and three feed sectors (Table 8). Each measured sector was manned by two controllers: Executive (EXC) and Planning (PLC) and equipped with two controller working positions (CWP).

Each feed sector was manned by one controller with the primary task of ensuring correct delivery conditions of traffic to the measured sectors, receiving traffic from the measured sectors and responding to co-ordination requests.

The supporting sectorisation was unchanged for the first prototyping session, with three existing MUAC sectors retained. The names and vertical limits of the three sectors were as follows:

- Delta: FL 255 to Unlimited[1];
- Munster: FL 245 to Unlimited;
- Ruhr: FL 245 to Unlimited.

The existing route network was removed and an individual routeing was designed for each flight that could correspond to the user preferred trajectory (Figure 2). The new routeings were:

- Direct from the entry to exit points of the MUAC airspace for overflights;
- Direct from the entry of MUAC airspace to coordination points positioned before the (IAF) for arrival flights. The coordination points enabled the convergence of arrival flights on a single point inside the En Route sectors prior to delivery to the Approach sectors.
- Direct from coordination waypoint (corresponding to Terminal Airspace exit points) to the exit of MUAC airspace for departure flights.

This introduced a new distribution of traffic throughout the MUAC airspace and significantly changed the location of the bunching/conflict points.

#### 4.5.1.2 *Evolution of the airspace design during the prototyping sessions*

During session 1, it became quickly apparent that the sectorisation applied in the first prototyping session would not support the new distribution and increased number of flights. With the 2015 traffic sample the controllers were overloaded and their situational awareness decreased rapidly, particularly in the Delta sector. The main reasons for the high workload were the number of aircraft on frequency simultaneously, the geographical size of the Delta sector, the spread of trajectories making it difficult for controllers to detect conflicts/bunching and the mix of evolving and over flying flights in the same airspace.

For the second prototyping session the distribution of flights was altered to segregate specific arrival and departure flows. Overflights were left on their direct routeings. Measures were also taken to ensure flights entering the airspace were free from conflict and departures from Amsterdam were better regulated (Figure 3). However, the Delta sector continued to experience overload while workload on the Ruhr sector was relatively low.

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[1] In reality, when traffic levels dictate the Delta sector can be split to distribute the workload.

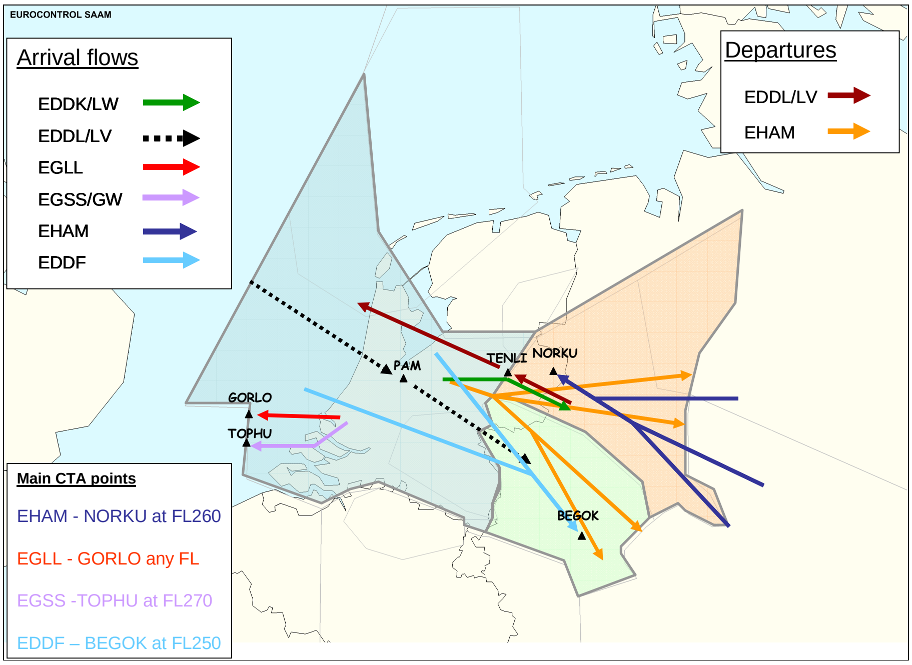

**Figure 3. Coordination waypoints and main arrival flows for session 2**

The traffic measures were retained for the third session but additional changes were made to the sectorisation with the introduction of a vertical split in the Delta sector and an enlarged Munster sector. The new Munster sector included the northern part of the Ruhr sector. This produced a more even balance of traffic load across the three sectors (Delta Upper, Delta Lower and Munster). Two segregated/reserved airspaces (military areas) were also included for the third session (Figure 4).

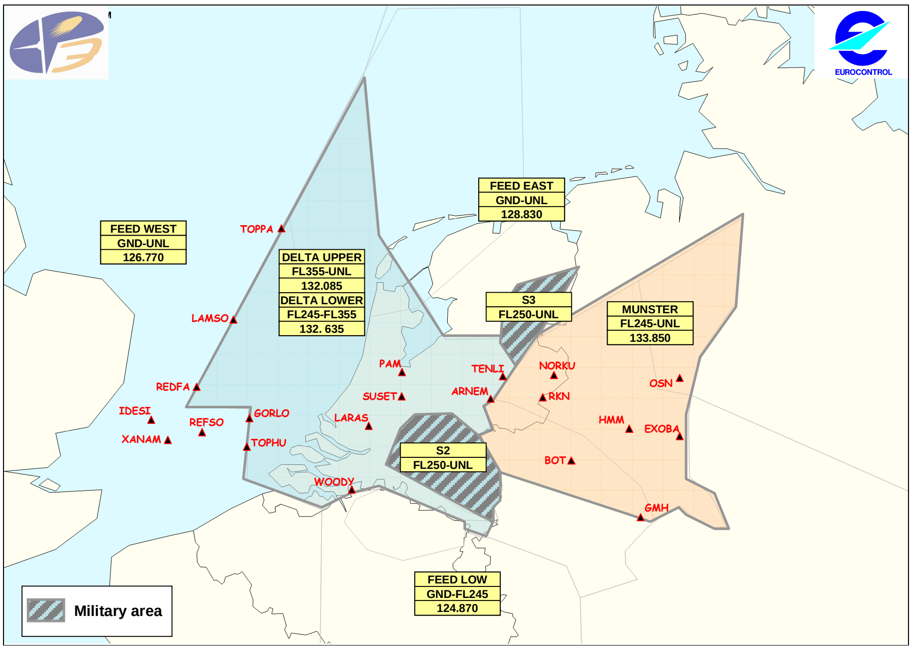

**Figure 4. Map of airspace for session 3**

### 4.5.1.3 Simulated airports and coordination points

The simulated airspace processed flights to and from busy TMAs. Current LoAs for delivery of traffic to agreed coordination points (transfer of control points) associated with these airports were respected.

In session 2 an additional transfer of control point was created (TOPHU) at the boundary between DD sector and London FIR to segregate over flying traffic and arrivals into Heathrow from arrivals to the other London airfields (London Stansted, Gatwick and Luton). This enabled a continuous descent for traffic landing at these airports.

With the introduction of the CTA in session 2, the coordination points, for an airport associated with an AMAN (or arrival management processes), became the CTA constraint waypoint. An aircraft flying to an airport with an AMAN was issued with a CTA once the aircraft entered the AMAN horizon for its airfield of destination (approximately 40 minutes before destination). Not all airports associated with en-route airspace will have an AMAN. A list of the simulated airports and those associated with an AMAN with their CTA waypoints in sessions 2 and 3 can be found in Table 7.

**Table 7. List of airports used including CTA waypoints**

| ICAO code | Airport name | CTA waypoint | |
|---|---|---|---|
| | | Session 2 | Session 3 |
| EBBR/EBMB | Brussels | - | SUSET, RUDEL, LARAS |
| EBCI | Charleroi/Brussels South | - | - |
| EDDF | Frankfurt | BEGOK | - |
| EDDK | Köln | - | - |
| EDDL | Düsseldorf | HMM, PAM | HMM, PAM |
| EDDW | Bremen | - | - |
| EDLV | Niederrhein | - | - |
| EDLW | Dortmund | - | - |
| EDDH | Hamburg | - | - |
| EDDV | Hanover | - | - |
| EDLP | Paderborn/Lippstadt | - | - |
| EDDN | Nurnberg | - | - |
| EGKK | London Gatwick | - | - |
| EGLL | London Heathrow | GORLO | GORLO |
| EGGW | London Luton | - | - |
| EGSS | London Stansted | TOPHU | - |
| EHAM | Amsterdam | NORKU | NORKU |
| ELLX | Luxembourg | - | - |

### *4.5.1.4 Overview*

An overview of the airspace description for the three sessions is provided in Table 8 below.

**Table 8. Airspace description**

| Sector Name | Sector Code | Sector Type | Category | Vertical Limits | Session |
|---|---|---|---|---|---|
| Delta | DD | Measured | Civil En-route | FL255 – UNL | 1, 2 |
| Delta Upper | DDU | Measured | Civil En-route | FL355 – UNL | 3 |
| Delta Lower | DDL | Measured | Civil En-route | FL245 – FL355 | 3 |
| Munster | HM | Measured | Civil En-route | FL245 – UNL | 1, 2, 3 |
| Ruhr | HR | Measured | Civil En-route | FL245 – UNL | 1, 2 |
| Feed West | FW | Feed | Civil En-route | GND – UNL | 1, 2, 3 |
| Feed East | FE | Feed | Civil En-route | GND – UNL | 1, 2, 3 |
| Feed Low | FL | Feed | Civil En-route | GND – FL245 | 1, 2, 3 |
| S2 | S2 | Segregated area | Military area | FL250 – UNL | 3 |
| S3 | S3 | Segregated area | Military area | FL250 – UNL | 3 |

To summarise, Figure 5 illustrates the main changes performed on the airspace throughout the prototyping sessions.

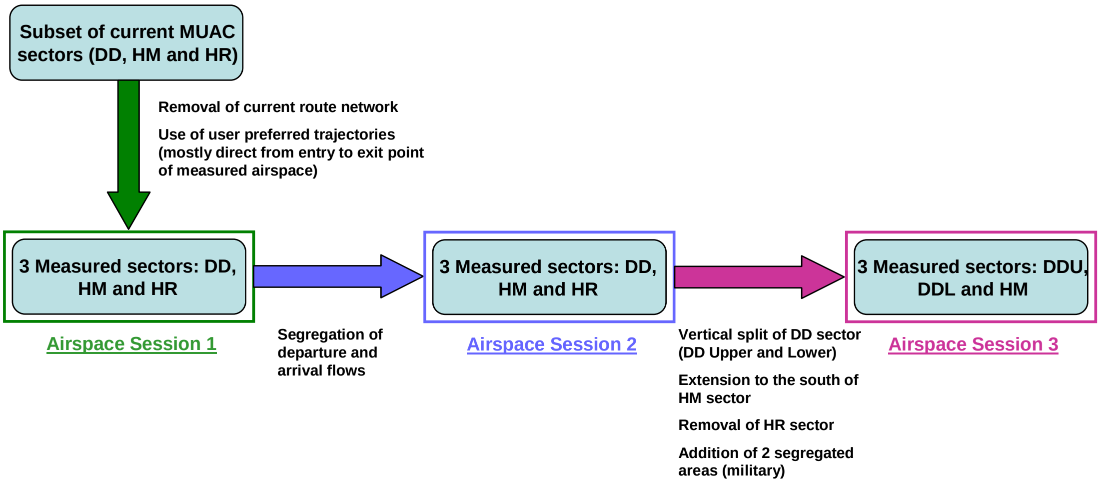

**Figure 5. Modifications of airspace throughout sessions**

## 4.5.2 Separation standards

Horizontal and vertical separations are applied as follows:

**Table 9. Separation standards**

| ***Horizontal Separation*** | | ***Vertical separation*** | |
|---|---|---|---|
| **Application** | **Separation** | **Application** | **Separation** |
| All | 5 NM | Below FL290 | 1000 FT |
| | | Above FL290 | 1000 FT (RVSM) |
| | | Above FL410 | 2000 FT |

## 4.5.3 Meteorological characteristics

The meteorological characteristics are applied as follows:

**Table 10. Meteorological settings**

| **METEO Condition** | **Environmental Setting** |
|---|---|
| Temperature | 15° Celsius |
| Wind | No wind |
| Atmospheric Pressure (QNH) | 1013 |

## 4.5.4 Traffic

### *4.5.4.1 Characteristics*

#### 4.5.4.1.1 SESAR traffic sample

One of the assumptions made was for the traffic samples to be representative of the 2015 SESAR forecast. This includes an increase in the number of flights and measures to reduce the complexity.

The samples were based on recorded traffic data from 18th of July 2006 (used for the last long Term Capacity Plan, thus insuring consistency with the ECIP/LCIP used in the ATFM delay assessment) and were increased using the STATFOR long term forecast. STATFOR predict that the global traffic demand from 2006 up to 2020 will increase by 70% (IP2 level2).

Using the STATFOR predictions a three hour sample of “2020 SESAR” traffic was obtained.

#### 4.5.4.1.2 Simulated traffic samples

Prior to session 1, six traffic samples were prepared, based on the raw 2020 SESAR traffic sample: They were as follows:

- 2 traffic samples corresponding to 2020 SESAR traffic. They were obtained by splitting the raw three hour sample in order to provide 2 samples of one and a half hours each;

- 2 traffic samples corresponding to an intermediate timeframe (2015 SESAR forecasts). These were created by reducing the 2020 samples by 12.8%;
- 2 training samples were created by further reducing the traffic load (–50% compared to 2015 traffic). In addition these samples were designed to progressively introduce elements of the 4D trajectory management and HMI (e.g. number of RTA equipped aircraft)

During session one it quickly became apparent that the 2015 traffic samples overloaded the controllers, so the decision was made to refrain from using the 2020 samples.

For the second session, the 2015 traffic samples were changed to make the presentation of traffic into the simulated airspace more manageable. Complexity management measures were taken to resolve the bunching of flights that had been observed during the first prototyping.

The SAAM tool was used to identify areas of greatest traffic density and conflicts. Operational experts examined the traffic samples to identify the individual flights that caused the conflicts and the entry times into the simulated airspace were manually modified to reduce the possibility of the conflict occurring. This process was also followed to restrict the bunching of traffic and to better sequence the departures from EHAM. Flights landing and departing airports in the vicinity of the simulated area joined a route network, designed, by the operational experts, to segregate this traffic from overflights.

A comparison was then made between the traffic sample before and after the conflict reduction measures. This showed that there had been a 32%[2] reduction in the number of conflicts.

De-bunching of traffic is inherent in the 4D Management concept and would, in reality, be applied during the planning phase (e.g. ATFM level). However, this planning phase cannot mitigate against all conflicts and tactical conflict resolution will still be required by controllers.

For the third prototyping session, two 2015 SESAR traffic samples, derived from the ones used during the second prototyping session, were prepared.

Additional arrivals to the CTA airports were also introduced to allow greater focus on the interface between the en-route and Terminal Airspace (see Table 11 below).

**Table 11. Number of arrivals added per airport**

| ICAO airport code | Traffic sample X | Traffic sample Y |
|---|---|---|
| EBBR | +5 arrivals (Total: 10 arrivals) | +1 arrivals (Total: 14 arrivals) |
| EGGL | +9 arrivals (Total: 19 arrivals) | +4 arrivals (Total: 7 arrivals) |
| EDDL | +3 arrivals (Total: 10 arrivals) | +2 arrivals (Total: 6 arrivals) |

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[2] Measurement was performed over 2020 traffic sample X.

### 4.5.4.1.3 Overview

To summarise, Figure 6 illustrates the main changes performed over the traffic sample throughout the prototyping sessions.

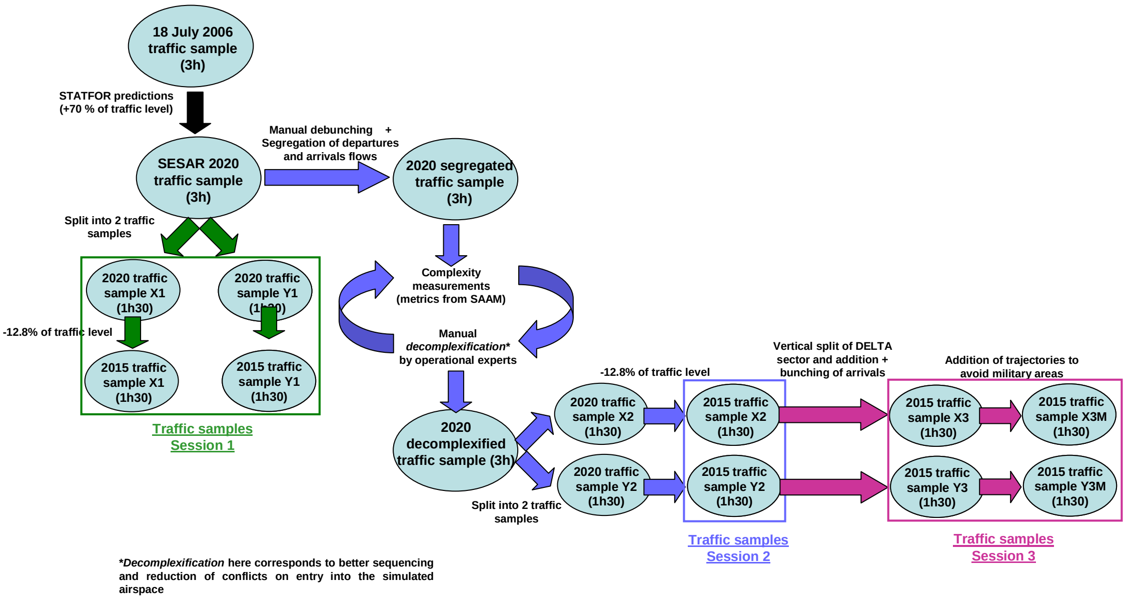

**Figure 6. Summary of the traffic design process**

### *4.5.4.2 Entry conditions*

In sessions 2 and 3, all aircraft entered the simulation with a 4D trajectory to fly (2D flight plan, initial and exit flight levels, and an RTA at a given waypoint):

- All overflights, departures and some arrivals had to respect an RBT, i.e. they had to respect the time tolerance window of [-120s; +180s] over the last waypoint of their route;
- All arrivals towards the airports listed in Table 7 had to respect a CTA, i.e. they had to respect the time tolerance window of [-30s; +30s] over a coordination waypoint corresponding to the delivery point to the approach sectors.

#### 4.5.4.2.1 RBT aircraft

To assess the impact of the RBT management, all aircraft entered the simulation with a 4D trajectory to fly (2D flight plan, initial and exit flight levels, and an RTA at a given waypoint). For simulation purpose, the RTA was set over:

- The last waypoint of the route for the overflights;
- The coordination points defined before the exit of every sector for the arrivals to: Amsterdam (Schiphol), Düsseldorf, Frankfurt.

To provide varied entry conditions, delays within the RBT tolerance window[3] ([-120 and +180s]) were set over the RTA waypoints. The initial delays were distributed over the traffic throughout the run: 70% of aircraft entered the simulated area in an optimal situation, 15% in a drifting situation and 15% in a warning situation (Figure 7).

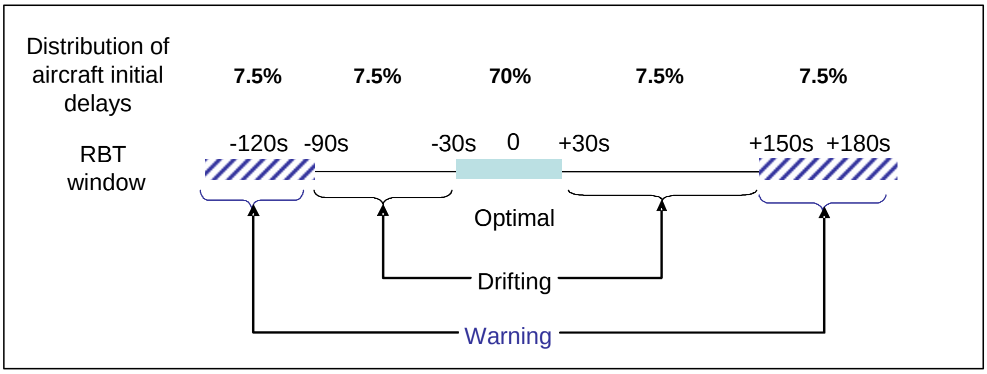

**Figure 7. Repartition of initial delays according to the RBT tolerance window**

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[3] It is assumed that pilots manage to respect the time constraint and maintain their aircraft within the tolerance window.

#### 4.5.4.2.2 CTA aircraft

CTA was not covered in session 1.

In session 2, entry conditions of arrival aircraft flying to a CTA were used as an experimental independent variable (see section 4.6.1). Depending on the run, as soon as the aircraft entered the AMAN horizon the distribution of initial delays was:

- On time: all CTA aircraft entering the AMAN horizon exactly on time (CTA= current ETA);
- Not on time: CTA aircraft entering the AMAN horizon got a delay as illustrated in Figure 8 below: 80% of aircraft were exactly on time, 10% of aircraft 40 seconds late and 10% of aircraft 40 seconds early.

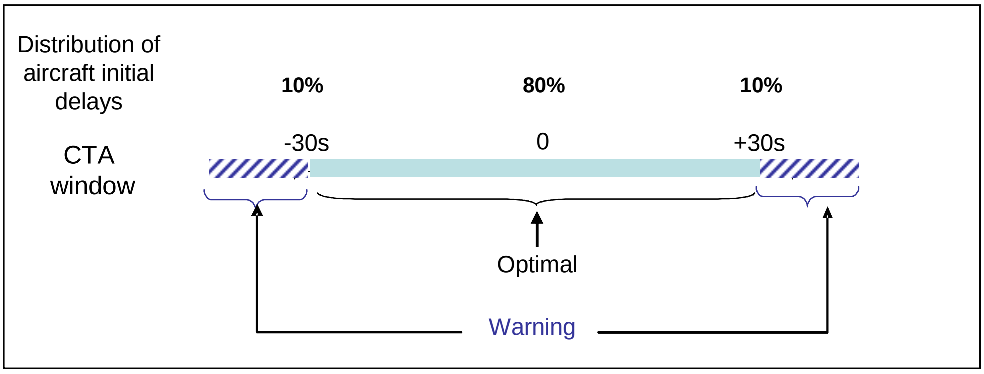

Figure 8. Repartition of initial delays according to the CTA tolerance window

In session 3, in order to provide varied entry conditions, a representative distribution of initial delays within the CTA tolerance window [-30 and +30s] was set over the coordination waypoints. The "not on time" condition was maintained in session 3 as it included some perturbations in the entry conditions (not all aircraft exactly on time) to reflect a more realistic traffic sample.

### 4.5.4.3 Aircraft capabilities

All simulated aircraft were:

- Aircraft capability (RTA): today's (2008) RTA functionality (no ETA calculation during open loop vectors phase) was simulated for the second and third prototyping sessions;
- ADS-B 100% equipage for all aircraft;
- Data Link equipage: 100% of DL equipped aircraft for 2015, with the same level of service for all aircraft (CAP and PPD).

## 4.5.5 Controller working position

Each controller working position was equipped with:

- A BARCO$^{TM}$ monitor, with a multi-window working environment;
- A three-button mouse;
- A digital voice communication system (Audio-LAN) with a headset, a loudspeaker, a footswitch and a panel-mounted push-to-talk facility;
- An ISA (Instantaneous Self-Assessment) subjective workload input device.

## 4.5.6 Tools and HMI

### 4.5.6.1 General characteristics

The HMI used for the session was an advanced stripless HMI (ECHOES), including the following main functions:

- Interactive radar labels and aircraft data lists, with colour coding of aircraft planning states enabling Data Link interactions;
- Standard On-Line Data Interchange (OLDI) of flight progress data, with SYSCO extensions specifically providing the support for aircraft transfer of communication, (i.e. there is no co-ordination of flight parameters);
- Safety Nets: Short Term Conflict Alert (STCA) and Area Proximity Warning (APW);
- Monitoring Aids (MONA), monitoring conformance of flights to the system trajectories and issuing trajectory non conformance warnings when level, lateral and speed deviation is detected;
- VERA (Verification and Resolution Advisory Tool) is a tool currently in operation in MUAC. It aims at displaying information on extrapolated future positions of aircraft based on radar data, in order to assist the controller in anticipating future aircraft separation.
- Conflict prediction: Medium Term Conflict Detection (MTCD), enabling a more accurate ‘look-ahead’ and providing controllers with automatic presentation of predicted conflicts. It was used to plan conflict-free sector transits before the aircraft enter the concerned sectors and to monitor the evolution of the predicted conflicts within the concerned sectors.

In session 3 a Trajectory Editor Tool (TED) was introduced. Among several features, the TED allows to edit an aircraft trajectory in the four dimensions (x, y, z, t). In the 4D environment context, the TED enables the controller to issue “closed loop heading” (via a new route instruction) thus providing the pilot with a complete route. The aircraft could thus adjust speed to meet the time through the FMS-RTA function, contrary to an open loop heading instruction where speed of aircraft is managed by the Cost Index rather than the RTA function while the aircraft is on the heading.

### 4.5.6.2 4D trajectory management dedicated displays

#### 4.5.6.2.1 RBT time status displays

For aircraft flying an RBT, the objective was to remain within a [-120s; +180s] time window. To calculate how this objective was achieved, for each aircraft, the ETA “air” (coming from the airside of the simulator) was compared to the RTA (ETA ”air”-RTA).

In session 1, to monitor the RBT time status of the aircraft, depending on the value of (ETA Air – RTA), dedicated displays were added in the aircraft label as described in Figure 9. The controller could display this information in the aircraft label via a menu included in the label configuration window. In a warning situation the RBT time status displayed in yellow always appeared in the aircraft unselected label. The controller can acknowledge the warning by clicking on the symbol, which results in removing/hiding the whole warning message (yellow +/-) but only from the unselected label of the aircraft to avoid an overload of information on the radar screen.

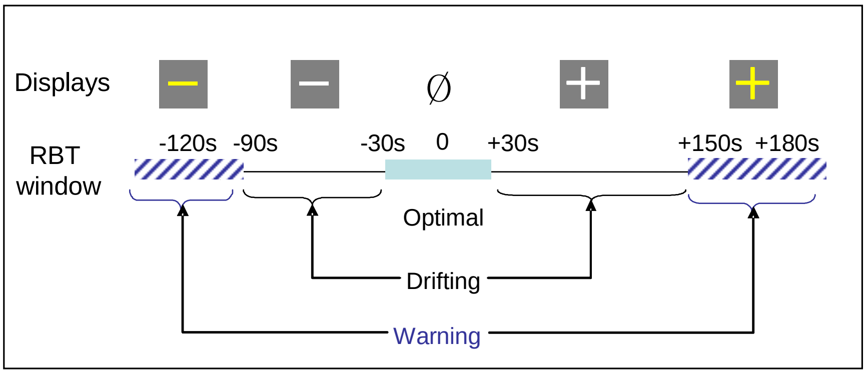

Figure 9. RBT time status displays

In the second session, following controllers' request, the deviation value in seconds was added beside the "+/-" symbol in the extended label only. In the third session, RBT information ("+/-") was provided only when aircraft were in the warning situation as information for drifting situations was not used by the controllers. In warning situation, the controller could acknowledge the warning by clicking on the symbol. That switched the symbol ("+" or "-") from yellow to white. The controllers were still aware of the aircraft time status without the yellow warning colour.

#### 4.5.6.2.2 CTA time status displays

The CTA was addressed only in the second and third sessions.

For aircraft flying a CTA (arrivals), the objective was to remain within a [-30s; +30s] time window. To calculate how this objective was achieved, for each aircraft, the ETA "air" (from the airside of the simulator) was compared to the RTA (ETA "air" -RTA).

Before entering the AMAN horizon, all aircraft, including arrivals had an RBT. Once arrival aircraft entered the AMAN horizon for their arrival airport they received a CTA. To warn the controllers that the aircraft had entered the AMAN horizon and that the tolerance time frame window was reduced to +/-30 seconds, the CTA time status information was always displayed in all aircraft label formats (unselected, selected and extended). Depending on the deviation from the RTA, the CTA time information was displayed as described in Figure 10.

In warning situation, the controller could acknowledge the warning by clicking on the symbol. That changed the squared symbol ("+" or "-") from yellow to white. The controllers were still aware of the aircraft time status without being too much distracted by the yellow warning.

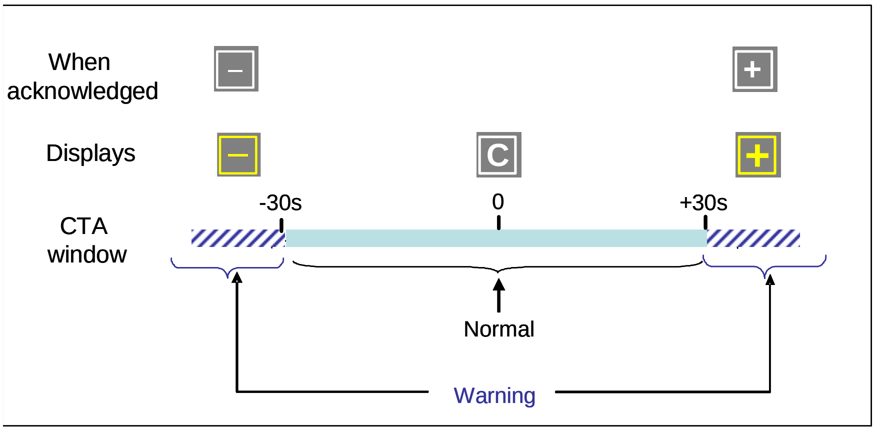

Figure 10. CTA time status displays

### 4.5.6.2.3 Sector exit list window

The sector exit list is related to the CTA and was developed as a consequence of comments made by the controllers during the first prototyping session. The list was introduced in the second session and further refined for the third session. The controller working position included a sector exit list (SEL) providing delivery sequence order over a given coordination point of the En-Route sectors. This list was a support to the controllers in their sequencing task and can also be seen as a constraint to respect to deliver aircraft as required and planned by the approach sectors.

The aircraft were listed in a dedicated window and sorted according to their CTA time over a given coordination waypoint. Each coordination waypoint was displayed in separate windows during session 2 (Figure 11), however, the different windows were superimposed in sessions 3 and accessed via specific buttons (Figure 12).

The list included aircraft callsign, CTA time and deviation compared to the CTA time (ETA-CTA in seconds). For aircraft flying outside the tolerance window (in CTA warning), the deviation value was displayed in yellow (as in the aircraft label) to warn the controllers that the aircraft was running late/early compared to planned delivery order. As a sector could include several coordination waypoints (e.g. towards several airports), the list also included buttons corresponding to each coordination waypoint of the given sector. It enables the controllers to switch from one arrival list to another with a left click on corresponding buttons named according to the coordination waypoint chosen.

To avoid a long list of aircraft on the radar screen, arrival aircraft appeared in the list only when they were flying a CTA (i.e. entering the AMAN horizon) and had been assumed by the sector in charge of delivering it to the relevant co-ordination point. Aircraft disappeared from the sector exit list once they had been transferred by the current sector or once the coordination waypoint had been reached.

| CALLSIGN | CTA FIX | CTA | DEV |
|---|---|---|---|
| CALLSG1 | IAF 1 | 09:04 | 0 |
| CALLSG2 | IAF 1 | 09:18 | +12 |
| CALLSG3 | IAF 1 | 09:19 | +38 |
| CALLSG3 | IAF 1 | 09:21 | -23 |

**Figure 11. Sector exit list display (session 2)**

| CALLSIGN | CTA | DEV |
|---|---|---|
| CALLSG1 | 09:04 | 0 |
| CALLSG2 | 09:18 | +12 |
| CALLSG3 | 09:19 | +38 |
| CALLSG3 | 09:21 | -23 |

**Figure 12. Sector exit list display (session 3)**

#### 4.5.6.2.4 Speed deviation monitoring aids

4D trajectory management implies an additional task for the pilots as they are responsible to achieve the agreed time. To do so, the pilots may have to make speed adjustments. Although in principle the pilots should report a speed increase/decrease of more than 20kts, they sometimes do not[4]. For this reason, following controllers requests during the first prototyping session, and confirming comments/recommendations collected during a previous En-Route simulation [15], a speed deviation warning was introduced in session 2 and kept in session 3.

Part of the MONA functionalities, the speed deviation warning was displayed as soon as the speed of aircraft in cruise phase (i.e. at a constant cruise flight level) deviates by 15kt or more (or more than 0.02M) from the cleared speed. The warning was displayed in all the aircraft label formats (unselected, selected, extended) through a “SPD DEV” message in yellow as illustrated in Figure 13. Unlike the other MONA warnings, the controllers could de-activate the speed warning message (with a left click on it) to remove it from the label[5].

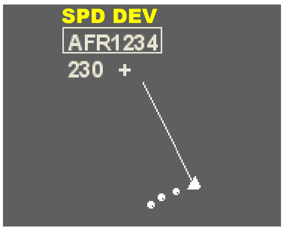

**Figure 13. Example of speed deviation warning displayed in unselected label**

### 4.5.7 Pilot working positions

The simulated environment provided pilot working positions enabling “pseudo-pilots” to handle several aircraft at the same time. New developments for the positions, allow the pilots to see the aircraft time status. However, due to the large number of aircraft being handled, the pseudo pilots could not monitor the aircraft trajectory closely (as a real pilot would do) leading to the inability for them to make appropriate requests (e.g. direct-to a waypoint to recover time if the aircraft was running late). In session 2, these situations were identified beforehand, and requests scripted for the pilots to make during the simulation on concerned aircraft and at the appropriate time.

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[4] This was observed during air simulation [16] where no speed deviation was reported to the controllers despite some large speed changes.

[5] However, if the aircraft continues to increase speed by more than 20kts compared to current speed when warning acknowledgment, the warning message is displayed again.

## 4.6 EXPERIMENTAL VARIABLES AND DESIGN

This section describes the experimental design based on the different variables.

### 4.6.1 Experimental variables

The experiment design of the prototyping sessions was built around the following variables.

**Level of RBT time information available to the controllers with two levels:**

- No RBT time status information displayed to the controllers;
- RBT time status information available to the controllers within the label through the "label configuration menu".

This variable was used to assess the impact of the 4D TM on controllers' roles and working method, i.e. whether they played an active role in the 4D TM and considered the time status of the aircraft for conflict resolution (when the time status was provided).

**Traffic type with two levels:**

- 2015: corresponding to the 2015 forecasted traffic load and treated according to SESAR assumptions. It also corresponds to the SESAR baseline traffic level;
- 2020: corresponding to the 2020 forecasted traffic load and treated according to SESAR assumptions. It also corresponds to the SESAR target traffic level.

This variable was used to assess the impact of traffic level on concept acceptability and operability, in comparing baseline and target SESAR level of traffic.

**Proportion of arrival aircraft flying under a CTA:**

- 0% (No): all aircraft flying an RBT only;
- 100% (Yes): all arrival aircraft landing during peak hours in a major airport located in the vicinity of measured airspace get a CTA. Other aircraft fly an RBT only.

This variable was used to assess both the impact of the RBT and the CTA. Runs providing only RBT aircraft were used to assess whether the new environment (airspace and traffic) was suitable for RBT management (compared to the one used in the first prototyping session). Runs with CTA aircraft were used to assess the controller feasibility and operability of managing 4D trajectory within a more accurate time tolerance window (+/- 30 seconds).

**Entry conditions for CTA aircraft:**

- On-time: all CTA aircraft entering the AMAN horizon exactly on time (CTA= current ETA);
- Not on-time: some CTA aircraft entering the AMAN horizon with an initial delay: 80% of aircraft exactly on time, 10% of aircraft 40 seconds late and 10% of aircraft 40 seconds early.

This variable was used to assess the impact of non-optimum entry conditions (not all aircraft on time) on CTA feasibility and operability (e.g. to deliver the traffic in the correct planned order).

**Provision of military activity:**

- NM: No military activity, all aircraft flying an RBT and/or a CTA according to the airspace;
- M: Military activity, all aircraft flying an RBT and/or a CTA providing trajectories avoiding military areas. The military areas were active from start to the end of the run (no opening during the run). It was assumed that the opening of the military areas was part of the planning phase (RBT).

This variable was used to assess both the impact of the RBT and the CTA and the impact of military activity on 4D trajectory management. Runs without military activity were used to assess the feasibility and operability of both RBT and CTA while focusing on the respect of delivery conditions to downstream sectors (TMA). Runs including military activity were used to assess the compatibility between the 4D trajectory management tasks and military activity.

Table 12 summarises in which session variables were used with corresponding number of runs (planned number of runs in brackets and experiment variables in bold).

**Table 12. Summary of independent variables usage during prototyping sessions**

| Variable | Modalities | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| RBT Information available | Yes | **4** | 8 | 8 |
|  | No | **4** | / | / |
| Traffic level | 2015 | 8 | 8 | 8 |
|  | 2020 | 0 (4) | / | / |
| Arrivals on CTA | No | 8 | **2** | / |
|  | Yes | / | **6** | 8 |
| CTA entry conditions | On-time | / | **3** | / |
|  | Not on-time | / | **3** | 8 |
| Military activity | Yes | / | / | **4** |
|  | No | / | / | **4** |

### 4.6.2 Control variables

Other variables were induced by the simulation characteristics in order to prevent controllers from getting too familiar with the traffic scenarios:

- Controller position: Ensure, as much as possible that each controller acted equally often as Executive and Planner controller on the different sectors;
- Traffic samples: Different but comparable[6] traffic samples were used in order to prevent the controllers from becoming too familiar with the traffic scenarios. This also allowed the data from the two samples to be grouped and analysed together for each condition.

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[6] The traffic variations were matched as far as possible in terms of load and complexity. The two samples presented the same characteristics (same load level, same aircraft capabilities). Their difference mainly lied in aircraft identification and a slightly different structure of the traffic.

# 5 CONDUCT

## 5.1 SCHEDULE

The three sessions took place on the following weeks:

- Session 1 week of 29th September – 3rd October 2008.
- Session 2 week of 1st – 5th December 2008.
- Session 3 week of 2nd – 6th February 2009.

All sessions took place over five days and consisted of one and a half days of training followed by three days of measured exercises. The last slot of the simulation session was used for final debriefing and questionnaires.

### 5.1.1 Training session

The objectives of the training were to:

- Provide the controllers with a sufficient knowledge of the 4D trajectory management concept assessed during the simulation;
- Familiarise the controllers with the airspace (including military areas, and new traffic patterns in the third session), the operational procedures and the working methods applied during the simulation;
- Provide the controllers with a sufficient knowledge of the platform functions and HMI, and the different support tools (e.g. MTCD).

During the training period, the controllers were first given several presentations concerning the simulation objectives, content and organisation, the operational concept, the working procedures and the HMI.

A stepwise training approach was adopted to enable the controllers to progressively build up their understanding of the concept, procedures, support tools and HMI applied and used in the simulation. In addition, controllers' comments expressed during the first prototyping session were considered to improve the training for the second and third sessions.

Initially, a controller handbook providing an overview of the 4D trajectory management concept and presenting the airspace, the tools and the HMI used during the simulation was sent to the participants. In addition, for the third session, a Computer Based Training tool (CBT) was sent to the participants in order to be able to interact with the HMI components in the EEC simulation platform. This resulted in a smaller presentation requirement on the contents and objectives of the simulation. Detailed usage of the tools and HMI was performed through hands-on exercises.

The participants performed five to six short training runs lasting 40 minutes, in order to become familiar with all the HMI aspects and possible interactions with the system. During these exercises, they had the opportunity to act successively as Planning and Executive controller on the various sectors. Familiarisation with traffic load was provided for the training exercises gradually increasing the level of traffic from light up to 2015 traffic level. This prevented the participants from being overloaded by the new features (e.g. airspace, tools, HMI). In addition, teams of controllers were built by mixing newcomers and previously exposed controllers to enhance the quality and efficiency of the training.

### 5.1.2 Measured session

The measured session consisted of performing eight measured runs. Each run lasted 1 hour 15 minutes, enabling to collect one hour of recordings, and was followed by a post-exercise questionnaire and a collective debriefing. In addition, observers present in the operations room captured spontaneous controller comments on the topics of interest and on problems that occurs.

A specific seating plan was made for each session to allow each controller:

- To act equally as an Executive and Planner controller;
- To control all the sectors;
- To handle both traffic samples as an Executive and Planner controller;
- Not to play the same role on the same position with the same traffic sample.

## 5.2 WORKING METHODS AND ROLES

### 5.2.1 Controller – Pilot task repartition

Even though one of the objectives of the sessions was to refine working methods, an initial definition of roles and working methods was initially proposed:

- Pilots are responsible for the 4D trajectory achievement;
- Controllers are tasked to facilitate the aircraft 4D trajectory (RBT and CTA), i.e. allow the aircraft to adhere as far as possible to the agreed trajectory.

### 5.2.2 Controllers tasks

Although controllers still had to ensure the separation, their roles and tasks were slightly different from today's operations. The management of and the adherence to an agreed trajectory is a change from today's practices. Controllers were asked to avoid expediting traffic through the sectors by offering directs and the use of open loop instructions (for separation management only) which could degrade the predictability of the 4D trajectory. However, controllers were still responsible for separation of aircraft and conflict resolution and this may warrant a deviation. Even though adherence was expected to be 4D, in the context of the prototyping sessions, controllers were tasked to respect essentially 2D adherence in avoiding as much as possible lateral deviation.

In addition, in sessions 2 and 3, the adherence to the CTA meant that the controllers had to respect the required delivery conditions to TMA (i.e. order and required separation), as planned by the AMAN[7]. A new tool, sector exit list (SEL), was introduced to support the controllers in the task of sequencing aircraft to the TMA. This sector exit list was therefore considered by the participants as a support to sequence aircraft in the required order but also as a constraint to respect.

### 5.2.3 Executive – Planning controller task repartition

Compared to today's working methods, the 4D TM did not introduce any change in the executive and planning controllers' tasks repartition. However, findings from a previous

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[7] Note that in the present validation exercise, the list is scripted and not directly come from an AMAN.

simulation [15] and successive prototyping sessions (sessions 1 and 2) showed that adherence to the trajectory, together with the use of Data Link, induced some changes in the planning controller (PLC) activities. As there was less pre-sector traffic planning and preparation, the PLC focused more on what was happening within the sector and supported the executive controller (EXC) more directly in his/her tasks – identifying and warning of potential conflicts, monitoring their evolution, informing the executive controller of any changes and advising on conflict resolution. In addition, some instructions usually issued by the EXC could be handled by the PLC (e.g. transferring aircraft). The EXC was now in a position to delegate more tasks associated with R/T to the PLC. Although each team of controllers were free to define their task allocation, they generally adhered to the suggested task sharing.

## 5.3 PARTICIPANTS

Up to eight controllers per session were committed by five ANSPs involved in Episode 3 WP 4: MUAC, DFS, DSNA, NATS and AENA.

In the first session, eight controllers (1 from MUAC, DFS and DSNA, 2 from NATS and 3 from AENA) were grouped in 4 teams of 2 controllers to man executive and planning positions. Each team was composed of controllers coming from different ANSPs to ensure a mix in experience and working methods. The same teams of controllers were retained throughout the simulation.

In the second session, half of the participants were newcomers not familiar with the simulation environment and the 4D trajectory management concept. The six controllers (2 from MUAC, DFS, NATS and 3 from AENA (part time)) were grouped in 3 teams of 2 controllers to man executive and planning positions. As in session one each team was composed of controllers coming from different ANSPs to ensure a mix in experience and working methods. In addition, teams of controllers were built by mixing newcomers and controllers who already performed the first prototyping session to enhance the quality and efficiency of training/learning process. The same teams of controllers were retained throughout the simulation (i.e. training and measured session).

In the third session, five of the eight participants already participated in at least one of the previous prototyping sessions. There were three newcomers, not familiar with the simulation environment and the 4D trajectory management concept. The eight controllers (2 from MUAC, DFS NATS and AENA) were grouped in 4 teams of 2 controllers to man executive and planning positions.

Detailed participants repartition throughout the three sessions are listed in Table 13 below.

**Table 13. Participants repartition**

| ANSP | Controller Id | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| **AENA** | **1** | X | X | - |
| | **2** | - | - | X |
| | **3** | X | - | - |
| | **4** | X | - | X |
| **DFS** | **5** | - | X | X |
| | **6** | X | X | X |
| **DSNA** | **7** | X | - | - |
| **MUAC** | **8** | - | X | - |
| | **9** | - | X | X |
| | **10** | X | - | X |
| **NATS** | **11** | - | - | X |
| | **12** | X | X | - |
| | **13** | X | X | - |
| | **14** | - | - | X |
| **Average age (min; max)** | | 42,8<br>(23; 56) | 38,3<br>(26; 46) | 38,6<br>(23; 56) |
| **Average experience (min; max)** | | 17,3<br>(2,5; 33) | 13,16<br>(5; 16) | 12,9<br>(2,5; 33) |

Note: “X” means present, “-” means not present.

## 5.4 DEVIATION FROM THE PLAN

Detailed weekly schedules of the three sessions are presented in annexes (tables in 9.2).

### 5.4.1 Deviation from session high level objective

The high level objectives (assess feasibility of RBT, assess feasibility of CTA and assess impact of 4D TM on TMA delivery conditions) were not modified.

However, the environment suitability objective, which was initiallyused for a large scale real time simulation had to be adapted for the three sessions.

### 5.4.2 Deviation from experimental design

For the first session, the limited time available for training (1 day) was not sufficient for controllers to become familiar enough with the overall experimental settings. As a result, given the controllers difficulty to handle 2015 traffic load, the second traffic sample (2020) was dropped. In the second and third sessions, continuity of participants may have enabled the 2020 traffic condition to be tested. However, only 1 participant was involved in the three sessions (Table 13). As a consequence, the initial objective of assessing the feasibility of 4D TM in 2015 and in 2020 timeframe could not be reached, and only the 2015 traffic load was tested in the three sessions.

### 5.4.3 Deviation from weekly and daily schedule

No run was lost during the sessions. As a result, the slots available to conduct additional runs (spare runs) were not used.

Because of the lack of continuity in participants, training duration and contents could not be reduced for sessions two and three. The same amount of training on concept, HMI, and tools had to be provided for each session.

# 6 RESULTS

## 6.1 INTRODUCTION

The prototyping sessions aimed at concept clarification. Conducted iteratively, each session lasted 1 week and involved a limited number of participants. As a result, even though the data collected were analysed with statistical tools, outcomes are considered as trends rather than strong statistical evidence. For this reason, statistical significance tests were not conducted.

Due to the limited time available for the sessions, it was decided to focus on the 2015 timeframe. No reference runs were conducted. In this section, the comparison with "today" is based on controllers' feedback provided during debriefing and in questionnaires.

## 6.2 OBJECTIVE 1: FAMILIARISE CONTROLLERS WITH THE 4D TM

### 6.2.1 Outcomes

The training was aimed at familiarising the controllers with the 4D TM and the simulated environment (airspace, traffic and HMI).The traffic was gradually increased to reach 2015 levels in order to familiarise controllers with the high traffic load proposed for the measured runs.

The adequacy of the training was rated between medium and high over the three prototyping sessions (Figure 14). However, the controllers felt that the training sessions were too short to be really familiar with all the new features introduced.

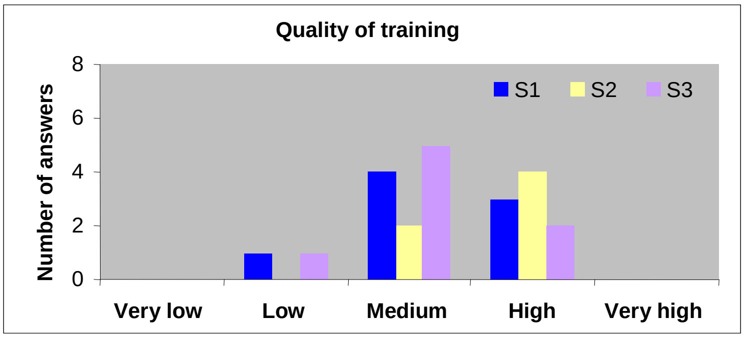

**Figure 14. Controllers' rating on quality of training over the three prototyping sessions**

The participants rated the simulation realism as medium overall in sessions one and two, but lower in session 3 (Figure 15). However, the limitations mentioned in terms of realism did not relate to the same topics throughout the three sessions. In the first two sessions controllers had problems related to technical issues e.g. aircraft performance, MTCD discrepancies. However, they expressed a lack of realism in terms of operational situations during the last session. The situations simulated were realistic in terms of load, airspace, traffic flows, but were considered as too ideal from the controllers' perspectives. They felt it would have been more realistic to test some degraded/abnormal situations (e.g. bad weather or emergencies) to assess their feasibility in a 4D environment.

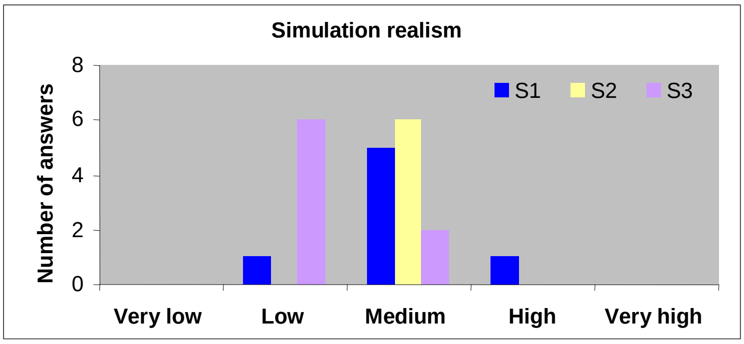

**Figure 15. Controllers' rating on simulation realism over the three prototyping sessions**

### 6.2.2 Summary on familiarisation

The main hypothesis was that "sufficient practice and training with the concept during the prototyping sessions will enable controllers to provide relevant and adequate feedback".

The level of familiarisation was acceptable and sufficient to understand the concept. However, there was insufficient time to conduct performance assessment. This was due to the following:

- Short duration of training period (one and half day per session);
- Need to retrain controllers at each session due to lack of continuity of participants, no possibility to build on experience with the concept at each session;
- Some controllers lack of experience with very high level of traffic load and complexity;
- Absence of route structure implied by the concept (direct routeing), increasing the difficulty for controllers to learn and acquire a basic knowledge of routes and traffic flows;
- A number of new tools and functions embedded in the controller working position to learn in addition to the 4D TM concept;
- For the runs addressing CTA, insufficient number of arrivals on CTA to practice with the concept;
- To assess the acceptability of pilots involvement in 4D TM, insufficient number of pilot requests.

The short time available for training raises an issue regarding the participants for a series of prototyping sessions. There should be continuity of participants, as much as possible, from one session to the next to avoid repetition of training on HMI and concept and allow more time for training on changes introduced from one session to the next. In addition, the participants should be, as much as possible, 'current' operational controllers used to a level of traffic comparable to the one used during the simulation (here, very high traffic load), typically controllers working full time in an operational centre.

To summarise, the contents of the training was considered appropriate and well balanced between principles and application. With continuity from one session to the next of experienced and current operational controllers, the duration of training may have been sufficient.

## 6.3 OBJECTIVE 2: DEFINE SUITABLE 4D ENVIRONMENT

Due to the low level of maturity of the concept, the first objective of the prototyping sessions was to clarify elements of the concept, and more specifically identify what the 4D Trajectory management requires in terms of airspace, traffic patterns, aircraft behaviour and tools. The introduction of a 4D environment was expected to be found challenging due to the changes implied compared to today's operations in terms of airspace (no route structure), traffic (+40% compared to 2006 traffic load) and aircraft behaviour (RTA equipped aircraft performing speed adjustments to meet the time constraints). Therefore, the prototyping sessions gradually refined and improved the environment on the basis of controller's feedback collected through questionnaires and debriefing.

### 6.3.1 Airspace and traffic

An initial design of airspace and traffic flows was proposed by the operational experts during the first session and then further refined throughout the successive sessions according to participants' feedback and expert group outcomes.

The three prototyping sessions were based on a subset (3 sectors) of MUAC airspace. 2015 traffic samples based on SESAR forecasts were used in each prototyping session. The simulated traffic level was a 40% increase compared to 2006 traffic level. The current MUAC route structure was removed to provide user preferred trajectories assuming that the routes were direct from the entry to the exit point of the MUAC airspace (see 4.5.1.1).

#### *6.3.1.1 Suitability of airspace and traffic*

During the first prototyping session, the suitability of airspace and traffic within the simulated 4D environment was between low and medium according to the controllers. All the participants mentioned that the airspace and associated traffic were too complex and generated a high level of workload (see figures 19 and 20). The complexity of traffic was essentially due to the lack of route network and the high traffic load (see figures of session 1 in Table 14). The lack of route structure, due to the use of user-preferred trajectories, led to trajectories spread throughout the sectors and resulted in the emergence of unexpected bunching areas. This impaired the controllers' planning of the evolution of traffic. The controllers felt they were following a plan rather than creating their own, resulting in them becoming more reactive than proactive. The lack of route structure also made it difficult to give continuous climb or descent to aircraft departing or landing airports.

**Table 14. Simulated sectors capacity over the three prototyping sessions**

| Sessions | S1 | | | S2 | | | S3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Sectors | **DD** | **HM** | **HR** | **DD** | **HM** | **HR** | **DDU** | **DDL** | **HM** |
| Nb aircraft on frequency/hour | 95 | 97 | 68 | 101 | 90 | 66 | 56 | 63 | 93 |

During the second session, traffic patterns were redesigned and included the introduction of complexity management measures by the operational experts (see 4.5.1.2) to manually de-bunch and segregate the flows of traffic. As illustrated in Figure 16, most of the controllers who participated in the first session agreed that these complexity management measures provided a more suitable traffic and airspace for the 4D TM. The resulting perceived workload was reduced compared to the first session despite an equivalent traffic load (Table 14). Thus, the controllers focused more on the handling of RBT and CTA aircraft, and mentioned that the use of a route network to segregate flows (mainly departures and arrivals) facilitated the 4D TM. The controllers nevertheless mentioned that the simulated airspace still provided unbalanced level of traffic among sectors where both DD and HM sectors were busier than

HR sector (see figures of session 2 in Table 14). The DD sector had quite a high level of workload due to the amount of aircraft on frequency rather than the complexity of the flows. In addition, although a few CTA aircraft were added in session 2 to familiarise the controllers with the handling of 4D trajectory within a tighter timeframe window (compared to RBT), the participants said they would require more CTA arrivals to assess CTA or the feasibility of CTA.

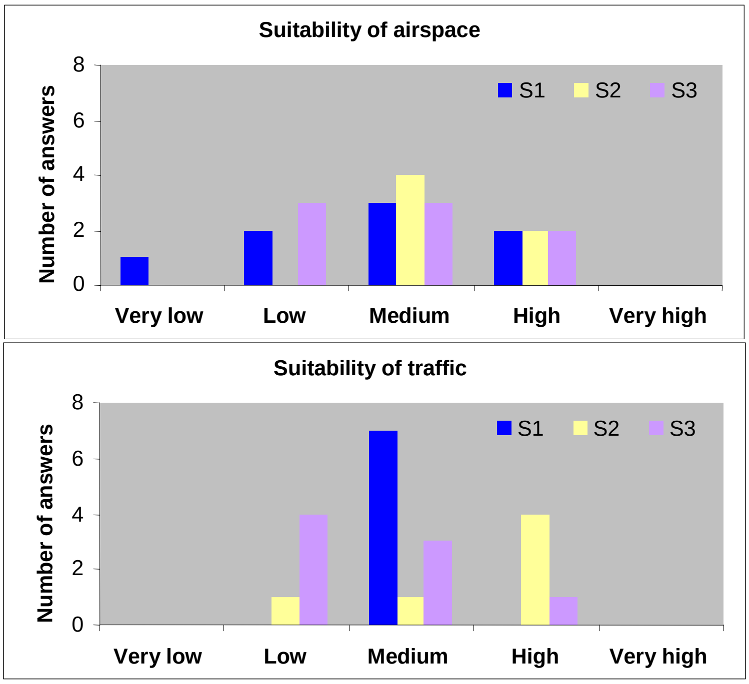

**Figure 16. Controllers' rating on realism of airspace (top) and traffic (bottom) over the three sessions**

Following controllers' feedback regarding the very high level of workload perceived during session two, in session three the DD sector was vertically split (DD High and DD Low) to try and balance the amount of traffic in that area. The HM sector was extended to the south to accommodate aircraft landing EBBR (Brussels) flying to a CTA. HR sector was removed from the simulated area and two segregated areas (military) were added for half of the runs (see 4.5.1.2). In addition, to assess the feasibility of CTA, the number of CTA aircraft was increased (see Table 11).

The controllers felt the vertical split of DD sector was suitable for the 4D TM as it provided a natural segregation of flows by construction: upper sector was dedicated to overflights with very few departures and CTA arrivals, whereas the lower sector was more focused on the delivery of arrivals (including CTA) to the TMA sectors. The HM sector was too complex due to the high number of aircraft in evolution (climbing and descending) and as a result recorded a high level of workload.

In session 1 the low rating was due to the complexity of traffic and the resulting high workload, in session three it was associated with reduced realism compared to current operations. Controllers expressed the need for more realistic situations, e.g. with perturbations such as weather, emergencies or aircraft failure, and more CTA aircraft.

#### *6.3.1.2 Conflict / bunching*

In comparison with today's operations, the 4D TM environment simulated during the prototyping session (i.e. using user preferred trajectories) was expected to lead to more numerous and more unpredictable conflict/bunching areas. In addition, these conflict/bunching areas were expected to be less predictable than in today’s operations where all aircraft flying on a route are converging over waypoints.

According to the participants, uncertainty in traffic evolution and therefore in bunching/conflict areas was a serious issue caused by the 4D environment. The direct routings led to a spread of the trajectories throughout the sectors and increased the number of potential conflict areas. With the high level of traffic, this raised a safety issue and required close monitoring and many label manipulations to de-clutter the screen. As the user preferred trajectories could change on a daily basis (depending on the day or weather), this could potentially result in a variety of traffic tracks making it difficult for the controllers to become familiar with the traffic pattern.

### 6.3.2 Aircraft behaviour

Adhering to an RTA within a 4D environment may modify the aircraft behaviour compared to today's operation. Instead of flying at a cruise speed, generally known to ATC, the aircraft speed could be modified by the FMS at any stage of the flight in order to achieve a time constraint. This implies possible automatic speed adjustments when the aircraft is late or early on the time schedule.

The controllers raised concerns about these automatic speed adjustments. RTA speed adjustments made it difficult for controllers to predict the intentions of flights. RTA speed adjustments in the simulation required constant monitoring and increased workload for ATC. In addition, asking controllers not to interfere with the speed of aircraft removed a primary separation method. The monitoring aid (MONA) provided to warn the controllers in case of speed changes was not considered adequate. The controllers require more reliable information from the aircraft (e.g. magnitude and duration of speed changes, TOD), to predict the conduct of the flight.

### 6.3.3 Tools

Tools were provided to the controllers for conflict detection (e.g. MTCD) and to especially support the 4D trajectory management (e.g. RBT/CTA time information, sector exit list and TED) (see 4.5.6). The iterative process of the prototyping sessions was used to define and then refine controllers' need in terms of 4D TM support tools.

#### 6.3.3.1 MTCD

In a 4D TM situation, the Medium Term Conflict Detection (MTCD) was useful in supporting the controllers in managing the traffic. However, the controllers said that the MTCD, provided in the simulation, was not sufficiently accurate- (e.g. when two aircraft were slowly converging). Therefore, to assess potential conflicts, the controllers used the VERA tool, which they felt was more reliable and useful, particularly with user preferred trajectories[8].

#### 6.3.3.2 RBT/CTA time status information

The display of RBT and CTA information was refined throughout the prototyping sessions. The settings agreed for the third session (Figure 9) were appropriate to assess whether the aircraft was on time or outside the time frame window without cluttering the aircraft label. It was agreed, that the deviation value should be displayed in the extended label window to be used only "on demand".

#### 6.3.3.3 Sector Exit List

The design of the Sector Exit List (SEL) was first used during session two and refined for session three to allow the controller to display one CTA waypoint list at a time by use of a toggle button (see Figure 12). The SEL was potentially useful to see the delivery order but the participants did not really consider it as there were not enough aircraft flying through the CTA waypoints. In addition, the controllers mentioned that CTA aircraft should be highlighted in the list when incoming[9] and that the pending aircraft should be added to the list before sector entry to allow them to plan better.

#### 6.3.3.4 TED

A trajectory edition tool (TED) enabling an uplink of route clearances was introduced during the last session. The controllers found it very useful in the 4D environment to solve conflicts with a low impact on the RBT and CTA. As opposed to a heading instruction, which can be used tactically to solve conflicts, the route clearance through the TED could be planned and instructed (up-linked) to the aircraft at an earlier stage. As the TED enables the uplink of a closed-loop instruction (entire trajectory), the aircraft remains under the RTA/FMS guidance and tries to achieve its time constraint[10], unlike an open loop heading where the aircraft FMS will revert to flying the cost index

As illustrated in Figure 17, the TED was used on average 4 times per run and slightly more when military areas were introduced in HM sector. The TED was used equally by the Executive and Planning controllers (after coordination) showing its usefulness at both

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[8] As user preferred trajectories were mostly direct route, VERA (based on aircraft track) was used to assess medium term conflict rather than MTCD (based on aircraft trajectory).

[9] As switch between CTA delivery point was done through a toggle button (displaying the sequence of aircraft for this point), the controllers did not notice via the list CTA aircraft flying towards another CTA waypoint.

[10] During open loop heading, in the cockpit, the RTA constraint is released and speed goes back to Cost Index speed instead of being adjusted to meet the time constraint.

positions. However, the controllers found the tool quite cumbersome to use requiring many inputs to build and issue a route. In the current settings, to account for data link exchange delays, the first two minutes of the aircraft trajectory are frozen[11], and no change of the trajectory can occur before reaching the end of this frozen path. To enable the TED to become a more dynamic and more tactical oriented tool, the controllers asked for a reduction of this frozen period. This change was introduced during the session, reducing the frozen path to 60 seconds, enabling the controllers to use the tool more tactically.

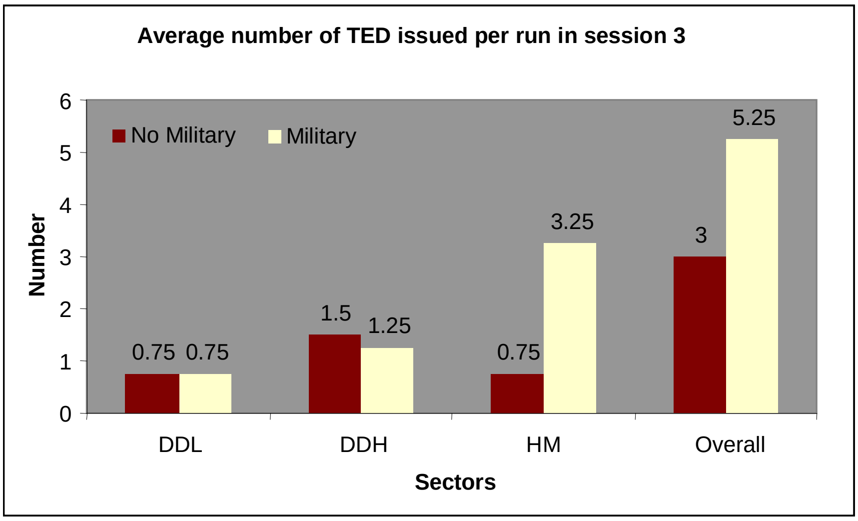

Figure 17. TED usage during session 3

### 6.3.4 Summary on environment for 4D TM

Approaching the prototyping sessions as an iterative process enabled the definition and refinement of an appropriate environment (airspace, traffic and tools) to facilitate the 4D trajectory management.

In terms of airspace and traffic, the modifications made from session 1 to session 2 (introduction of complexity management measures) and then to session 3 (balanced traffic load among sectors) helped to reduce the complexity of the traffic. However, the airspace and traffic mostly contributed to the high workload perceived during the three prototyping sessions (~81 aircraft per hour on frequency on average). The lack of predictability of the traffic flows due to preferred trajectories possibly changing from day to day and as a result the conflict and larger bunching areas changing and the inability to predict aircraft behaviour (aircraft adjusting speed to meet the time constraint) all made it difficult for the controllers to handle the traffic.

In sectors where aircraft were in evolution (climbing and descending) the problem with the 4D traffic was greater. Due to the dispersion of traffic throughout the sectors on direct routes, aircraft in climb or descent needed to be stepped up or down, very few continuous climbs or descents could be applied, interfering with the vertical profile of the trajectories.

Reducing the number of conflict resolutions tools used by the controllers today e.g. speed control, open loop headings, to avoid impacting the time constraint associated with RBT, imposed more workload on the controllers. Because aircraft were adjusting speeds to achieve

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[11] The 2 minutes delay corresponds to the maximum delay for answering a Datalink instruction. However, following controllers request, this time delay was reduced to 1 minute for the last run to allow controllers to test whether it was beneficial.

time constraints and flying preferred trajectories as opposed to a route structure, controllers were reacting to the traffic situation rather than proactively controlling it.

To facilitate 4D trajectory management, controllers would need more information exchange from the aircraft to reduce the uncertainty of the intentions of the aircraft (pilot intention, targeted speed etc.)

MTCD, with its accuracy improved, would be a requirement in a trajectory based environment. Display of the RBT and CTA time information, as displayed in session three was useful (information available but not permanently displayed). Sector exit lists (SELs) displaying the delivery order to TMAs, although not fully utilised by the controllers during the final session, have the potential to support the controllers to achieve a sequenced delivery to TMAs. Although initially the TED was found cumbersome to use, its potential was appreciated by the controllers, particularly in providing closed loop headings to the aircraft.

## 6.4 OBJECTIVE 3: ASSESS FEASIBILITY AND OPERABILITY OF THE 4D TM

### 6.4.1 Introduction

When applicable, each indicator was considered with regards to RBT, then CTA and finally globally.

### 6.4.2 Operability

The E-OCVM methodology [1] defines operability as, '*usable by and suitable for those who operate the system, e.g. controllers and pilots. Satisfaction of usability and suitability issues lead to operational acceptability*.' This is not a SESAR KPA but it is nevertheless important for the success of Episode 3 concept validation.

#### *6.4.2.1 Feasibility*

##### 6.4.2.1.1 Perceived workload

For the three sessions the level of workload was medium to high. Although the level of workload depended on the sectors, the EXC recorded a higher level of workload than the PLC (Figure 18). The increase in workload was mainly due to the lack of route structure (e.g. no standard points of conflict) and the high traffic load (Figure 19). However, the complexity management measures applied to the traffic samples in session 2 and airspace modifications applied in session 3 helped to reduce the level of workload perceived by the controllers throughout the three sessions (Figure 18 and Figure 19). During the third session, EXC and PLC spent most of the time (~75%) at a low level of workload. Speed adjustments via the FMS RTA function increased the workload due to the sustained monitoring it implied for the controllers.

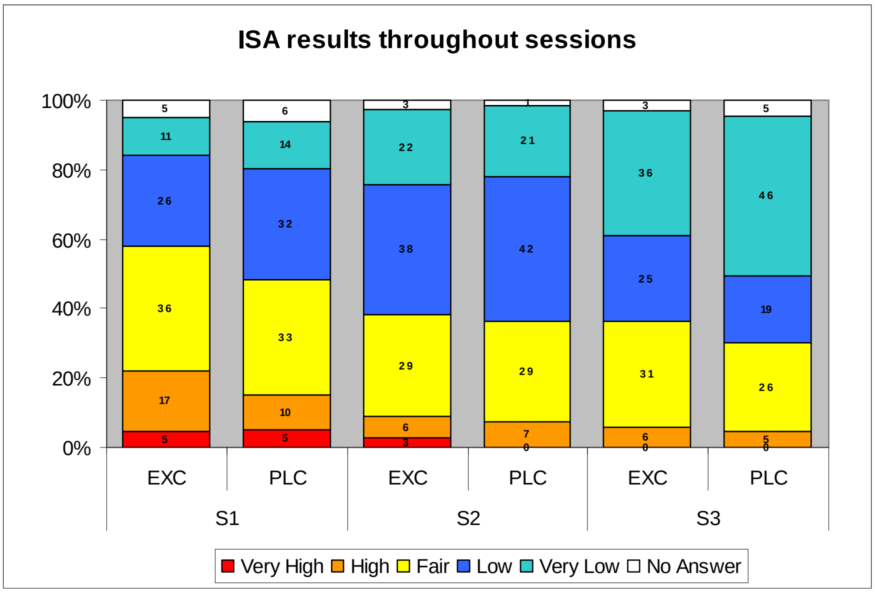

**Figure 18. ISA ratings throughout sessions**

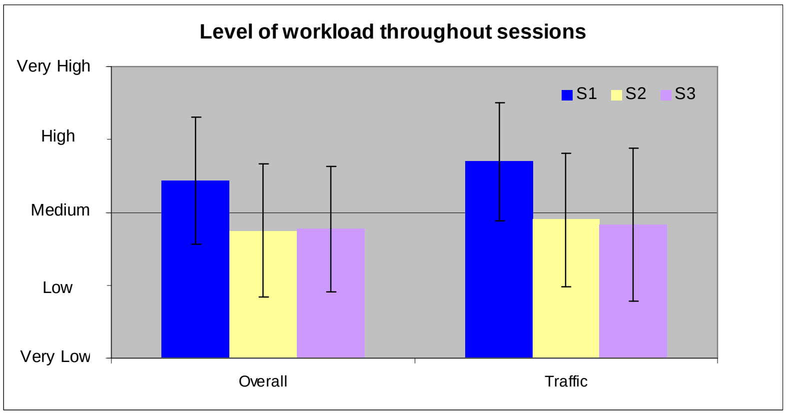

Figure 19. Controllers' rating on workload throughout sessions

Finally, although controllers' ratings evolved throughout the three sessions, they agreed that the 4D environment as proposed during the simulation slightly increased the workload at both positions compared to today's operations. Enhanced tools, further traffic complexity measures and airspace refinement (e.g. sector shape based on the main flows, fixed route within very busy sector) and more information from the cockpit could facilitate the handling of RBT and CTA.

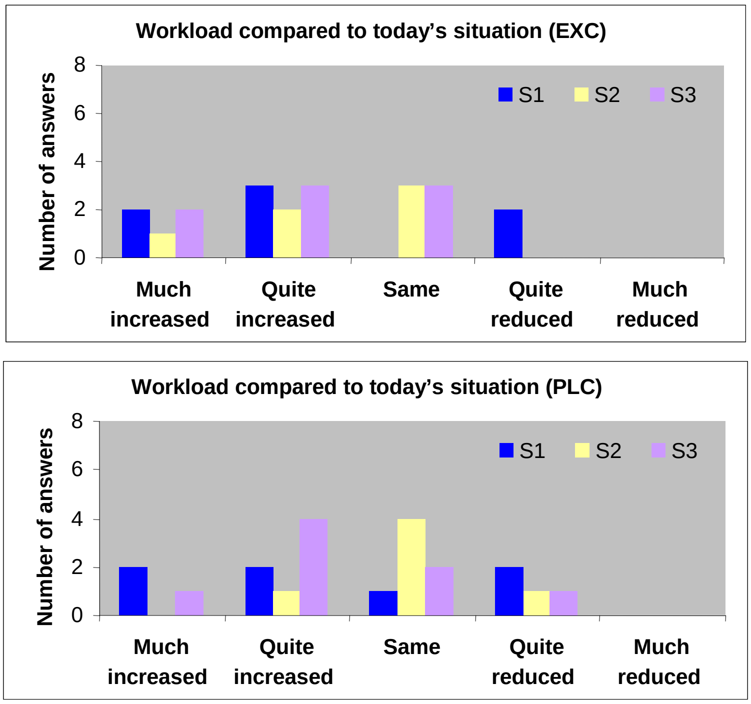

Figure 20. Controllers' ratings on level of workload compared to today's operations in EXC (top) and PLC (bottom) positions

#### 6.4.2.1.2 Subjective feedback on feasibility

The controllers found that the facilitation of RBT was feasible when workload permitted it. RBT management was easier in sectors of low complexity. After the complexity management measures were introduced in session 2, the adherence to the RBT was easier (Figure 21). Overall, the adherence to the lateral path and the time constraint of a trajectory were achievable. The adherence to the vertical profile of the trajectory however was difficult in an environment with a high level of traffic and no route structure. The controllers were forced to issue step descents/climbs (for arrivals and departures) and on occasion changed the requested flight level for overflights for conflict resolution. As a result, the optimum vertical profile was not always achieved (see **Erreur ! Source du renvoi introuvable.**). The agreed trajectories (RBT) should, among other things, include the desired vertical profiles also agreed by ANSPs (e.g. aircraft TOD ≠ desired TOD for a controller).

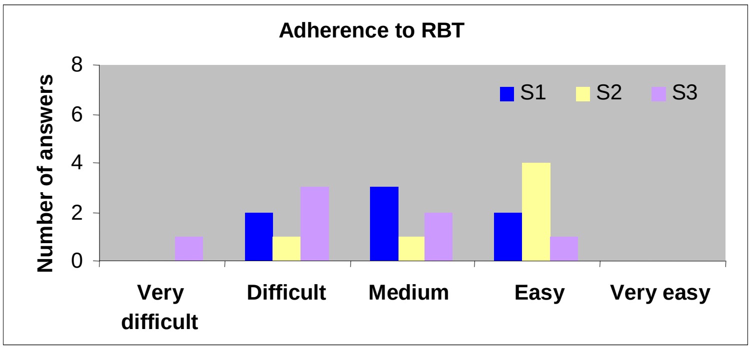

Figure 21. Controllers' ratings on feasibility of the adherence to RBT

Although the controllers expressed no major difficulties in handling aircraft flying to a CTA and found it quite easy to comply with the arrival order (Figure 22), they agreed that there were not enough aircraft flying to CTAs to create a challenge for them to pre-sequence the traffic according to the order in the Sector Exit List and give a better assessment of the workload involved. They did suggest, however, that, in busy situations, traffic flying to CTAs could be delegated to a dedicated controller for delivery to TMAs.

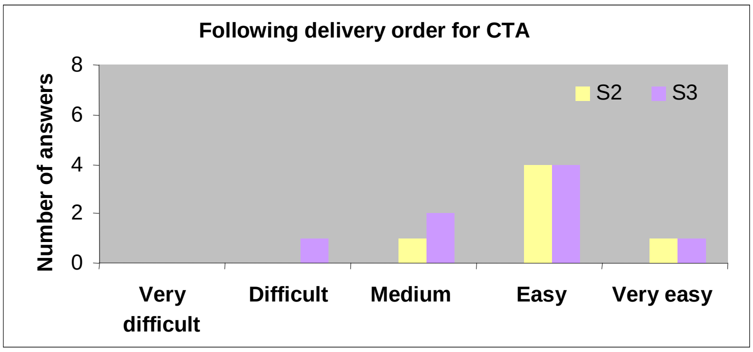

Figure 22. Controllers' ratings on feasibility of following CTA delivery order

During the third session, the introduction of segregated areas (military) did not cause any feasibility issue for the handling of both RBT and CTA once the military opening hours were part of the overall plan (as simulated). However, if military areas were to become active at short notice, this would have a completely different effect on the controllers, issuing new avoidance routes to the aircraft.

### *6.4.2.2 Working practices*

#### 6.4.2.2.1 Task allocation

As expected, the use of CPDLC modified the task allocation between EXC and PLC. The PLC tended to perform more tactical actions (e.g. assume, transfer aircraft, issue route clearances). The 4D trajectory management involved the PLC more in decision making when solving conflicts (e.g. considering the time status while identifying the best solution for conflict resolution). The controllers spent a lot more time discussing the most appropriate solution to solve a conflict with the least impact to the RBT, whereas today the EXC would solve the conflict with no discussion.

#### 6.4.2.2.2 Controller activity

The controllers issued, on average, between 50 and 82 manoeuvring instructions per sector depending on the session (Figure 23). Level instructions were used far more than other manoeuvring instructions (more than 75%). While there were many arrivals and departures the controllers used level instructions, as a preference, to solve conflicts as level changes had a lower impact on achieving the time constraint compared to a heading or a speed instruction. The use of speed instructions (1.6 on average) or heading/direct instructions (5 on average) was very limited. However, in addition to creating extra workload for controllers, the high number of level instructions also had an impact on flight efficiency in terms of vertical profiles. The results described in 6.4.3 show that the vertical profiles were not always optimised (e.g. overflights receiving level instructions and step descent/climb for arrivals/departures). This could have an impact on fuel consumption.

Although working practices did not change throughout the sessions, the total number of instructions to aircraft decreased from session one to session three. This is as a result of the segregation of routes in session two and the improved traffic load allocation among sectors in session three. The RBT/CTA time status information (late/early) was considered for conflict resolution by the controllers, only when workload permitted it. In busy situations the controllers reverted to resolving conflicts in the most efficient way for them. As this may have meant a deviation from one of the components of the 4D trajectory (headings/directs), the controllers agreed that the separation management task was not totally compatible with 4D Trajectory Management.

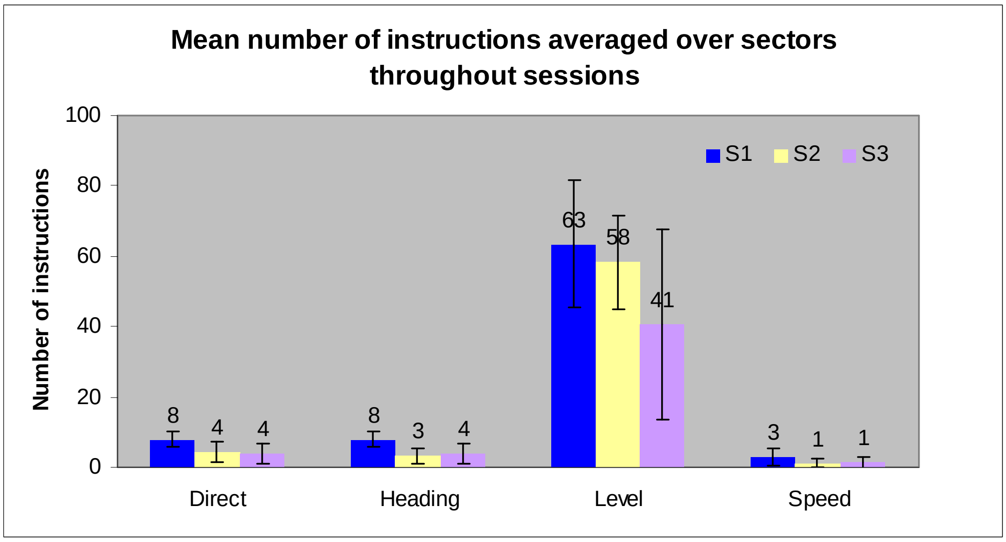

**Figure 23. Mean number of instructions throughout the sessions**

### 6.4.2.3 *Subjective feedback on acceptability*

While the controllers accepted the overall 4D trajectory management concept they did have issues with it in the simulated environment. Unfamiliarity with the airspace, the tools and the lack of adequate time for training added to their concerns. The lack of route structure caused a dispersion of traffic patterns and thus unfamiliarity with tracks.

The main benefits identified were:

- Greater predictability in times and routing -less interference with planned trajectory by ATC ensuring flights arriving as planned in downstream sectors and on time
- Less congestion at current bunching waypoints - traffic spread more throughout sectors with less concentration over route intersection waypoints
- Shorter routings and reduced holdings leading to fuel savings - preferred routings are more direct and better planned to arrive on time
- Less delays - better pre-departure planning
- Better network overview for controllers – controllers more aware of the impact of their actions on downstream sectors and overall plan

The main limitations identified in the simulated environment were

- Reduced situation awareness for controllers - lack of familiarity with airspace
- Unfamiliarity with traffic patterns (e.g. bunching areas) with possible safety implications - possibility of traffic flows changing on a daily basis
- Reduced capacity - only feasible with low traffic load
- Reduced flexibility - controllers facilitate planned trajectory
- Controllers' role becoming reactive rather than proactive
- Reliance on perfect planning which is easily negated by everyday events (e.g. weather, military activity, etc);
- Where all parties (e.g. ANSPs, airlines, pilots, airports, etc) do not adhere to the agreements

Controllers remain responsible for separation (in addition to expediting traffic) and depending upon the situation they assess which actions will most efficiently achieve this. From the moment they are notified of an aircraft entering the sector for which they have responsibility, each controller assess the likelihood of that flight continuing their planned trajectory unimpeded. Whenever a potential conflict is detected a change to the profile of one or more flights is actioned by the controller (normally through speed control, heading or level change). This ensures separation and an expeditious flow of traffic and negates the need for intensive monitoring of a particular flight or flights.

During the prototyping sessions the introduction of RBT presented the controllers with a major change in their working methods. Whilst they were still expected expedite the traffic and retained responsibility for separation they were asked to refrain from interfering with the aircraft profiles. However, as the RBTs were not guaranteed to be conflict free the controllers still had to act to ensure separation. With a spread of trajectories and no notification of speed variations to the controller it became more difficult to predict potential conflicts and increased the monitoring task considerably. Controllers were forced to monitor all flights more closely and act later whenever a potential conflict was detected.

The perception was that in attempting to adhere to the planned trajectories the role of the controller changed to one that was more reactive to the situation rather than taking control. It was the view of the controllers that this changing role would increase workload considerably and could only be safely achieved by reducing sector capacity and/or improving predictive tools.

#### 6.4.2.4 Summary

4D trajectory management task was a challenge for the controllers in the simulated 4D environment. The high traffic load and lack of route structure created high workload, however, the complexity management measures introduced for session 2 and 3 made the task easier. The controllers' role became more reactive rather than proactive. To enable implementation of such a concept, changes would be required to airspace and route structures, with more support tools available.

Adhering to lateral path and the time constraint was more feasible than adhering to the desired vertical trajectory. Controllers mainly issued level instructions to solve conflicts as it had a lower impact on time. As a result the optimum vertical profile was not always achieved. Without arrival and departure flows being separated from each other and over flying traffic, vertical restrictions would have to be imposed by ANSPs as part of the agreed trajectory.

The introduction of the TED in Session three proved to be very successful both from the controllers' viewpoint and the fact that it allowed the aircraft to remain under the RTA constraint despite changes in the 2D profile. They agreed that 4D TM could optimize the ATM system for all actors but this relies heavily on perfect planning.

**Table 15. Review of initial operability-related hypotheses**

| Hypothesis | Status | Comments |
|---|---|---|
| HO1. The 4D TM will be found difficult but feasible by the controllers due to the several changes implied: no route structure to support the task, no homogeneous speed between aircraft, speed variations due to the RTA function, less degree of freedom and aircraft time status to consider as much as possible. | Confirmed. | |
| HO2. The controller will need more tools (e.g. trajectory editor) to handle the 4D trajectory more efficiently. | Confirmed. | |
| HO3. The 4D TM will increase the level of controllers' workload compared to today's operation due to less anticipation of conflicts (facilitate aircraft adherence), consideration of aircraft status. | Confirmed. | |
| HO4. The 4D TM will increase monitoring tasks load and reduce planning tasks load. | Confirmed. | By subjective data |
| HO5. RBT condition will lead the controller to "only" facilitate the trajectory whereas the CTA conditions will increase the level of cooperation between controllers and pilots (e.g. controllers considering the time status for conflict resolution). | Not assessed. | No Relevant Data as not enough aircraft were on a CTA |

### 6.4.3 Efficiency

This KPA addresses the 4D trajectories actually flown by aircraft in relation to their *Shared Business Trajectory*. The impact of 4D trajectory management on efficiency was addressed from both the service providers and customers' perspectives in terms of quality of service and flight efficiency.

### 6.4.3.1 Quality of service

This first indicator refers to the quality of service provided by the controllers in terms of allowing aircraft to fly their lateral profile and achieve their time constraint whilst delivering CTA arrivals in the planned order to the TMA.

#### 6.4.3.1.1 Lateral deviation

Time spent on open loop headings was the main indicator considered to analyse the aircraft adherence to its 2D trajectory.

In line with the number of instructions issued (Figure 23 in 6.4.2.2.2), Figure 24 shows that over the 8 measured exercises, a small number of aircraft (from 8% in session 1 to 5% in session 3) flew open loop headings. This indicates that the majority of aircraft (95%) were allowed to fly the 2D (lateral) agreed trajectory. In session three, the 5% of aircraft deviating from their 2D profiles spent on average of 3min42sec in open loop vectors (~28% of their total flight time within measured sectors). This result shows that, on average, each aircraft flew ~1% of its flight time in open loop heading. (Figure 25). The controllers managed to facilitate the aircraft 2D trajectory, avoiding, as much as possible, the use of heading instructions.

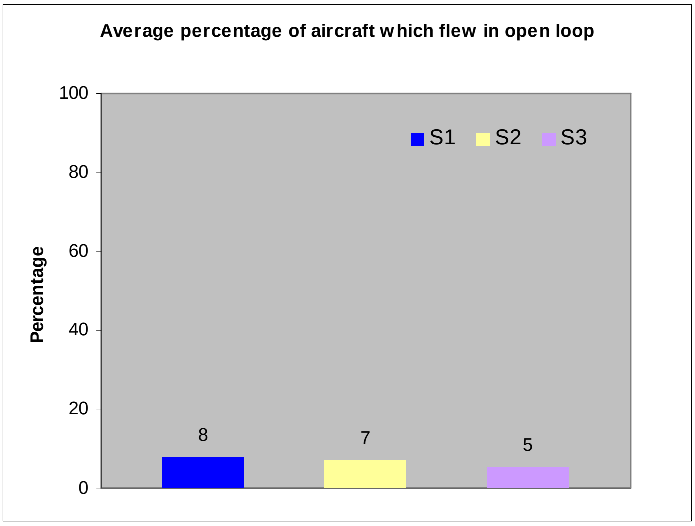

**Figure 24. Percentage of aircraft flying an open loop vector**

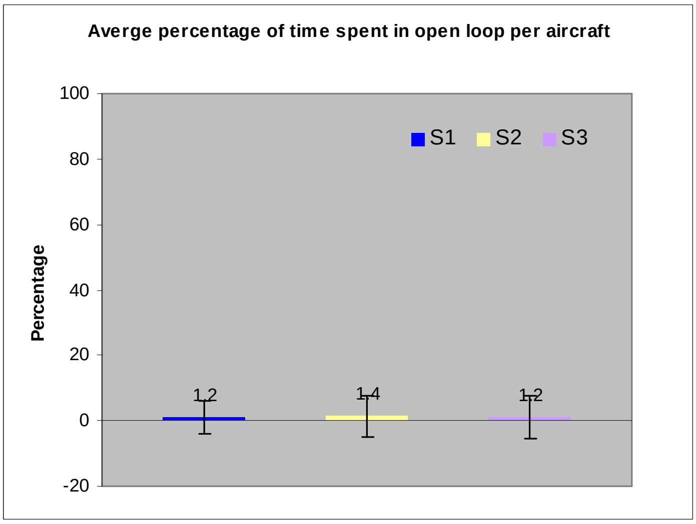

**Figure 25. Percentage of flight time, per aircraft, spent in open loop**

#### 6.4.3.1.2 Temporal deviation

The 4D trajectory includes the time aspect by respecting a time constraint at a given waypoint on the route (in the simulation this was the last waypoint of the route or a coordination waypoint). The impact of controllers' interventions on the temporal dimension of the 4D trajectory was assessed in terms of aircraft deviation from their schedule.

The deviation from expected time of arrival (ETA) was analysed at entry and exit to the measured sectors. The deviation measured corresponds to the ETA value minus RTA value (time constraint).

As scripted delays were set-up during traffic preparation (see 4.5.4.2.1 and 4.5.4.2.2), the time achieved was compared to the initial time delay (ETA start) in the figures. The results show that the temporal dimension of the trajectory was efficiently maintained within the time tolerance window of [-120s; +180s] for RBT aircraft. This indicates that the controllers' actions had a low impact on the time achieved at the exit of the sector.

Note: For RBT aircraft, the initial delays did not exactly correspond to the traffic characteristics planned, with all aircraft within the tolerance window of [-120s; +180s]. It can be observed that a very few number of aircraft (~8%) were outside this window when entering the measure airspace probably due to some actions in feed sectors upstream.

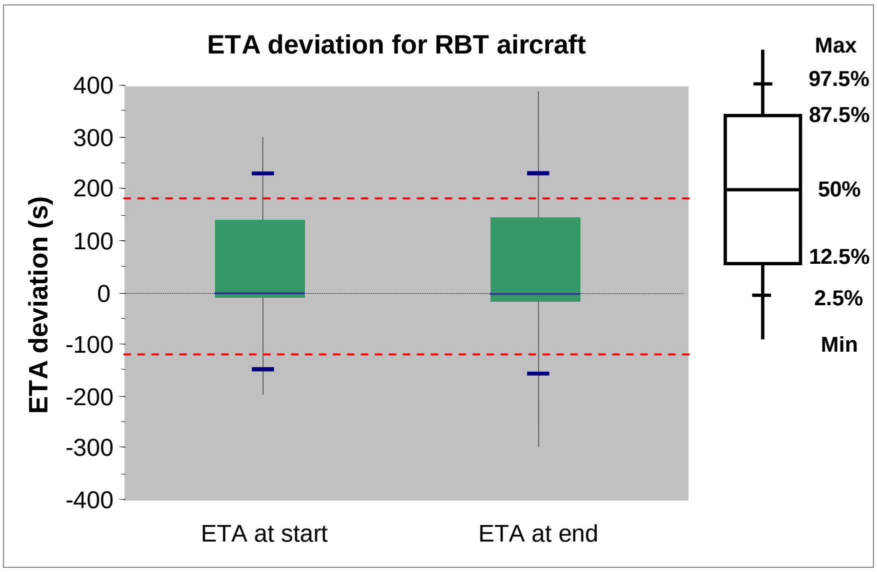

**Figure 26. ETA deviation distribution for RBT aircraft**

The same analysis conducted with CTA aircraft show similar results: the same distribution of deviation at sector entry and sector exit (Figure 27), with 75% of aircraft entering the measured sectors with initial delays contained within [-1.5s; +31s] and reaching the constraint waypoint with a delay contained within [-4s; +33s]. Also 95% of aircraft entered and exited the measured sectors with delays contained within [-60s; +61s].

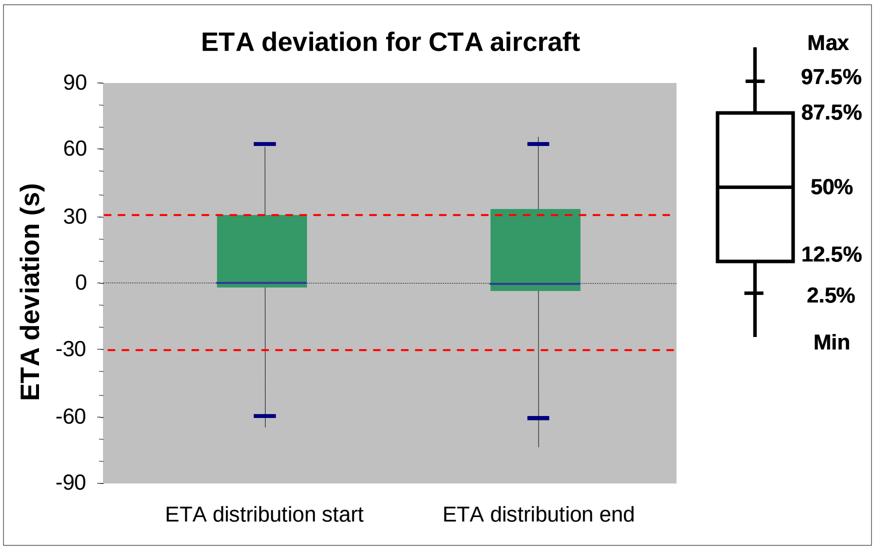

**Figure 27. ETA deviation distribution for RBT aircraft.**

The same analysis conducted with CTA aircraft shows similar results.

These results are confirmed when looking at the ratio of aircraft inside and outside the tolerance window ([-120s; +180s] for RBT and [-30s; +30s] for CTA) at sector entry and at sector exit. The controllers' interventions did not impact the time element of the CTA.

#### 6.4.3.1.3 Vertical deviation

To assess vertical deviation for traffic in level flight, the flight level over the last waypoint was compared with the planned exit flight level. We included a 900ft buffer to account for aircraft still in climb or descent at the last waypoint.

The analysis shows that on average, 18% of the over flights did not exit at their planned exit FL (Table 16) This concurs with the subjective feedback of the controllers who used more vertical instructions for conflict resolution rather than lateral and speed deviation.

**Table 16. Percentage of overflights with vertical deviation from XFL**

| Session 2 | | | Session 3 | | |
|---|---|---|---|---|---|
| **DD** | **HM** | **HR** | **DDU** | **DDL** | **HM** |
| 16% | 24.5% | 22.5% | 14% | 22% | 11.5% |

#### 6.4.3.1.4 Delivery conditions to TMA

One of the objectives of session 3 was to assess the impact of 4D TM on the delivery conditions to TMA. Respect of delivery conditions included the planned delivery order over the coordination waypoint and a specified flight level. The expected delivery order of CTA aircraft was defined on time of arrival and displayed on the sector exit list tool. The actual delivery order was compared to the expected one over each CTA point.

The results show that all aircraft were delivered in the correct sequence as indicated by the sector exit.

#### 6.4.3.1.5 Flight efficiency

The quality of service addresses ability of the controller to manage the 4D trajectory, whereas the flight efficiency addresses the 4D trajectory from the airline perspective. The following chapter describes the possible impact of the controller working methods on the flight efficiency.

#### 6.4.3.1.6 Trajectory flown

The 4D trajectories used in the prototyping sessions were based on a direct track from entry to exit of the simulated airspace. Controllers generally succeeded in managing the aircraft 4D trajectories without interfering with the agreed trajectory lateral path and planned time. In theory the increase in predictability should allow the airline operator to plan the flight better and at the optimum cost. However, the optimum vertical profile was sometimes altered in order to separate traffic.

#### 6.4.3.1.7 Track miles

To assess the track mileage, the distance flown by each simulated aircraft was compared to the planned route (flight plan distance). Any difference reflected the aircraft deviation from its trajectory, e.g. resulting from a heading instruction. In session 3 (Figure 28), the results show that with or without military activity there was little variation on the track mileage[12] (less than 1 NM per flight). A similar result was observed for session 2, regardless of the time constraint (RBT only, CTA on time and CTA not on time).

The absence of route extension or shortening shows that globally the controllers managed to allow the aircraft to adhere to the agreed trajectory. The limited use of heading and direct instructions had very little impact on the route extension.

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[12] The negative values obtained correspond to the simulator execution of aircraft turns, where these latter cut corners.

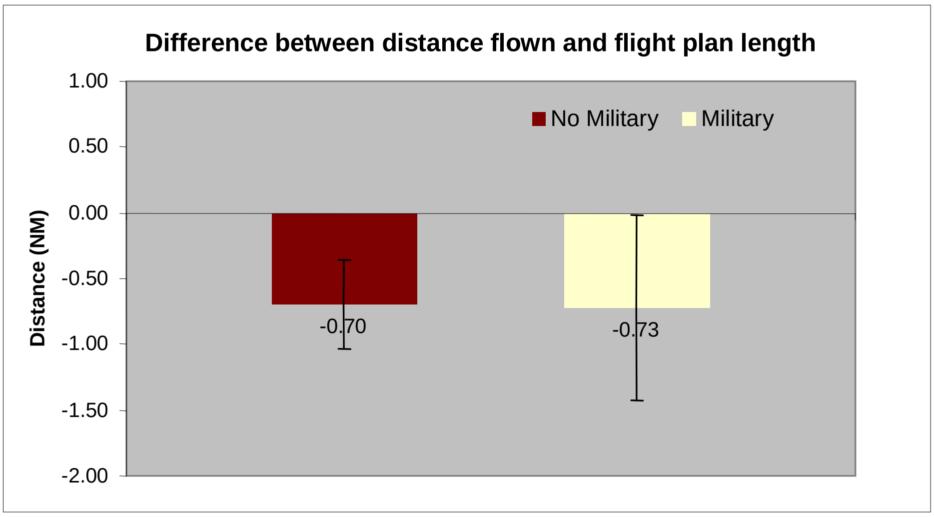

**Figure 28. Difference between distance flown and flight plan length**

#### 6.4.3.1.8 Subjective feedback

Controllers feedback regarding the impact on efficiency was quite inconclusive with both positive and negative views (Figure 29).

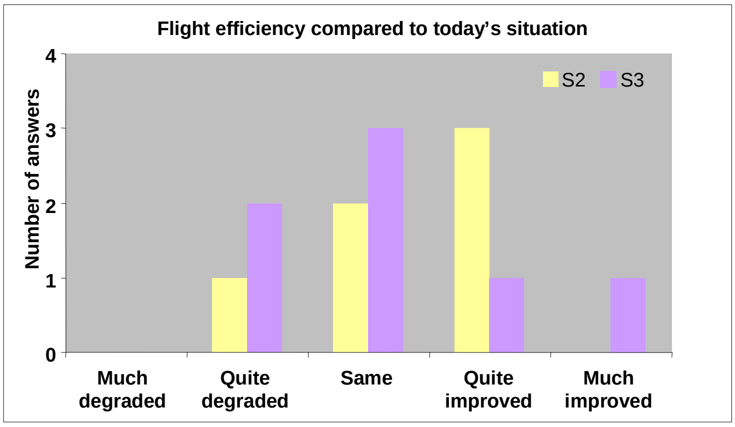

**Figure 29. Controllers' feedback regarding the impact of 4D TM on flight efficiency**

At the end of the second session, controllers mentioned potential benefits, such as shorter routing, reduced fuel burn and possibly fewer delays. At the end of the third session, the same benefits were mentioned, but counterbalanced with concerns regarding the vertical profile (aircraft descending before their Top of Descent to solve conflicts resulting in less continuous descent/climb profiles. This concern was confirmed in the measured results in that 20% of the aircraft did not adhere to their vertical profile.

### *6.4.3.2 Summary*

Overall, despite a high level of workload the controllers efficiently managed the 4D trajectory of the aircraft. In terms of lateral profile, an average of 95% of aircraft maintained their planned trajectory while the other 5% of aircraft spent an average of 3min 42sec on open loop vectors. The time constraint was generally maintained within the time tolerance window of [-120s; +180s] indicating that controllers' interventions had little impact on time achievement. Controllers considered that the 4D trajectory could provide benefits to pilots and aircraft operators in terms of flight efficiency. The increase in predictability could reduce cost.

**Table 17. Review of initial efficiency-related hypotheses**

| Hypothesis | Status | Comments |
|---|---|---|
| HE1. The 4D trajectory flown will be close to the reference trajectory planned as routes are already “direct” and controllers have to facilitate adherence to it. | Confirmed. | Mitigation: 2D trajectory and time to achieve were close to the planned trajectories and times, however vertical profiles were sometimes not achieved as planned (optimised). |

### 6.4.4 Predictability

This KPA addresses the ability of the ATM System to ensure a reliable and consistent level of 4D trajectory performance. In other words: the deviation between the *flown 4D trajectories* and the *Reference Business Trajectory*. The focus area i.e. on-time operation- covers the arrival punctuality and the time spent in each phase of flight (airborne time). The distance flown was also addressed as an indicator of predictability.

The indicators considered were similar to the efficiency-related ones. The following indicators potentially provide information on the impact of 4D TM on predictability:

- The time spent on open-loop vectors and any deviations from 4D trajectory indicate whether the aircraft adhered to its agreed and expected trajectory within the en route sector;
- The delivery conditions and the deviation from the sector exit list reflect whether transfer conditions between sectors, and more specifically between En-Route and TMA sectors were met.

As shown in 6.4.3.1.1, the controllers managed to facilitate the agreed trajectory with few interventions to the 2D profile. As a result, 95% of aircraft respected their agreed lateral path, contributing to the system predictability. In current operations controllers expedite traffic (through direct instruction) and pilots request short cuts (directs). In addition, it was shown that the controllers’ interventions had little impact on the CTA/RTA time.

The controllers nevertheless stated that pre-departure planning for flights would have to be excellent to achieve this level of predictability. Any unexpected event (e.g. weather) would have a huge impact on the predictability of the system.

**Table 18. Review of initial predictability-related hypotheses**

| Hypothesis | Status | Comments |
|---|---|---|
| HP1. Aircraft will mostly respect their 4D agreed trajectory (respect of lateral profile, vertical constraint and be maintained within time tolerance windows) for RBT and CTA as far as they will start inside the tolerance window. | Confirmed. | |
| HP2. The achievement of time constraint and achievement of the delivery order will be detrimental to other trajectory dimensions (first vertical profile and then lateral profile). | Not confirmed. | Evoked in controllers subjective feedback, but not reflected in measurements. |

## 6.4.5 Capacity

This KPA addresses the ability of the ATM System to cope with air traffic demand.

### 6.4.5.1 Subjective feedback

The capacity aspect (airspace and controllers) was assessed through controller comments rather than objective measurement.

The controllers mentioned two items concerning the impact of the 4D trajectory management on capacity. They agreed that, in theory, the 4D TM could possibly increase the airspace capacity. Adherence to the agreed flight plan (RBT and CTA) could lead to less congestion in sectors particularly over converging waypoints (e.g. delivery/coordination points to approach sectors) which create bottlenecks today. However the high traffic load during the simulation exercises reduced the controllers' capacity to facilitate 4D trajectories particularly in the vertical profile. With perfect planning, appropriate airspace design and complexity measures in place, the controllers felt the concept could help to increase capacity.

**Table 19. Review of initial capacity-related hypotheses**

| Hypothesis | Status | Comments |
|---|---|---|
| HC1. The increase in traffic load will be manageable by controllers using the 4D TM, due to the complexity management measures and adaptation of the airspace. | | Potentially with some improvements |

## 6.4.6 Safety

This KPA addresses the risk, the prevention and the occurrence and mitigation of air traffic accidents. This includes, for example, collisions on the ground and in the air.

### 6.4.6.1 Subjective feedback

During all sessions the controllers considered that safety was compromised compared to today's situation. Traffic flying user preferred trajectories made it difficult for the controllers to anticipate the traffic evolution and thus predict conflicts. The variable speeds, managed by the pilots, constrained the controllers in predicting conflicts and merge points and increased their monitoring task.  Asking controllers not to interfere with the speed removed a primary technique used by controllers today for conflict resolution. The high number of flights on frequency simultaneously reduced the controllers' situational awareness. During the sessions conflict resolution:

- was performed later in order to facilitate the agreed trajectories and let the aircraft fly their profiles as often as possible;
- increased the communication workload between EXC and PLC.

To increase the level of safety in the 4D environment, the controllers would require segregated traffic (e.g. a route network in case of high traffic load) and the support of an improved MTCD for conflict detection task.

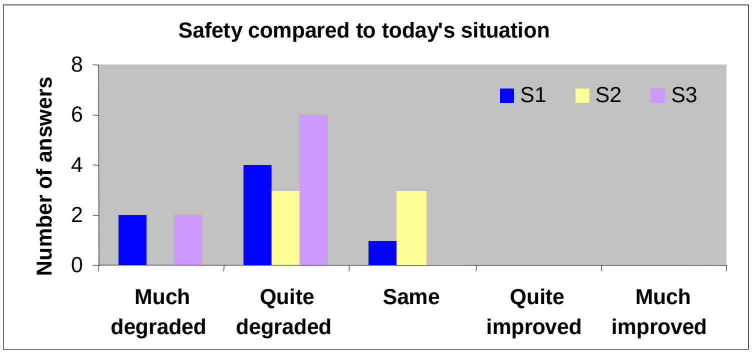

Figure 30. Controllers' ratings on safety compared to today's situation

The controllers stated that in all sessions their ability to maintain a good level of situational awareness was degraded. This was due to:

- The lack of route structure;
- The fact that speed changes were managed by the pilot (FMS speed adjustments to meet the time constraints).

This led to difficulties in planning the evolution of the traffic and at crossing/bunching waypoints. Improved tools (i.e. more accurate MTCD) and more information from the cockpit about aircraft intentions, could improve the situation.

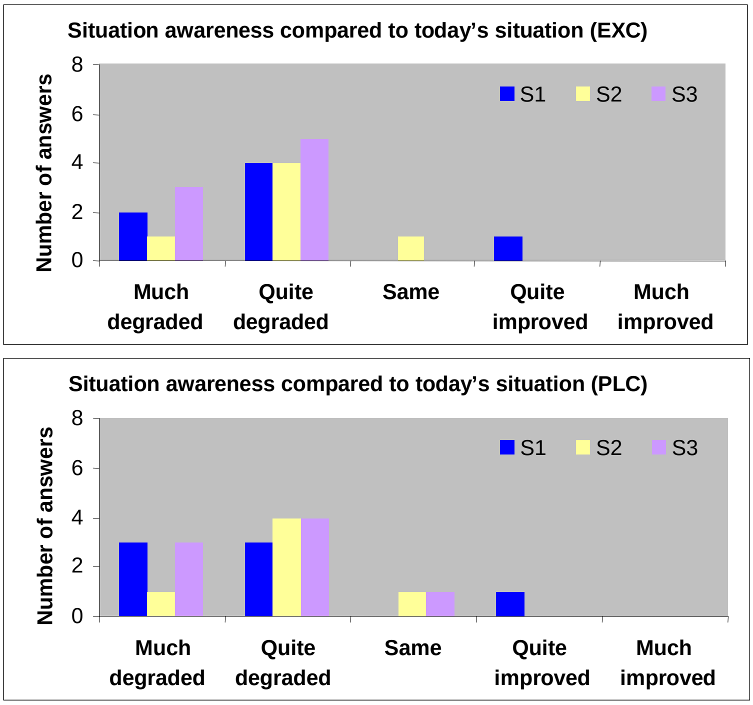

Figure 31. Controllers' ratings on situation awareness at the EXC (top) and PLC (bottom) positions

For subjective feedback on the workload refer to section 6.4.2.1.

The analysis made on the level of bunching (0) highlighted three points:

- The use of user preferred trajectories led to the dispersion of trajectories;
- User-preferred routes might change on a daily basis;
- The trajectories caused bunching “areas” rather than bunching points.

### 6.4.6.2 Losses of separation

With no reference organisation to measure against it, is impossible to draw any conclusions on the recorded number of losses of separation. The following figures are presented to give indication of the type and geographical location of the losses of separation.

The results show that over the three sessions there were a total of 38 losses of separation (Figure 32). 84% were classified as minor involving aircraft slightly less than 5NM apart or slightly less than 1000ft apart for a limited period (e.g. 20 seconds).

Losses of separation mainly occurred in the sectors with a high number of evolving flights. This was particularly true during session 1 (22 losses of separation). The following two sessions, had a fewer of losses of separation (3 in session 2 over eight runs and 13 in session 3 over eight runs) probably due to the introduction of segregated routes and the complexity management measures ).

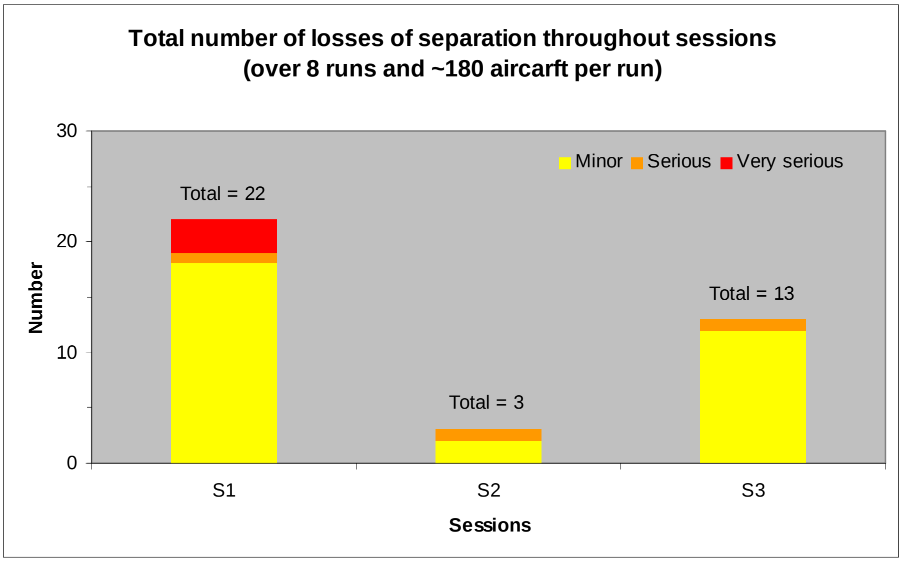

Figure 32. Total number of losses of separation throughout sessions

### 6.4.6.3 Summary

The high traffic levels on user-preferred trajectories (direct routings) greatly increased the level of workload and decreased situation awareness. The controllers raised the issue of reduced ability to safely handle the traffic due to the unpredictability of conflict/bunching points, which would have an impact on capacity The introduction of segregated traffic flows and complexity measures helped to reduce the number of losses of separation from session one to sessions two and three. However, the controllers expressed the view that safety was degraded in the simulated environment compared to today. Enhanced MTCD and information concerning aircraft intentions from the cockpit would be beneficial.

**Table 20. Review of initial capacity-related hypotheses**

| Hypothesis | Status | Comments |
|---|---|---|
| HS1. The 4D TM will increase the level of controllers' situation awareness compared to today's operation as all aircraft will follow as much as possible their planned trajectory, but the lack of route structure will impair the controllers' picture of traffic (e.g. plan evolution of traffic). | Open | To be confirmed in a full SESAR environment in terms of airspace design and automation support. |
| HS2. The level of safety will be perceived lower than in today's operation, as more dispersed aircraft trajectories will create more numerous, larger and less predictable bunching areas (compared to today's bunching waypoints). | Confirmed | |
| HS3. With 4D TM the conflict resolution will be done later and with less resolution tools as controllers have to let the aircraft fly its reference trajectory as far as possible. | Confirmed | |

### 6.4.7 Main conclusions on the 4D Trajectory Management assessment

The controllers found the 4D trajectory management task challenging in the simulated environment. The high traffic load and variety of trajectories increased workload although the complexity management measures introduced for sessions 2 and 3 made the task easier. The controllers stated that the 4D TM imposed a change to current practices making them more reactive than proactive. They suggested that improvements to the airspace design and better support tools would be needed.

Nevertheless in the simulation 95% of aircraft maintained their planned 2D trajectory while the other 5% spent time (~3min) on open loop vectors). In terms of temporal constraint, results on RBT aircraft confirm that the conflict resolution actions (mainly level changes) had little impact on the time over RTA/CTA points. It was a similar case for delays at the measured airspace entry and exit points. The delivery conditions for CTA aircraft were met (time and order).

The results indicate that the 4D trajectories could provide benefits to the ATM system in terms of predictability and flight efficiency. Increased predictability should also allow the aircraft operator to plan the flight better and at the optimum cost

The management of the 4D trajectory in terms of the lateral and temporal dimensions was achieved efficiently.  However, of the use of level instructions to solve conflicts meant ~20% of aircraft in level flight received level changes. Departures and arrivals will need to be segregated from other traffic if continuous climb or descent is to be allowed. Controllers felt that vertical profiles must also be agreed by ANSPs in the RBT as aircraft operators TOD will not necessarily be in the same place as the ATC requirement to commence descent.

The controllers suggested that, in theory, 4D TM could increase capacity but this would require perfect planning, appropriate airspace design and complexity measures to be put in place, if capacity is to remain constant or increase.  Situational awareness was degraded in all sessions and as a result the controllers perceived degradation in the level of safety. The lack of a route structure and speed changes managed by the FMS but not known to ATC, were the major causes of this.

After three prototyping sessions the controllers agreed that the 4D TM could optimize the ATM system for all actors (e.g. less delays, shorter routes and enhanced predictability). However, the requirement for perfect planning, the reduced flexibility, unfamiliarity with the traffic pattern and the related safety implications, were raised as major limitations of the concept.

# 7 CONCLUSIONS AND RECOMMENDATIONS

## 7.1 CONCLUSIONS

In the framework of EPISODE 3 WP4.3.4, a series of three prototyping sessions were conducted between September 2008 and February 2009. The main aim of the simulations was to clarify the 4D trajectory management concept in the En-Route environment focusing upon controllers' operability with initial trends on SESAR KPAs (e.g. efficiency, predictability, capacity and safety). The iterative approach allowed the scope of the prototyping sessions to be adjusted. This was communicated and agreed through Expert Group meetings.

The first session aimed at refining the controllers' roles, working methods and ATC procedures, and assessed the impact of the Reference Business Trajectories (RBT) on controller tasks. The second session assessed the introduction of an improved environment and Controlled Time of Arrival (CTA). The third session including segregated/reserved areas (military) focused on the impact of CTA on the delivery conditions of aircraft to TMAs.

Overall the controllers did not reject the concept. However there were important caveats that they wished to be noted.

In a high workload situation the CTA/RTA goals "go out the window". The controllers will be concentrating on the higher priority separation tasks. As the aircraft are flying to target times by using speed control and controllers were, therefore, discouraged from using speed control. A consequence of this is that they felt that one element of the currently available Controller toolset had been removed.

In the prototyping sessions every flight is flying a unique preferred trajectory this had consequences for the controllers as potential conflicts are now distributed across sectors rather than at defined crossing points. In order to mitigate this it was reported that:

- Information exchange from cockpit to controller is required to help the controller to make an overall assessment of how aircraft will be flown
- The airspace and route structure need to be addressed. There needs to be optimisation of the shape of the airspace and structures within it particularly for complex traffic
- The agreed RBTs must consider vertical profile
- The agreed RBT profiles should segregate traffic

## 7.2 RECOMMENDATIONS TO DEVELOPMENT OF THE DODS

The implications of these exercises on the development of the Episode 3 DODs will be assessed by the Episode 3 Work Package 4 Expert Group.

## 7.3 RECOMMENDATIONS RELATED TO 4D TM

As the prototyping sessions were of a short duration and involved a limited number of participants the results should be regarded as trends rather than results backed by statistical evidence. This needs to be taken into account in the following recommendations:

- A large scale Real Time simulation should be conducted, involving more sectors and trajectories designed from TMA to TMA;
- Sectorisation should be dynamic to accommodate changing trajectories;
- In high traffic density areas a fixed route network may be needed to segregate the traffic;
- To increase the situational awareness of controllers, information on aircraft intent should be available to the ground system, in particular speed.
- Enhanced and new tools are required to support the controllers in the 4D trajectory management:
  - Conflict detection tools;
  - A tool to issue closed loop headings for planning and tactical use;
  - A tool displaying the required delivery sequence to TMAs;
  - A tool providing information on the time status of the aircraft (in relation to the RBT/CTA time).

## 7.4 RECOMMENDATIONS RELATED TO PROTOTYPING APPROACH

The introduction of the prototyping approach in Episode 3 was aimed at providing efficient support for clarifying some concept elements.

Its advantages are:

- Reduced cost: small scale focusing on specific issues;
- Iterative process, building from one session to the next
- Flexibility: implementation of changes from one session to the next

Its limitations are:

- Limited time to train the controllers (1-1,5 day max per session);
- Limited representation of results, which must be considered as trends rather than strong performance measures
- Limited time between sessions to conduct acceptance tests on the platform

The following recommendations can be made with regard to future conduct of a series of prototyping sessions:

- With the limited time available for training, continuity of controllers in each session would help.
- More time between sessions to enable analysis and refinement of remaining objectives and conduct acceptance tests.

# 8 REFERENCES AND APPLICABLE DOCUMENTS

[1]. European Operational Concept Validation Methodology E-OCVM - V 2.0, 17/03/2007.

[2]. Episode 3 WP 4 Validation Strategy Document (www.episode3.aero) – D2.0-01

[3]. Episode 3 WP4.3.4 Prototyping Consolidated Experimental Plan.- D4.3.1-01

[4]. SESAR D3 The ATM Target Concept, DLM-0612-001-02-00 - September 2007.

[5]. SESAR Identification of limits/blocking points for airspace environment, DLT-0507-321-00-96_T321_D1

[6]. SESAR Concept of Operations - DLT-0612-222-00.

[7]. SESAR D1 The Current Situation - DLM-0602-001-03-00 - Approved & Accepted.

[8]. SESAR D2: Air Transport Framework, The Performance Target - DLM-0607-001-01-00 -.

[9]. Episode 3 WP 4.3.1.1.2 Expert Group on 4D Management and ASAS 21st/22nd April 2008, DSNA, Toulouse (n.b. WP ref from EP3 DOW version 2.2). (www.episode3.aero, WP4 Meeting folder, 080422_Toulouse.

[10]. Episode 3 Contract Annex I Description Of Work (DOW) Version 3.0, 10th July 2008.

[11]. PHARE Final Report, PHARE/EHQ/MAN/FR; Edition 1.0, Brussels, November 1999. (www.eurocontrol.int/phare) Van Gool, M. and Schröter, H.,

[12]. AFAS www.euroafas.com/afas

[13]. L.G.V “Flight trials: "runway-to-runway" required time of arrival evaluations for time-based ATM environment”, Digital Avionics Systems Conference, October 2001. Wichman, K.D.; Carlsson, G.and Lindberg,

[14]. “Contract-based Air Transportation System to fulfil the arriving-on-time objective” in the proceedings of the 26th International Congress of the Aeronautical Sciences, ICAS 2008, Anchorage, Alaska, USA, September 2008. Guibert, S., Guichard, L., Rihacek, C., Castelli, L., Ranieri, A.,

[15]. Eurocontrol “4D Trajectory Management Controller Simulation”, EEC report no 407, July 2008. Chalon, C., Dowling, F., Box, L. and Zeghal, K.,

[16]. Eurocontrol “4D Trajectory Management Pilot Simulation”, EEC report no 408, June 2008, Dowling, F., Trzmiel, A and Zeghal, K.,

[17]. Episode 3 SESAR General Purpose (G) Detailed Operational Description (DOD) E3-D2.2

[18]. Episode 3 SESAR Detailed Operational Description “Conflict Management in En-Route High & Medium/Low Density Operations – E6” E3-D2.2 .

[19]. Episode 3 Performance Framework. - D2.4.1-04

# 9 ANNEXES

## 9.1 PROTOTYPING SESSIONS OVERVIEW

This section provides an overview of the key aspects of the three prototyping sessions. First, Table 21 summarises and justifies the choices made for each sessions (e.g. in terms of objectives or traffic) in following the stepwise approach in which outcomes from each session feeds the following ones. Then, Table 22 describes the key elements of the three prototyping sessions' experimental plan illustrating the main changes and the progression of the validation.

**Table 21. From previous sessions outcomes to sessions requirements**

| **Issues** | **Outcomes from session 1** | **Requirements for session 2** | **Outcomes from session 2** | **Requirements for session 3** |
|---|---|---|---|---|
| Participants | • Half of the participants not current controllers had difficulty to cope with level of traffic. | • Should be current operational controllers in busy En-Route sectors. | • Among the nine participants, 3 of them were still not "current" operational controllers. | • Should be current operational controllers in busy En-Route sectors |
| Training | • Felt too short. | • Method and duration improved (longer hands-on training runs).<br>• Continuity of participants would help. | • Felt more efficient (than session 1) although still short for newcomers. | • Method and duration retained (longer hands-on training runs)<br>• Provision of Computer Based Training tool (CBT) prior to the simulation.<br>• Continuity of participants would help. |

| Issues | Outcomes from session 1 | Requirements for session 2 | Outcomes from session 2 | Requirements for session 3 |
|---|---|---|---|---|
| Airspace/<br>Traffic | • Numerous bunching areas.<br>• Crossing between arrivals/departures and overflights.<br>• Unacceptable level of workload and difficulty to consider 4D TM due to traffic not decomplexified. | • Fixed route network for arrival/departure flows (from/to cruise).<br>• Redesign the sectorisation and segregate flows (lateral/vertical split).<br>• Decomplexified traffic (measures achieve it). | • Segregation of flows helped the handling of traffic.<br>• Unbalanced traffic load over measured sectors.<br>• Still high level of workload especially in a sector due to the high traffic load rather than complexity of traffic.<br>• Too few arrival aircraft under CTA to really handle it and perform a sequencing task.<br>• Question about compatibility with military activity. | • Retain the same segregated flows of traffic.<br>• Vertical split of a sector to reduce number of aircraft handled by this sector and much balanced traffic load distribution.<br>• Increased number and bunching of CTA aircraft to focus on delivery condition to approach sector.<br>• Activation of military areas. |
| Tools | • Low usability of MTCD and MONA. MTCD should be more accurate and more Executive oriented (possible need for a TCT).<br>• Acceptable usability of VERA.<br>• Need for additional tools to edit trajectory and to support sequencing task (arrival flights). | • Sector exit lists to designated TMAs.<br>• TED (trajectory editor) specified (but not planned before session 3). | • Too few arrival aircraft under CTA to really assess the usefulness and usability of the Sector exit lists. | • Improved HMI of the Sector exit including mean to present several lists on the same window.<br>• Provision of TED (trajectory editor). |

**Table 22. Overview of the three prototyping sessions' experimental plan**

| | | **Session 1** | **Session 2** | **Session 3** |
|---|---|---|---|---|
| Validation objectives | Session objectives | • Investigate the acceptability and operational feasibility of the RBT management. | • Further assess the operational feasibility of the RBT management within a new environment (redesigned airspace and decomplexified traffic).<br>• Investigate the acceptability and operational feasibility of the CTA management (few arrivals on CTA). | • Further assess the operational feasibility of the RBT management within a new environment (redesigned airspace, vertical split of a sector, segregated areas).<br>• Further assess the acceptability and operational feasibility of the CTA management (more arrivals on CTA). |
| | High level Hypotheses | • 4D TM will be perceived as an additional task hardly compatible with en route control (new working practices, loss of situation awareness due to absence of route network and aircraft speed adjustments).<br>• RBT information will be useful and used by the controller to facilitate 4D trajectory.<br>• Managing 4D trajectory under 2015 traffic level will be easier and more acceptable than with 2020 traffic level due to resulting lower workload. | • Despite difficulties introduced, RBT management will be easier than during session 1 due to reduced complexity of the new environment (airspace and traffic);<br>• Adherence to CTA will be found more difficult than RBT due to the tighter time frame window.<br>• Impact of controllers' actions on RBT and CTA aircraft will be minor in terms of time achieved. | • Airspace changes (sector vertical split) will increase the feasibility of 4D trajectory management due to the reduced number of aircraft to handle.<br>• The larger number of CTA arrivals will increase the controllers' taskload due to the additional task of sequencing the traffic according to the sector exit list.<br>• New tools introduced will support controllers in their tasks and contribute to the acceptance of 4D TM.<br>• Military activity will lead to more bunching due to less available airspace. |

| | | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| | | | | |
| Simulation settings | Airspace | - Based on MUAC airspace.<br>- 3 Measured sectors: DD, HM and HR.<br>- Existing ATS route network replaced by:<br>o Direct from entry to exit points of MUAC airspace (overflights);<br>o Direct from entry of MUAC airspace to coordination points (arrival);<br>o Direct from coordination points to exit of MUAC airspace (departure). | - Based on MUAC airspace.<br>- 3 Measured sectors: DD, HM and HR.<br>- Session 1 direct routing, plus segregated routes and decomplexified traffic (30% of reduction of complexity). | - Based on MUAC airspace.<br>- 3 measured sectors :DDL, DDU, HM:<br>o DD sector vertically split to decrease the traffic load;<br>o HM slightly extended to the South.<br>- Addition of 2 segregated (military) areas.<br>- Same routes as during session 2 except when military areas active (new routes avoiding military areas set-up). |
| | | To summarise, Figure 33 illustrates the main changes performed over the measured airspace throughout the prototyping sessions. | | |

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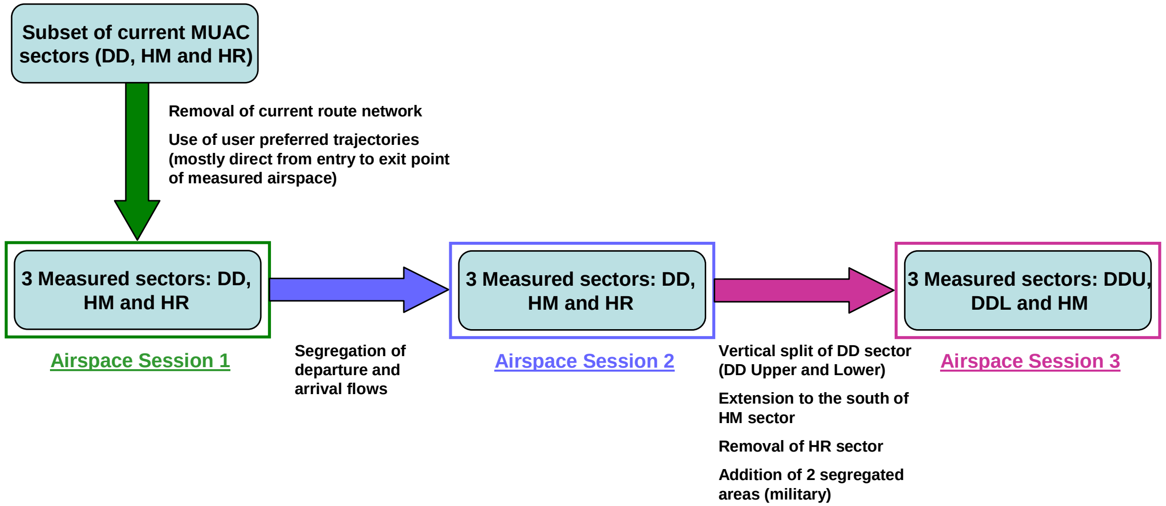
<tr><th></th><th></th><th>Session 1</th><th>Session 2</th><th>Session 3</th></tr>
<tr><td></td><td></td><td colspan="3">

**Figure 33. Simulated airspace design process from session 1 to session 3**</td></tr>
<tr><td></td><td>Traffic</td><td>• 2020 traffic load (+70% compared to 2006 traffic load).<br>• 2015 traffic load (+40% of traffic compared to 2006 traffic load).<br>• All Aircraft RTA and Data Link (100% ADS-B) equipped.<br>• All aircraft flying RBT, with delays distribution: 70% of aircraft within</td><td>• 2015 traffic load (+40% compared to 2006 traffic load).<br>• Segregated and decomplexified traffic.<br>• Same as session 1 (RTA, Data Link and RBT distribution).<br>• Some arrivals under CTA:<br>• All CTA aircraft entering the AMAN</td><td>• 2015 traffic load (+40% compared to 2006 traffic load).<br>• Addition of CTA arrivals. Same as session 2, except for arrivals under CTA.<br>• CTA aircraft entering the AMAN horizon with a delay: 80% of aircraft were exactly on time, 10% of aircraft were 40 seconds late</td></tr>
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<tr><th></th><th></th><th>Session 1</th><th>Session 2</th><th>Session 3</th></tr>
<tr><td></td><td></td><td>tolerance window, 15% in “drifting” situation and 15% in warning situation.</td><td>horizon exactly on time;<br>- CTA aircraft entering the AMAN horizon with a delay: 80% of aircraft were exactly on time, 10% of aircraft were 40 seconds late and 10% of aircraft were 40 seconds early.</td><td>and 10% of aircraft were 40 seconds early.</td></tr>
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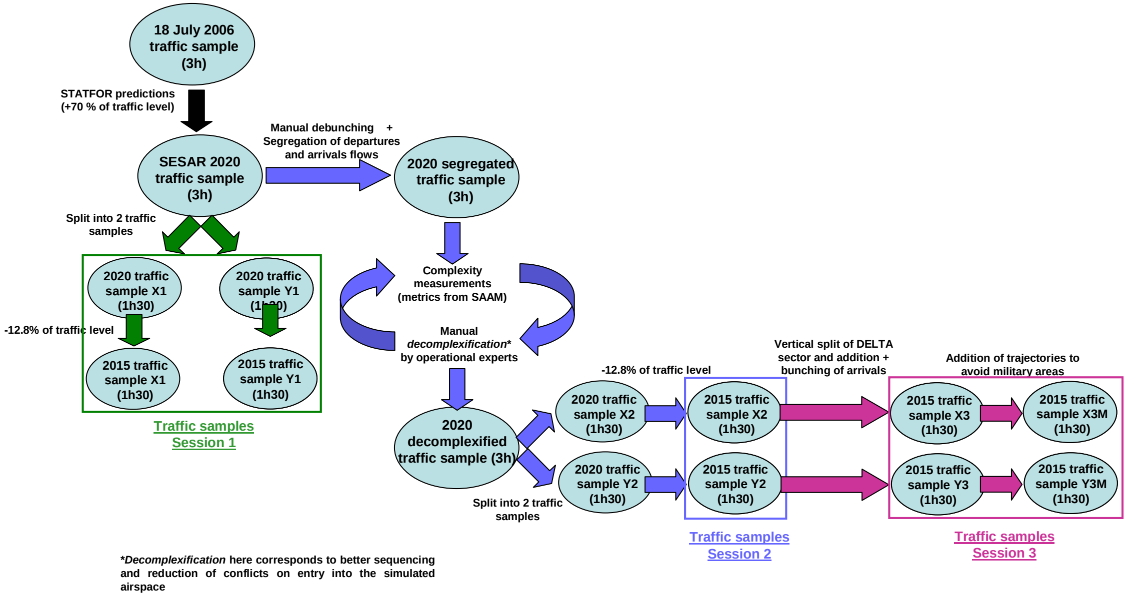


To summarise, Figure 34 illustrates the main changes performed over the traffic sample throughout the prototyping sessions.

</td></tr>
</table>

| | | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| | | **Figure 34. Simulated traffic samples definition process from session 1 to session 3** | | |
| | Controllers and tools | • 8 controllers from 5 ANSPs (1 from MUAC, DFS and DSNA, 2 from NATS and 3 from AENA).<br>• Tools and HMI:<br>o ECHOES HMI: Interactive radar labels and aircraft data lists, enabling Data Link interactions;<br>o OLDI of flight progress data, with SYSCO extensions;<br>o STCA and Area Proximity Warning (APW);<br>o MONA: monitoring conformance of flights trajectory<br>o VERA: Verification and Resolution Advisory Tool<br>o MTCD for medium term conflict detection;<br>o STCA for short term conflict alert;<br>o RBT information displays. | • 6 controllers from 3 ANSPs (2 from MUAC, DFS and NATS), including 3 newcomers.<br>• Tools and HMI: Same as during session 1 plus:<br>o Speed deviation monitoring aid;<br>o CTA information displays;<br>o Sector Exit List showing delivery order towards approach sectors to be followed. | • 8 controllers from 4 ANSPs (2 from MUAC, DFS, NATS and AENA), including 3 newcomers.<br>• Tools and HMI: Same as during session 2 plus:<br>o RBT, CTA displays and Sector Exit List redesigned;<br>o TED for trajectory edition (i.e. closed loop heading instruction). |
| Experimental | Experimental | Two variables: | Two variables: | One variable: |

| | | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| design | variables | • Level of RBT time information available to the controllers:<br>o No RBT time status information displayed to the controllers;<br>o RBT time status information available to the controllers within the label.<br>This variable was used to assess the impact of the 4D TM on controllers' roles and working method: whether they play an active role in the 4D TM and consider the time status of the aircraft for conflict resolution (when the time status was provided).<br>• Traffic type:<br>o 2015: 2015 SESAR forecasted traffic load;<br>o 2020: 2020 SESAR forecasted traffic load.<br>This variable was used to assess the impact of traffic level on concept acceptability and operability, in comparing baseline and target SESAR level of traffic. | • Proportion of arrival aircraft flying under a CTA:<br>o 0%: all aircraft flying an RBT;<br>o 100%: all arrivals aircraft landing during peak hours in a major airport located in the vicinity of measured airspace get a CTA.<br>This variable was used to assess both the impact of the RBT and the CTA.<br>Runs providing only RBT aircraft were used to assess whether the new environment (airspace and traffic) was suitable for RBT management (compared to the one used in the first prototyping session).<br>Runs with CTA aircraft were used to assess the controller feasibility and operability of managing 4D trajectory within a more accurate time tolerance window (+/- 30 seconds).<br>• Entry conditions for CTA aircraft:<br>o On-time: all CTA aircraft entering the AMAN horizon exactly on time;<br>o Not on-time: some CTA aircraft entering the AMAN horizon with | • Provision of military activity:<br>o NM: No military activity;<br>o M: Military activity (active from start to end of the runs – activation process out of scope).<br>This variable was used to assess both the impact of the RBT and the CTA and the impact of military activity on 4D trajectory management.<br>Runs without military activity were used to assess the feasibility and operability of both RBT and CTA while focusing on the respect of delivery conditions to downstream sectors (TMA).<br>Runs including military activity are used to assess the compatibility between the 4D trajectory management tasks and military activity. |

| | | Session 1 | Session 2 | Session 3 |
|---|---|---|---|---|
| | | | an initial delay: (80% exactly on time, 10% 40 seconds late and 10% 40 seconds early).<br>This variable was used to assess the impact of non-optimum entry conditions (not all aircraft on time) on CTA feasibility and operability (e.g. to deliver the traffic in the correct planned order). | |
| | Experimental conditions | Four conditions:<br>• 2015 – No RBT;<br>• 2015- RBT;<br>• 2020-No RBT;<br>• 2020-RBT. | Three conditions:<br>• RBT only;<br>• RBT + CTA on-time;<br>• RBT + CTA not on-time. | Two conditions:<br>• No military;<br>• Military.<br>• |
| | Schedule | • 29/09/08 – 03/10/08.<br>• 6 training runs (45 min);<br>• 8 measured runs (75 min): 2 in each condition. | • 01/12/08 – 05/12/08.<br>• 6 training runs (45 min);<br>• 8 measured runs (75 min): 2 in RBT only condition, 3 in RBT + CTA on-time and in RBT + CTA not on-time conditions. | • 02/02/09 – 06/02/09.<br>• 6 training runs (45 min);<br>• 8 measured runs (75 min): 4 in each condition. |
| Measurements | See<br>Table 23 below | | | |

Table 23. List of Episode 3 En -Route metrics, with associated performance areas and corresponding sessions

| Metrics \ Performance Areas | Operability | Predictability | Efficiency | Safety | Capacity | Session |
|---|---|---|---|---|---|---|
| Delivery conditions | X | X | X |  | X | 3 |
| Deviation from sector exit list | X | X | X |  |  | 2, 3 |
| Display of RBT information | X |  |  |  |  | 1 |
| Evolution of time deviation throughout centre |  | X | X |  |  | All |
| (2D) Flown trajectory |  | X | X | X |  | All |
| Instruction repartition | X |  |  | X | X | All |
| ISA (workload) ratings | X |  |  | X | X | All |
| Level of bunching | X |  |  | X | X | 2, 3 |
| Number and severity of losses of separation | X |  |  | X | X | All |
| Time deviation achieved | X | X | X |  |  | 1 |
| Time spent in open loop vectors | X | X | X |  |  | All |
| Track miles |  | X | X | X |  | 2, 3 |
| Vertical deviation | X | X | X |  |  | 2, 3 |

## 9.2 EXECUTED SCHEDULES

**Table 24. Schedule of the first prototyping session**

| Presentation | Training run | Break | Debriefing | Measured run |
|---|---|---|---|---|

| | Monday 29/09/2008 | Tuesday 30/10/2008 | Wednesday 01/10/2008 | | Friday 03/10/2008 |
|---|---|---|---|---|---|
| 09:00 | Welcome<br>Presentation of simulated environment (Airspace, HMI, Tools)<br>SESAR | Presentation of 4D trajectory management and objectives of the simulation | (De)briefing | (De)briefing | Measured run 8 T2015Y1 -- D* (RBT+ value) |
| | | | Measured run 2 T2015X1 -- D | Measured run 5 T2015Y1 -- ND | |
| | | | | | Final debrief and final questionnaire |
| 10:30 | Coffee break | Coffee break | Run debrief and questionnaire | Run debrief and questionnaire | |
| | Presentation HMI | Training run 4 T2015YTR2(ND) | | | |
| | | | Coffee break | Coffee break | |
| | | | Measured run 3 T2015Y1 -- ND | Measured run 6 T2015X1 -- ND | |
| | | Run debrief | | | |
| | Training run 1 T2015YTR1(ND) | Training run 5 T2015YTR3D (crash) | | | |
| 12:30 | Run debrief | Lunch | Run debrief and questionnaire | Run debrief and questionnaire | |
| | Lunch | | | | |
| | | | Lunch | Lunch | |
| | | Training run 6 T2015YTR3D | | | |
| 13:45 | Presentation MTCD + D/L | | | | |
| | | | Measured run 4 (crash) | Measured run 7 T2015X1 -- D* (RBT+ value) | |
| | | Run debrief | | | |
| | | Training run 7 T2015YTR3D | Measured run 4 T2015X1 -- ND | | |
| | Coffee break | | | | |
| 15:00 | Training run 2 T2015YTR2(ND) | Run debrief | | | |
| | | Measured run 1 (crash) | | Run debrief and questionnaire | |
| | | Measured run 1 T2015Y1 -- D | | | |
| | Run debrief | | Run debrief and questionnaire | | |
| 16:00 | Training run 3 T2015YTR2(ND) | | | | |
| 17:00 | Run debrief | Run debrief and questionnaire | | | |

Run name de-code: EP3 = Episode 3; E = En-route; 1 = Prototyping session 1; M = Measured run; 15 = 2015 traffic level and treatment; D = RBT information Display, ND = No RBT information Display; 1 = Traffic sample 1 / 2 = Traffic sample 2.

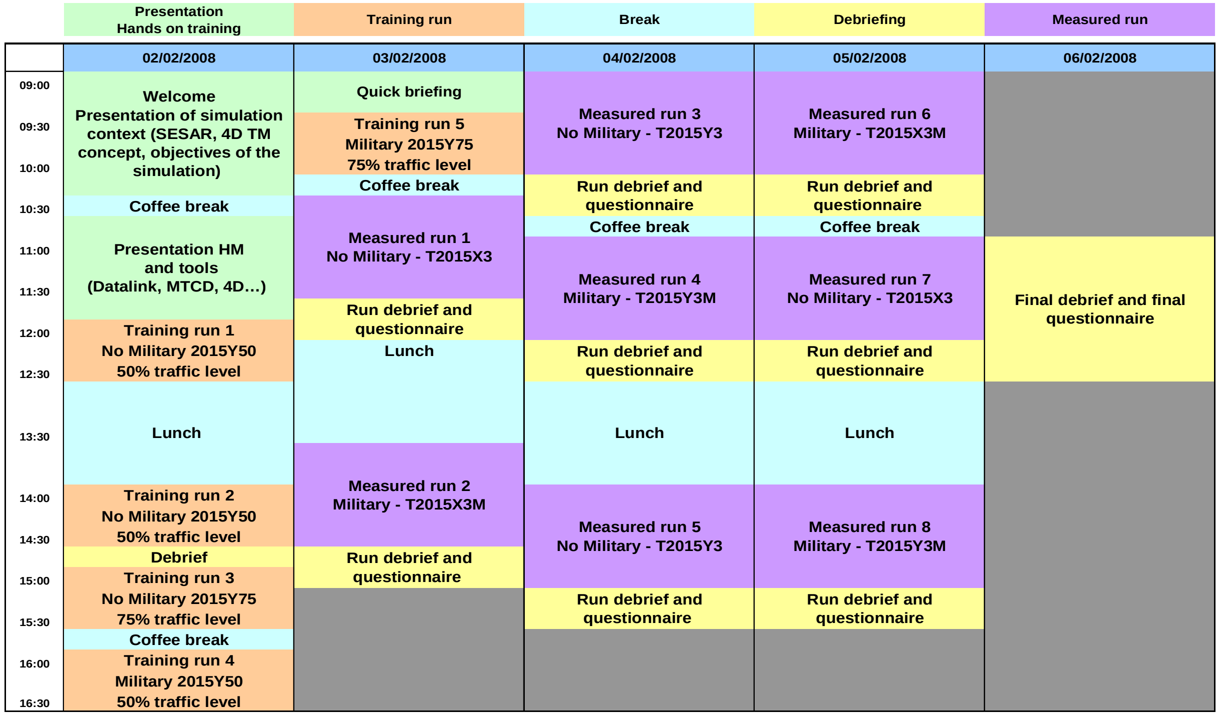
Table 25. Schedule of the second prototyping session

| Presentation Hands on training | Training run | Break | Debriefing | Measured run |
|---|---|---|---|---|

| | 01/12/2008 | 02/12/2008 | 03/12/2008 | 04/12/2008 | 05/12/2008 |
|---|---|---|---|---|---|
| 09:00 | Welcome Presentation of simulation context (SESAR, 4D TM concept, objectives of the simulation) | Quick briefing | Measured run 3 EP3E2M15COX - 2015X2OT | Measured run 6 EP3E2M15CNY - 2015Y2NT | |
| 09:30 | | Training run 5 RBT+CTA (NT) 2015Y75 75% traffic level | | | |
| 10:00 | | Coffee break | Run debrief and questionnaire | Run debrief and questionnaire | |
| 10:30 | Coffee break<br>Presentation HM and tools (Datalink, MTCD, 4D…) | Measured run 1 EP3E2M15RBY - 2015RBT | Coffee break | Coffee break | |
| 11:00 | | | Measured run 4 EP3E2M15COY- 2015Y2OT | Measured run 7 EP3E2M15CNY - 2015Y2NT | Final debrief and final questionnaire |
| 11:30 | | Run debrief and questionnaire | | | |
| 12:00 | Training run 1 RBT+CTA (NT) 2015Y50 50% traffic level | Lunch | Run debrief and questionnaire | Run debrief and questionnaire | |
| 12:30 | Lunch | | Lunch | Lunch | |
| 13:30 | | Measured run 2 EP3E2M15RBY - 2015RBY | | | |
| 14:00 | Training run 2 RBT+CTA (NT) 2015Y50 50% traffic level | | Measured run 5 EP3E2M15COX - 2015X2OT | Measured run 8 EP3E2M15CNY - 2015Y2NT | |
| 14:30 | Debrief | Run debrief and questionnaire | | | |
| 15:00 | Training run 3 RBT+CTA (NT) 2015Y50 50% traffic level | | Run debrief and questionnaire | Run debrief and questionnaire | |
| 15:30 | Coffee break | | | | |
| 16:00 | Training run 4 RBT+CTA (NT) 2015Y75 75% traffic level | | | | |
| 16:30 | | | | | |

Run name de-code: EP3 = Episode 3; E = En-route; 2 = Prototyping session 2; M = Measured run; 15 = 2015 traffic level and treatment; RB = RBT only, CO = CTA on time, CN = CTA not on time; X/Y = Traffic sample X / Y.

**Table 26. Schedule of the third prototyping session**



| Presentation Hands on training | Training run | Break | Debriefing | Measured run |
|---|---|---|---|---|

|  | 02/02/2008 | 03/02/2008 | 04/02/2008 | 05/02/2008 | 06/02/2008 |
|---|---|---|---|---|---|
| 09:00 | Welcome Presentation of simulation context (SESAR, 4D TM concept, objectives of the simulation) | Quick briefing | Measured run 3 No Military - T2015Y3 | Measured run 6 Military - T2015X3M |  |
| 09:30 |  | Training run 5 Military 2015Y75 75% traffic level |  |  |  |
| 10:00 |  | Coffee break | Run debrief and questionnaire | Run debrief and questionnaire |  |
| 10:30 | Coffee break<br>Presentation HM and tools (Datalink, MTCD, 4D…) | Measured run 1 No Military - T2015X3 | Coffee break | Coffee break |  |
| 11:00 |  |  | Measured run 4 Military - T2015Y3M | Measured run 7 No Military - T2015X3 | Final debrief and final questionnaire |
| 11:30 |  | Run debrief and questionnaire |  |  |  |
| 12:00 | Training run 1 No Military 2015Y50 50% traffic level | Lunch | Run debrief and questionnaire | Run debrief and questionnaire |  |
| 12:30 |  |  |  |  |  |
| 13:30 | Lunch | Measured run 2 Military - T2015X3M | Lunch | Lunch |  |
| 14:00 | Training run 2 No Military 2015Y50 50% traffic level |  | Measured run 5 No Military - T2015Y3 | Measured run 8 Military - T2015Y3M |  |
| 14:30 | Debrief | Run debrief and questionnaire |  |  |  |
| 15:00 | Training run 3 No Military 2015Y75 75% traffic level |  | Run debrief and questionnaire | Run debrief and questionnaire |  |
| 15:30 | Coffee break |  |  |  |  |
| 16:00 | Training run 4 Military 2015Y50 50% traffic level |  |  |  |  |
| 16:30 |  |  |  |  |  |

Run name de-code: EP3 = Episode 3; E = En-route; 3 = Prototyping session 3; M = Measured run; 15 = 2015 traffic level and treatment; NM = No Military, M = Military; X = Traffic sample X / Y = Traffic sample Y.

## 9.3 Summary of Objectives and Hypotheses for VDR

### Assess feasibility and operability of 4D TM (RBT and CTA)

| Objectives | Hypothesis |
|---|---|
| **Operability** | HO1. The 4D TM will be found difficult but feasible by the controllers due to the several changes implied: no route structure to support the task, no homogeneous speed between aircraft, speed variations due to the RTA function, less degree of freedom and aircraft time status to consider as much as possible.<br>HO2. The controller will need more tools (e.g. trajectory editor) to handle the 4D trajectory more efficiently.<br>HO3. The 4D TM will increase the level of controllers' workload compared to today's operation due to less anticipation of conflicts (facilitate aircraft adherence), consideration of aircraft status.<br>HO4. The 4D TM will increase monitoring tasks load and reduce planning tasks load.<br>HO5. RBT condition will lead the controller to "only" facilitate the trajectory whereas the CTA conditions will increase the level of cooperation between controllers and pilots (e.g. controllers considering the time status for conflict resolution). |
| **Predictability** | HP1. Aircraft will mostly respect their 4D agreed trajectory (respect of lateral profile, vertical constraint and be maintained within time tolerance windows) for RBT and CTA as far as they will start inside the tolerance window.<br>HP2. The achievement of time constraint and achievement of the delivery order will be detrimental to other trajectory dimensions (first vertical profile and then lateral profile). |
| **Efficiency** | HE1. The 4D trajectory flown will be close to the reference trajectory planned as routes are already "direct" and controllers have to facilitate adherence to it. |
| **Safety** | HS1. The 4D TM will increase the level of controllers' situation awareness compared to today's operation as all aircraft will follow as much as possible their planned trajectory, but the lack of route structure will impair the controllers' picture of traffic (e.g. plan evolution of traffic).<br>HS2. The level of safety will be perceived lower than in today's operation, as more dispersed |

| Objectives | Hypothesis |
|---|---|
| | aircraft trajectories will create more numerous, larger and less predictable bunching areas (compared to today's bunching waypoints).<br>HS3. With 4D TM the conflict resolution will be done later and with less resolution tools as controllers have to let the aircraft fly its reference trajectory as far as possible. |
| **Capacity** | HC1. The increase in traffic load will be manageable by controllers using the 4D TM, due to the complexity management measures and adaptation of the airspace. |

| Hypothesis | Status | Comments |
|---|---|---|
| HO1. The 4D TM will be found difficult but feasible by the controllers due to the several changes implied: no route structure to support the task, no homogeneous speed between aircraft, speed variations due to the RTA function, less degree of freedom and aircraft time status to consider as much as possible. | Confirmed. | |
| HO2. The controller will need more tools (e.g. trajectory editor) to handle the 4D trajectory more efficiently. | Confirmed. | |
| HO3. The 4D TM will increase the level of controllers' workload compared to today's operation due to less anticipation of conflicts (facilitate aircraft adherence), consideration of aircraft status. | Confirmed. | |
| HO4. The 4D TM will increase monitoring tasks load and reduce planning tasks load. | Confirmed. | By subjective data |
| HO5. RBT condition will lead the controller to "only" facilitate the trajectory whereas the CTA conditions will increase the level of cooperation between controllers and pilots (e.g. controllers considering the time status for conflict resolution). | Not assessed. | No Relevant Data as not enough aircraft were on a CTA |

| Hypothesis | Status | Comments |
|---|---|---|
| HE1. The 4D trajectory flown will be close to the reference trajectory planned as routes are already “direct” and controllers have to facilitate adherence to it. | Confirmed. | Mitigation: 2D trajectory and time to achieve were close to the planned trajectories and times, however vertical profiles were sometimes not achieved as planned (optimised). |

| Hypothesis | Status | Comments |
|---|---|---|
| HP1. Aircraft will mostly respect their 4D agreed trajectory (respect of lateral profile, vertical constraint and be maintained within time tolerance windows) for RBT and CTA as far as they will start inside the tolerance window. | Confirmed. | |
| HP2. The achievement of time constraint and achievement of the delivery order will be detrimental to other trajectory dimensions (first vertical profile and then lateral profile). | Not confirmed. | Evoked in controllers subjective feedback, but not reflected in measurements. |

| Hypothesis | Status | Comments |
|---|---|---|
| HC1. The increase in traffic load will be manageable by controllers using the 4D TM, due to the complexity management measures and adaptation of the airspace. | | Potentially with some improvements |

| Hypothesis | Status | Comments |
|---|---|---|

| | | |
|---|---|---|
| HS1. The 4D TM will increase the level of controllers' situation awareness compared to today's operation as all aircraft will follow as much as possible their planned trajectory, but the lack of route structure will impair the controllers' picture of traffic (e.g. plan evolution of traffic). | Open | To be confirmed in a full SESAR environment in terms of airspace design and automation support. |
| HS2. The level of safety will be perceived lower than in today's operation, as more dispersed aircraft trajectories will create more numerous, larger and less predictable bunching areas (compared to today's bunching waypoints). | Confirmed | |
| HS3. With 4D TM the conflict resolution will be done later and with less resolution tools as controllers have to let the aircraft fly its reference trajectory as far as possible. | Confirmed | |

**END OF DOCUMENT**