UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

MASTER THESIS

Study of the Free Route Airspace in the future Southwest (Spain-Portugal) Functional Airspace Block

César Antonio Nava Gaxiola

SUPERVISED BY

Dr. Cristina Barrado

Universitat Politècnica de Catalunya
Master in Aerospace Science & Technology

March 2015

This Page Intentionally Left Blank

Study of the Free Route Airspace in the future Southwest (Spain-Portugal) Functional Airspace Block

BY

César Antonio Nava Gaxiola

DIPLOMA THESIS FOR DEGREE

Master in Aerospace Science and Technology

AT

Universitat Politècnica de Catalunya

SUPERVISED BY:

Dr. Cristina Barrado

Departament d'Arquitectura de Computadors; UPC, Barcelona, Spain

This Page Intentionally Left Blank

ABSTRACT

The present European airspace configuration defined by national airspaces according to political borders, affects directly to aircraft efficiency and air navigation service cost. For that reason, the Single European Sky programme promotes the Functional Airspace Block (FAB) initiative between state members. FAB is based on operational requirements established regardless of States boundaries.

According to FAB implementation, there will be only nine FABs across European airspace. The Southwest FAB (SW FAB) is related to Portuguese and Spanish airspace and is under study in this master thesis.

This project pretends to evaluate the future SW FAB development by studying the planned phases and simulating them using an airspace evaluation tool (NEST Eurocontrol). All these to bring an evaluation of benefits or problems from three different perspectives: Airspace Users, Safety and Air Navigation Service Providers.

The thesis objectives are focused in providing metrics like distance saving, traffic conflicts or ATC taskload, to assess and compare with an baseline scenario. Additionally, another project aim is to obtain ATC controller opinions, to contrast simulation results with controllers subjective appreciations.

The structure of this thesis starts with a FAB and SESAR theory review, from the legislative background to operational concepts, followed by a project metrics proposal. Then, this project includes scenarios design steps and a simulation process for evaluation. Finally a discussion on the results and conclusions are presented.

In general, the master thesis results adds evidence that airspace users are greatly benefited from the future SW FAB programme, and at the same time indicates that safety is maintained. Furthermore, the ANSPs present similar values of ATC taskloads in sectors evaluation.

This Page Intentionally Left Blank

Acknowledgments

First and foremost, I offer my sincerest gratitude to my advisor, Dr. Cristina Barrado, who has supported me throughout my thesis with her kindness, patience and knowledge.

I would like to express my gratitude to IFACTA and APCTA, the ATC controllers association of Portugal and Spain, for their support in resolving the questions raised during this research. Furthermore, I would like to especially thank to controllers: Jaume Assens Serra, Paloma Merino, Maria Serrano Mulet and Paulo Encarnação.

Last but not least, I would like to thank to Mamen, my wife; for her unconditional and unlimited support, throughout my master degree.

This Page Intentionally Left Blank

Table of Contents

This Page Intentionally Left Blank

List of Figures

This Page Intentionally Left Blank

List of tables

This Page Intentionally Left Blank

INTRODUCTION

The European air traffic management (ATM) systems handle around 26,000 flights daily. Recent long term forecasts inidicate that in 2030 about 5 to 19% of the demand might not be accommodated [1].

So, taking into account this scenario, European ATM systems have to look for solutions for accommodates the increasing air traffic flows in future airspaces, whilst cutting costs and improving its performance.

One of these solutions came with the initiative of organizing airspace into functional airspace blocks, according to traffic flows rather than to national borders. Such a project was not possible without common rules and procedures at European level.

Functional Airspace Blocks implementation pretends to reduce Air Navigation Service Providers (ANSPs) costs and offer more direct routes to airspace users; in the same way FAB permits to settle new concepts like the Free Route Airspace.

This master thesis evaluates the Portuguese and Spanish airspace that will be form the South West FAB, and brings an overview of benefits from three different points of views (users, safety and ANSPs).

The thesis structure is organized as follows:

- First chapter describe all theory and concepts related with Functional Airspace Blocks, in especial those linked to the Southwest FAB. Also, this part includes the legislative framework where European FABs are settled, the study of this chapter permits to understand the next thesis stages.

- Second chapter presents the projects included in the operational plan for build the future SW FAB, as the most important ones, Free Route phases are explained in detail.

- Third chapter define which metrics are going to be evaluated along the thesis, most of them comes from simulation. In addition, an ATC questionnaire is introduced for contrast those metrics.

- Fourth chapter shows the airspace scenarios designed for evaluation; also the processing simulations with main steps are described in this chapter.

- Fifth chapter presents thesis results, from simulation and ATC questionnaire responses. This part is considered as the most important from this thesis because it discusses and contrasts results.

- Sixth part exposes a series of conclusions recovered from the entire master thesis.

As a final part, a set of annexes complements this project, where detailed results and maps exposed contribute to understand the study.

CHAPTER 1

INTRODUCTION TO SOUTHWEST FUNCTIONAL AIRSPACE BLOCK

1.1. Introduction to FAB concept

The first chapter introduces the main concepts and definitions related to Functional Airspace Block and South West FAB.

It is important to say that the review of these concepts pretends to settle a background that helps to understand the next steps developed through the project. As many studies, the theory represents the guideline for expand current ideas, for all these reasons, this thesis considers to include them.

1.1.1. European airspace situation

The liberalization of the European aviation market in 1993 made travel much more accessible and has stimulated growth in air services. Since then, European air traffic has increased by 54%. At this point, the air traffic control in Europe is fragmented, and as a consequence inefficient.

Comparing the European and American airspace, which are roughly the same size, Europe has 38 en route air navigation service providers (ANSP) and the United States has just one, the Federal Aviation Administration (FAA). Also FAA manages 40 % more of flights as Europe with the same costs, (46,000 flights a day vs. 26,000 in Europe) [1] [2].

Nowadays, European airspace is structured around national boundaries, thus flights are scarcely able to take direct routes which would save fuel, costs and be more environmental friendly. The estimated cost of airspace fragmentation in Europe amounts to 4 billion EUR a year [3].

1.1.2. SESAR programme

The Single European Sky ATM Research (SESAR) programme focuses in the modernization of the European air traffic control and airspace management with a uniform high level of safety, interoperability and efficiency.

In the same way, SESAR aims at developing the new generation of ATM system capable of ensure safety and fluidity of the air transport in Europe for the next several decades [4].

Undoubtedly, SESAR is the operational and technological tool for the Single European Sky (SES), which establishes cross-border blocks of airspace.

1.1.3. FAB Concept

As was mentioned before, one of the key elements of the Single European Sky (SES) is the introduction of cross-border airspaces defined like Functional Airspace Blocks (FAB). With FAB, routes and airspace structures are no longer defined in accordance with national borders but in accordance with the operational traffic needs. The air navigation services and related functions are optimized thought enhanced cooperation between ANSP, reducing navigation cost.

On the other side, FABs are expected to increase capacity and flight efficiency for airspace users. According to the future SES program, the current reorganization of the 67 airspace blocks in Europe (all based on national boundaries) are going to be reorganized into only nine functional airspace blocks [5].

The next figure (Fig 1.1), represent the horizontal scope of the future European airspace configuration, taking into account FAB concept.

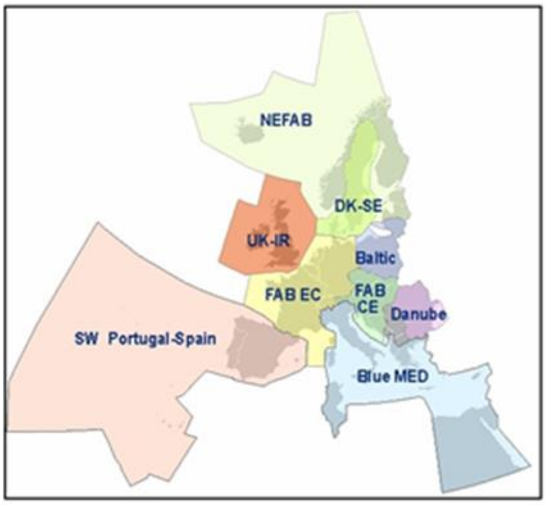


Figure 1.1 Functional Airspace Blocks in Europe [4].

1.1.4. FAB background: MUAC

The Maastricht Upper Area Control Centre (MUAC), operated by EUROCONTROL on behalf of four States, provides air traffic control for the upper airspace (above FL 245) of Belgium, the Netherlands, Luxembourg and north-west Germany [6].

The value of this area for this thesis is that represents a current and perfect example of the harmonization of airspace, and a model for cross-border projects in the spirit of the Single European Sky. In the same way, MUAC settled the base for the future FABEC (FAB for Central Europe).

In addition, MUAC is a successful example of functional airspace integration, leading to major safety and efficiency gains.

1.1.5. Southwest FAB

The Southwest FAB (SW FAB) comprises the Portuguese and Spanish airspace. The relevance of SW FAB is due to it is geographical situation, being one of the most important interconnection nodes for the American transatlantic flights and the European northern-southern corridor [7].

Approximately six thousands flights a day cross this airspace and the type of traffic makes it ideal for implementing Free Route Airspace (FRA).

Figure 1.2 illustrates the future SW FAB airspace, the SW FAB cross section allow trajectories flights of more than 2200 NM.

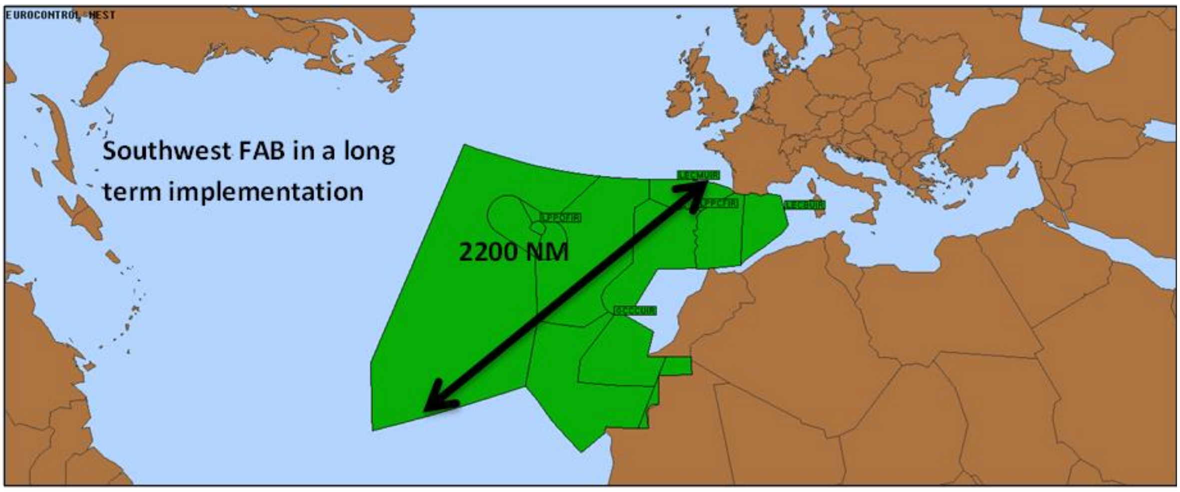


Figure 1.2 Horizontal extension of the Southwest FAB

1.1.6. Free Route Concept

The definition of Free Route Airspace (FRA) as given in reference [8] is as follows:

"A specific airspace within which users shall freely plan their routes between an entry point and an exit point without reference to the air traffic services (ATS) route network. In this airspace, flights will remain subject to air traffic control."

According to this definition, it can be said that the main aim of Free Route Airspace is to remove the constraints imposed by the fixed route structure and through the optimized use of all the airspace obtain benefits of capacity, flexibility, flight efficiency and cost savings, while maintaining safety standards.

As was mentioned before, in Free Route Airspace users can flight their preferred trajectories, this impacts directly in flight efficiency. In contrast, the Air Traffic Control requires particular tools and procedures for the establishment of aircraft separation.

The next figure (Fig 1.3) presents the basic concept of Free Route Airspace. It can be seen that FRA have a group of entry and exit points for users, so airliners can plan trajectories based on these entry and exit points, this results in a notorious distance saving, fuel consumption, flight time, CO2 emissions, etc., all these comparing with conventional route network trajectories.

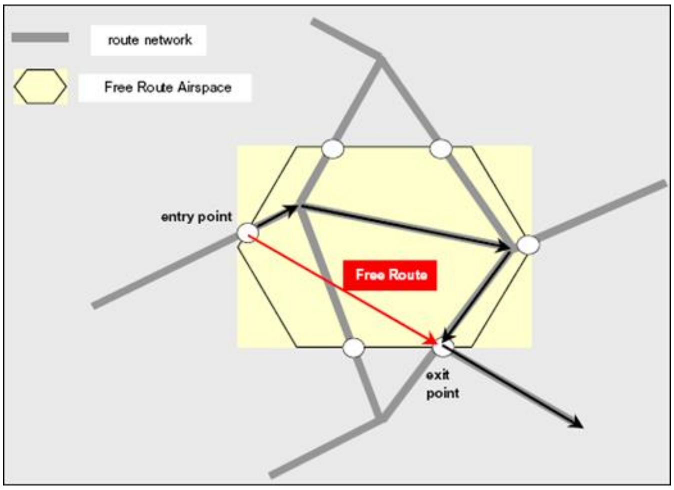


Figure 1.3 Free Route Airspace concept [9].

Normally, fixes in a Free Route Airspace can be defined as entry, exit or intermediate points. The waypoints locations take into account traffic flows and operational requirements for define the fix label.

The next table present the possible labels for waypoints inside a Free Route Airspace.

Table 1.1 Waypoint designations in free route airspace

Navigation fix type	Fix function
Departure (D)	Airport departure point linked to SIDs (Standard Instrument Departures)
Arrival (A)	Airport arrival point linked to STARs (Standard Arrivals)
Arrival and Departure (AD)	Both functions, arrival and departure navigation
Intermediate (I)	Middle navigation points in the airspace
Entry (E)	Compulsory entry point to Free Route
Exit (X)	Compulsory exit point from Free Route
Entry and Exit (EX)	Both functions permitted in that fix, entry or exit.

1.2. FAB Regulatory Framework

The importance of the regulatory framework is based on the need to establish a legal basis for define, develop and operate the future FAB. In this project, the regulatory framework is exposed from the global scenario (SES) down to particular applications of guidelines in the Southwest (Portugal-Portugal) area.

The legal initiatives and mandates come from the European Commission (EC), who develops legislative regulations based on evaluations from experts and professionals of the airspace.

1.2.1. SES (Single European Sky) Regulations

The regulatory background related with FAB and FRA concepts starts with regulations for Single European Sky; this regulatory framework is contained in two legislative packages, adopted by the European Parliament in March 2004 and March 2009. The legislations were drafted by the European Commission with the assistance of Eurocontrol.

The first regulatory package for SES (Single European Sky) was launched in 2000 by the European Commission, following the severe delays to flights in Europe experienced in 1999. A High Level Group was established and building on the recommendations in its report, the Commission drafted a legislative package at the end of 2001. This first package was adopted by the European Parliament and Council in March 2004 [10] [11].

This first package contains the next main regulations:

- The Framework regulation (EC No 549/2004), this is the legislative base for the creation of the single European sky.

- The Service provision regulation (EC No 550/2004) is focused on the provision of air navigation services in the Single European sky.

- The Airspace regulation (EC No 551/2004) defines the organization and use of airspace in the Single European sky.

- The Interoperability regulation (EC No 552/2004) is based on the interoperability of the European Air Traffic Management network.

The second SES legislative package created by the European Commission, is focused in create a single safety framework for the development of safety regulations and their effective implementation, in the same way looks for improve the performance of the ATM system through setting of targets.

Furthermore, the second package opens doors to new technologies, the implementation of new operational concepts, and exposes some objectives like increase safety levels by a factor of ten as the airport capacity is increased.

The follow regulations are included in the second SES legislative package:

- The Performance Scheme (EC No 691/2010) is related with ATM cost-efficiency, capacity and environment. In the same way, requires that National Supervisory Authorities present national (or FAB level) performance plans.

- The Functional Airspace Blocks are bottom up initiatives led by the States that enhance cooperation between the air navigation service providers (ANSPs) and the national supervisory authorities (NSAs). All this for defragment the airspace and obtain the operational efficiency gains through such strategies as common procurement, training, and optimization of air traffic controllers (ATCs) resources.

- The Network Manager is a centralized function at EU level, the main function is to carry out the management of the ATM network functions (airspace design, flow management) and management of scarce resources (transponder code allocations, radio frequencies) as defined in EC N° 677/2011.

- The Charging Regulation (EC N° 1191/2010) on the en-route charging system, lays down a legal framework of transparent reporting of en-route charges, and costs components of the Member States.

1.2.2. FAB Regulation Background

As was explained in last part, the legislative framework of FAB comes from the SES regulation framework where the FAB concept is defined and developed, all this to cope with a sustained air traffic growth and air traffic operations, under the safest and environmentally friendly conditions.

The FAB concept, was developed in the 1st legislative package of the Single European Sky (SES I) as one of the main means for reducing airspace fragmentation. The 2nd legislative package (SES II) tackled the creation of FABs in terms of service provision, in addition to the airspace organization issues [3].

So, is important to take into account, that from the last set of regulations exposed, the regulation framework of FAB particularly comes from Regulation (EC) No. 1070/2009 amending Regulation (EC) No. 549/2004.

It can be said that the establishment of Functional Airspace Blocks is a key element of Single European Sky. The specific regulation (EC) No 1070/2009 in [12] related to FAB, states that:

“The functional airspace blocks are key enablers for enhancing cooperation between air navigation service providers in order to improve performance and create synergies. Member States should establish functional airspace blocks within a reasonable time-frame. For that purpose and in order to optimize the interface of functional airspace blocks in the single European sky, the Member States concerned should cooperate with each other and where appropriate they should also cooperate with third countries”.

1.2.3. Southwest FAB Regulation

The SW FAB documentation is based in accordance with Regulation (EC) No 550/2004 Article 9a, where indicates that a FAB has to be established by mutual agreement between the Member States concerned.

In this regard, the civil aviation authorities of Portugal and Spain signed on May 17th, 2012, a Joint Declaration on the SWFAB Portugal-Spain initiative, whereby agreement is reached the establishment of the Southwest Functional Airspace Block (SW FAB), between Portugal and Spain [12] [13].

1.2.4. SW FAB Operational Task Force Documentation

At this level, is important to mention the official and more useful documentation that serves like a guideline for this master thesis. These reports and operational plans are developed by an Operational Task Force (OTF) group, integrated by Portuguese and Spanish experts.

The documents are:

- SW FAB Operational Requirements Doc: is a document that describes the expected operational scenario from the user perspective, and the proposed operational improvements in the main ATM areas. Presents an analysis of demand/capacity balancing, safety, flight efficiency, environment and airspace organization management [12].

  According to this document, some of the operational targets for the long term (2020) of SW FAB implementation are focused in reaches an improvement of 10% in flight efficiency and increase in order of 70% of safety as traffic grows.

- SW FAB Compliance Summary Doc: the document provides the legal, organizational and operational framework where the SW FAB has to evolve in order to meet the SES requirements for FABs. Additionally, explains the SW FAB expectations in terms of performance improvements and their consistency with the EU-wide performance targets [13].

- SW FAB Airspace Organization and Classification Doc: this document presents information about its organization and classification of the Portuguese and Spanish airspaces, the number of ACC’s and airspace sectors, their capacity, the number of configurations of every ACC, the airspace management and a full up characterization of current traffic demand and the forecasted traffic in the next years managed by ATS providers [14].

CHAPTER 2

SW FAB OPERATIONAL PLAN

2.1. SW FAB Airspace Organization

To get a deep knowledge of the Portuguese and Spanish airspace; is necessary to know concepts about the SW FAB airspace organization and its subdivision.

Taking this into account, Chapter 2 describe the organization of the SW FAB airspace structure along with the full detailed information, all these makes possible to understand the scenarios presented in the following chapters of this project.

At beginning, it is important to say that the Portuguese and Spanish airspace have been organized according ICAO rules, exposed in ICAO Annex 11.

2.1.1. FIRs and UIRs

The first largest divisions inside the national airspaces are the FIRs (Flight Information Region) and UIRs (Upper Information Region); these regions have the responsibility of provide flight information and alerting service to all the flights that cross their borders.

Thus, in this case the Spanish airspace is divided in three FIR/UIRs Regions: Madrid, Barcelona and Canarias. On the other hand, Portugal has two: Lisbon and Santa Maria Oceanic [14] [15].

The next figure exposes the Portuguese and Spanish airspace with FIRs division; it can be considered the total SW FAB area.

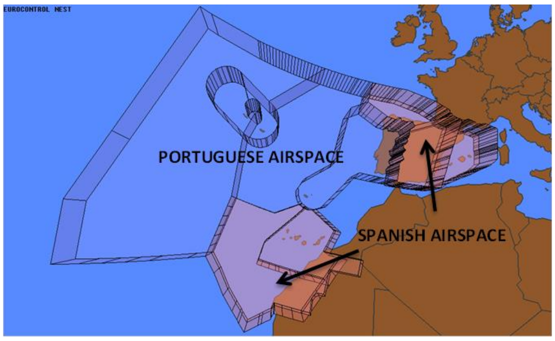


Figure 2.1 FIRs division in Portuguese and Spanish airspace

The upper airspace (UIR) covers the same area as the lower airspace (FIR), except for the Canary Islands, where it is slightly smaller. The vertical separation between the UIR and FIR for Portugal and Spain is established in flight level 245 (FL 245).

2.1.2. ACCs (Area Control Centres)

The second important subdivision are the ACCs, these centres provides the air traffic control service to aircrafts flying in en-route phase and approach, depending on the FIR/UIR dimension and air traffic density, it can exist one or more ACC inside the FIR/UIR areas.

The Spanish airspace has six ACCs: Madrid, Seville, Barcelona, Canarias, Palma and Valencia. On the other side, Portugal counts with Lisbon and Santa Maria ACCs.

2.1.3. Sectors

The ACCs may be further administratively subdivided into areas comprising sectors. Each area is staffed by a set of controllers trained on a defined number of sectors in the area.

The sectorisation of the airspace can be done in en-route airspace (high flight levels) or in TMA (Terminal Manoeuvre areas), that corresponds to sectors closest to airports and low flight levels.

Normally each sector employs a distinct radio frequency for communication with aircraft, also has secure landline communications with adjacent sectors, approach controls, flight service centres, and military aviation control facilities.

For identify the location of sectors that are evaluated in this thesis, see Annex 1.

2.1.4. Terminal Manoeuvres Areas (TMAs)

This particular subdivision is very important because is related to the lower airspaces that are closest to airports, normally are defined as congested airspaces compared with en-route areas.

The terminal manoeuvres areas are established at the confluence of ATS Routes, in the vicinity of one or more major aerodromes. In this case, instructions for flight in TMAs come from Approach controllers.

As summary, Table 2.1 presents the Portuguese and Spanish airspace subdivisions, including FIR/UIRs, ACCs and number of sectors (en-route and TMA).

Table 2.1 Portuguese and Spanish airspace subdivision [14] [15].

FIR/UIR	ACC	Sectors		Military Approach Control
		En-route	TMA	
LISBOA	LISBOA	8	5	5
SANTA MARIA	SANTA MARIA OCA	3	1	1
MADRID	MADRID	North: 9 South: 8	10	3
	SEVILLA	6	2	2
BARCELONA	BARCELONA	14	6	1
	PALMA	--	7	--
	VALENCIA TACC	--	5	--
CANARIAS	Canarias	4	5	--

2.2. SW FAB Operational Plan

The joint collaboration towards the establishment of a FAB in the Southwest region of Europe was initially promoted by the Portuguese and Spanish air navigation services providers (ANSPs), NAV Portugal and ENAIRE respectively.

According to the SW FAB Operational requirements document in [12], the process for build the future SW FAB requires studies about traffic flows, airspace capacity analysis, safety and human factors evaluation.

It is important to mention that the SW FAB Plan includes different projects; but this thesis only evaluates the final idea of the SW FAB focused in the implementation of Free Route Airspace (FRA), in especial this project is presented in 2.2.7.

Figure 2.2 shows the future extension of the SW FAB, based in a long term implementation plan to 2020.

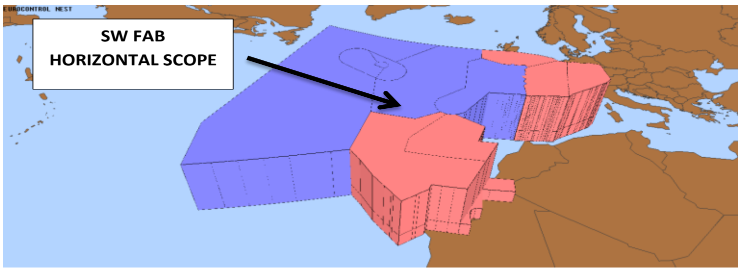


Figure 2.2 Future SW FAB planned in long term

Other projects that complements the SW FAB are based in create and improve airspace structures like ATS Route network and ATC sectors. Some of these projects are presented in the next parts of the text (2.2.1 to 2.2.6).

2.2.1 SW FAB New ATS route network structure

This project is based in developing proposals for airspace design improvements and carrying out feasibility analysis through a high detailed traffic demand characterization. As can see in the Figure 2.3, the ATS route network in the SW FAB area is complex and requires a detailed study for improvements.

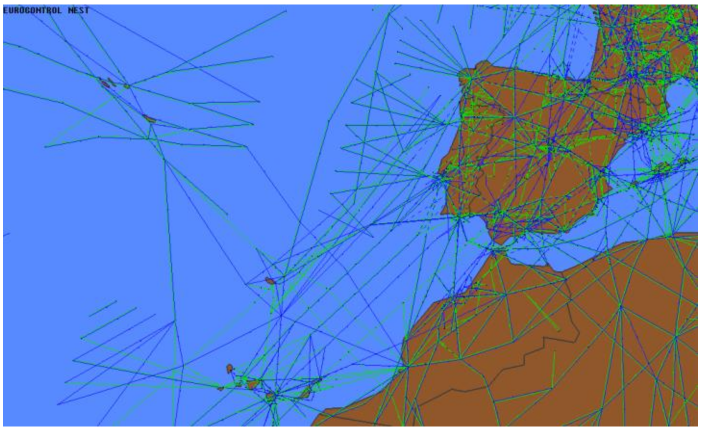


Figure 2.3 ATS network view

The analysis of the main traffic flows has served to identify the main areas of improvement, and at same time the new ATS route network considers civil/military airspace integration, according to FUA (Flexible Use of Airspace) guidelines.

2.2.2 FIR/UIR Casablanca (Morocco) reorganization project

The reorganization project between Casablanca FIR and Peninsula comes from the necessity of accommodate in an efficient way the traffic that entry or exit from the Canary Islands.

The restructuration is focused in improve the group of parallel airways that connect the Iberian Peninsula with the Canary Islands across the Moroccan airspace.

The next figure (Figure 2.4) brings an overview of this new reorganization; also identify some new possible waypoints across the FIRs.

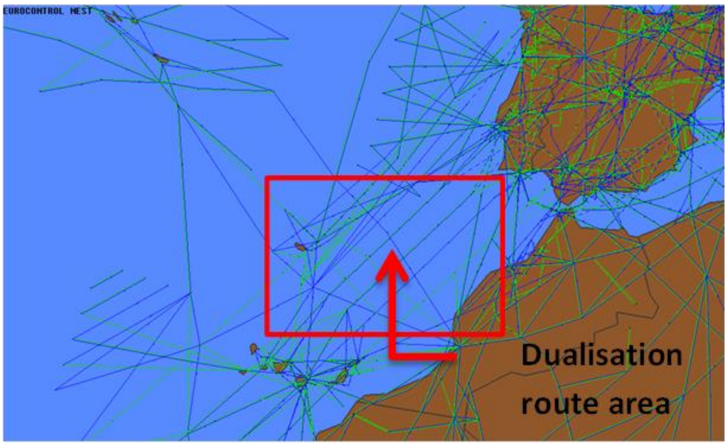


Figure 2.4 Parallel airways over Moroccan airspace

These airways permit unidirectional routes, also are planned to implementing 7 B-RNAV procedures, that allow aircraft flight along to, or near as possible to direct routes.

2.2.3 Restructuration of the main interface between SW FAB/Marseille FIR

The project pretends to change the traffic that converges in five waypoints: NILDU, MAMES, VATIR, DIBER and LUMAS.

The new configuration tries to reduce the number of conflicts between Barcelona and Marseille FIRs. Additionally, the goal is to achieve better traffic demand sharing among entry/exit points, with an improve in flow organization.

Figure 2.5 exposes the location of these 5 waypoints between both FIRs.

Figure 2.5 Waypoints for improve in Barcelona FIR border

2.2.4 New route option for NW traffic departing LEMG

This project is associated to the importance of Malaga airport in terms of traffic demand to UK; for this reason, a new route for traffic departing Malaga to UK will be implemented, basically consists in fly directly to VOR Zamora without pass Madrid VOR.

The next image in Figure 2.6 presents some flights that are affected.

Figure 2.6 Current route via Madrid

2.2.5 Restructuration of the airway UN-733

This project implements changes in airway UN-733 that allows a high traffic density between Peninsula and Balearic Islands.

Taking this into account, the restructuration will modify the track to the north of the current one; as a consequence a more direct route will be offer to airspace users. An approach of the airway UN-733 can be appreciated in the next figure (Figure 2.7).

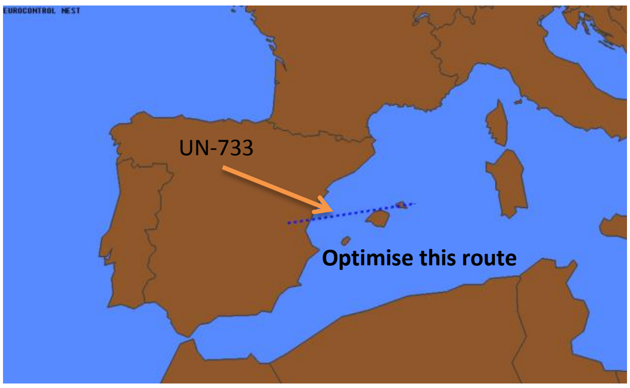


Figure 2.7 Part of airway UN-733 for optimize

2.2.6 Night direct ATS routes network project

This project is focused in set up a new night time airspace different from the daytime. In this nocturne scenario, traffic demand is different, so direct routes are good solutions.

These routes permit to users reduce flight times and fuel burn, all this for enhance the flight operations. The following figure illustrates the nocturne ATS network in the Iberian Peninsula.

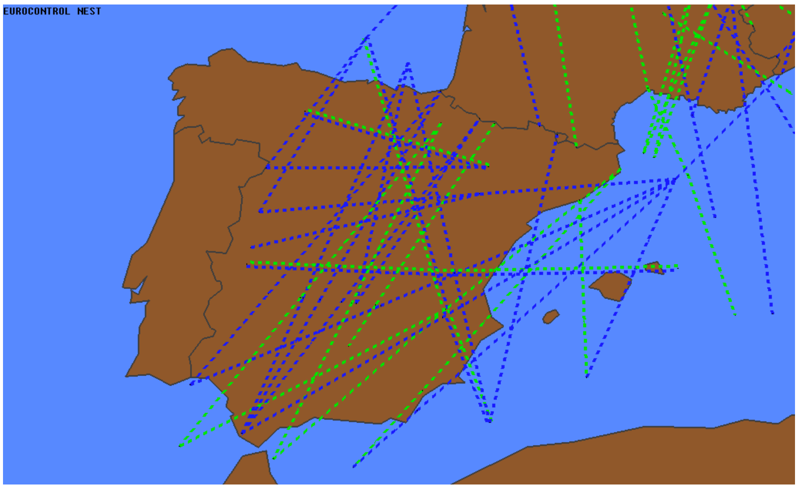


Figure 2.8 Night ATS network over Iberian Peninsula

2.2.7 Free Route Airspace in the SW FAB

The Southwest Functional Block will include a large area operating with Free Route concept, this extension will count with Spanish and Portuguese airspace [12].

It is important to mention that Lisbon FIR operates with Free Route since May 7, 2009 [16], before SW FAB project has been established (see 1.2.3).

Lisbon FIR was pioneer in Europe in Free Route implementation and aims to remove the constraints imposed by the fixed route structure and through the optimized use of the entire airspace obtaining benefits of capacity, flexibility, flight efficiency and cost savings, while maintaining safety standards.

On the other side, the first FRA in Spain was established in May, 2014 and is related to Asturias and Santiago sector (FRASAI).

As many projects, the total implementation has to be done by steps, so in this case it was divided in three main levels.

The first Free Route phase (Phase I) is focused in carry out the concept in Santiago and Asturias (FRASAI) jointly with Lisbon FRA. The location of FRASAI sector is presented in Figure 2.9.

Nowadays, national airspace still limited by politics borders, but there exist a good coordination between both Free Route areas.

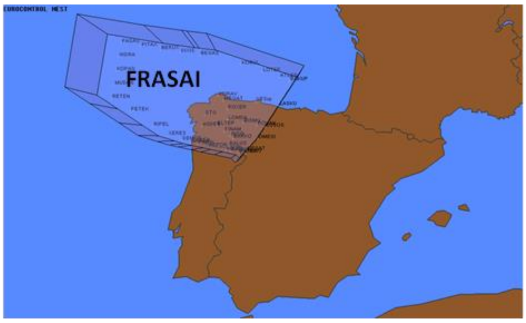


Figure 2.9 FRASAI location

This new FRA implies some change in the limits between FRA flights and conventional ones, in the same way it is necessary evaluate the coexistence between both ways of operate.

As primary goal of this phase, is to enhance the traffic that flows via Lisbon FIR to Brest FIR, that corresponds to the French FIR located in the northern limit of FRASAI, with an important transatlantic flow.

This first phase (see Fig 2.10) considers an airspace operating above FL245. As results, it will possible to offer aircraft operators a full free route serving with a significant traffic accommodated in the SW FAB. In contrast this new restructuration implies changes in the Central and West Operational Airspace Blocks.

The Phase I was planned to be finished planned in 2014, but is expected to be finished in 2015 [7] [12]. The next figure (Fig 2.10) clearly exposes the dimension of FRASAI and Lisbon FRA for Phase I.

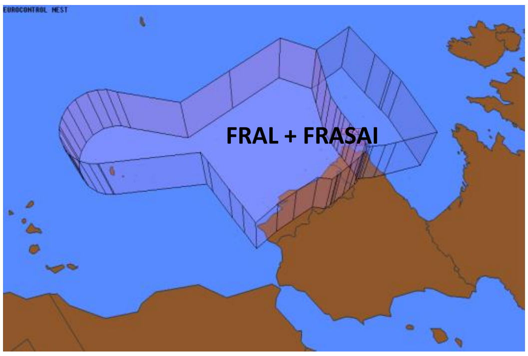


Figure 2.10 Phase I extension

The second part of SW FRA project (Phase II) is based in the extension to Santa Maria Oceanic FIR. This phase will be initiated successively after completion of Phase I and is part of the long term SW FAB airspace projects for 2020 [7] [12].

The most interesting point of Phase II is the possibility to offer long flights without restrictions (direct routes), so at the end of this phase will be possible to offers flights from the exit point of a Madrid SID (Standard Instrument Departure procedure) to New York Oceanic FIR, at 40 W.

Figure 2.11 identifies the dimension of this second FRA phase, including Santa Maria Oceanic FIR.

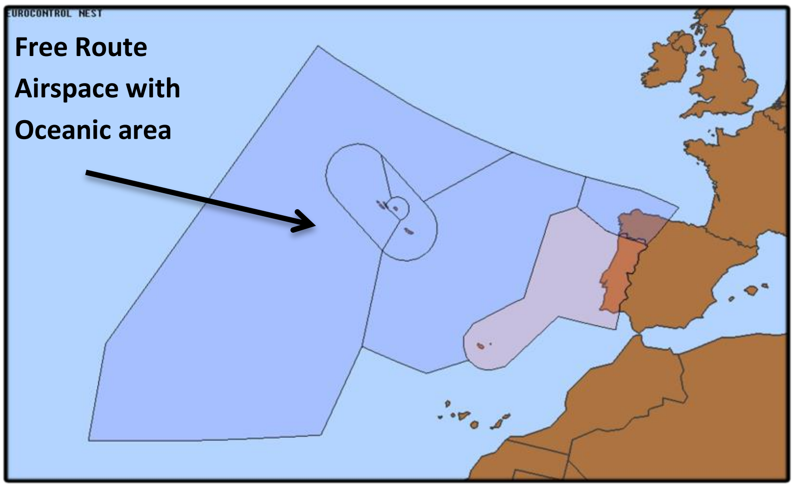


Figure 2.11 Future Phase II in OTF plan of 2011

The final step (Phase III) of the implementation of Free Route, extends to Canary Islands FIR, this extension represents a big change in the SAT (South Atlantic Corridor), due to the significant traffic demand increase.

The Operational Requirements Doc says that this extension will be effective only for overflying traffic; as a consequence will necessary a new restructuration of SIDs and STARs from Canary Islands airports to entry/exit waypoints of Free Route Airspace.

As can be seen in the next figure (Figure 2.12), the total Free Route Airspace from the SW FAB is considerable, and the implementation being part of the longer term SW FAB projects to 2020 [12][13][14].

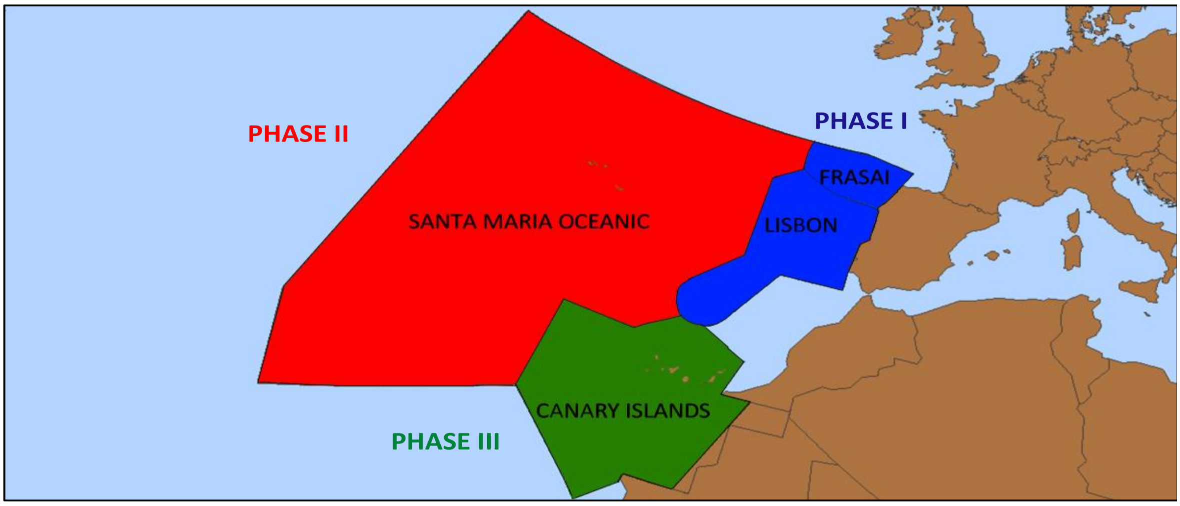


Figure 2.12 SW FAB phases

In order to achieve the complete SW FAB, it is necessary to create a new configuration of the current ATC sectorisation, in the same way is important to consider an unique CNS infrastructure for reduce ANSPs costs.

CHAPTER 3

METRICS EVALUATED IN THE SOUTHWEST FAB

3.1 ATM metrics

The approach to metrics evaluation is present in the SESAR feasibility reports for future FABs. Those reports take into account safety issues, capacity evaluation, cost-effectiveness, flight efficiency, environmental issues, military mission and controller productivity [13] [17] [18]. In line with these feasibility reports, this master thesis produces metrics grouped in three main guidelines: airspace user, safety and ANSP.

The realization of the vision for the future air traffic management (ATM) in Europe, needs to count with significant information and collaboration from all stakeholders. In this way, the airspace 'industry' has decided to use the Performance Based Approach (PBA) as the methodology to follow to face the challenges of increasing air traffic demand.

According to ICAO Manual on Global Performance of the Air Navigation System, the PBA concept is defined as “a decision making method, based on three principles: strong focus on desired/required results, informed decision making driven by those desired/required results, and reliance on facts and data for decision making” [19].

In the long term, the PBA concept application will result in a more efficient ATM system through identified cost savings, reduction in waste of resources, more equitable charging practices, and more efficient provision of services [19].

Following this approach, in its Master Plan the SESAR programme identifies the “need for a single, simplified European ATM System coupled with a performance-based approach that will satisfy all stakeholders’ requirements” [20].

Two important items can be extracted from these two documents: First the need to rely on data to make decisions and to follow results, and second the importance of defining metrics for all involved stakeholders.

In fact, Eurocontrol evaluations mention that FAB establishment between State members has to be supported and justified by its overall added value based on cost-benefit analysis, considering that operational advantages are linked to all stakeholders [21].

For instance, the introduction of new operational procedures at the tactical level has been assessing in [22] [23] [24] [25].

Looking into previous works related to airspace users metric, there is a variety of ways for measures flight efficiency, distance saving, fuel consumption, flight time saving, delays performance, etc.

In the first case, the impact of cruise-speed reduction to absorb delays is evaluated in a paper by Knnor et al in [22] using metrics of fuel consumption. In addition, the same metric is used to assess other three operational performance measures (schedule aircraft, airborne delay and departure delay) in [23].

A similar evaluation for airspace users was carried by D. McNally et al in [24], considering dynamic weather routes that is a promising system that searches and proposes changes on the cruise route depending on the weather situations (threads, wind, etc), had analysed the flights of a commercial company during a 3-month period proposing route changes through an automated system. For this case, the metrics were flight minutes saved, and the impact of rerouting in the sector congestion.

The author B. Zou, M. Elke and M. Hansen covers in paper [25] the flight efficiency metric for airliners. The authors define the flight inefficiency in terms of fuel consumption using three approaches: ratio-based, deterministic and stochastic.

The first approach links a unit of burned fuel with some output metrics such as distance, passengers of economic benefits. The deterministic frontier model uses a linear function to model fuel consumption. Finally, the stochastic frontier model introduces a new term in the previous linear formula to model idiosyncratic errors. The new term is stochastic and follows a half-normal distribution.

The study was done for 15 airlines accounting the 80% of the fuel consumption in U.S. domestic airspace. The results show average fuel inefficiencies of 9-20 %.

On the other hand, the safety metric studies take into account the number of conflicts related to aircraft separation losses. Gaydos, Liao, Smith, and Wang in [26] have evaluated the increase of the number of medium-term conflict resolution advisories produced by trajectory-based descends.

This study was carried out with the traffic of Denver International Airport per period of 90 minutes long, involving 80 aircraft, 36 of them in descend and the rest as en-route. An average of one false alarm every 2.5-3 minutes showed that the current tools are not acceptable for dealing with trajectory-based descends.

Moreover, Pozzi et al. in [27] focus on the evaluation of safety as a way to highlight the gap that exists when trying to transform large amount of real-time data into operationally relevant recommendations.

The authors combine big-data processing systems with operational expertise to detect loss of separation and predict dynamics of disturbance propagation. The safety data processing system was evaluated using real-time radar data at the Italian ANSP (ENAV) experimental centre.

The aircraft synchronization concept exposed in [28], is also a metric proposed for measure the safety of airspace given a list of aircraft trajectories. This metric is related to those aircrafts that have some degree of dependent behaviour and show to be a good indicator of the loss of separation situations, especially by some previous route deviation action.

In the case of FAB measures, T. Mihetec, S. Steiner and Z. Jakšić in paper [29] indicate that the number of operational concepts currently put in place in the FAB implementation makes it difficult to meet the objective of a win-win situation for the individual stakeholders.

For ANSP metrics, a long list of works has measured workload/taskload of the controllers, especially of interest for airspace capacity calculation.

The paper of Welch et al. in [30] proposes a full workload model to be used by an ANSP in deciding sector capacity in case of weather events. The model applies regression on an extensive list of metrics related to ANSP: aircraft count, peaks of traffic, throughput (aircraft per hour), weather, task recurrences, mean transit time, size of the sector volume. The model shows to predict capacity more accurately in all weather conditions.

A similar metric approach to this thesis is exposed in [31], where the benefits and feasibility of the Flexible Airspace Management concept (FAM) from different perspectives. FAM concept is part of the NextGen implementation plan which allows dynamic reconfiguration of the airspace structure.

In FAM concept the sector boundaries are modified to balance air traffic peak demands over capacity. The evaluation is done through simulation and takes into account the efficiency interests of the airlines (flight distance and time), the controllers' taskload (number of rerouting, aircraft counts) and safety issues (bad weather penetrations, separation violations). Since the simulations have human-in-the-loop, also subjective useful information is obtained about the roles, procedures and tools.

3.2 Metrics evaluated in the project

3.2.1 Airspace user metric

From airspace user perspective (commercial aircraft operators), the most important goal for them is to complete a safe operation with the highest benefit. This is translated in flying the shortest or most direct route available for the operation; resulting in a reduction of fuel burn, flight times saving, pollution decreases, etc.

For all these reason, <u>"flight distance (NM)"</u> is the first user metric proposed for evaluating the FRA flight trajectories. The weather and winds conditions influence are not taking into account.

In the same way, the second metric is defined like <u>"route efficiency (%)"</u>, it helps to bring an overall idea of Free Route benefits.

The route efficiency takes into account the "ideal or most direct route" of the flight planned and the route simulated in this thesis. So for each flight trajectory, the function calculates the difference and presents the overall result.

The calculation of route efficiency metric follows the next rule [32]:

$$[\text{Direct Route (NM)} / \text{Free Routed Route (NM)}] \times 100 = \text{Route Efficiency (\%)} \quad \textbf{(3.1)}$$

The flight efficiency metric is expressed in percentage, so highest values indicate efficient flights.

Finally for airspace users, the "flight time saving (total minutes per day)"complements the airspace user metrics, all these focus in benefits that the SW FAB brings to users.

The last metric measures the time spent for each traffic sample in the scenario studied, so the summatory of all flight times are presented in a value for each traffic day; the flight time is exposed in minutes.

3.2.2 Safety metric

Safety is considered a prerequisite of implementing the Southwest FAB initiative, and will be the basis for the development of the operational concept and all the airspace projects considered.

Therefore, potential conflicts derivate from possible aircraft separation losses have to be evaluated.

In order to gives an overview of how conflicting the airspace will turn in terms of possible separation losses, the safety metric is defined as the "number of conflicts" of the traffic samples.

The threshold assumed in the safety metric definition is the RVSM in vertical (1000 ft), and 10 NM in horizontal, those limits has been considered in previous simulation studies for the Lisbon Free Route establishment [33].

3.2.3 ANSPs metric

The ANSP metrics are related to main traffic flow demand, traffic flow complexity and taskload considerations. This work proposes the taskload of the controllers as the ANSP the guideline for measures in the case of ANPs.

The method for evaluate ANPs metrics in this thesis follows the CAPAN-like process [32], based in accounting for a set of basic controllers' tasks for each flight crossing one sector, according to the flight profiles, the critical flight events and the conflicts detected.

The CAPAN like method says that each controllers' task has a position responsible (executive or planning) and an execution time.

Thus, in this sense the thesis proposes two metrics: the "total taskload per day (total minutes per day)" and the "peak taskload per hour (percentage)", both metrics are measured for each controller position.

While the first taskload measures the volume of work in minutes in a whole day, the second one is measured in percentage; this provides better understanding of the traffic coincidence in time.

For the peak taskload per hour, this thesis considers similar limit values like CAPAN (Eurocontrol) method for measure ATC loads [34].

The values between 0-40% are related to light loads. Then from 40% to 50 it can be considered as medium ATC loads. The next range is between 50-65%, defined like a heavy load, following by a very heavy ATC load for 65-70% range. Finally, the overload reaches values above 70%, defined like the ATC operational limit.

3.2.4 Metrics validation with ATC responses

For contrast metrics, this master thesis includes a set of responses from the ATC controller perspective, which contribute to understand and discuss results from the operational point of view.

So, for accomplish with metric validation, a questionnaire for Free Route controllers was developed. The questions were focused in Free route aspects and ATC tools for manage flights in this kind of airspace.

This questionnaire exposed in Annex IV was answered by ATC controllers from Lisbon Free Route Airspace. It is important to mention that these controllers are pioneers in Free Route introduction in Europe, and their experience brings rewarding information to this project.

Finally as summary Table 3.1 shows the project metrics that are evaluated in this master thesis.

Table 3.1 Master thesis metrics

MASTER THESIS METRICS		
Airspace Users	**Safety**	**ANSPs**
*Distance Saving (NM) *Route Efficiency (%) *Fligth Time Saving (total minutes per day)	*Number of Conflicts related with aicraft separation losses	*ATC Volume Taskload (total min per day) *ATC Taskload peak per hour (%)
Metric Validation with ATC Responses		

CHAPTER 4

SIMULATION PROCESSING

4.1 Simulation Tool

The calculations of the SW FAB metrics are done using NEST (Network Strategy Tool) software from Eurocontrol.

This tool provides a fully capability for airspace structure design and development, in the same way is possible to use it for capacity planning, post operations analysis, strategic traffic flow organization, scenario preparation for fast and real-time simulations and for ad-hoc studies at the local and network level [35].

It can be said that NEST is similar to most modelling tools; the user creates scenarios, then run analysis routines and obtains results.

4.2 Traffic Samples

The traffic samples evaluated in this master thesis are related to flight trajectories loaded previously to the flight operation day and are defined like “initial traffic” or “M1 traffic” in the Demand Data Repository from Eurocontrol.

This project takes into account two reference scenarios, baseline A and B for the simulation process; as a consequence two sets of traffic samples need to be considered.

The reason of presenting two baselines is to obtain measures both in the short term (more realistic and accurate) and in the long term (best suited for the SW FAB long term implementation).

The first baseline scenario, baseline A, is based in historical air traffic from 2013-2014, and in the case of second baseline scenario (baseline B); it considers a traffic forecast for 2019.

Additionally, traffic sample extraction considers data from AIRAC cycles before the implementation of FRASAI (Asturias-Santiago Free Route Airspace), specifically before May, 1 2014. In contrast, Lisbon FIR traffic included in this thesis operates in Free Route Airspace, because this area has been working with this modality since 2009.

For baseline A, it was selected five days of 2013-14 and extracts the 24h flight trajectories from Eurocontrol DDR2 (Data Demand Repository) [36]. So, the selected days are from different AIRAC cycles, and the traffic traces contain only the segments inside the SW FAB.

The selection criterion was to consider normal operational days of different seasons that have been not affected by adverse weather phenomena, strikes, holidays, or any other external perturbation. Only one of the 5 days selected presents a slightly higher traffic density; this is linked to a Saturday from summer.

In the case of baseline B, a traffic forecast to 2019 was performed with NEST based on the traffic samples of baseline A. The prognosis increments traffic to 2019 in a 10-16%, depending on day. Table 4.1 presents the traffic samples characteristics for baseline A and for baseline B.

Table 4.1 Traffic samples in the simulation processing

Sample	Day 1 Tue 04/13/13	Day 2 Sat 08/17/13	Day 3 Wed 11/13/13	Day 4 Tue 01/21/14	Day 5 Thu 04/03/14
Traffic Operation	Normal	High	Normal	Normal	Normal
Nb Flights Baseline A	1423	1901	1371	1221	1629
Nb Flights Baseline B	1618	2177	1510	1423	1805

4.3 Scenarios configuration

The scenarios of baselines (A and B) and the simulated ones, consider the vertical limits in accord with the SW FAB plan: from FL245 to FL660.

The opening scheme or configuration of sectors during the day is considered to be fix, with 14 sectors. This configuration is decided according to the actual airspace configuration of the Day 1, during the longest period at day/busy time.

Figure 4.1 present a list of all sectors evaluated, for locate each sector in the SW FAB airspace see Annex 1.

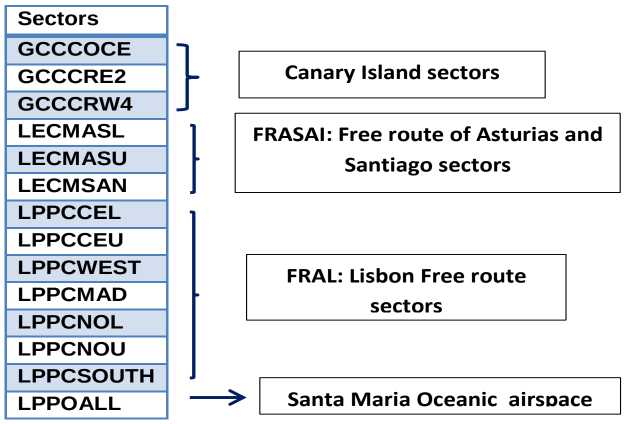


Figure 4.1 Sectors evaluated

4.3.1 User metric in baseline scenarios

4.3.1.1 Distance in baselines

In the case of the airspace user metric (see 3.2.1) linked to baseline A and B, Figure 4.2 presents the distance flown (in NM) for each traffic sample according the baselines, those values are used as starting point for the study.

The overall distance values are between 713,000 to 1.55 million of NM, with a notable difference among both scenarios.

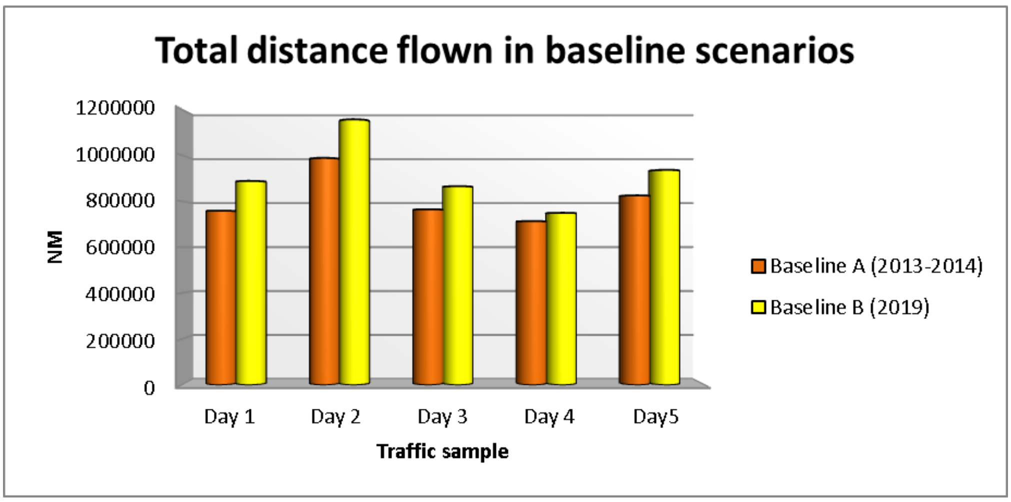


Figure 4.2 Total distance flown in baseline A and B

For baseline A, the lowest value of distance is presented in Day 4, with a total value around 713,000 NM. On the other side, the maximum values are linked to Day 2 with 988,000NM, which correspond with the day of high traffic count.

To better understand this large number of distance,it is important associate them with fuel consumption and cost. In this way, it is necessary to take into account a relation between distance saving, fuel consumption and emissions. So, this thesis considers the AIRE programme report in 2011 [37], where medium and large aircraft distance saved were evaluated in Lisbon and Casablanca FIRs.

The relation used is the follows:

$$1 \text{ NM} = 10.44 \text{ fuel kg} = 3.15 \text{ CO2 kg} \qquad \textbf{(4.1)}$$

In addition, considering the aircraft fuel price average to 550 Euros per fuel ton, all this according to IATA monitor of fuel price in [38].

In the case of distance for Day 4 (713,000NM), it represents 7450 tons of fuel with a cost of 4.1 million Euros, and this fuel consumption produces approximately 23.5 thousand tons of CO2 emissions.

For Baseline B, the forecast simulation for samples to 2019 presents an overall increment of 14.5% (see Fig. 2) with respect with Baseline A. The lowest distance value for 2019 is linked to Day 4, but in this case with 799,000 NM.

The forecast traffic method implemented used for this master thesis considers the medium-term forecasts (MTF STATFOR), that combine flight statistics with economic growth and with models of other important drivers in the industry such as costs, airport capacity, passengers, load factors, aircraft size, etc [32].

4.3.1.2. Route efficiency in baselines

The evaluation of the efficiency metric in baseline scenarios, will permit to compare in an easy way how favourable turn the route projection in the SW FAB simulations. Next table presents the efficiency values according to each baseline scenario.

The values for efficiency in both baselines scenarios are above 98.80%, the difference to the “ideal route” that is related to an efficiency of 100% is translated in extra nautical miles that aircraft have to fly.

Table 4.2 Route Efficiency metric in baseline scenarios

Traffic Samples	Efficiency (%) Baseline A	Efficiency (%) Baseline B
Day 1	98.80	98.80
Day 2	98.85	98.87
Day 3	99.15	99.16
Day 4	98.96	98.83
Day 5	99.17	99.15

4.3.1.3. Flight time in baselines

As final evaluation for users, but not least important; the flight time metric measured by each traffic trajectory is presented in minutes. Basically, this metric evaluates how much time takes the aircraft inside the airspace in study.

As can be in the next figure, value range for flight time in baseline scenarios are between 92900 minutes (64.5 flight hours) to 148500 minutes (103 flight hours).

Figure 4.3 exposes the flight time required for the complete traffic samples of baseline A and B.

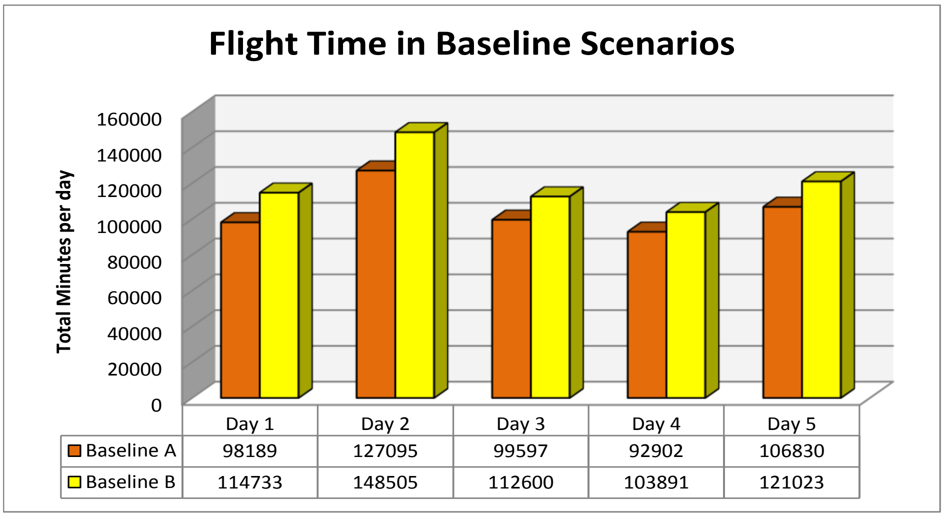


Figure 4.3 Flight time metric in baseline scenarios

4.3.2 Safety metric in baseline scenarios

In the case of safety metric for baselines, Figure 4.4 shows that the overall numbers of possible conflicts are between 271 and 714. So, this range of values serves like a reference of conflicts for future comparasions.

For baseline A, it can be appreciated in Figure 4.4 that the highest safety compromise is given in Day 2 with 534 conflicts.

Notice that the traffic registered in Day 3 was lowest than Day 1 (1371 vs 1423), but the geometries and timings of that day generated more potential conflicts than Day 1.

In general the average of conflicts per day is around 400 in the whole extension of the SW FAB. This value can be considered safe and perfectly manageable by controllers.

For baseline B, Day 2 and Day 5 present the highest number of conflicts; the behaviour of baseline B (future traffic estimation) is similar to baseline A as can be seen in next figure.

The increment in potential conflicts in baseline B is because the traffic forecast for those days, estimated around 2,000 flights for 2019.

Figure 4.4 represents by bars the values of the number of conflicts according each baseline, those values are considered as starting points in the evaluation of safety.

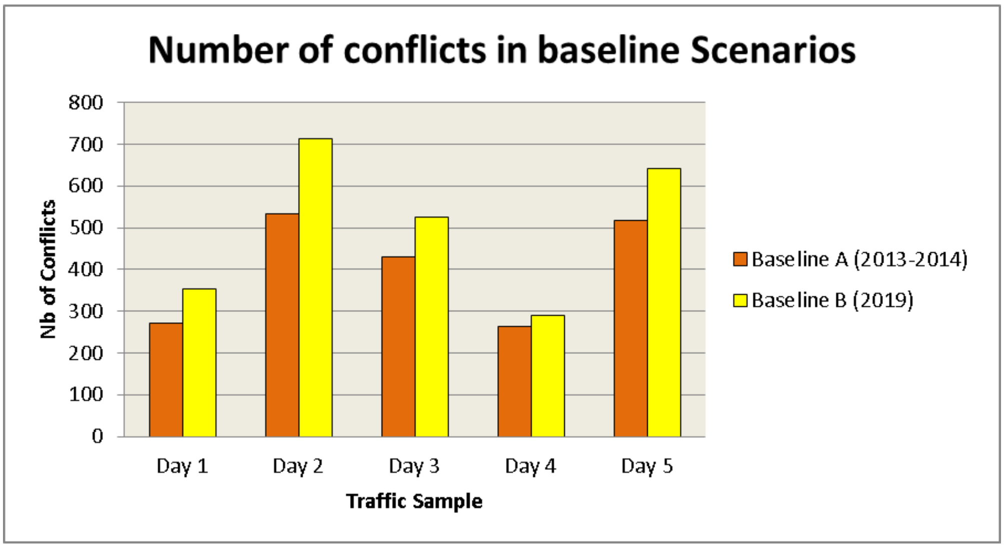


Figure 4.4 Total conflict number for baseline scenarios.

4.3.3 ANSP metrics in baseline scenarios

The evaluation of volume taskload per day and taskload peak per hour is presented for each controller position. Thus, each controller (executive or planning) has two sets of values for each baseline, which correspond with the metrics mentioned before.

The representation of values for volume taskload is carried out using box plots, where the highest and lowest values are represented by lines extending vertically from the boxes (whiskers), and the median sample value is presented in the middle of the boxes. The size of the box shows the confidence interval of the sample.

It is important to say, that ANSP metric is plotted taking into account all traffic sample (5 Days) for obtain the quartiles (Q1, Q2 and Q3), additionally an average was carry out for identify the most important values for this study (see Annex 2 for all ANSP values).

In contrast, the taskload peak per hour is represented by a map with the more important values for evaluate. This map presents an ATC taskload range that is defined in 3.2.3.

An important point that can be appreciated, is that the volume of taskload for the planning controllers, is always lower and less disperses than volume taskload of the executive controllers. In contrast is easy to note that both plots show a big correlation, showing clearly which sectors, are more active than others.

4.3.3.1 Baseline A (2013-2014)

Volume taskload for executive controllers

The global values of volume task load for executive controllers are between 70 to 255 minutes. Those volumes are measured by all day, so comparing with 1440 minutes from 24h, it can be said that are totally assumable by the ATM system, because they distributed along the day.

The volume taskload and taskload peak for baseline A, are presented in Figure 4.5 and 4.6 respectively.

In the first case, Figure 4.5 clearly shows the controllers volume taskload for executive controllers and the values are presented separately for each sector of the SW FAB configuration.

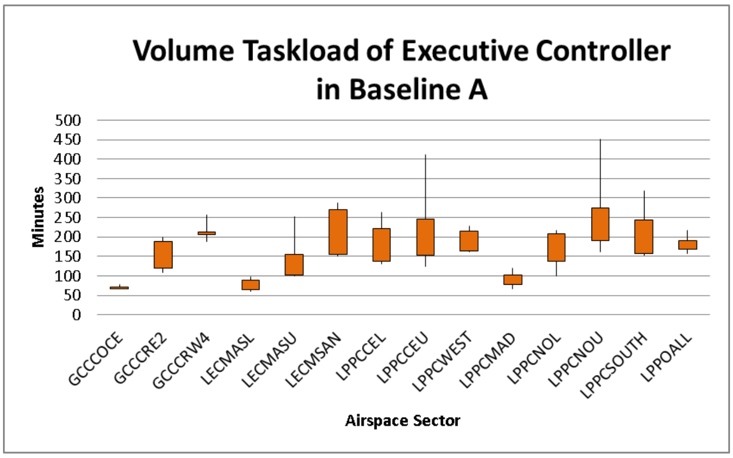


Figure 4.5 Volume taskload for executive controller in baseline A

For the executive controller, the largest volumes were registered in sector LPPCCEU (411 min) and LPPCNOU (452 min) in Lisbon FIR.

Moreover, evaluating the average per day (see Annex II for detailed values), the sector with lower taskload is GCCCOCE (located in Canary Islands) with 70 minutes per day approximately. On the other hand, sector LPPCNOU shows the high value with 256 minutes.

Volume taskload for planning controllers

The planning position presents overall values among 60-195 minutes, evidencing a lower volume taskload for planning tasks, in respect with executive controllers. In this case, the 60 minutes spread in 24h indicates a low activity in that specific sector.

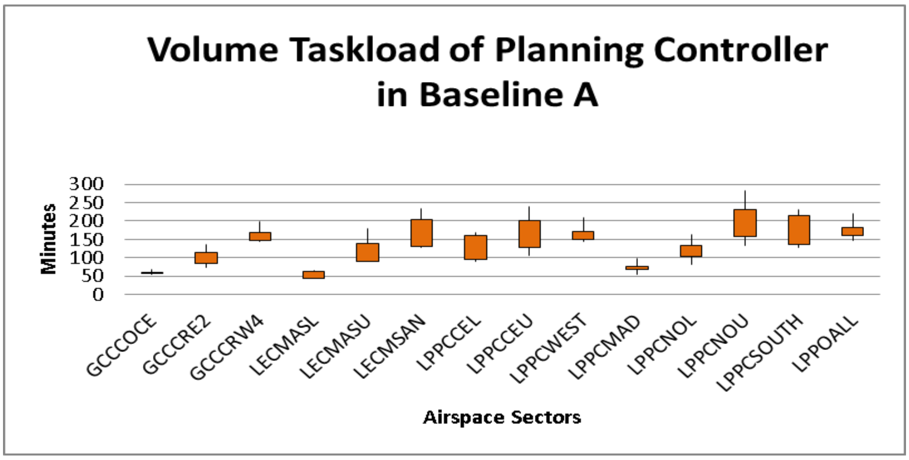


Figure 4.6 Volume taskload for planning controller in baseline A

For planning tasks in baseline A, the Figure 4.6 shows that LPPCNOU registered the high volume taskload with an average of 195 minutes, and the highest volume for planning taskload with 282 minutes. In contrary, the lowest activity was in sector LESMASL (Asturias lower airspace) with a volume taskload average of 52 minutes.

With the current airspace configuration, sectors are collapsed during less busy hours, thus we should look at the mean taskload measures just as a quantification of the volume of work, and do not directly related them with capacity or overload.

Taskload peak for executive controllers

The map represented helps to localize the sectors and to easily visualize the busiest areas; in this case the metric of controllers taskload peak per hour provides data about controllers' temporal overload and is more adequate for capacity estimation.

As was mentioned in metric definition (see 3.2.3), it is commonly accepted that the maximum continuous work for a controller is 70% of the time (42 minutes per hour) [32] [34]. Taking into account this, the established map colored in this research sets red to any taskload peak over 70%.

The executive controller in baseline A presents a peak day with overload. In contrast, the general overview indicates that in particular days exist some taskload peaks, but most of them are lower than 65%.

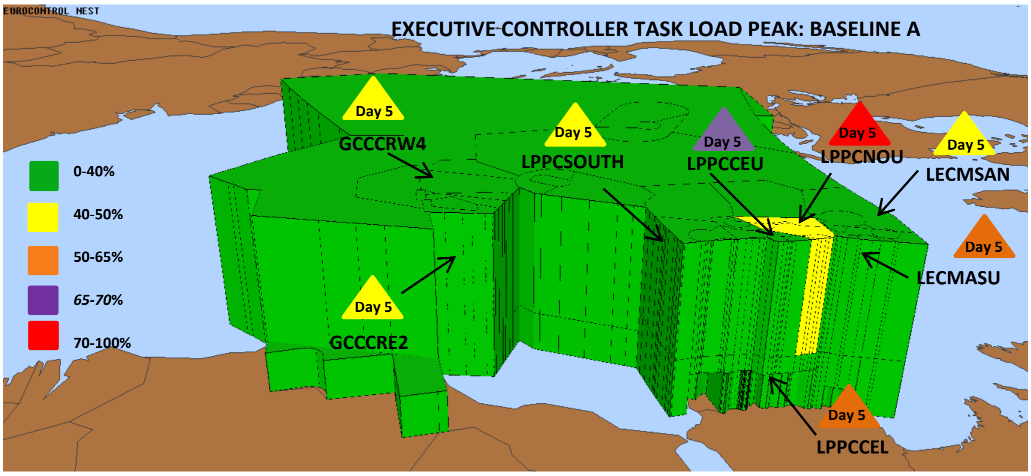


Figure 4.7 Executive taskload peak per hour in baseline A

Figure 4.7 depicts the taskload peak of executive controllers over a map. The thesis uses a set of five colours for five levels of controller taskload peak. The background colours of the sectors show the average of the taskload per hour of the five days of the baseline scenario.

A triangle represented in top of a sector shows that at least one day the taskload per hour has exceeded the 40% of the taskload. Again the colour of the triangles shows the interval of the taskload peak and holds the name of the day with highest taskload.

As can be observed, in the case of baseline A the highest taskload per hour is presented in sectors LPPCNOU, with a daily average higher than 40 %.

The other notable peak values are linked to sectors GCCCRW4, GCCCRE2, LECMSAN, LPPCSOUTH, LECMASU, LPPCCEL and LPPCCEU, with taskload peaks between 42-65%, all registered in the fifth day (see Annex 2 for detailed values).

Taskload peak for planning controllers

The overview represented for taskload peak in planning tasks, says that ATC days evaluated do not present heavy taskload peaks or problems.

For planning controllers in baseline A (see Fig 4.8), the taskload peaks averages are always lower than 40%. In contrary, there are two taskload peaks that exceed that limit (both with 48%). The first case is in the oceanic area (sector LPPOALL) and the second is related to LPPCNOU sector.

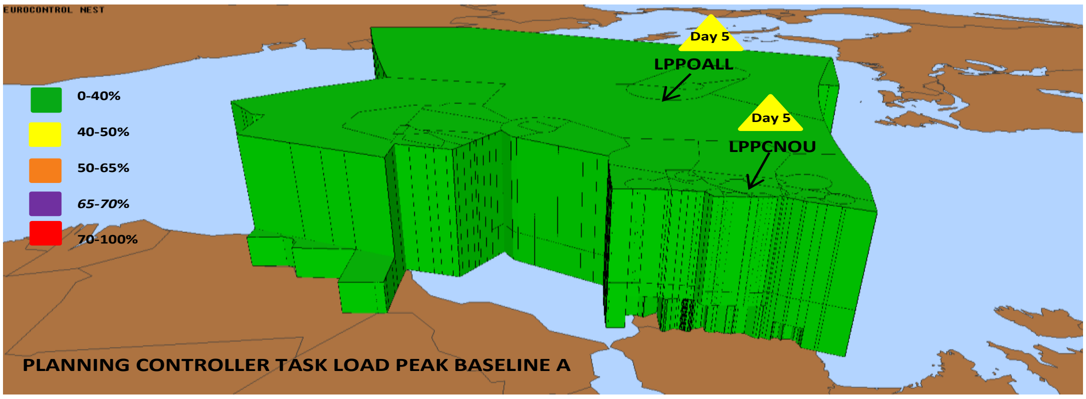


Figure 4.8 Planning taskload peak per hour in baseline A

4.3.3.2 Baseline B (2019)

Volume taskload for executive controllers

The taskload metrics of baseline B have a similar profile than those obtained for baseline A, in this case the average values are between 84 to 287 minutes. The slight increment is according to the traffic forecast to 2019.

The values of taskload for executive controller in 2019, indicates that the sectors with highest volume of taskload are LPPCNOU, LPPCSOUTH and LPPCCEU, with averages between 262-287 minutes. The minimum value is related to LECMASL sector, with 84 minutes.

It is important to mention that the highest value in the box plot (Fig 4.9) indicates that LPPCNOU exceed 505 minutes in one traffic sample (Day 5).

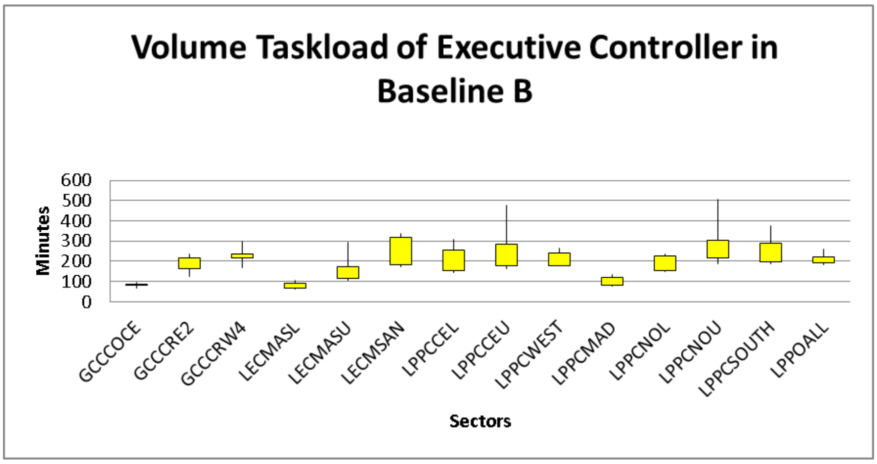


Figure 4.9 Volume taskload for executive controller in baseline B

Volume taskload for planning controllers

The overall values in planning taskload for 2019, presents average values between 73 to 220 minutes for all day. As was mentioned before, the increment registered in planning controllers in respect with baseline A, is linked to the traffic increase of 10 to 16% exposed in traffic samples definition (see part 4.2).

As can see in Figure 4.10, the taskload evaluated for planning controllers in baseline B, presents more dispersion (bigger boxes) in comparing with executive controller, and the average values are lower as has been presented.

The most representative high values are related to LPPCNOU, this sector demand presents a daily average of 220 minutes, and in Day 5 the volume taskload was 315 minutes.

On the other side, according to Figure 4.10 the lower values of taskload are located in sectors LEMASL and GCCCOCE.

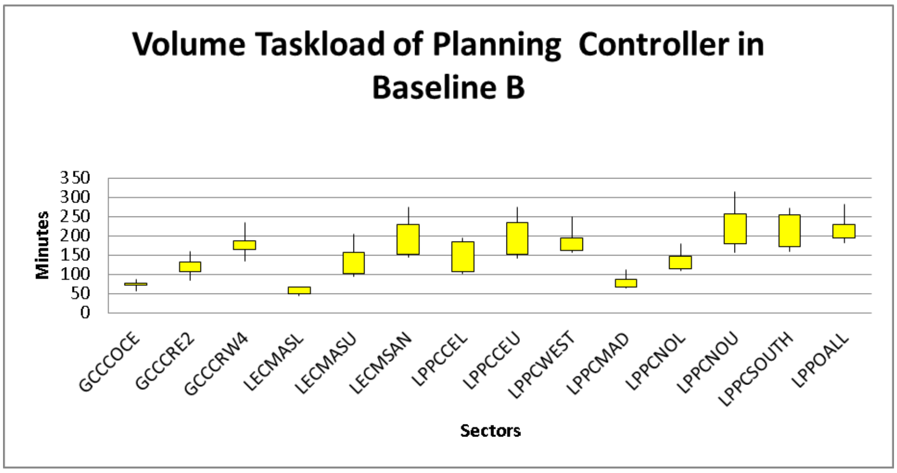


Figure 4.10 Volume taskload for planning controller in baseline B

Taskload peak for executive controllers

The taskload peak for baseline B, presents a complicated scenario for the executive controller with the current airspace configuration. In the same way, a general comparation with taskload peak from baseline A, the number of sector with highest loads has increased.

The global overview indicates that the airspace configuration used for simulation (current one), tends to present problems in future, because there are a notable number of sectors with peak overloads.

The values of taskload peak for 2019 (see Fig 4.11) show that sector LPPCNOU will work with fully overload in future, exceeding the 100% of the controller's time, that can be translated in unmanageable values for current ATM system. Also for sectors LPPCCEL, LPPCCEU and LPPCSOUTH the values of taskload peaks are going to be exceeding the 70%, defined as overloads.

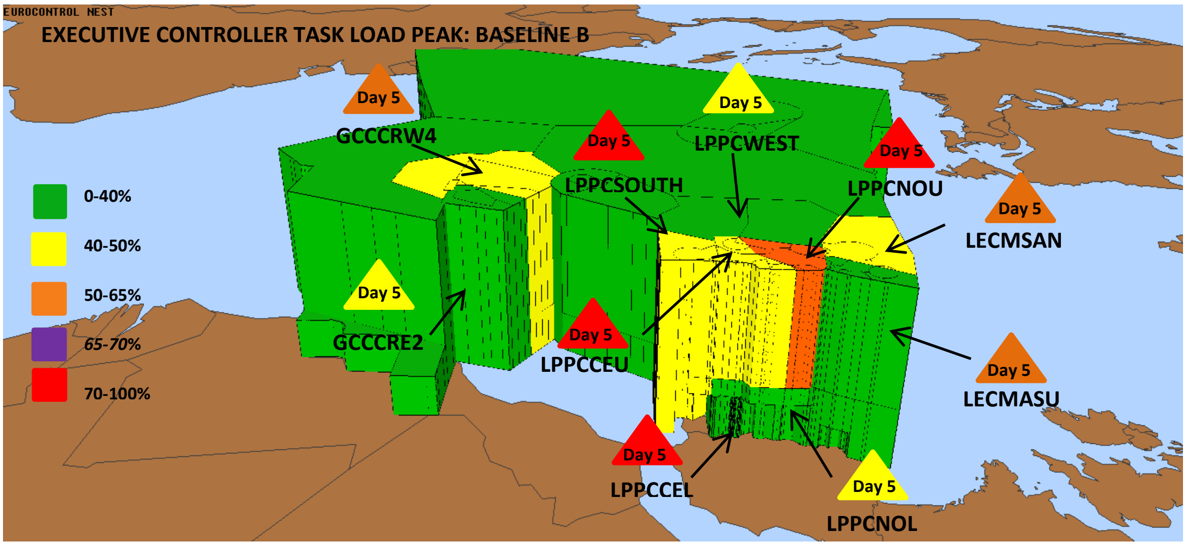


Figure 4.11 Executive taskload peak per hour in baseline B

Taskload peak for planning controllers

The values of taskload peaks in planning controllers for 2019, register a slight increment respect baseline A, the most notable change is the increase of taskload peak average in Santa Maria Oceanic sector.

According to Figure 4.12, all values indicate an increment of planning taskload respect baseline B. The sector LPPCNOU has a heavy peak average of 50% and the surrounded sectors (LPPCCEU, LPPCCEL and LECMSAN) present taskload peak averages of 40% approximately.

For planning controllers in 2019, the most significant value is the average of taskload peak in the oceanic area, with more than 40%, and in Day 5 exceeds the 54%.

Other representative values of taskload peaks in baseline B, are in planning tasks related to sectors: GCCCOCE, LPPCSOUTH, LPPCCEU and LECMSAN.

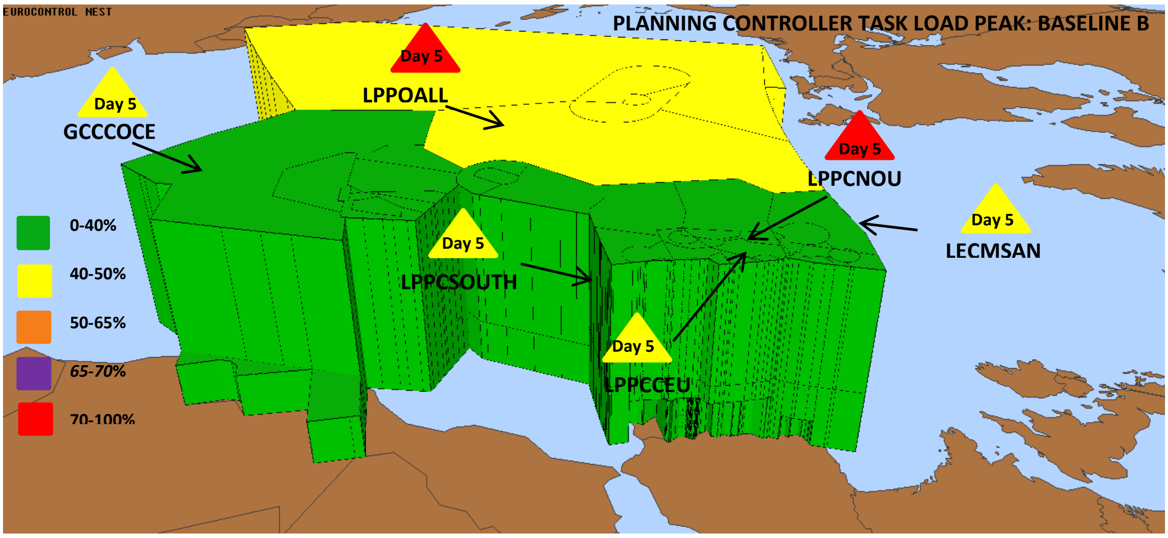


Figure 4.12 Planning taskload peak per hour in baseline B

In accord with values from baseline B, it can be said that executive controller will present a complicated scenario in future, because volume and peaks of task load indicate numerous sectors with considerable loads, so the current airspace configuration have to change.

In contrast, the planning tasks indicate a slight increase in respect with previous baseline, but with manageable values for the ATM system.

4.4. Process for evaluating SW FAB phases

The process for run a traffic day simulation and obtain results includes a number of steps, as summarize, these steps can be grouped in three main stages (see Fig 4.13).

As a first stage, it is necessary to design the SW FAB model (scenario evaluated), this model include specific coordinates, navigation points, flight levels and sectors like the future ones.

Then, the traffic sample is extracted from DDR according to the scenario previously mentioned in 4.2, the traffic sample are flight trajectories included inside SW FAB 3D block, the outside flight legs from the border of the SW FAB design are excluded in this study.

The second stage is data processing of the proposal scenario and traffic sample (each SW FAB model and traffic day). This is carried out using the NEST functions [32].

Finally, the last stage is focused in obtain metric values, and comparing them with the baseline scenarios (A and B).

Figure 4.13 brings a general overview of the three main stages of the simulation processing, the architecture for the processing samples inside the software tool is detailed in Annex 3, where a series of more than ten steps can be identify for obtain a metric value.

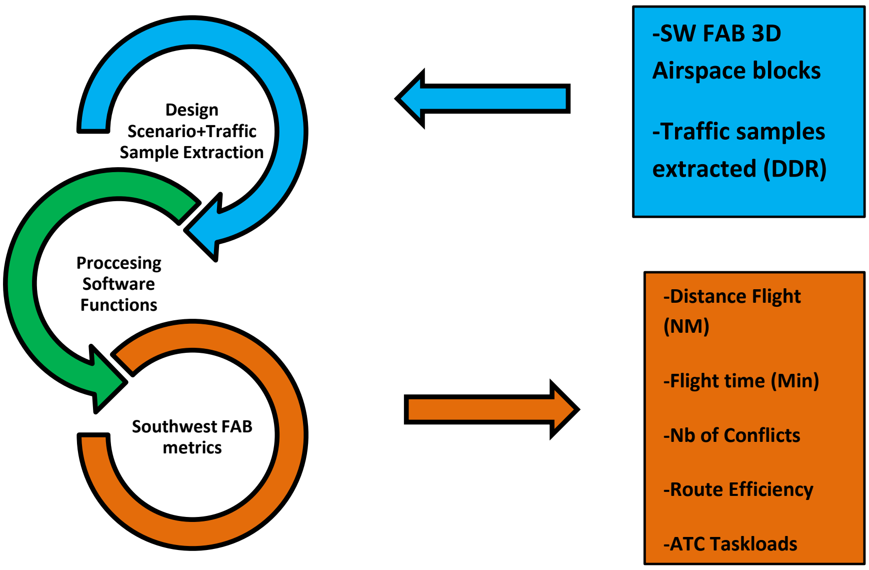


Figure 4.13 Simulation processing scheme

According to last figure (Fig 4.13), the inputs needed for simulation processing have to be clearly defined, one of these is related to the traffic sample for study, and the second one is linked to the SW FAB scenarios described in the next part (4.5).

The middle stage of the process is related with a set of functions (algorithms) of NEST software, like distance comparison, ATC workload measurement, airspace conflict counts, etc.

Finally, the metrics are obtained and exported for analysis and comparison.

4.5. SW FAB scenarios simulated

The scenarios modelled in the NEST tool follow the Operational Plan [7] [12] phases of the SW FAB; the implementation details and calendar are given in Chapter 2.

During the scenario design, the navigation waypoints maintain their current coordinates, as in the baseline scenarios. But, some changes related to the configuration navigation point label have appeared in phase I and II.

As was mentioned in 1.1.6, fixes in a Free Route Airspace can be defined as entry, exit or intermediate points, as established in the SW FAB plan.

For instance, as the Free Route phases increase the area in the SW FAB, the navigation points label need to be changed.

For better understand this label changes, a simple case is exposed:

- DETOX (located in Lisbon FIR) is an entry/exit point in Phase I, but in Phase III this fix becomes as an intermediate point, because now this fix is not in the FRA limits as was in Phase I.

4.5.1 Phase I Southwest FAB

The first phase evaluated in this thesis includes the airspace related to Lisbon FIR (Portuguese) and FRASAI (Spanish); both airspaces are joined in a unique air block with free route configuration, the surrounded airspace still operating with the current ATS network configuration.

The navigation points (entry, exit, intermediates, arrival and departures) and frontiers are designed according the SW FAB Plan. The FL (flight level) limit of the Phase I, II and III airspace is from FL245 to FL660.

In addition, the first phase includes 87 navigation points, and their navigation functions are according to the order of Table 4.2.

As can be appreciated in Figure 4.14, the design of Phase I considers FRAL (Lisbon Free Route) and FRASAI (Asturias-Santiago).

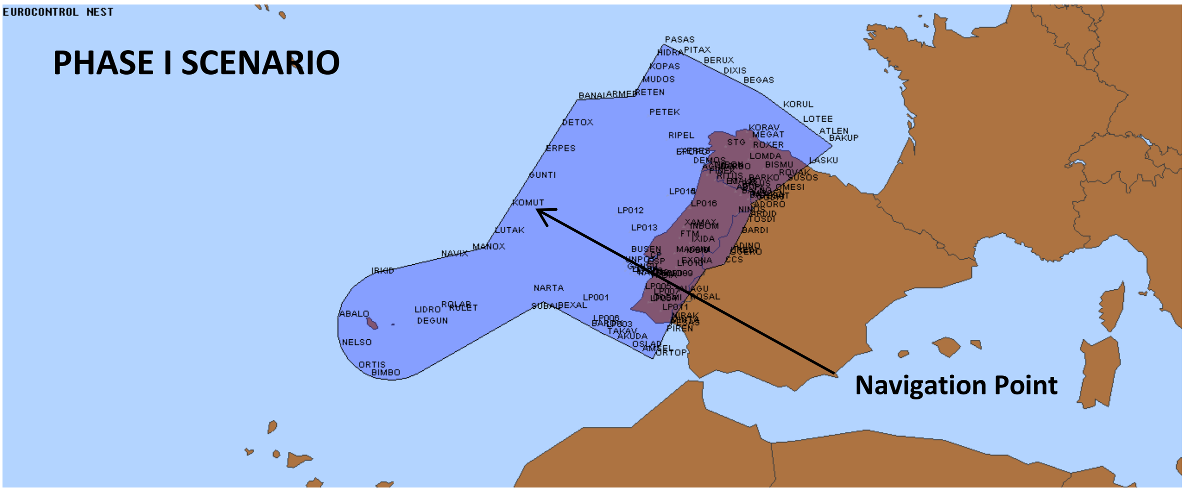


Figure 4.14 Phase I scenario

In addition, next figure (Fig 4.15) pretends to illustrate the vertical side and dimensions of this airspace block.

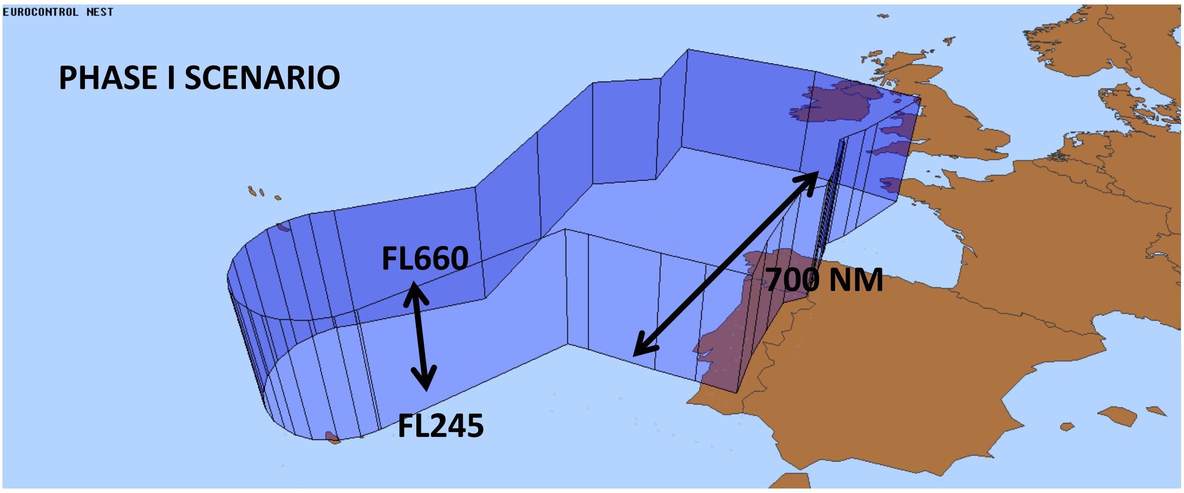


Figure 4.15 Vertical limits of Phase I scenario

4.5.2 Phase II Southwest FAB

The second phase of FRA project is based in the extension to Santa Maria Oceanic FIR, this is according to the operational plan [7] [12].

The most interesting point, as was defined before, is the possibility to offers long flights without restrictions (direct routes), so at the end of this phase, will be possible to offers flights from the exit point of a Madrid SID (Standard Instrument Departure) to New York Oceanic FIR, at 40 W (see Fig 4.16).

This phase consider approximately 220 navigation fixes. In the same say, the design stages take into account the current sector frontiers and FIRs limits.

The next figures (Fig 4.16 and Fig 4.17) show the Phase II dimensions.

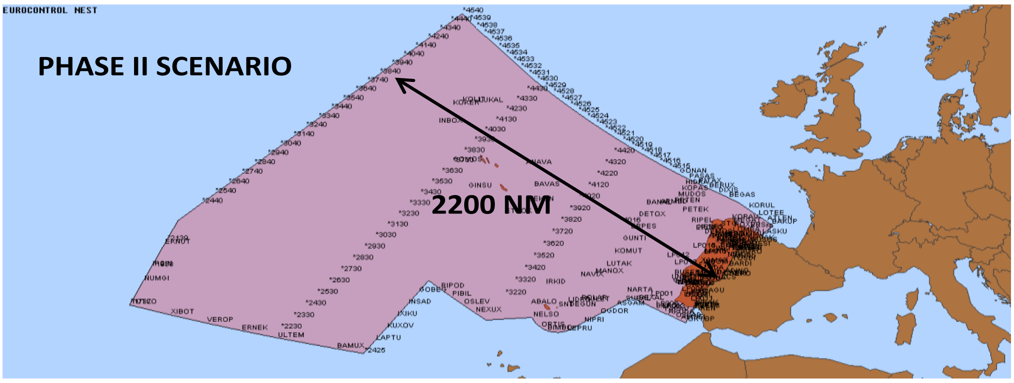


Figure 4.16 Horizontal view of Phase II scenario

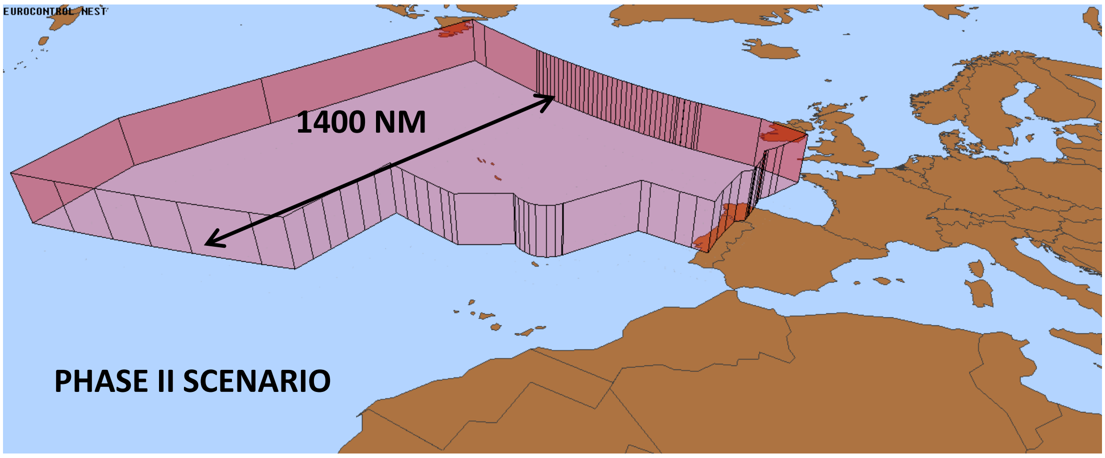


Figure 4.17 Extension of Phase II scenario

4.5.3 Phase III Southwest FAB

The final phase includes the implementation of Free Route extension to Canary Islands' FIR; this inclusion represents a big change in the SAT (South Atlantic Corridor), due to the significant traffic demand increase.

Phase III will be a natural gateway to Central and South America, it plays an important role in the European and international air transport being the main link between Europe and a South America community [7].

Figures 4.18 and 4.19 show Phase III dimensions, where 230 waypoints are considered.

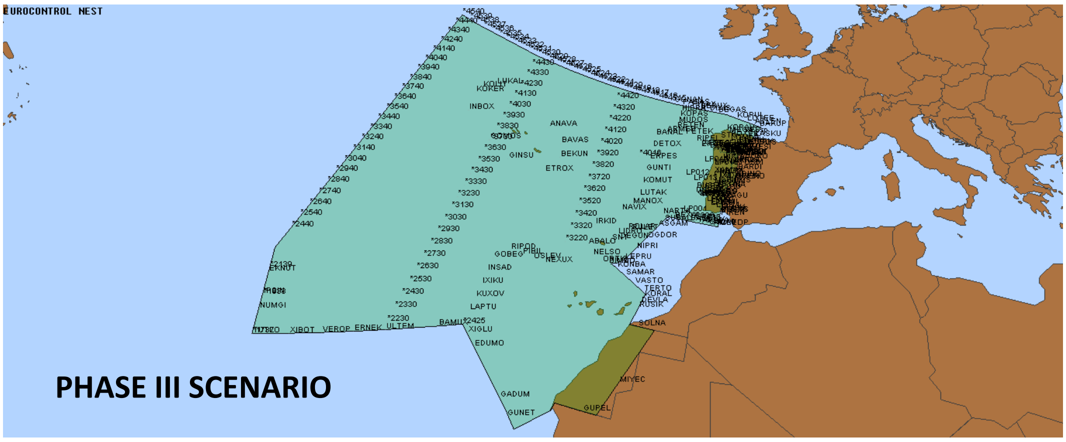


Figure 4.18 Phase III scenario and included waypoints

As can see in Figure 4.19, is easy to note the large extension of this phase, the approximate distance from GUNET waypoint to the latitude 45 is around 1550 NM.

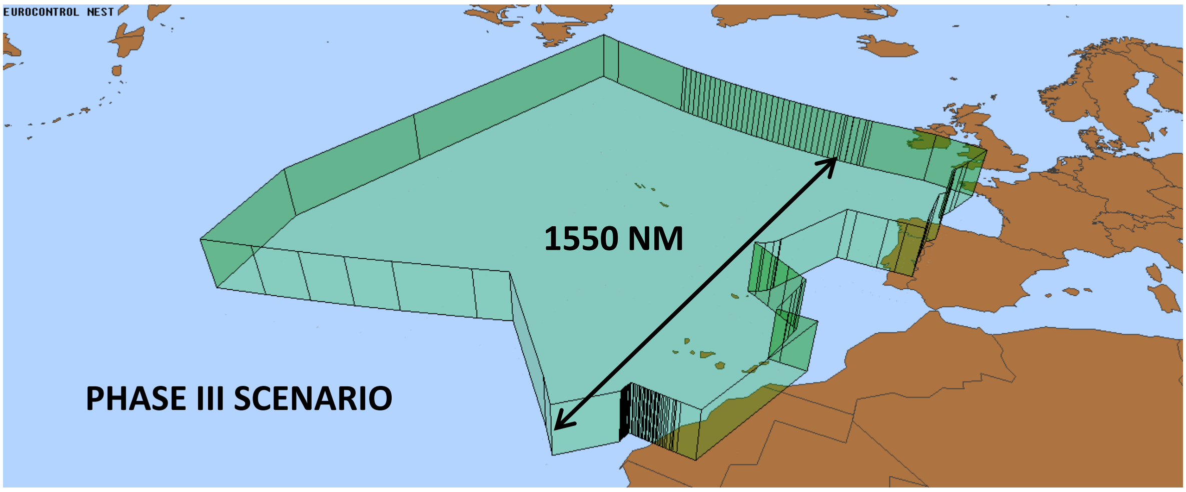


Figure 4.19 Phase III horizontal scope considering canary islands airspace

4.6 Simulations

The simulations developed in this master thesis are organized according each traffic samples type: baseline A or B. So, for the case of traffic samples of baseline A, that correspond with traffic planned in 2013-2014, simulations are carried out in scenarios of Phase I, II and III.

The evaluation of traffic in these three scenarios permits to study more closely the benefits or problems for users, safety and ANSPs.

In contrast, simulations for baseline B traffic samples (2019), only consider the scenario of Phase III, because as was exposed in Chapter 2 it corresponds with a long term plan.

The next figure summarizes the simulations carried out in this thesis.

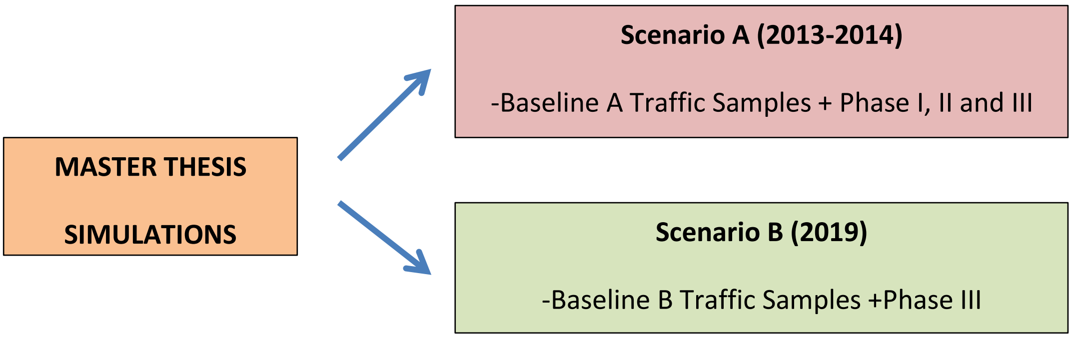


Figure 4.20 Master thesis simulations scheme

CHAPTER 5

RESULTS

Chapter 5 presents all the results from this thesis, mostly of them come from the simulation part. In addition, the ATC controllers responses are concentrated and discussed according each concept. The final part of this chapter exposes the ATC questionnaire.

The results presentation is mainly separated by scenario A and B. The scenario A is related to all results from traffic samples of baseline A (2013-2014) and SW FAB phases (I, II and III). In contrast, scenario B results describe simulation values from traffic sample of baseline B (2019) and SW FAB phase III.

5.1 Scenario A (2013-2014) results

The results presentation for scenario A is organized as follows: firstly, the airspace user's results are described; in this case the representation of values in figures and tables includes the three SW FAB phases and baseline A (2013-2014) values for facilitate the understanding. Additionally, the ATC responses linked to each result context were added for compares and validate simulation values.

Then the metric related to safety is presented and linked with some responses from ATC controllers.

Finally, the ANSPs metrics (volume and peak task loads) are exposed separately for each controller position and SW FAB phase, resulting in large set of values discussed.

The detailed results values that complement this chapter are illustrated in Annex 2.

5.1.1 Airspace user

Results for airspace users show important advantages for all metrics evaluated. The first and most important metric studied, is distance saving, which evidence a gradual saving with the increase of the SW FAB area, in some cases reaching around 2.5% in distance savings.

The next metrics: flight efficiency and flight time also present positive results for commercial aircrafts. In the case of route efficiency, aircrafts pass from values of 98.8% to 99.8% approximately, that represent a great improvement in flight route efficiency.

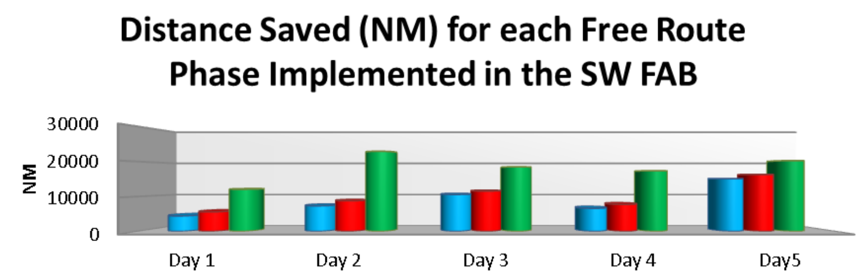
As is exposed in next parts, all these results are related to flight time savings; as well it is translated in cost reduction and environmental friendly flights.

5.1.1.1. Distance saving results

The simulation results determine that aircraft operators can save a considerable distance flying in the future Southwest FAB, so, it can be said that the future FAB will bring a notable benefit for airliners.

Figure 5.1 clearly shows that metric results evaluated for all days and Free Route phases support the distance saving. As can be seen, the distance saving is continuous from 4450 NM in the worst case (implementing only Phase I) to 22900 NM for the best case that considers Phase III implementation.

.



	Day 1	Day 2	Day 3	Day 4	Day5
Phase 1	4446	7347	10597	6642	15112
Phase 2	5602	8781	11566	7774	16305
Phase 3	12074	22907	18464	17345	20257

Figure 5.1 Distance saved results for each SW FAB phase

Additionally, Table 5.1 shows specific values for each of the distance savings in nautical miles and percentage in respect with reference A. It can be observed that these results represent overall distance saving from 0.60% to 2.50%.

Table 5.1 Distance results values for SW FAB phases

Days	Baseline A Distance Flown (NM)	Phase 1 Distance Saved (NM) and Percentage	Phase 2 Distance Saved (NM) and Percentage	Phase 3 Distance Saved (NM) and Percentage
Day 1	758185	**4446** **0.6%**	**5602** **0.74%**	**12074** **1.6%**
Day 2	987482	**7347** **0.74%**	**8781** **0.9%**	**22907** **2.3%**
Day 3	764105	**10597** **1.4%**	**11566** **1.5%**	**18464** **2.4%**
Day 4	712746	**6642** **0.9%**	**7774** **1.1%**	**17345** **2.4%**
Day 5	824664	**15112** **1.8%**	**16305** **2%**	**20257** **2.5%**

The Free Route implementation in the SW FAB (see Table 5.1) presents a notable behaviour that relates the FAB extension with the distance savings. So as the Free

Route extension increase is easy to observe that more distance is saved by airspace users.

For the final scenario of the South West FAB (Phase III), results expose the similar conditions, benefits for all airspace users. In this phase, the extension in distance saving from Phase II to Phase III is notorious, resulting in a difference of 0.5% in the worst situation (Day 5) to 1.4% in Day 3.

For summarize, simulations in Phase III scenario brings overall distance savings between 12000 to 23000 NM per day. It can be say that the distance savings is up of 1.5% for all flights.

In the other side, taking into account the distance relation with fuel cost and emissions that has been described in Chapter 4, which indicates the follows:

$$1 \text{ NM} = 10.44 \text{ fuel kg} = 3.15 \text{ CO2 kg} \quad \textbf{(5.1)}$$

Adding to this relation a fuel price for aircraft approximate in 550 € per fuel ton [38]. It can be presented a final summary for airspace users expressed in distance savings, fuel cost savings and emissions (see Table 5.2).

Table 5.2 Overall airspace user results for SW FAB phases

Days	Phase 1	Phase 2	Phase 3
Day 1	4446 NM 46.4 fuel tons 14 CO2 tons 25500 €	5602 NM 58.5 fuel tons 17.6 CO2 tons 32200 €	12074 NM 126 fuel tons 38 CO2 tons 69300€
Day 2	7347 NM 76.7 fuel tons 23.1 CO2 tons 42200 €	8781 NM 91.7 fuel tons 27.7 CO2 tons 50400 €	22907 NM 239 fuel tons 72.2 CO2 tons 131500 €
Day 3	10597 NM 110.6 fuel tons 33.4 CO2 tons 60800 €	11566 NM 120.8 fuel tons 36.4 CO2 tons 66400 €	18464 NM 192.8 fuel tons 58.2 CO2 tons 106000 €
Day 4	6642 NM 69.3 fuel tons 20.9 CO2 tons 38100 €	7774 NM 81.2 fuel tons 24.5 CO2 tons 44700 €	17345 NM 181.1 fuel tons 54.6 CO2 tons 99600 €
Day 5	15112 NM 157.8 fuel tons 47.6 CO2 tons 86800€	16305 NM 170.2 fuel tons 51.4 CO2 tons 93600€	20257 NM 211.5 fuel tons 63.8 CO2 tons 116300€

It can be concluded that Free Route implementation over the SW FAB brings notable reductions in distance savings, finally this is translated in cost savings between 25000 € per day in the worse case of Phase I extension, to 130000 € savings per day with the last SW FAB phase implementation.

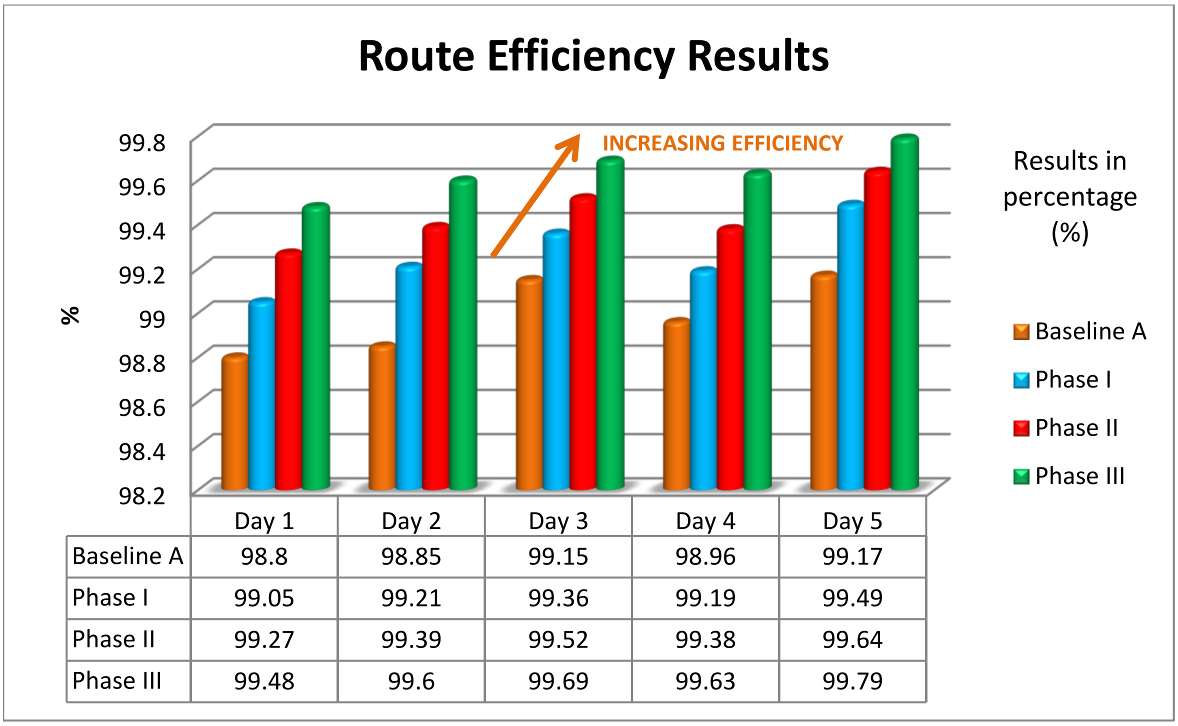
5.1.1.2. Route Efficiency results

The results of route efficiency give evidences of a connection with the distance savings previously presented. So, it can be said that results of route efficiency represent another way to express distance saving.

Route efficiency results are presented in Figure 5.2, from this figure is easy to observes that route efficiency has increased when a bigger phase is simulated.

The overall analysis of route efficiency shows that values are close to the "direct route", that's mean from 100%. But even with those values, the small differences until the 100% represent important losses for commercial aircrafts; these losses are reflected in longer routes for airplanes.

Starting with values from baseline A, the route efficiency was between 98.8-99.17%, depending on day, and with an increasing tendency as the SW FAB extends; values from baseline A changes in some cases are around 0.7% in efficiency with Phase III, resulting in large distance savings as was exposed in last part.



	Day 1	Day 2	Day 3	Day 4	Day 5
Baseline A	98.8	98.85	99.15	98.96	99.17
Phase I	99.05	99.21	99.36	99.19	99.49
Phase II	99.27	99.39	99.52	99.38	99.64
Phase III	99.48	99.6	99.69	99.63	99.79

Figure 5.2 Route Efficiency results for SW FAB phases

The values from Figure 5.2 show a smooth increase in route efficiency, from baseline A to Phase I implementation the increase is gradual, around 0.25% in efficiency.

Then from Phase I to Phase II, approximately 0.15%, finally, from Phase II to Phase III another 0.15%.

According Figure 5.2, the best result case is focused in Phase III, where efficiency results show that routes can be close to 99.17-99.79 %. In others words this indicates how close are the simulated routes from the “direct route”.

5.1.1.3. Flight Time results

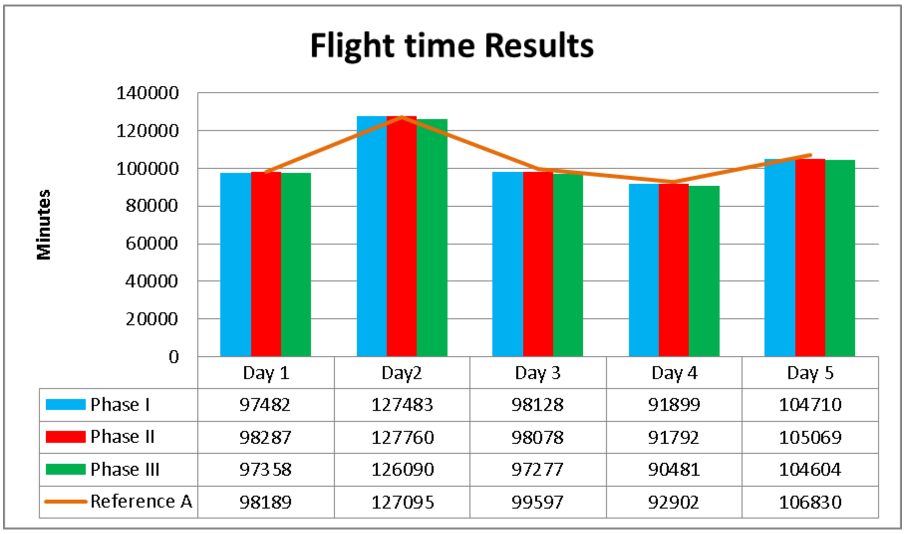
The flight time evaluation brings interest results to this master thesis because the flight time savings presents variability according the traffic day and scenario simulation. Taking into account the number of flights and flight time savings in minutes, it can be said that average savings applying to Phase III are around 0.5 minutes to 1.7 minutes per flight.

In the same way, the overall results stated that flight time saving with Phase III is between 0.8-2.6 percent of the global time, this is translated in a saving of 1000 to 2300 minutes per day (see Figure 5.3).

According simulation results, most of them present savings in respect with users, but there were a few values that have presented a slight increment, in especial values related to Day 1 and Day 2 and linked to Phase I and Phase II. In addition, Day 5 results focused in Phase II presents some increments.

As was mentioned before, the results present variability. So, for implement only Phase I, savings can be around 700-1400 minutes. Then for Phase II savings are from 1100 to 2400 per day.

The study of flight time from all traffic samples, found some relations between FL (flight levels) assigned after Free Route processing stage and flight time results (strongly related to aircraft velocity), giving evidence that those slight increments previously commented, are linked to the aircraft performance model used in the processing of 3D/4D trajectory profiles.



	Day 1	Day2	Day 3	Day 4	Day 5
Phase I	97482	127483	98128	91899	104710
Phase II	98287	127760	98078	91792	105069
Phase III	97358	126090	97277	90481	104604
Reference A	98189	127095	99597	92902	106830

Figure 5.3 Flight time results

5.1.1.4. Users results validation

From the ATC controllers perspective, the benefits that can carry out with the SW FAB implementation are directly related to airspace users, like airliners, pilots and passengers.

In accord with the questionnaire evaluated in this thesis, that take into account opinions from 69 controllers, Figure 5.4 shows that 98.6 % of them believe that Free Route implementation brings advantages to commercial airlines; in the same way the 91.3 % of the controllers thinks that passengers are greatly beneficiated as airlines.

The next important opinion from ATC controllers about airspace user benefits, indicates that 58% of controllers believe that pilots are the third group with benefits.

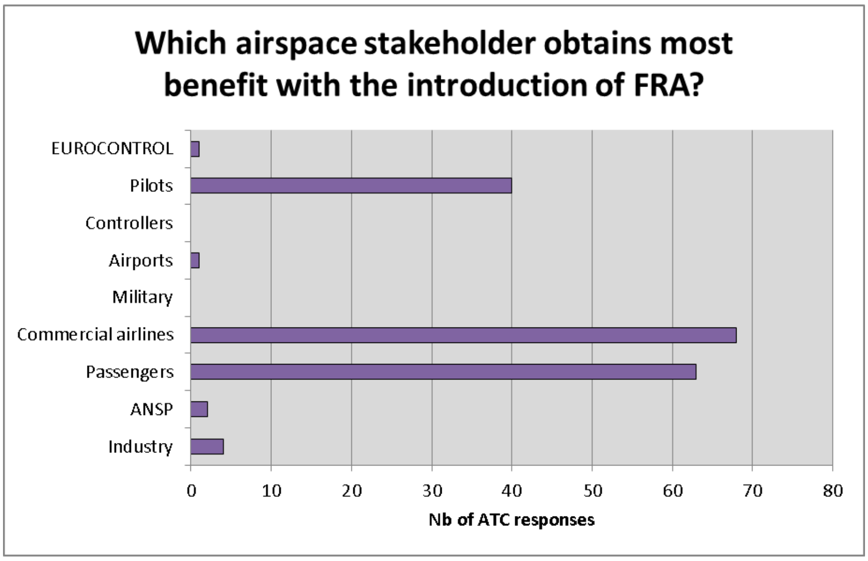


Figure 5.4 ATC responses about benefits for stakeholder

The next figure (Fig 5.5) clearly illustrates that around 94.2% of Lisbon FIR controllers, believe that flight distance will be more favourable with Free Route, and 69.6 % of them think that this implementation improves pre-flight tasks.

Finally, 20.3% of ATC controllers believe that flight time and fuel consumption will be enhanced.

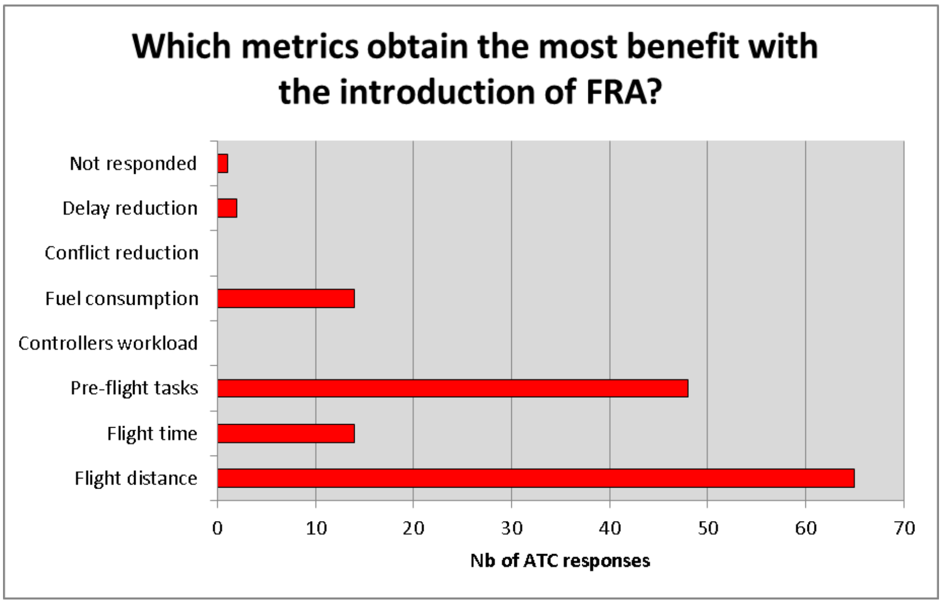


Figure 5.5 Benefit metrics reponses from ATC controllers

As was contrasted before, the ATC controllers' support the idea that Free Route Airspace included in the SW FAB , offers gains to airspace users and these gains are reflected in distance, pre-flight tasks, fuel consumption and flight time.

This master thesis has presented the large benefits in distance savings for airspace users when Free Route is applied, so in this sense, ATC controllers opinion support the idea that is the main benefit.

In the case of benefits of pre-flight tasks, Free Route Airspace permit to reduce notably the number of waypoints in Flight Plans, all these comparing with ATS networks operations.

Simulation results show that flight time savings presents variability depending on the day and scenario simulated. On the other hand, ATC controllers responses establish that the flight time saving is not in all clear, because them have positioned the time savings in a fourth level as a benefit for users. This can be related to the imprescindible consideration of winds and meteorological forecasts in flight planning tasks, where Flight Levels are limited and re-routings are applied, producing an increase in flight times.

Through the presented results, this master thesis is giving some evidence of this existing connection between direct routes a distance saved. The results for airspace users demonstrate attractive benefits with SW FAB for airlines, even in the case that only Phase I is implemented.

Furthermore, it can be expressed that as the Free Route Airspace extension increase, also distance savings increases , presenting advantages like less fuel consumption, environmental friendly flights or flight time savings.

5.1.2 Safety results

The safety metric is based in the number of conflicts related to probable aircraft separation losses, and according to simulation results, the future Southwest FAB does not increment the conflicts in respect with the reference scenario A.

The general overview of safety results says that considering any of the SW FAB phases, the number of conflicts tends to reduce, except for Day 2 with the highest traffic day.

As was mentioned before, the measures of conflicts consider vertical separations between 1000 ft and horizontals of 10 NM, as in previous simulations from studies that were focused in Free Route Airspace implementation [33].

Figure 5.6 represents the simulations results based in the three Free Route phases and baseline A, following this, Table 5.3 present the detailed values for a more precise study.

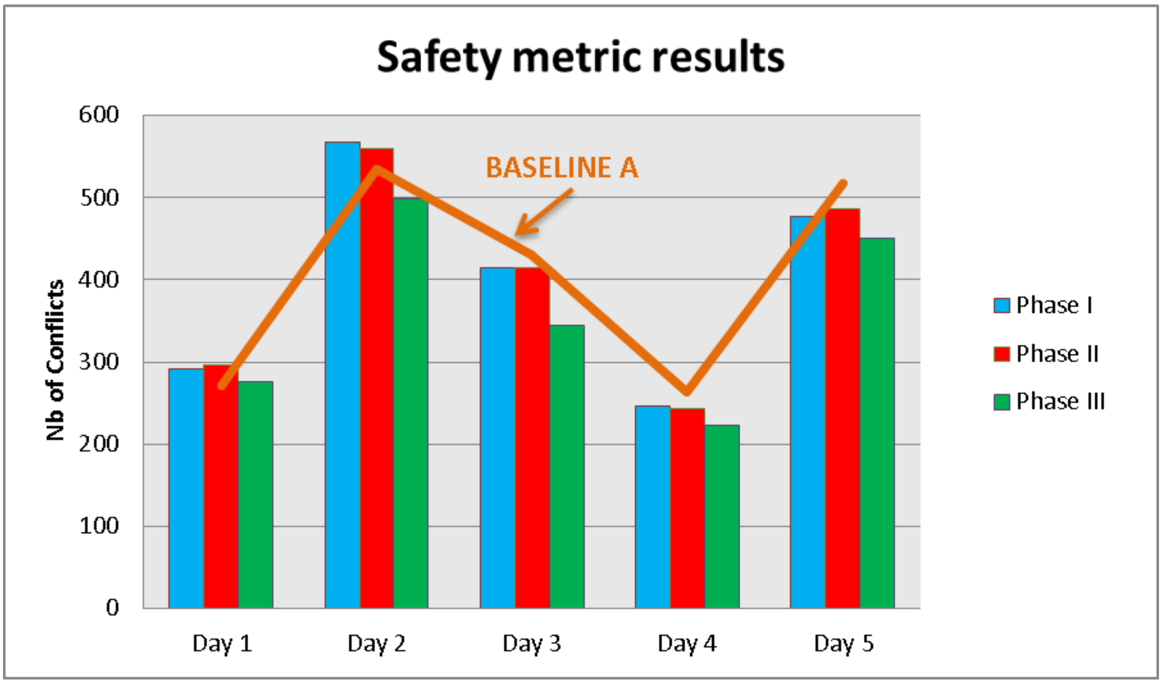


Figure 5.6 Safety results for each SW FAB phase

The general overview of the evaluation of conflicts shows than the SW FAB implantation keeps reasonable values according the reference scenario (baseline A). The results of conflicts evidence advances since Phase I simulation, but the real benefit is observed in Phase III evaluation.

In accord with Table 5.3, where results show that the conflict numbers tend to reduce as the SW FAB area increase, this relation is possible linked to a dispersion of the traffic samples over the airspace, instead of the baseline airspace, where aircraft are accumulated in ATS airways producing more conflicts.

Table 5.3 Number of conflicts results for SW FAB implementation

Traffic Day	Baseline A	Phase I Nb of conflicts	Phase II Nb of conflicts	Phase III Nb of conflicts
D1	271	292	296	276
D2	534	567	560	499
D3	430	414	414	345
D4	264	247	243	223
D5	518	477	486	450

5.1.2.1. Safety results validation

From the ATC controller opinion, the safety perception for Free Route operation in Lisbon FIR respect the ATS network airspace, do not present unfavourable results, safety in Free Route remains in high operational levels, all these responses can be observed in the next figure (Fig 5.7).

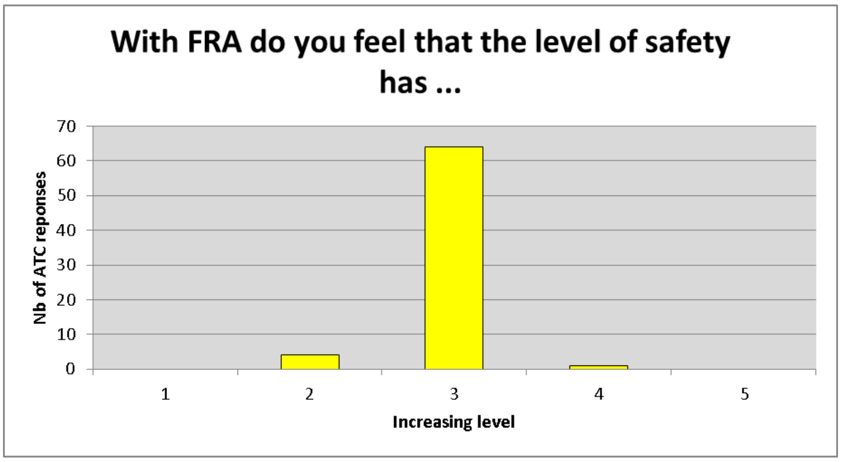


Figure 5.7 Safety responses from ATC controllers

The 93% of the 69 controllers believes that safety is maintained with Free Route operation as was in the airspace configuration with ATS network.

The metric contrasted before by ATC controllers, is greatly significant for this evaluation, because as was explained before (Chapter 2), the Lisbon FIR controllers are the most experienced Free Route controllers in Europe, working with this airspace type since 2009.

Finally, from this conflict measures it can be said that the Southwest FAB implementation does not increment conflicting situation for airspace users and thus does not compromise safety for this amount of traffic.

5.1.3 ANSP results

The results from Air Navigation Service Providers metrics are presented by scenario simulated and ATC controller position. In addition, those results are separated by each metric: volume taskload per day and taskload peak per hour respectively.

As has been presenting in last metrics, the validation of results come from ATC controllers responses from the Portuguese ANSP.

It is important to mention that for ANSPs metrics, ATC responses only are valid for Phase I, because controllers are responding in accord with a similar extension area with Phase I.

The validation of ANSP metrics is applied only for current Portuguese sectors because the ATC questionnaire was responded by controllers from Portugal. In this way, it can be appreciated in figures that Portugueses sectors are presented from the middle of the figures to right (starting with LPP initials).

On the other hand, results show that executive controllers have more volume taskload than planning controllers, and a tendency for more high values; this comparison can be appreciated along the next parts of this master thesis and it can be said that is a general characteristic in all simulations.

5.1.3.1 Phase I

The general overview of results from Phase I indicate that volume task load and task load peaks have been reduced in relation with the starting scenario.

In respect with baseline A results, in the case of volume taskload where the average values were between 70-256 minutes for executive, the Phase I scenario reduces that average to 68-209 minutes. This difference in maximum values of the range (around 50 minutes) is a notable advantage for ANSP because it can be translated in a capacity increase.

In the same way, for planning controllers, the simulations of Phase I show a range of 56-177 minutes per day, instead of 52-195 from baseline A.

On the other hand, the global analysis of taskload peaks in Phase I simulations show that executive controllers have reduced their taskload peaks per hour, from 14-43 percents in baseline A to 14-32 percents in Phase I.

In contrast, the planning controllers do not present important changes in taskload peaks results.

Volume taskload for executive controlllers

In the first phase, the results of volume taskload hour are presented in Figure 5.8, which is the total time by day (24 h) required per each sector for cover a controller position, and the number of sectors exposed are related to the opening scheme modelled.

From Figure 5.8 it can be observed the results of the executive volume taskload have been presented in boxplot diagrams. So, in this evaluation the highest values are located in five sectors: GCCCRW4, LPPCCEU, LPPCNOU, LECMSAN and LPPCSOUTH.

Results write down that the highest volume taskload average, with 218 minutes, corresponds to GCCCRW4 sector (in Canary Islands), similar with the baseline A. besides, the largest taskload value was registered in this sector, with approximately 281 minutes in Day 4.

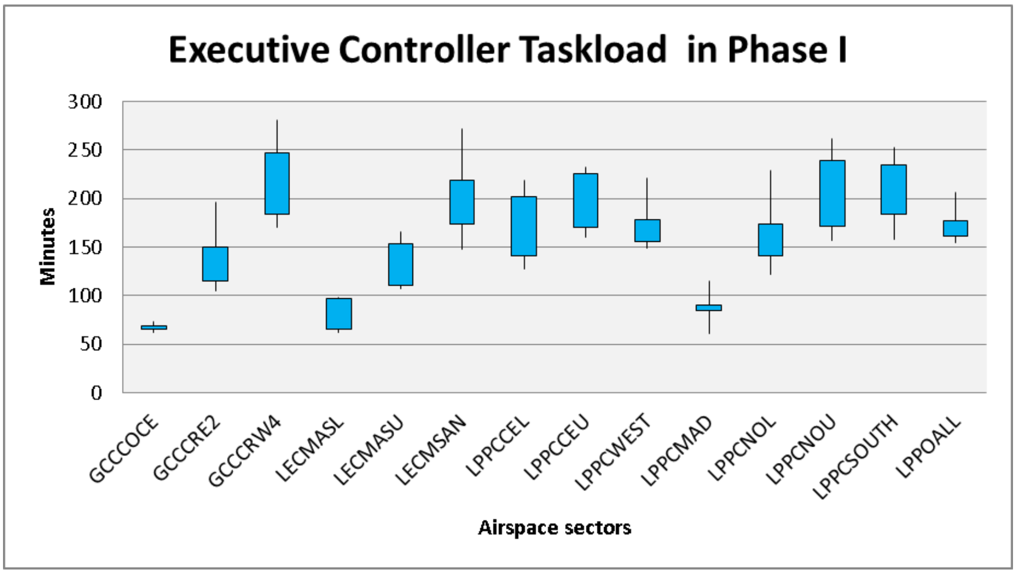


Figure 5.8 Executive taskload results in Phase I

The next sector with a high taskload is LPPCSOUTH, with an average executive load of 209 minutes per day, and a maximum value of 253 minutes in Day 2.

Furthermore, central sectors of Lisbon FIR: LPPCEU and LPPCNOU, bring evidence of a high executive controller taskload, linked to averages of 200 minutes per day; following this, from FRASAI region, LECMSAN sector indicates a high average of 200 minutes and a peak of 271 minutes in Day 2.

On the other hand, Figure 5.8 shows that the lower activity was demanded by sector GCCCOCE, LECMASL and LPPCMAD. In especial, Madeira sector (LPPCMAD) is the sector that lower demand registers with a value of 60 minutes per day. The other two sectors mentioned register approximately 62 minutes per day of executive controller demand.

Volume taskload for planning controllers

For planning controllers in Phase I, Figure 5.9 illustrates a high planning taskload for sectors LPPOALL, LPPCSOUTH, LECMSAN and LPPCNOU.

The maximum taskload value was recorded in sector LECMSAN, in Day 2 with 237 minutes. But, the highest planning taskload average was found in sectors LPPOALL and LPPCSOUTH with 177 minutes, followed by LPPCNOU and LECMSAN with 172 minutes approximately.

In contrast, the lower volume work for planning controllers is linked to LECMASL with an average of 56 minutes per day, this sector has recorded the lowest value of demand with a 42 minutes. Another sector with low activity is GCCCOCE, which presents an average of 61 minutes per day.

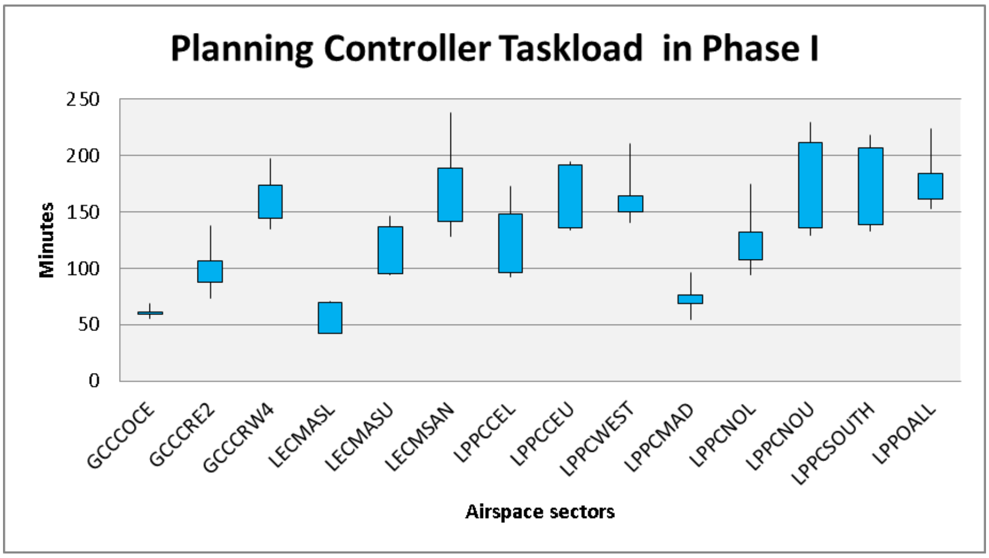


Figure 5.9 Planning taskload results in Phase I

Validation of volume taskload results in Phase I

The ATC controller opinions related to sectors with highest volume task load for executive position show a notable correspondence with the simulation values.

According to ATC questionnaire responses (see Annex 4, questionnaire responses of ATC controllers), 67% believes that LPPCNOU sector concentrated the highest taskload, followed by a 28% with LPPSOUTH sector.

Figure 5.10 shows these ATC responses, as well it can be said that simulation results have a valid support from the operational point of view.

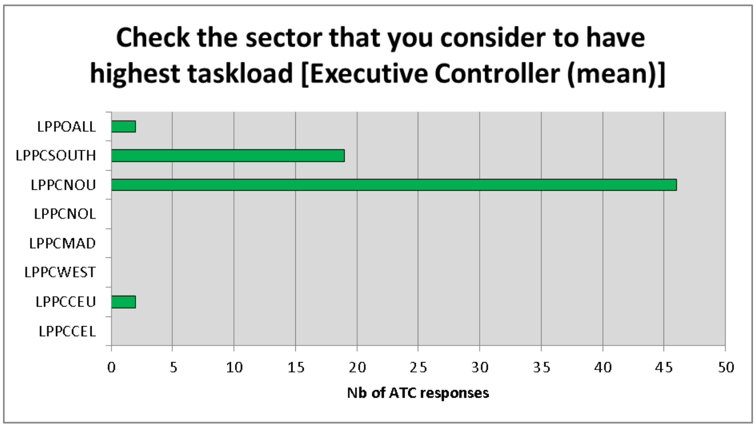


Figure 5.10 ATC responses about executive highest taskload sectors

In In the case of planning controllers and taskload volume, the results and opinions are like executive position (see Fig 5.11), ATC controllers show that sector LPPCNOU with 65% of quiz responses, is the most conflicted, and followed by LPPCSOUTH.

Those responses show coherency with planning simulation results, in Phase I scenario.

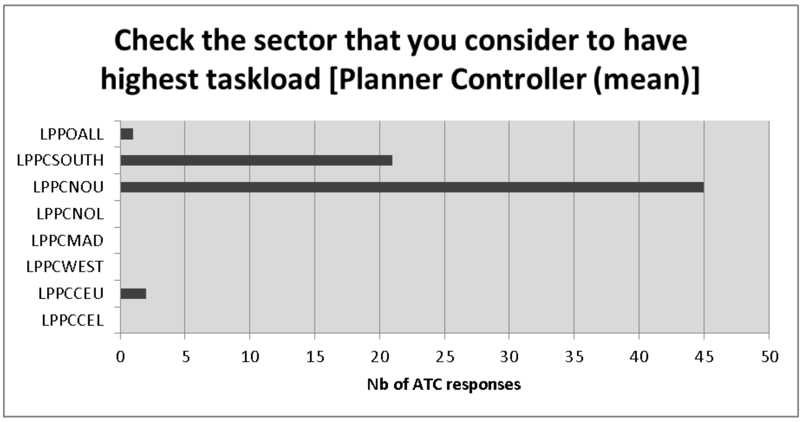


Figure 5.11 ATC responses about planning highest taskload sectors

Taskload peak for executive controllers

As was explained for this metric, the controller taskload peak is limited to a maximum 70 % of taskload per hour [32] [34], that's mean that no more than 42 minutes ATC work can be exceeded.

In the case of Phase I simulation, Figures 5.12-5.13 show that for both controllers (executive and planning), the daily peak average have not passed the 40% of taskload (24 minutes in one hour). So, for this reason maps illustrated appears with all sectors coloured in green.

The executive controllers present two sectors that have registered particular values (no averages) of volume taskload over 40%, in a specific day (see Fig 5.12), both situations come from Day 4.

Those sectors are: GCCCRW4 with 63% of taskload peak and LPPCCEL sector with 43%, both are represented in the map.

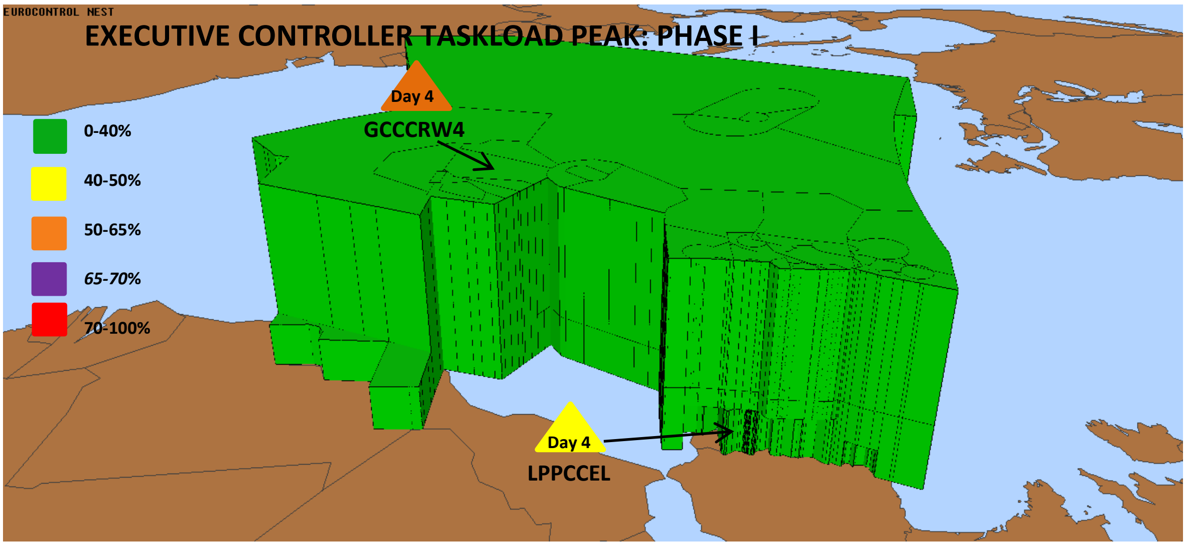


Figure 5.12 Executive taskload results for Phase I

Taskload peak for planning controllers

It can see in Figure 5.13, that planning taskload peak in Phase I do not presents notable changes in respect with executive position, in this case the sectors simulated have recorded average values lower than 40%.

The only important result comes from LPPOALL (Santa Maria Oceanic) sector, where Day 2 peak value was around 48%, it corresponds to 29 minutes of planning taskload in an hour.

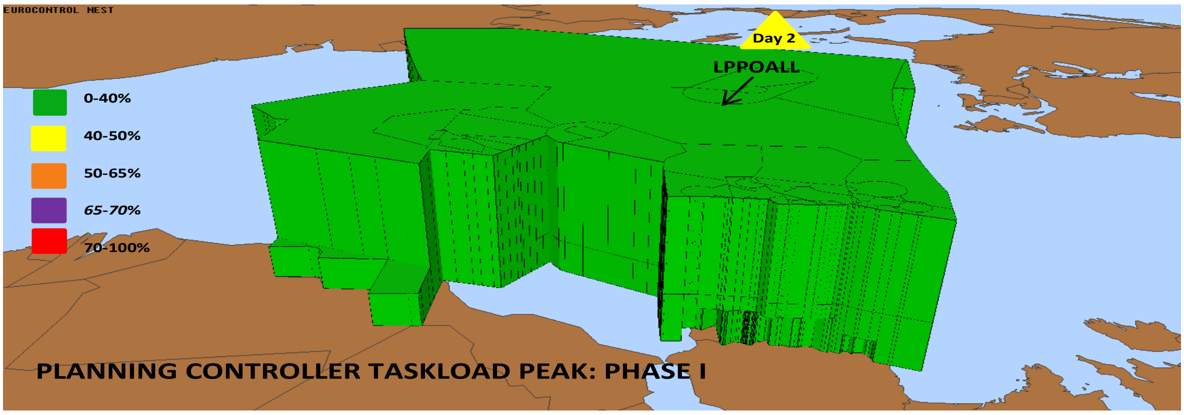


Figure 5.13 Planning taskload results for Phase I

Validation of taskload peak metric for Phase I

From simulations of taskload peaks, the general results indicates that taskload peaks in Phase I scenario do not evidence a complex situation for executive and planning controllers.

From the study of this metric, the sector that presented the highest average for executive controllers was located in Canary Islands, but as was mentioned before, it cannot be validated by ATC responses because this is located in the current Spanish airspace, where the proposed questionnaire was not completed.

According to ATC controllers, 74% of them believe that LPPCCEU is the sector with highest taskload peak, followed by LPPCNOU sector with a 23% of all responses (see Fig 5.14).

So, simulations values link sectors: LPPCSOUTH, LPPCCEU, LPPCNOU and LPPCCEL with high values, but all with averages lower than 40%. All them are located in central Lisbon FIR, and some show a notable coincidence with controllers responses.

Moreover, the values of peak taskload values: LPPCSOUTH with 32%, LPPCCEU and LPPCNOU with 31% and finally LPPCCEL with 30% of taskload peak.

The only sector that has not been considered by ATC controllers corresponds with LPPSOUTH, registering the highest value in Lisbon FIR, but always with a large margin for manage it.

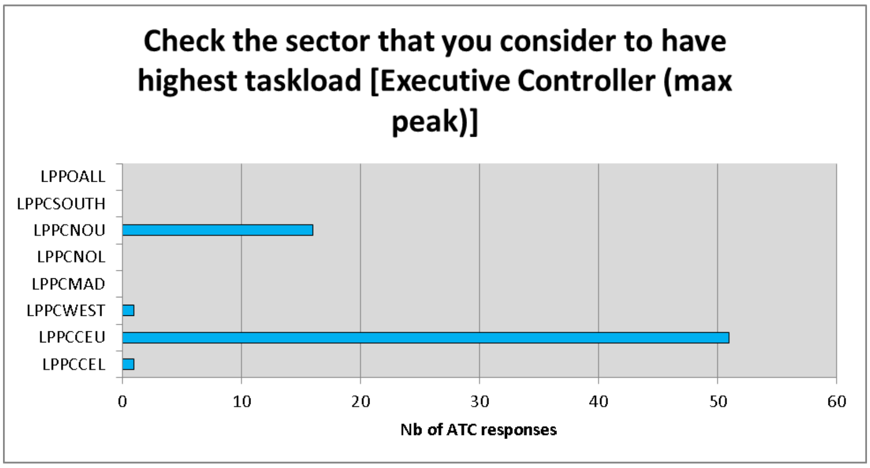


Figure 5.14 ATC responses about taskload peak for executive controllers

In contrast, for the taskload peaks of planning controllers, the sector related with the highest value is LPPOALL (Santa Maria Oceanic), but ATC responses do not correspond with it.

In accord with controllers (Fig 5.15), for the Portuguese airspace the more complex sector in taskload peak is LPPCNOU with a 45% of all opinions, then LPPCSOUTH with a 29%. The third sector positioned by ATC controllers is LPPCCEU with 19 % of responses, and only the 3% believes that LPPOALL represent the highest taskload peak for planning tasks.

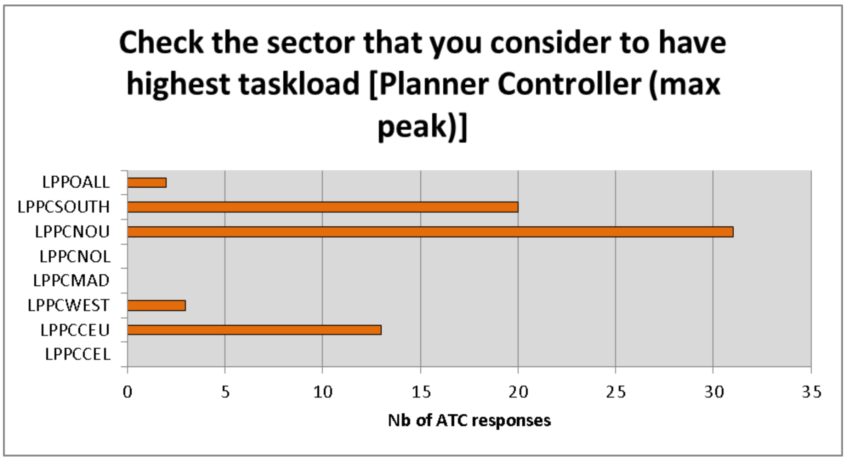


Figure 5.15 ATC responses about taskload peak for planning controllers

The overall results show a great coincidence with ATC controllers opinions, except for results for planning peak taskload, where ATC controllers believe that LPPCNOU is the more complicated sector, instead of LPPOALL as simulation values indicate.

The results of ANSP metric in Phase I presented indicate that the application of a complete Phase I of the SW FAB plan, it is possible and not generates excessive overloads and problems from the ANSP point of view.

5.1.3.2 Phase II

The overview of Phase II simulations indicates symmetry with values of Phase I, with a slight increment in respect with this previous phase, but always lowers than baseline A.

The range of average values for executive taskload is between 73-209 minutes per day, a little bit more than Phase I (68-209 minutes per day), but with a margin over reference A (70-256 minutes per day).

In the case of planning controllers, the taskload values for Phase II maintain the LPPOALL sector (Santa Maria Oceanic) as the sector with highest demand, as was in baseline A and Phase I. The averages values of taskload in Phase II are from 56 to 186 minutes per day.

For the peak taskloads, Phase II simulations show a great similitud with Phase I results, and in general all sectors have averages lower than 40%, that’s means manageable values for the ANSPs.

The results of executive and planning controllers, in respect with Phase I, only change in a few values in peak evaluation. So, the extension of the SW FAB to Santa Maria Ocenic does not produce notable overloads in the ATM system.

Finally, the second phase results are exposed in Figures 5.16 and 5.17 for volume taskload representation, and Figures 5.18-5.19 for controller taskload peak.

Volume taskload for executive controllers

The values plotted for executive controller in Figure 5.16 show that the highest volume taskload average with 220 minutes is located in GCCCRW4 sector. Furthermore, this sector presents the maximum volume taskload in Day 4 with 285 minutes.

Sectors LPPCSOUTH and LPPCNOU keep a similar behaviour as Phase I simulation, because both sector appears related with highest volume loads and with average values of 209 and 203 minutes respectively.

In addition, these sectors recorded the maximum taskload in Day 2, the day with more traffic from all samples. Simulation results indicate that in that day around 267 minutes were demanded by LPPCNOU and 253 minutes in the case of LPPCSOUTH sector (see Annex 2 for detailed results).

The lower volume taskload for executive controllers is related with sectors GCCCOCE and LECMASL, and is clearly differentiated from high volume sectors. In particular, LECMASL sector give a result of 61 minutes of volume per day, followed by GCCCOCE with 68 minutes.

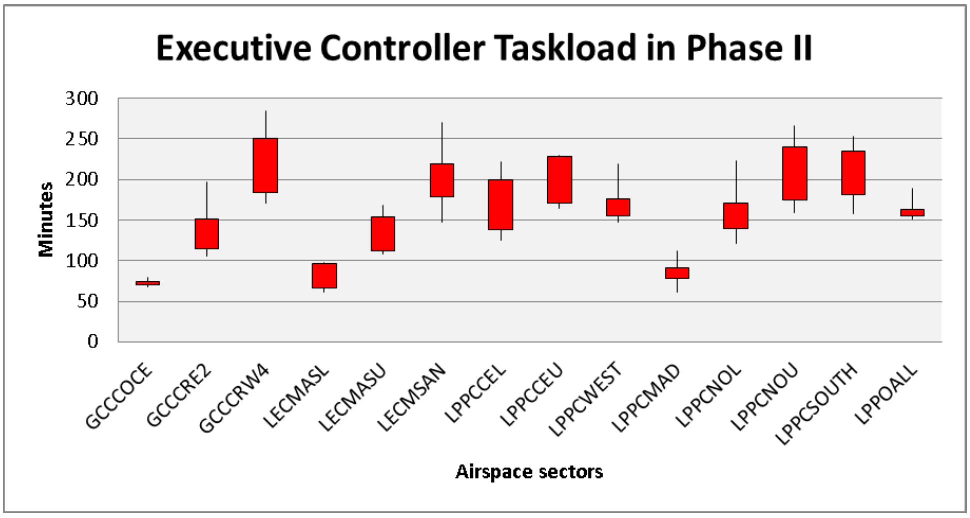


Figure 5.16 Executive taskload results in Phase II

Volume taskload for planning controllers

For planning controllers (see Fig 5.17), the maximum values were recorded in sectors LPPOALL (186 min), LPPCSOUHT (177 min) and LPPCNOU and LECMSAN with approximately 174 minutes.

The highest volume taskload in Phase II comes from LECMSAN in Day 2 with 238 min, and the lowest from LECMASL with 42 minutes in Day 4. It can be observed in Annex 1 (sector locations), that both sectors are together and in general results show values with a notable difference, this result gives more evidence that exist an important traffic flow over LECMSAN (Santiago sector).

In the case of lower volume taskload in planner tasks for Phase II, the next figure presents that sector GCCCOCE, LECMASL and LPPCMAD reflected the lowest average values, and in especial LECMASL gives a result of only 56 minutes of demand per day.

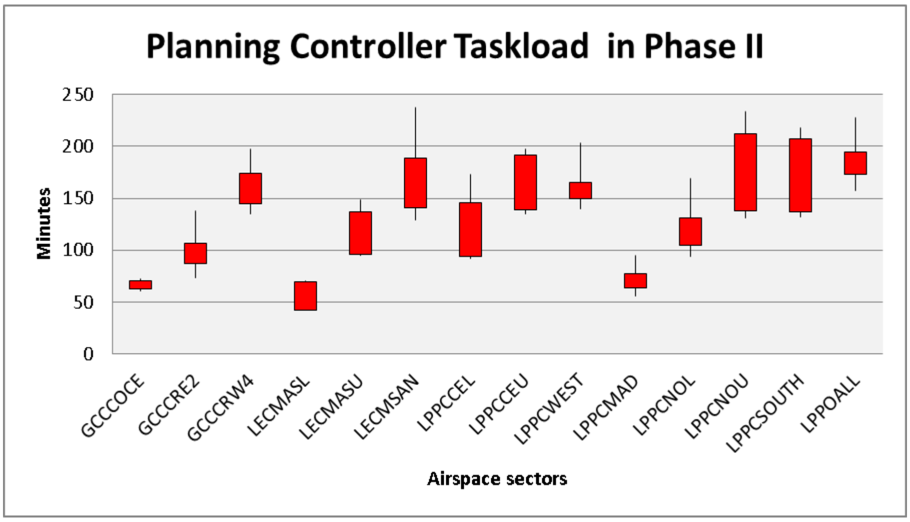


Figure 5.17 Planning taskload results in Phase II

Taskload peak for executive controllers

The study of controller taskload peak is represented in the maps of Figs 5.18 and 5.19, and values are similar to results from last simulated scenario.

For phase II, Fig 5.18 exposes the executive controller peak loads of all sectors, and results show values lower than 40%. Only three sectors presented particular peak days with high values.

In this case, the first high peak taskload corresponds to GCCCRW4 with 65% in Day 4. Secondly, sectors LPPCCEL and LPPCCEU, record values over 40%, also from fourth day.

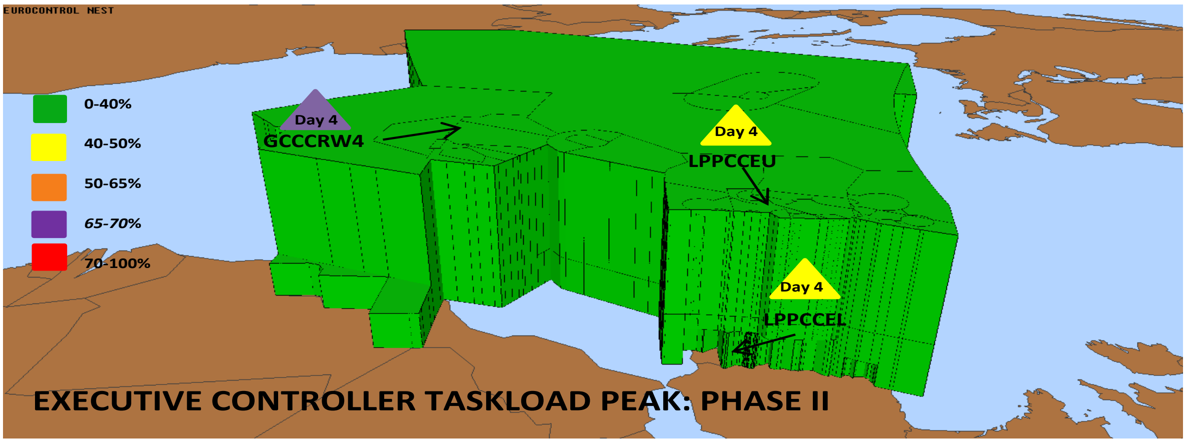


Figure 5.18 Executive taskload peak results in Phase II

Taskload peak for planning controllers

In the case of the planning controller for Phase II (see Fig 5.19), results evidence that just one sector presents a peak taskload over 40%, this sector is the LPPOALL ,with a value around 50%.

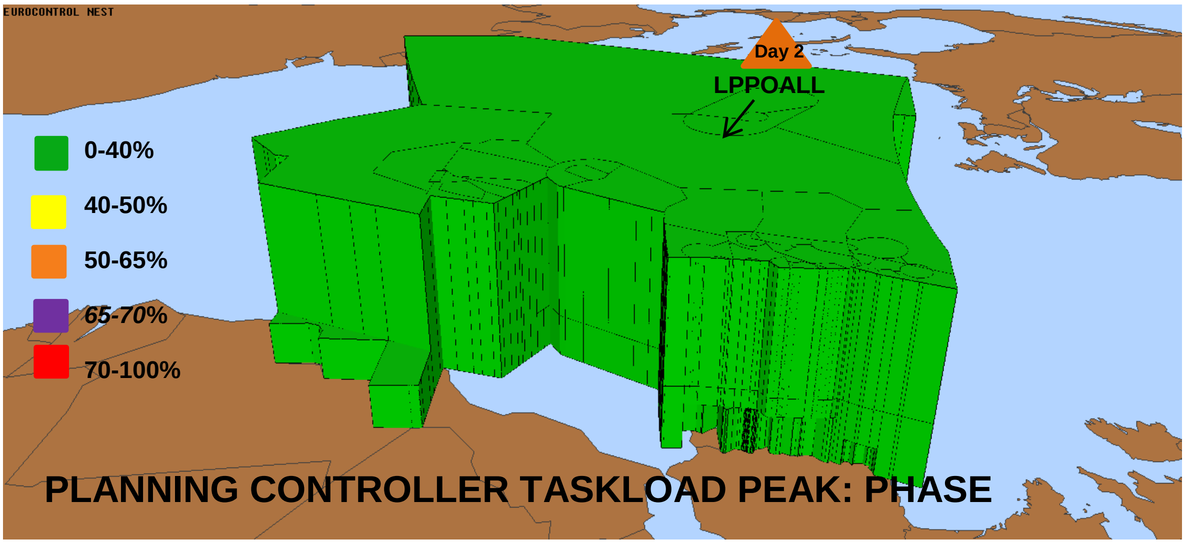


Figure 5.19 Planning taskload peak results in Phase II

The general evaluation of results from the Phase II simulated in this thesis, give evidences that the addition of Santa Maria Oceanic (LPPOALL, considered one of the most important changes in the SW FAB scenarios), do not produce a negative impact in volume taskload and peak taskload measures for both controller types.

5.1.3.3 Phase III

The evaluation of Phase III presents notable changes in respect with previous scenarios (baseline A, Phase I and II). There is an increase in volume taskload in the executive position, which reflects an average increment around 10% of taskload for executive controllers in respect the reference A, and 25% in relation with Phase I and II.

For the planning controllers taskload in Phase III, the values are similar with baseline A, but there is an increased between 5-10% in respect Phase I and II, respectively.

Those increments mentioned before, are dimensioned in the peak taskload evaluation for executive controllers (maps in Fig 5.22 and 5.23), where can it be observed that 7 sectors recorded loads over 40%, in comparing with anyone in Phase I and II.

The planning taskload peaks present similar results to the other scenarios exposed along this thesis.

Even with those increments mentioned before, the range of values of Phase III is manageable by the ATM system, because taskload peaks do not present important excesses over operational limits.

Volume taskload for executice controllers

The global values of taskload for executive controllers in Phase III simulation present a range of values between 67-285 minutes per day, so it is approximately a 25% more than the range of Phase I (73-209 minutes per day) and Phase II (73-209 minutes per day).

Fig 5.20 shows the volume taskload for the executive controllers in Phase III, where sector LPPCNOU gives the highest average value of simulations, with 285 minutes per day. It represents a 10 % more respect the 256 minutes in the baseline scenario A. Moreover, LPPCNOU register the maximum value with 410 minutes of taskload demand in Day 4.

In the same way, the highest volume taskload are related to sector LPPCCEU (258 min), LPPSOUTH (244 min), GCCCREW4 (243 min) and LECMSAN (241 min).

In accord with Fig 5.20, the lower activity for executive tasks is linked to sector GCCCOCE and LECMASL, with 67 and 84 minutes respectively. Adding to this, Madeira sector (LPPCMAD) registers the lower taskload average with 84 minutes, but the lowest representative value of this sector was 59 minutes of demand in Day 3.

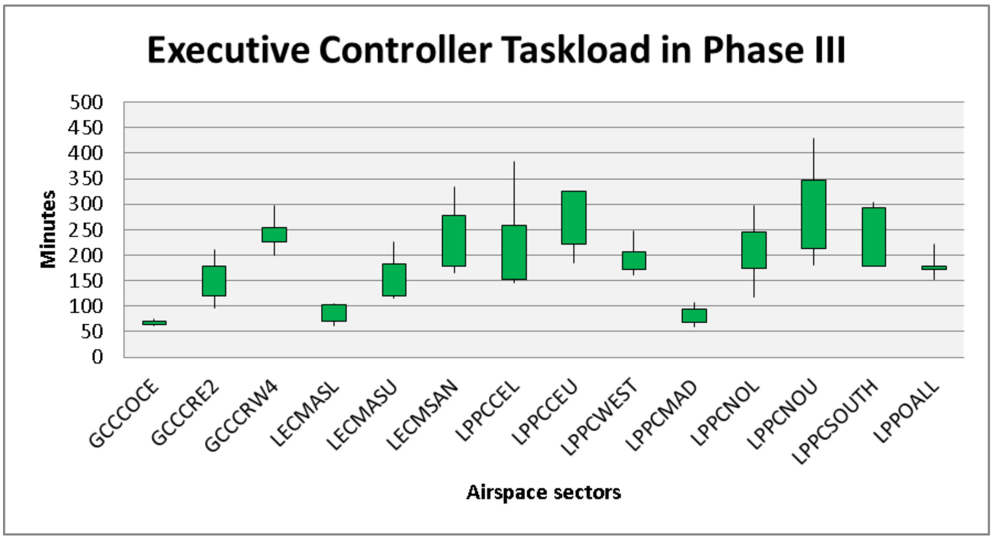


Figure 5.20 Executive taskload results in Phase III

Volume taskload for planning controllers

For planning controllers in the third phase (see Fig 5.21), the LPPCNOU sector (one of the most conflicted sector evaluated) shows a similar values in respect with baseline A, with 196 minutes required per day.

Most of the planning taskload presents a slight increment (around 5%), like LPPCSOUTH, LPPOALL, or LPPCCEU sector. From this analysis, two important values have to be mentioned; the highest value recorded in sector LPPCCEU with 239 minutes in Day 5, and the high value from sector LECMSAN (239 minutes) in day 2.

As the other planning evaluations in Phase I and II, this scenario do not brings a significant difference for the lower activity in planning controllers. The sectors: LECMASL, GCCCOCE and LPPCMAD show the lowest taskload demands (for detailed values, see Annex 2).

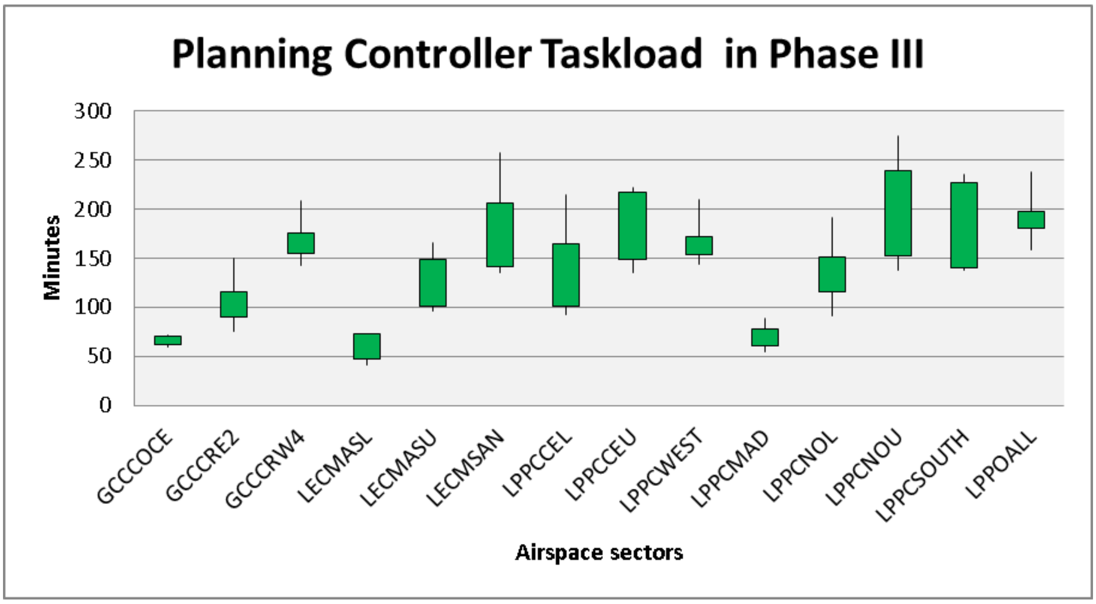


Figure 5.21 Planning taskload results in Phase III

Taskload peak for executive controllers

The metric related to taskload peaks per hour for executive controllers in Phase III, is represented in Figure 5.22, it clearly evidences a congested airspace in central sectors of Lisbon FIR, but all daily peaks averages maintains a reasonable margin with the operational ATC limit established (70%).

As was explained before, the main difference respect baseline A, is that taskload over sectors has increase and it is reflected in the next map, passing from only one sector in baseline A that exceed the 40% peak to seven sector in Phase III (Fig 5.22).

For the peak taskload per hour, this thesis has defined similar limit values like CAPAN (Eurocontrol) method for measure ATC loads [34].

So, the values between 0-40% are related to light loads. Then from 40% to 50 it can be considered as medium ATC loads. The next range is between 50-65%, defined like a heavy load, following by a very heavy ATC load for 65-70% range. Finally, the overload reaches values above 70%, defined like the ATC operational limit.

In the studying of the averages values, the most notable values were found in the next sectors: LPPCNOU (51%), GCCCRW4 (50%), LPPCCEL (48%), LPPCCEU (48%), LECMSAN (43%), LPPCNOL (43%) and LPPCSOUTH (41%). Those average values are plotted in the map of Figure 5.22.

In accord with simulations, the maximum value recorded is located in LPPCNOU, where in baseline A, the maximum peak taskload was 48%, and in Phase III this increases to 68%, but this was only for one day (Day 2).

The general evaluation of peak taskload for executive controllers indicate an increment in ATC loads, but it is important to said that the evaluation limit for detect ATC loads is extremely low (40%), this low limit established in the study helps to evaluate the largest number of changes in sectors with SW FAB scenarios.

Furthermore, the operational limit of 70% proposed in [36] was not exceeding in any sector in all the simulation; even in the most complicated case (Phase III).

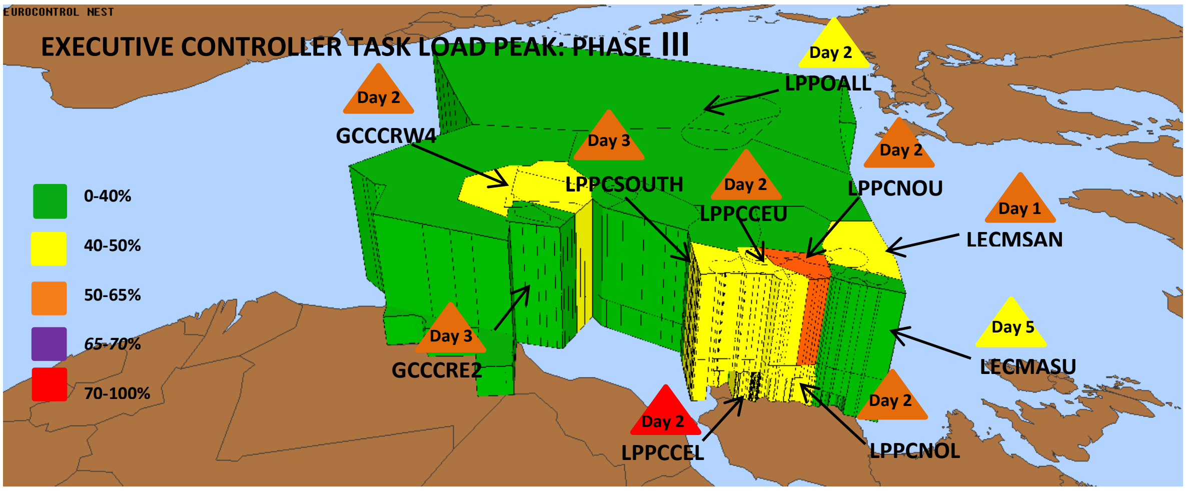


Figure 5.22 Executive taskload peak results in Phase III

Taskload peak for planning controllers

For the planning control in Phase III (see Fig 5.23), only LPPOALL gives evidence of increment in taskload peak, with a peak of 50% in Day 2; all the other evaluated sectors have presented lower values to 40%.

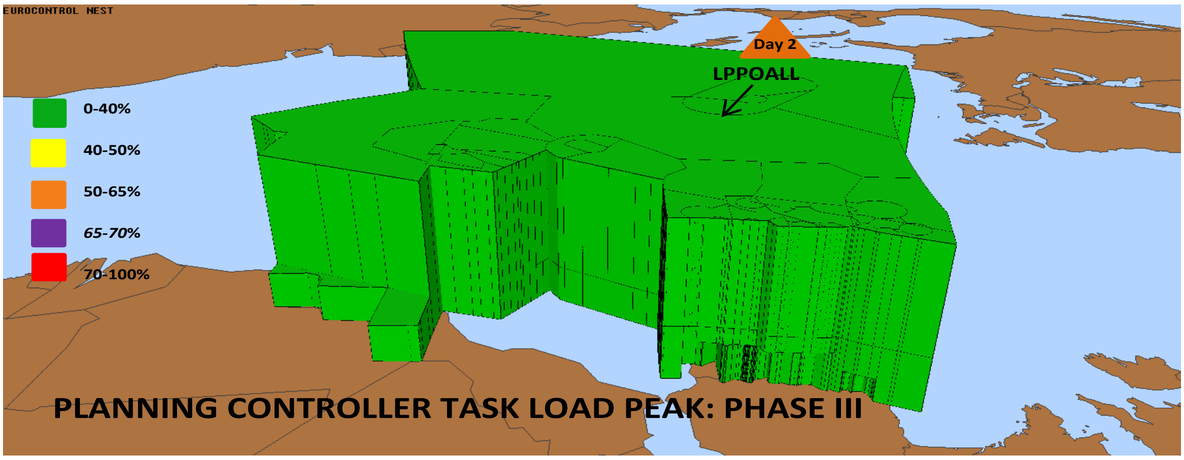


Figure 5.23 Planning taskload peak results in Phase III

The general evaluation of metrics related to the Air Navigation Service Provider write down that SW FAB simulation produces some slight increments in controller volume taskload and controller task load peak, but in all cases are safe values and not represent overloads for sectors.

According with all the results from ANSPs metric presented in this master thesis, it can be said, that the SW FAB scenarios programmed do not produce overloads that the ATC system cannot manage, and the values exposed keeps a reasonable margin with ATC operational taskload limit.

5.2 Scenario B (2019) results

The simulations carried out for the baseline B with the future traffic prognosis to 2019 considers two important issues to mention.

Firstly, the traffic prognosis to 2019 considers traffic loads of airports and ATS network constraints. So, the forecast uses the MTF STATFOR method (mentioned in Chapter 3), which is based in the addition of repetitive traffic to original samples.

Secondly, the scenario used for obtain results in baseline B, is the Phase III. This consideration intend to obtain the more close result adapted to the long term plan.

The results from estimated traffic to 2019 demonstrate that the SW FAB implementation bring benefits for airspace users, in terms of distance savings, route efficiency and flight time savings. At the end, those benefits are translated in fuel cost savings for commercial airlines and environmental friendly flights.

On the other hand, the general values of safety determine that the future FAB in study does not produces a conflicting airspace, so values show similitude with earlier simulations.

In the case of the ANSPs metric, results show greatly improvements with SW FAB, because sector values for 2019 indicate results that are manageable for ANSPs. All this in contrast with the starting scenario (baseline B), which presented a complex scenario for taskload peaks, with a considerable number of sectors overloaded.

5.2.1 Airspace user (2019) results

The overview of simulation results for airspace users reflects benefits in the three metrics evaluated.

From distance savings, it can be said that the future SW FAB will let to save large distances to airliners routes, approximately between 1.7-2.7% of the route route in relation with the starting scenario B, around 15000 to 25000 NM.

In relation with distance savings, the route efficiency metric indicates an improvement between 0.65 to 0.80% in respect with baseline B; and in all cases present route efficiencies at least of 99.50%.

The flight time savings estimation to 2019 with SW FAB phases, show that the total flights in one day, can save between 1000-2800 minutes.
.

5.2.1.1. Distance savings

The results for the traffic estimation to 2019 (see Table 5.4), confirms an important distance savings for airliners, with values between 1.7-2.7%, in respect with the reference scenario B.

Table 5.4 presents the flight distance savings for the 2019 traffic forecast. It can be clearly appreciated a positive impact of SW FAB implementation.

The distance savings are between 15200 NM to 26700 NM per day, depending on the traffic sample and the maximum value is related to Day 2 with 26664 NM per day, it corresponds with the highest traffic (estimation of 2177 flights in 2019).

Table 5.4 Results of distance saving for airspace user in 2019

	Day1	Day2	Day3	Day4	Day5
Traffic 2019 Distance	887566 NM	1155172 NM	864701 NM	798881 NM	935433 NM
Traffic 2019 with SW FAB Distance	872333 NM	1128509 NM	842913	780391 NM	910193 NM
Total Distance Saved	**15233 NM 1.7%**	**26663 NM 2.3%**	**21788 NM 2.5%**	**18490 NM 2.3%**	**25240 NM 2.7%**

From distance savings results in 2019, it can be said that Phase III implementation produces clear advantages for commercial aircrafts, and as was discussed before in this thesis, all this is translated to fuel cost savings and less emissions.

5.2.1.2. Route efficiency

In addition, the route efficiency metric evaluated in 2019 traffic samples, presents great coincidences with distance savings results from 2013-2014 traffics, with a similar tendency.

The route efficiency results in Table 5.5 for 2019 traffic samples, show that the use of Free Route scenarios produce more efficient routes, in other words, it can be flown more direct routes; in some cases passing from 98.8% to 99.5% in route efficiency, and as consequence there is notable distance and flight time savings.

Another important result to remarks, is that using the Phase III scenario, produce results in all cases with a route efficiency above 99.5 %, and in some especial cases up to 99.7%.

Table 5.5 Route Efficiency results for traffic samples of 2019

Traffic Samples	Inefficiency Baseline B (%)	Inefficiency Traffic 2019 (%)
Day 1	98.84	99.51
Day 2	98.86	99.61
Day 3	99.16	99.70
Day 4	98.81	99.60
Day 5	99.15	99.79

5.2.1.3. Flight time savings

On the other hand, for flight time evaluations for traffic of 2019, results present favourable values, because in all simulations, airplanes save some minutes.

As was mentioned before, the global flight time savings in respect with baseline B are from 1040 minutes to 2791 minutes.

SW FAB simulations (see Table 5.6) indicate that savings are between 0.85-2.5 percent of the total flight time. Those results produce in advantages for airspace users, especially airlines and passengers.

Table 5.6 Flight time results in 2019

	Day1	Day2	Day3	Day4	Day5
2019 REF	114733 min	148505 min	112600 min	103891 min	121023 min
2019 SW FAB	113693 min	147248 min	109809 min	101665 min	118238 min
Min Saved	**1040 min**	**1257 min**	**2791 min**	**2226 min**	**2785 min**
% Saved	**0.91%**	**0.85%**	**2.5%**	**2.14%**	**2.3%**

5.2.2 Safety (2019)

For the safety metric approach to 2019, Figure 5.24 shows that conflicts between baseline B (see Chapter 3), and the future traffic in the SW FAB are not increased.

Thus, it can be said that SW FAB simulation indicates that in future, this SW FAB extension keeps similar or a less conflicted airspace, if it is compared with baseline B (based in the current airspace configuration).

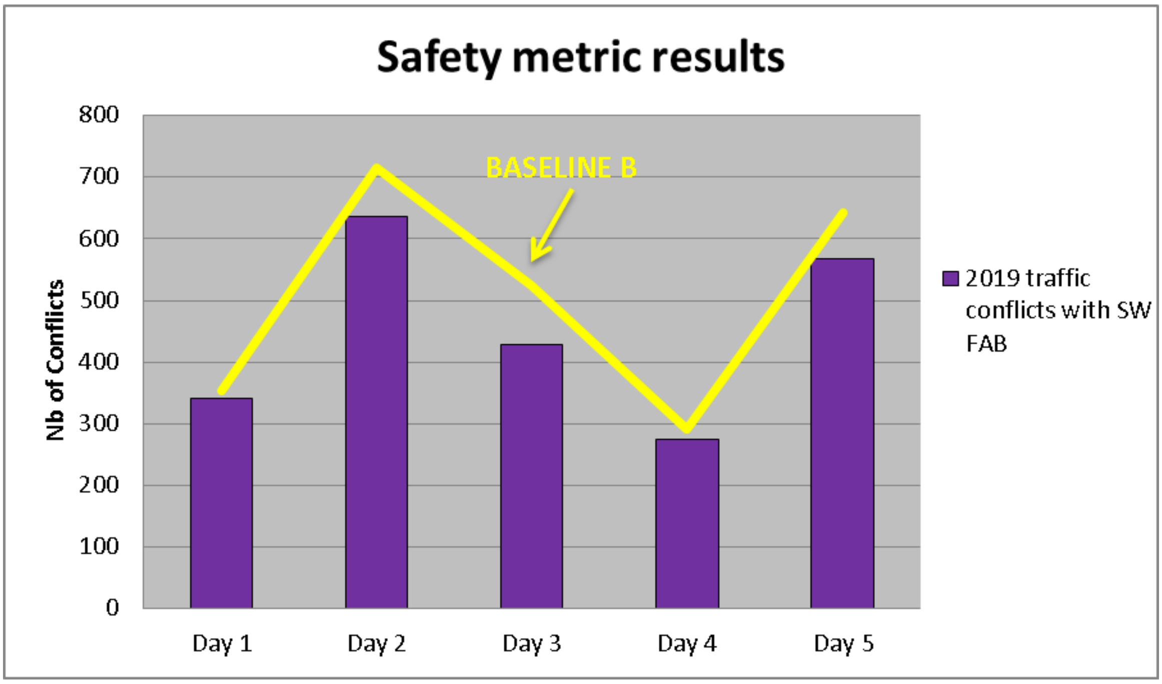


Figure 5.24 Number of conflicts in 2019 traffic simulations

The numbers of conflicts registered by the 2019 simulation are always less than baseline B, approximately between 4 to 12 % less than the reference B.

The most notable cases are reflecting in Day 2, 4 and 5, where conflicts have been reduced in an 11 to 12%.

So, simulations results evidence that introducing of the final extension of the SW FAB, do not increase conflicts and consequently, safety standard related to aircraft separation losses are maintained similar as the current airspace configuration.

5.2.3 ANSP (2019)

Simulations show important improvements in the scenario to 2019, those are easy to observe in a comparation with baseline B.

As was exposed in Chapter 4, the values related to baseline indicate a complicated airspace in future, comparing with the current airspace configuration.

The reference B writes down a taskload for executive controllers of 82-287 minutes per day, and in 2019 simulations those values have been reduced around 80-260 minutes.

In the case of planning controllers, the 2019 scenario present a slight increment in the taskload range, this range is between 64-236 minutes per day and the baseline B around 55-220 minutes.

The most notable changes with SW FAB implementation are demonstrated in the taskload peak from both controller positions.

Coming back to baseline B, where values of taskload peaks for executive controllers show five conflicted days with overloads (over 70%), and comparing it with 2019 simulations, the number of sector with overload have reduced to only one day.

In the case of planning controllers, the improvement was from two days loaded to a scenario without overloads.

5.2.3.1 Volume taskload for executive controllers

The results of the executive controller taskload for the future SW FAB indicate that volume taskload maintains similar values in respect with baseline B.

The first results are related to the executive controller taskload in 2019, these are presented in Figure 5.25, and with the same representation used in this project.

The sector LPPCNOU with 259 minutes taskload average in baseline B, keeps the same value in 2019, but the maximum peak taskload registered in Day 5 is reduced from 505 minutes in baseline B to 397 minutes in 2019 traffic sample.

Others high load sectors are: LPPSOUTH and LECMSAN, these present average values of 259 and 247 respectively, with a slight decrease in taskload.

In the case of low executive taskloads, sectors GCCCOCE and LECMASL increment their values in 2019, but still catalogued as lower values in the overall evaluation.

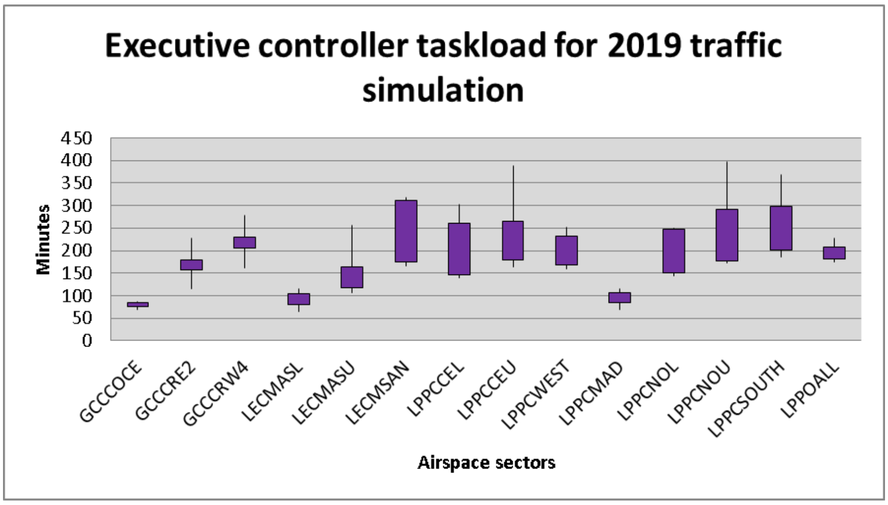


Figure 5.25 Executive taskload results with 2019 traffic simulation

5.2.3.2. Volume taskload for planning controllers

The planning taskload results for 2019 simulation are plotted in Fig 5.26, where Santa Maria Oceanic (LPPAOLL) is defined with the high taskload sector, with 235 minutes per day. In the same way in Day 2 recorded a peak taskload value of 294 minutes.

The next sectors: LPPSOUTH (214 min), LPPCNOU (200 min), LECMSAN (200 min) LPPCCEU (188 min) presented high values in 2019, but were very similar to reference B.

The lower values from this simulation (see Fig 5.26) are linked to the same sectors exposed before in this project; GCCCOCE sector evidences the lowest average value with 79 minutes. The next less active sector is LECMASL with 64 minutes of planning demand per day, and it registered the minimum simulation value for 2019, in Day 4 with just 45 minutes of demand.

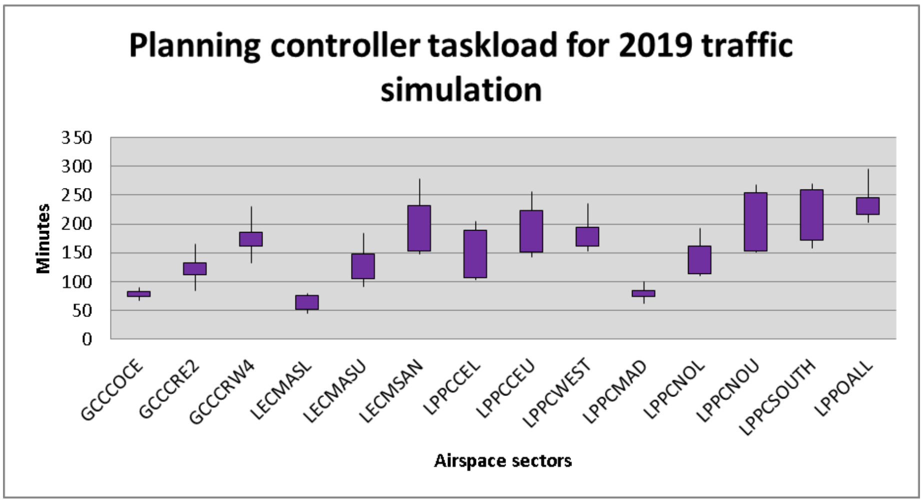


Figure 5.26 Planning taskload results with 2019 traffic simulations

5.2.3.3. Taskload peak for executive controllers

The taskload peak results are represented on maps of Figures 5.27-5.28, and for detailed values of this simulation see Annex 2.

For the executive position (see Figure 5.27), the most notable value in the 2019 simulation is represented by LPPCSOUTH sector, which is the only sector from baseline B that indicate an average peak value above 40%.

Then, in 2019 simulations, ten days (peak values) have exceeded the 40% limit. In addition, it is important to mention that the most conflicted sector (LPPCNOU) registered a value of 72%, passing the operational limit considered in this thesis, but with a greatest difference in respect baseline B, which included five values over passing of 70%.

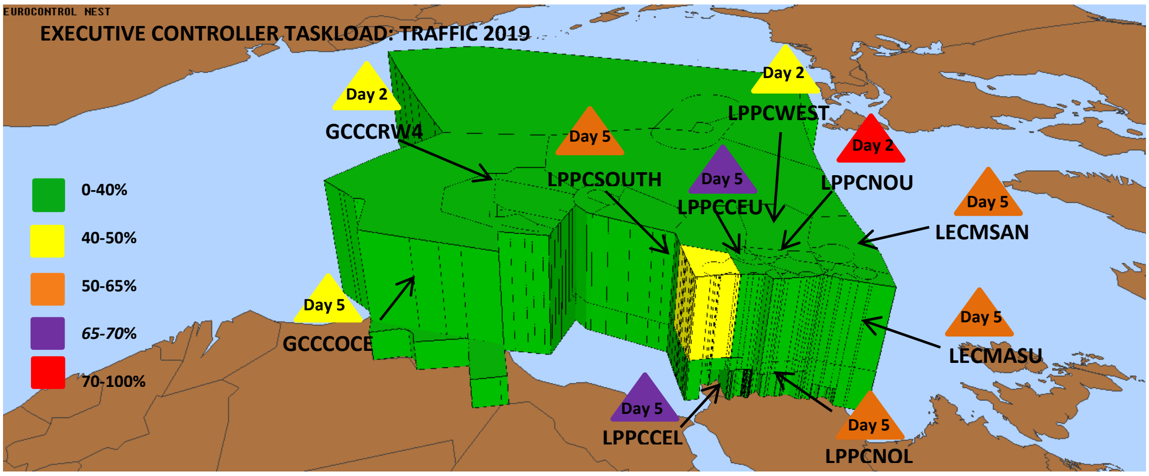


Figure 5.27 Executive taskload peak results for 2019 traffic

5.2.3.4. Taskload peak for planning controllers

For planning taskload peaks, simulation results (see Figure 5.28) show that LPPOALL sector is the most loaded, with an average superior to 40%, and the highest peak with 54% in Day 2.

The other particular sectors (GCCCOCE, LPPCCEU and LPPCWEST) indicate values around 41% on represented days.

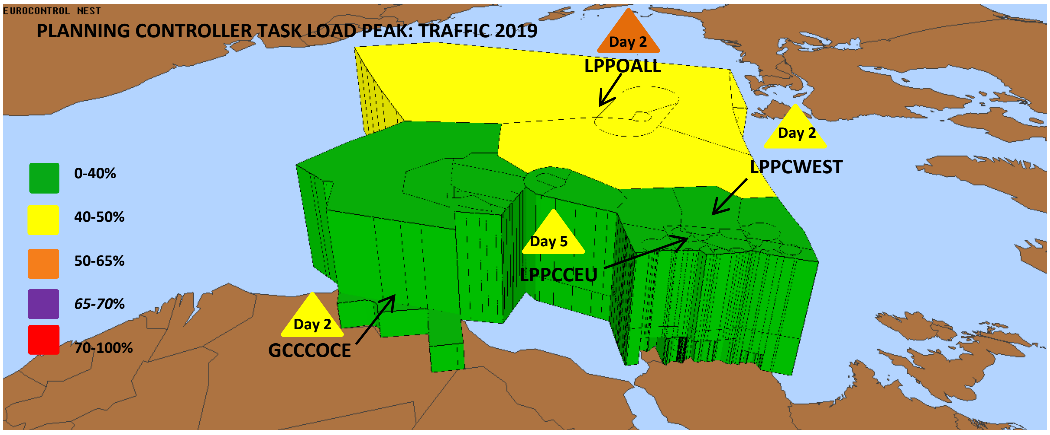


Figure 5.28 Planning taskload peak results for 2019 traffic

Thus, it can be concluded from last results that FRA simulation in 2019 shows benefits for all three studied stakeholders, also when it considers forecast traffic with significant increment.

So, these results add evidence the idea that the future SW FAB planned brings improvements, in especial for airspace users.

5.3 ATC Perspective responses

As was described in Chapter 3, the final part for thesis results validation is related with professional opinions from Free Route controllers, those responses are considered as very important data for this master thesis, because it permits to contrast all concepts and results from simulation with the operational activity.

Many of controller responses are linked to different metrics, all this for discuss results in a more objective way. So, this part described a responses summary for bring a general overview of the questionnaire.

The questionnaire was answered by 69 professionals, with an average experience of 15 years like ATC controllers. All controllers responses come from FROM (Lisbon Free Route Airspace), which can be considered the most mature Free Route Airspace in Europe.

As was mentioned before, the most representative answers are exposed in this part, but the complete set of question and their responses are in Annex 4.

The starting point in ATC questionnaire considers their knowledge about SESAR and the Functional Airspace Block concept, where around 80% of controllers are included in a notable level.

Secondly, controllers believe that Free Route Airspace brings benefits, and these are mainly focused in commercial airlines, passengers and pilots as were showed in Figure 5.4.

In the same way, ATC controllers think that metrics that present more favourable results with Free Route are: flight distance, pre-flight task and fuel consumption.

In accord with Figure 5.29, most of ATC controllers (59%) believe that Free Route implementation brings benefits for stakeholders, and another 39% thinks the same, but with a less level (fourth level in scale to five).

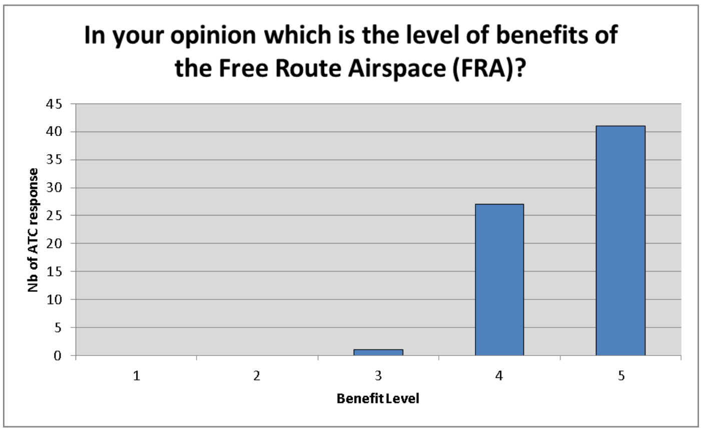


Figure 5.29 Benefits level opinion from ATC controllers

On the other hand, 88% (see figure 5.30) of controllers' responses supports a high necessity in FRA implementation; and the same way, another question answered indicates that the 71% of controllers consider that in 2030 a big Free Route extension will be in Europe.

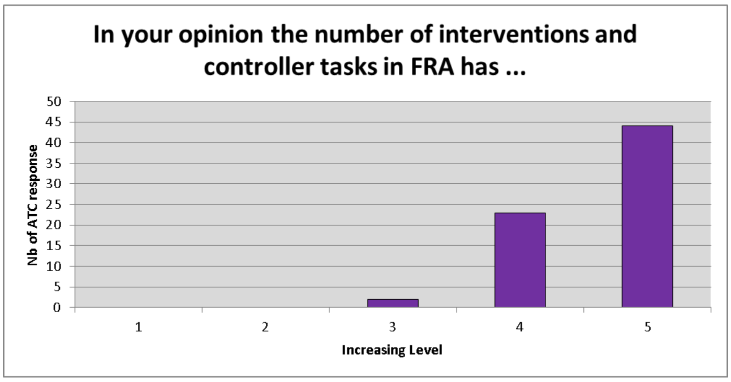


Figure 5.30 Benefits level opinion from ATC controllers

The Lisbon ATC controllers evaluated their manage skills around with 3 and 4 points in a 1 to 5 point scale, and 64% of them considers that ATC interventions in Free Route has increases in respect with ATS network configuration.

According to controllers, 75% believes that aircraft rerouting has increased, and consequently this impacts directly in ATC interventions.

Another important result of questionnaire is the general opinion that FRASAI and FRAL transfer operates without problems; this is reflected in 90% answers with 3 point, in a 1-5 scale.

In the case of controller training, 58% of controllers consider good training, but there is a 10% of responses that evaluate Free Route controller training like poor (with 2 points in scale 1-5 points).

In addition, ATC professionals show that they use the Short Term Collision Avoidance Tool, but it is assessed like a poor tool by their responses, with approximately 77% and a 10% like extremely poor (1 point in 1-5 point scale), as can see in Figure 5.31.

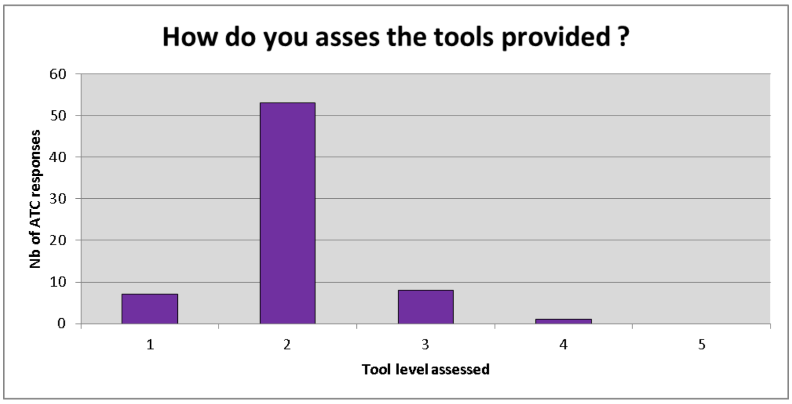


Figure 5.31 Benefits level opinion from ATC controllers

From the questionnaire, 61% responses indicate that the FRA design in Lisbon FIR is a good design, furthermore this question imply waypoints, sectors, etc.

The final set of questions is related to ATC taskload, and most of them were exposed in Phase I results, and from all answers, mostly of controllers considers sectors: LPPCNOU, LPPCSOUTH, LPPOALL, LPPCCEL and LPPCWEST as the most conflicted.

As a result summarize, it is important to mention that this master thesis shows enough evidence from different points of view that Southwest FAB can bring a lot of benefits for airspace users, as well in safety values as the current airspace configuration.

On the other side, from the ANSPs evaluation, it can be said that ATC loads can be manages perfectly with Free Route Airspace implementation, but there are some steps and operational issues that need to be clearly define before carry out SW FAB phases.

These needs are related to ATC tools for establish aircraft separation and in the methods for measure ATC loads in Free Route Airspaces.

CONCLUSIONS

In general, this thesis presents important results that evidence benefits of SESAR FABs implementation and Free Route operations, in the same way, the project describe interest results related to safety and ATC taskloads of the future SW FAB.

The results shown that the three phases approach is correct, starting with small and ending with big, and obtaining more benefits (economical, operational and environmental) after each step.

This approach allows contrasting the expected benefits with the actual ones before taking the next phase. The current situation is very close to Phase I, except that the FRA is still divided by national borders.

The main goal of present thesis was to study the Southwest FAB implementation and the advantages from airspace users, safety and ANSPs perspective. Based on these aims the conclusions of this study are as follows:

- Airspace users

This thesis concludes that implementation of Free Route Airspace between States member and without consider boundaries presents more advantages than with current airspace configuration, that is based in airspace frontiers. In this way, Functional Airspace Block is the organizational concept of SESAR that aims at the elimination of this disadvantage.

The SW FAB development for a long term contains the biggest Free Route Airspace in Europe, permitting an increase in flight efficiency for those oceanic flights on the northern-southern corridor. In addition, the main beneficiaries of SW FAB implementation are commercial airlines, pilots and passengers.

Those benefits are estimated in distance saving at least of 15000 NM per day, that represent an estimated daily saving of 157 fuel tons, 47 CO_2 tons and approximately 90000€ per day. In the same way, a flight time reduction is expected for airspace users in the future SW FAB.

- Safety

From SW FAB simulations, this project concludes that safety is maintained with similar values as the ATS network airspace.

This conclusion is supported by controllers opinions, which indicate that current Free Route operation do not decreases safety standards.

- ANSPs

The study brings important conclusions from ATC taskload evaluations. Firstly, simulations shows evidence that SW FAB scenarios do not overload sectors to unmanaged limits.

In this aspect, the evolution and study of the three SW FAB phases separately, permit to conclude that the final phase can work without problems.

Secondly, from ATC responses, where tools for manage traffic in Free Route Airspace are qualified with low marks “poor”, in especial the Short Term Conflict Detection Tool; this thesis concluded that controllers from Free Route Airspace need a more complete tool that helps to improve their activity, because that actual tool operates with an incomplete satisfactory performance.

Finally, is important to mention that Free Route Airspace will be complemented by other ATM global performance improvements, such as the 4D trajectory or the collaborative decision making. Putting all these technological and operational elements together, and with a unified calendar, is the big challenge of SESAR and NextGen programme.

Future Works

This master thesis has opened two important points for future works, these come from Free Route simulations and ATC questionnaire responses.

The first one is related to simulation processing using NEST-Eurocontrol tool, in especial in the stages for calculate a Free Route trajectory.

So, for future studies with Free Route Airspace using NEST tool, this thesis indicates that an algorithm for free routing processing have to be improved, reducing in one stage, the final trajectory desired. All this have to result in a simplification of the process based in one input/out trajectory in 4D, without profile calculation.

The second, but not least important point is linked to ATC questionnaire. From ATC responses about Free Route tools, there comes an issue related with a operational need of a more complete Short Term Conflict Detection Tool, that helps to avoid any possible separation losses between aircraft that fly in Free Route Airspace.

In this way, an evolution of the current Short Term Conflict Detection tool needs to be developed, based on a conflict detection previous that aircraft enters to Free Route Airspace, and a dialog with ATC for solve or consider those possible conflicts.

This can reduce ATC taskload peaks and it only has to affect the aircraft that has not yet flied inside Free Route Airspace.

REFERENCES

[1] Eurocontrol, fact sheet “The Single European Sky ” February, 2011.

[2] EUROCONTROL on behalf of the European Union FAA Air Traffic Organization System Operations Services. “Comparison of Air Traffic Management-Related 2013 Operational Performance: U.S./Europe” report, June, 2014.

[3] European Comission, Single European Sky (online) retrieved from http://ec.europa.eu/transport/modes/air/single_european_sky/index_en.htm.

[4] Skybrary, Functional Airspace Block, (online) retrieved by http://www.skybrary.aero/index.php/Functional_Airspace_Block_%28FAB%29.

[5] Eurocontrol, Functional Airspace Blocks (online), retrieved by https://www.eurocontrol.int/dossiers/fabs.

[6] Eurocontrol “MUAC” in website. https://www.eurocontrol.int/muac

[7] Southwest FAB (website), retrieved by . http://www.swfab.eu/home

[8] Eurocontrol: Eigth-states Free Route Airspace Project Free Route Airspace Concept Doc.Februrary,2002.

[9] J. Kraus, “Free route airspace (fra) in europe”, December, 2011, pp. 3-7.

[10] Eurocontrol, Regulatory support for the SES: http://www.eurocontrol.int/articles/regulatory-support-single-european-sky.

[11] Skybrary: http://www.skybrary.aero/index.php/Single_European_Sky_(SES)

[12] SW FAB Operational Task Force “Airspace operational requirements report” , Annex L, June,2012. pp.61–83.

[13] Portuguese and Spanish Directorate of Civil Avitation, “Southwest FAB Compliance Summary Document” report, June 2012.

[14] SW FAB Operational Task Force report, “SW FAB Airspace Organisation and Classification report”, Annex O, June, 2012.

[15] Aena website: Airspace organization, retrieved by http://www.aena.es/csee/Satellite/navegacion-aerea/en/Page/1047658457254/.

[16] NAV Portugal Circular “Implementation of Free Route Airspace within Lisbon FIR/UIR (FRAL) above FL245”, AIC 002-2009.

[17] Eurocontrol, Report: “At the heart of a high-performance cross-border airspace”, February, 2011.

[18] Administration de la Navigation Aerienne de Luxembourg, Belgocontrol, DFS, DSNA, LVNL, Eurocontrol MUAC and Skyguide. “FABEC Feasibility Study Report” .August, 2008.

[19] ICAO “Manual on Global Performance of the Air Navigation System”, ICAO Doc 9883, AN/468, 2008.

[20] Eurocontrol, SESAR consortium “SESAR Master Plan D5”, April, 2008.

[21] Eurocontrol final report “To support the establishment of functional airspace blocks (fabs)”, May, 2005.

[22] D. Knorr, X. Chen, M. Rose, J. Gulding P. Enaud and H. Hegendoerfer,“ Estimating ATM Efficiency Pools in the Descent Phase of Flight,” in 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin, 2011.

[23] M. Ryerson, M. Hansen and J. Bonn,“ Fuel Consumption and Operational Performance,” in 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin, 2011.

[24] D. McNally et al, “Operational Evaluation of Dynamic Weather Routes at American Airlines,” in Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013.

[25] B. Zou, M. Elke and M Hansen, “ Evaluating Air Carrier Fuel Efficiency in the U.S. Airline Industry,” in Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago

[26] T. Gaydos, B. Liao, E. Smith, and L. Wang, “Analysis of Conflict Detection Performance for Trajectory-Based Descent Operations,” in Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013.

[27] S.Pozzi, C.Valbonesi,V. Beato, R.Volpini, F. Giustizieri, F. Lieutaud and A. Licu,“ Safety Monitoring in the Age of Big Data,” in 9th USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), Berlin, 2011.

[28] M. Zanin,“ Synchronization Likelihood in Aircraft Trajectories,” in Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013.

[29] T. Mihetec, S. Steiner and Z. Jakšić, “Analysis of expected ATM processes changes in central europe”.2012. , pp 4- 12.

[30] J. Welch, J. Cho, N. Underhill, and R. DeLaura, “Sector Workload Model for Benefits Analysis and Convective Weather Capacity Prediction”, in Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013.

[31] P. Lee, C. Brasil, J. Homola, A. Kessell, H. Lee, M. Mainini and T. Prevot," Benefits and Feasibility of the Flexible Airspace Management Concept: A Human-in-the-loop Evaluation of Roles, Procedures, and Tools," in 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin, 2011.

[32] Eurocontrol, NEST user manual, version 1.3, 2013-2014.

[33] Vanda Cruz, "FRAL project Free Route Airspace Lisboa FIR" by NAV Portugal, March, 2011.

[34] Description of CAPAN method doc. by Eurocontrol. URL: https://www.eurocontrol.int/sites/default/files/field_tabs/content/documents/nm/airspace/airspace-capan.pdf

[35] Eurocontrol fact sheet "Airspace Design & Capacity Planning NEST", November, 2012.

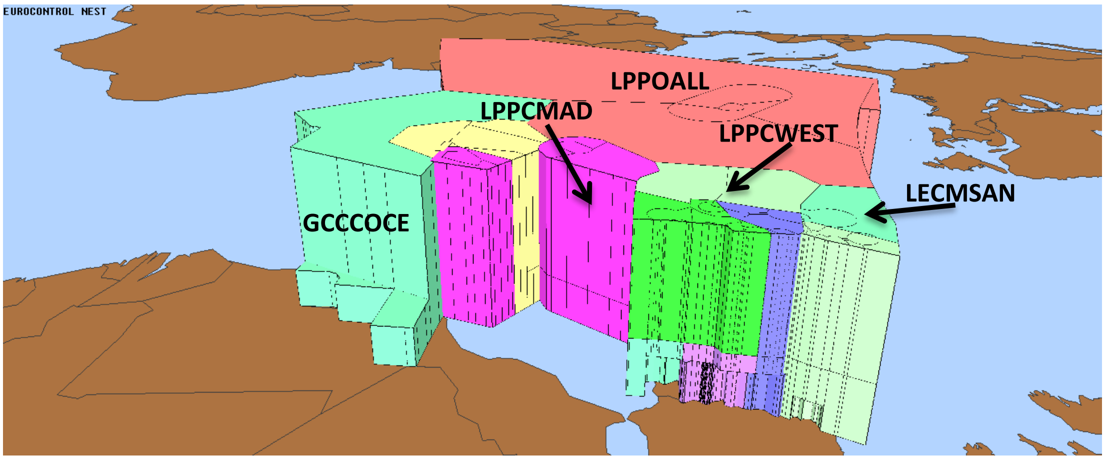
[36] Eurocontrol: Demand Data Repository (DDR) information avaible in URL: http://www.eurocontrol.int/ddr.

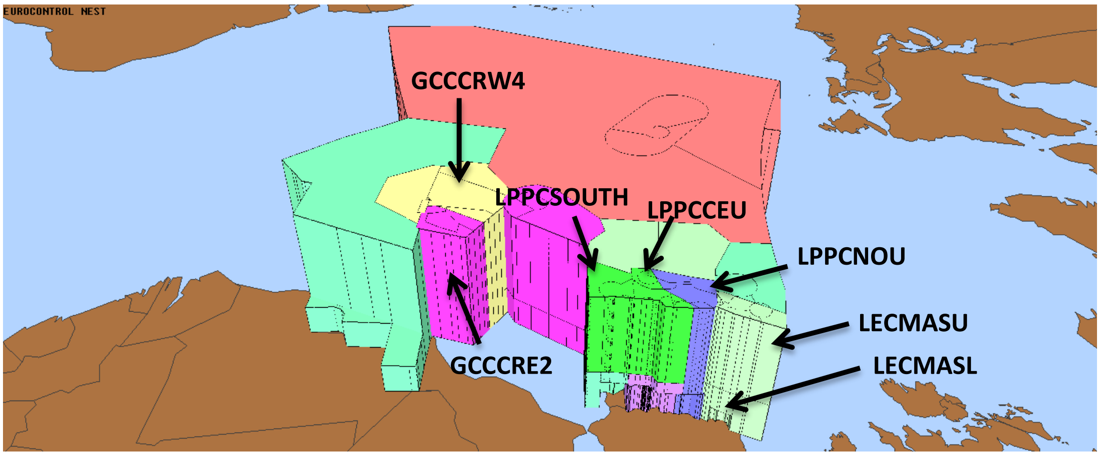
[37] ONATAP Project Final Report D2 "AIRE Performance of flight trials and demostrations validing solutions for the reduction of CO2 emission", pp 38-42, November, 2011.

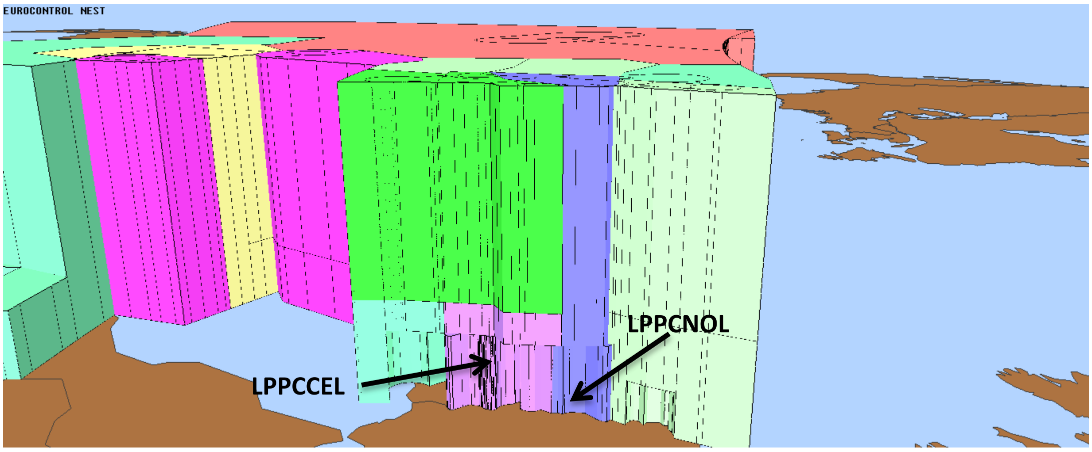
[38] Jet Fuel Price Monitor (IATA) avaible in URL: http://www.iata.org/publications/economics/fuel-monitor/Pages/index.aspx.

ANNEXES

Annex 1 Sector Locations







Annex 2 Detailed values of simulation

Baseline A (2013-2014)

BASELINE A DISTANCE RESULTS				
Days	**Baseline A Distance Flown (NM)**	**Phase 1 Distance Saved (NM) and Percentage**	**Phase 2 Distance Saved (NM) and Percentage**	**Phase 3 Distance Saved (NM) and Percentage**
Day 1	758185	**4446 0.6%**	**5602 0.74%**	**12074 1.6%**
Day 2	987482	**7347 0.74%**	**8781 0.9%**	**22907 2.3%**
Day 3	764105	**10597 1.4%**	**11566 1.5%**	**18464 2.4%**
Day 4	712746	**6642 0.9%**	**7774 1.1%**	**17345 2.4%**
Day 5	824664	**15112 1.8%**	**16305 2%**	**20257 2.5%**

BASELINE A CONFLICTS COMPARISON				
	Baseline A	PHASE I	PHASE II	PHASE III
D1	271	292	296	276
D2	534	567	560	499
D3	430	414	414	345
D4	264	247	243	223
D5	518	477	486	450

Executive controller Baseline A Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	71.03	78.08	65.88	67.08	67.38	69.89
GCCCRE2	188.35	200.22	108.62	120.9	145.7	152.758
GCCCRW4	211.85	256.35	187.48	205.22	208.37	213.854
LECMASL	88.43	98.68	61.18	64.25	71.08	76.724
LECMASU	155.02	252.2	100.55	102.07	122.98	146.564
LECMSAN	269.07	288.43	151.03	155.15	191.17	210.97
LPPCCEL	222.08	264.53	130.18	138.38	149.33	180.9
LPPCCEU	244.85	410.52	124.93	152.33	178.85	222.296
LPPCWEST	214.82	227.92	162.3	163.58	171.85	188.094
LPPCMAD	102.98	120.05	65.95	77.78	91.72	91.696
LPPCNOL	208.2	216.07	99.28	137.97	159.92	164.288
LPPCNOU	273.75	452.2	162.23	191.2	200.08	255.892
LPPCSOUTH	244.4	319.17	152.5	157.63	220.05	218.75
LPPOALL	191.12	217.68	158.17	169.25	187.65	184.774

Executive controller Baseline A Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	31.3611	22.75558
GCCCRE2	43.25	29.70556
GCCCRW4	43.1389	36.8389
LECMASL	17.3611	14.00556
LECMASU	62.1667	29.37222
LECMSAN	41.9722	32.0111
LPPCCEL	53.75	31.21666
LPPCCEU	64.6944	34.27778
LPPCWEST	33.3333	29.48332
LPPCMAD	25.3056	17.82222
LPPCNOL	36.2222	26.82776
LPPCNOU	94.6667	43.82778
LPPCSOUTH	48.3611	33.76112
LPPOALL	28.0833	25.23888

Planning controller Baseline A Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	61.13	68.98	55.47	58.93	59.58	60.818
GCCCRE2	113.45	135.13	72.23	84.75	96.82	100.476
GCCCRW4	167.5	199.18	143.78	145.62	157.53	162.722
LECMASL	61.57	64.28	43.45	43.67	45.98	51.79
LECMASU	139.03	179.48	88.48	89.33	111.75	121.614
LECMSAN	203.37	235.1	127.12	131.02	159.63	171.248
LPPCCEL	161.13	168.93	91.03	94.55	109.57	125.042
LPPCCEU	201.18	238.73	105.72	128.38	154.57	165.716
LPPCWEST	171.85	209.9	144.25	150.67	154.08	166.15
LPPCMAD	76.47	96.65	54.85	66.72	75.85	74.108
LPPCNOL	133.95	163.13	80.87	103.57	120.25	120.354
LPPCNOU	231.82	282	132.77	158.67	170.28	195.108
LPPCSOUTH	216.18	230.8	128.63	135.27	190.48	180.272
LPPOALL	182.78	221.5	147.32	161.37	162.95	175.184

Planning controller Baseline A Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	29.6944	21.14444
GCCCRE2	22.0278	17.95
GCCCRW4	30.9444	25.94998
LECMASL	12.1667	9.08892
LECMASU	33.75	21.65
LECMSAN	31.1944	26.05
LPPCCEL	28.3611	20.55556
LPPCCEU	33.8889	25.07222
LPPCWEST	32.4167	26.3
LPPCMAD	17.5	13.94444
LPPCNOL	25.3889	19.76666
LPPCNOU	48.0278	31.87222
LPPCSOUTH	33.8333	27.12222
LPPOALL	48.1944	33.1889

BASELINE B (2019)

Distance saved (NM) 2019					
	Day1	Day2	Day3	Day4	Day5
Traffic 2019 Distance Flown	887566	1155172	864701	798881	935433
Nb of Flights	1615	2173	1509	1421	1802
Traffic 2019 with SW FAB Distance Flown	872333	1128509	842913	780391.14	910193
Total Distance Saved	15233 NM 1.7%	26664 NM 2.3%	21788 NM 2.5%	18490 NM 2.3	25240 NM 2.7%

Conflicts B 2019					
	Day 1	Day 2	Day 3	Day 4	Day 5
Traffic 2019	354	714	524	291	643
Traffic 2019 SW FAB	342	636	429	274	567

Executive controller Baseline B Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	88.57	96.52	66.55	83.22	83.8	83.732
GCCCRE2	219.08	235.15	125	161.28	164.05	180.912
GCCCRW4	238.1	300.6	169.53	217.6	236.65	232.496
LECMASL	91.03	107.35	64.43	67.37	79.57	81.95
LECMASU	173.52	292.25	105.38	116.25	141.87	165.854
LECMSAN	316.65	336.32	173.13	183.58	217.13	245.362
LPPCCEL	254.23	309.42	143.18	154.47	175.18	207.296
LPPCCEU	283.28	476.2	164.12	179.52	202.8	261.184
LPPCWEST	242.07	267.42	175.68	179.22	186.2	210.118
LPPCMAD	120.2	136.87	75.42	79.07	103.67	103.046
LPPCNOL	227.92	237.25	147.03	152.58	171.58	187.272
LPPCNOU	303.98	505.42	186.17	214.68	225.15	287.08
LPPCSOUTH	289.65	377.52	185.42	198.68	246.77	259.608
LPPOALL	221.98	258.07	184.15	193.73	221.13	215.812

Executive controller Baseline B Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	37.9444	27.78334
GCCCRE2	49.0556	34.12778
GCCCRW4	52.5	40.56666
LECMASL	23.7778	16.37222
LECMASU	62.8611	29.9889
LECMSAN	51	39.57778
LPPCCEL	71.6667	38.00558
LPPCCEU	79.6944	40.44998
LPPCWEST	43.4722	32.77778
LPPCMAD	35.6389	21.74446
LPPCNOL	41.0556	30.51112
LPPCNOU	106.1111	49.68332
LPPCSOUTH	70.1667	43.30556
LPPOALL	32.6389	28.28332

Planning controller Baseline B Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	76.98	87.38	56.38	71.38	71.6	72.744
GCCCRE2	131.03	158.8	83.67	107.27	114.55	119.064
GCCCRW4	187.28	235	133.77	163.17	170.32	177.908
LECMASL	65.73	67.12	43.65	48.7	51.45	55.33
LECMASU	155.95	203.15	94.05	101.67	128.23	136.61
LECMSAN	230.32	273.68	144.43	151.82	181.4	196.33
LPPCCEL	183.77	193.72	100.42	107.52	127.2	142.526
LPPCCEU	233.23	274.57	141.35	151.98	175.05	195.236
LPPCWEST	194.38	248.88	157.82	160.67	172.18	186.786
LPPCMAD	85.9	111.38	63.4	66.75	85.43	82.572
LPPCNOL	145.43	178.85	110.17	114.17	130.22	135.768
LPPCNOU	257.9	315.5	157.37	179.02	192.58	220.474
LPPCSOUTH	254.1	271.08	160.05	171.8	213.9	214.186
LPPOALL	229.95	282.07	180.73	194.2	195.22	216.434

Planning controller Baseline B Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	40.1944	27.38332
GCCCRE2	24.3889	20.35556
GCCCRW4	34.5556	28.16666
LECMASL	12.8889	9.9889
LECMASU	37.6667	23.83334
LECMSAN	40.3333	31.51112
LPPCCEL	36.2222	24.67778
LPPCCEU	41.1944	29.41664
LPPCWEST	42	29.85554
LPPCMAD	19.4167	15.7389
LPPCNOL	27.3889	21.57224
LPPCNOU	54.4444	36.44998
LPPCSOUTH	42.3056	34.40002
LPPOALL	58.3611	41.27224

PHASE I

Executive controller Phase I Volume Taskload (Minutes)						
Sectors	**Q3**	**Max**	**Min**	**Q1**	**Q2**	**Average**
GCCCOCE	68.6	73.32	62.63	65.82	67.13	67.5
GCCCRE2	150.68	196.7	104.95	115.17	144.73	142.446
GCCCRW4	247.03	281.53	170.85	183.57	206.12	217.82
LECMASL	97.43	97.72	61.63	65.53	74.85	79.432
LECMASU	153.07	166.33	107.3	110.33	115.4	130.486
LECMSAN	219.23	271.42	147.5	174.23	185.67	199.61
LPPCCEL	202.42	218.68	127.83	140.85	147.75	167.506
LPPCCEU	225.58	232.85	160.32	170.38	186.95	195.216
LPPCWEST	178.05	221.52	149.4	155.7	173.47	175.628
LPPCMAD	90.07	115.03	60.53	85.15	87.4	87.636
LPPCNOL	173.73	229.48	122.23	141.47	162.42	165.866
LPPCNOU	239.05	261.28	156.65	171.22	175.45	200.73
LPPCSOUTH	235.17	252.85	157.68	183.58	215.13	208.882
LPPOALL	177.58	206.1	155.08	161.18	174.25	174.838

Executive controller Phase I Taskload Peak (%)		
Sectors	**Max**	**Average**
GCCCOCE	27.8889	21.47224
GCCCRE2	32.1111	24.85554
GCCCRW4	63.4444	38.67778
LECMASL	16.0556	13.81668
LECMASU	28.8056	23.45002
LECMSAN	34	31.1
LPPCCEL	43.3333	30.39444
LPPCCEU	40.25	31.41112
LPPCWEST	32.8056	27.55558
LPPCMAD	19.9722	16.40554
LPPCNOL	33.3889	28.07222
LPPCNOU	35.5833	30.9611
LPPCSOUTH	38.6667	32.22222
LPPOALL	27.1111	24.15002

Planning controller Phase I Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	61.13	68.95	55.33	59.28	59.45	60.828
GCCCRE2	106.32	137.37	73.12	87.25	98.15	100.442
GCCCRW4	173.25	197.22	134.87	144.17	165.13	162.928
LECMASL	69.95	70.35	41.9	42.15	56.08	56.086
LECMASU	136.95	146.57	94.42	94.85	95.68	113.694
LECMSAN	188.7	237.98	128.17	141.03	163.35	171.846
LPPCCEL	147.65	172.27	92.4	95.97	103.22	122.302
LPPCCEU	191.13	194.48	133.58	135.68	147.8	160.534
LPPCWEST	164.03	210.3	140.82	150.03	159.82	165
LPPCMAD	75.85	96.08	54.45	69.05	72.72	73.63
LPPCNOL	131.57	174.98	93.83	107.08	130.05	127.502
LPPCNOU	211.07	229.15	129.35	135.67	151.7	171.388
LPPCSOUTH	207.13	218.32	132.52	138.25	189.33	177.11
LPPOALL	184.07	223.42	153.13	161	161.6	176.644

Planning controller Phase I Taskload Peak (%)		
Sector	**Max**	**Average**
GCCCOCE	29.1667	20.57778
GCCCRE2	21.9444	17.68888
GCCCRW4	31.9722	26.3111
LECMASL	11.6111	9.43334
LECMASU	24.9444	20.20556
LECMSAN	30.8889	26.4389
LPPCCEL	25.1111	20.02222
LPPCCEU	27.1667	24.54446
LPPCWEST	34.4167	26.68334
LPPCMAD	17.5833	13.86112
LPPCNOL	25.5	20.5111
LPPCNOU	29.8056	25.77778
LPPCSOUTH	34.4722	27.33332
LPPOALL	48.1944	33.1722

PHASE II

Executive controller Phase II Volume Taskload (Minutes)						
Sectors	**Q3 Min**	**Max Min**	**Minimum Min**	**Q1 Min**	**Q2 Min**	**Average Min**
GCCCOCE	74.82	79	68.13	70.83	71.6	72.876
GCCCRE2	150.68	196.7	104.95	115.17	144.73	142.446
GCCCRW4	250.07	284.82	170.72	183.65	206.17	219.086
LECMASL	96.1	97.43	61.73	65.9	74.85	79.202
LECMASU	153.43	168.37	107.98	111.8	115.3	131.376
LECMSAN	219.33	269.73	147.43	179.03	187.05	200.514
LPPCCEL	200.23	221.75	125.53	138.85	149.72	167.216
LPPCCEU	228.23	229.92	163.78	171.27	185.72	195.784
LPPCWEST	175.85	218.78	147.73	155.1	174.32	174.356
LPPCMAD	90.98	111.98	61.18	78.02	87.63	85.958
LPPCNOL	170.47	222.77	121.87	138.98	163.03	163.424
LPPCNOU	239.73	266.48	159.1	174.53	174.83	202.934
LPPCSOUTH	235.47	253.02	157.43	181.42	215.3	208.528
LPPOALL	163.58	189.05	151.78	154.6	157.9	163.382

Executive controller Phase II Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	29.2778	24
GCCCRE2	32.1111	24.85554
GCCCRW4	65.4444	39.55
LECMASL	16.0556	13.81668
LECMASU	28.8056	23.57224
LECMSAN	38.6667	32.19446
LPPCCEL	43.3333	30.23334
LPPCCEU	40.1944	31.27776
LPPCWEST	35.25	28.1
LPPCMAD	19.3611	15.87778
LPPCNOL	32.5833	27.75
LPPCNOU	33.8611	30.73334
LPPCSOUTH	38.6667	32.24998
LPPOALL	23.1389	21.5

Planning controller Phase II Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	70.8	72.23	61.1	62.82	65.58	66.506
GCCCRE2	106.32	137.37	73.12	87.25	98.15	100.442
GCCCRW4	174.08	197.22	134.88	144.18	165.13	163.098
LECMASL	69.07	70.35	42	42.47	56.08	55.994
LECMASU	137.27	148.23	94.75	95.68	96.32	114.45
LECMSAN	188.7	237.82	129.35	140.87	165.13	172.374
LPPCCEL	145.78	172.72	91.57	94.13	101.42	121.124
LPPCCEU	191.62	197.17	135.27	138.43	148.62	162.222
LPPCWEST	164.88	203.58	139.7	149.43	160.97	163.712
LPPCMAD	77.32	95.13	55.98	64.03	73.42	73.176
LPPCNOL	131.13	169.4	93.45	104.82	128.95	125.55
LPPCNOU	212.07	233.65	131.07	137.68	154.77	173.848
LPPCSOUTH	206.92	218.32	132.18	136.67	189.32	176.682
LPPOALL	194.18	227.62	157.32	173.02	178.5	186.128

Planning controller Phase II Taskload Peak (%)		
Sectors	**Max**	**Average**
GCCCOCE	30.9167	23.2889
GCCCRE2	21.9444	17.68888
GCCCRW4	32.2778	26.3778
LECMASL	11.6111	9.43334
LECMASU	24.9444	20.31112
LECMSAN	30.8889	26.32778
LPPCCEL	25.1111	19.9111
LPPCCEU	27.1667	24.34446
LPPCWEST	30.8333	25.69444
LPPCMAD	17.6944	13.88888
LPPCNOL	24.6667	20.16112
LPPCNOU	30.3333	26.26668
LPPCSOUTH	34.4722	27.40554
LPPOALL	49.8056	34.61114

PHASE III

Executive controller Phase III Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	70.85	73.78	61.6	64.53	65	67.152
GCCCRE2	178.07	210.75	97	119.8	159.88	153.1
GCCCRW4	254.83	297.93	199.2	224.97	235.88	242.562
LECMASL	101.92	105.82	61.43	71.03	77.73	83.586
LECMASU	182.2	225.25	115.98	119.05	122.67	153.03
LECMSAN	276.75	334.58	166.32	179.17	246.38	240.64
LPPCCEL	258.28	384.32	146.93	151.7	180.08	224.262
LPPCCEU	324.67	326.35	185.22	220.72	229.5	257.292
LPPCWEST	206.53	247.22	161.55	171.28	178.8	193.076
LPPCMAD	94.2	107.65	59.3	67.93	88.95	83.606
LPPCNOL	245.18	296.5	118.28	173.73	235.98	213.934
LPPCNOU	347.77	428.6	181.37	212.72	252.68	284.628
LPPCSOUTH	291.95	304.78	177.55	178.18	266.82	243.856
LPPOALL	177.48	220.8	152.8	171.48	172.62	179.036

Executive controller Phase III Taskload Peak (%)		
Sectors	**Max**	**Average**
GCCCOCE	26.8611	22.55556
GCCCRE2	59.4167	36.25
GCCCRW4	57.3611	49.62778
LECMASL	21.7778	17.13888
LECMASU	42.3611	29.49444
LECMSAN	55.0556	43.11668
LPPCCEL	78.3333	48.18888
LPPCCEU	59.0833	48.18334
LPPCWEST	35.4444	32.23332
LPPCMAD	18.6111	16.57778
LPPCNOL	60.3056	43.26112
LPPCNOU	68.0556	50.94998
LPPCSOUTH	52.0833	44.63888
LPPOALL	40.8333	28.78334

Planning controller Phase III Volume Taskload (Minutes)						
Sectors	**Q3**	**Max**	**Min**	**Q1**	**Q2**	**Average**
GCCCOCE	**70.75**	**71.42**	**58.87**	**61.27**	**64.43**	**65.348**
GCCCRE2	**115.53**	**149.62**	**75.77**	**89.35**	**112.78**	**108.61**
GCCCRW4	**175.78**	**208.38**	**141.93**	**155**	**167.62**	**169.742**
LECMASL	**73.17**	**73.33**	**41.37**	**47.02**	**59.15**	**58.808**
LECMASU	**148.27**	**165.15**	**95.52**	**100.42**	**102.17**	**122.306**
LECMSAN	**205.6**	**256.87**	**135.72**	**141.2**	**182.2**	**184.318**
LPPCCEL	**164.72**	**214.17**	**92**	**101.4**	**118.43**	**138.144**
LPPCCEU	**216.63**	**221.6**	**135.57**	**149.18**	**166.87**	**177.97**
LPPCWEST	**172.25**	**209.73**	**143.17**	**154**	**161.45**	**168.12**
LPPCMAD	**78.07**	**89.23**	**54.68**	**59.97**	**76.17**	**71.624**
LPPCNOL	**151**	**191.6**	**91.28**	**116.13**	**149.48**	**139.898**
LPPCNOU	**239.63**	**275**	**137.43**	**151.73**	**176.65**	**196.088**
LPPCSOUTH	**227.27**	**235.98**	**137.25**	**139.7**	**205.95**	**189.23**
LPPOALL	**197.05**	**237.27**	**158.9**	**180.95**	**185.45**	**191.924**

Planning controller Phase III Taskload Peak (%)		
Sectors	**Max**	**Average**
GCCCOCE	29.5556	23.20002
GCCCRE2	25.4444	20.32222
GCCCRW4	33.25	27.95
LECMASL	13.9444	10.3611
LECMASU	29	22.26666
LECMSAN	34.3333	28.99446
LPPCCEL	34.8889	23.52222
LPPCCEU	33.6667	28.75556
LPPCWEST	30.1111	26.38332
LPPCMAD	16.1389	13.59442
LPPCNOL	29.4444	22.69444
LPPCNOU	35.7778	30.05556
LPPCSOUTH	37.9167	30.26668
LPPOALL	50.1944	35.10554

TRAFFIC SIMULATED TO 2019

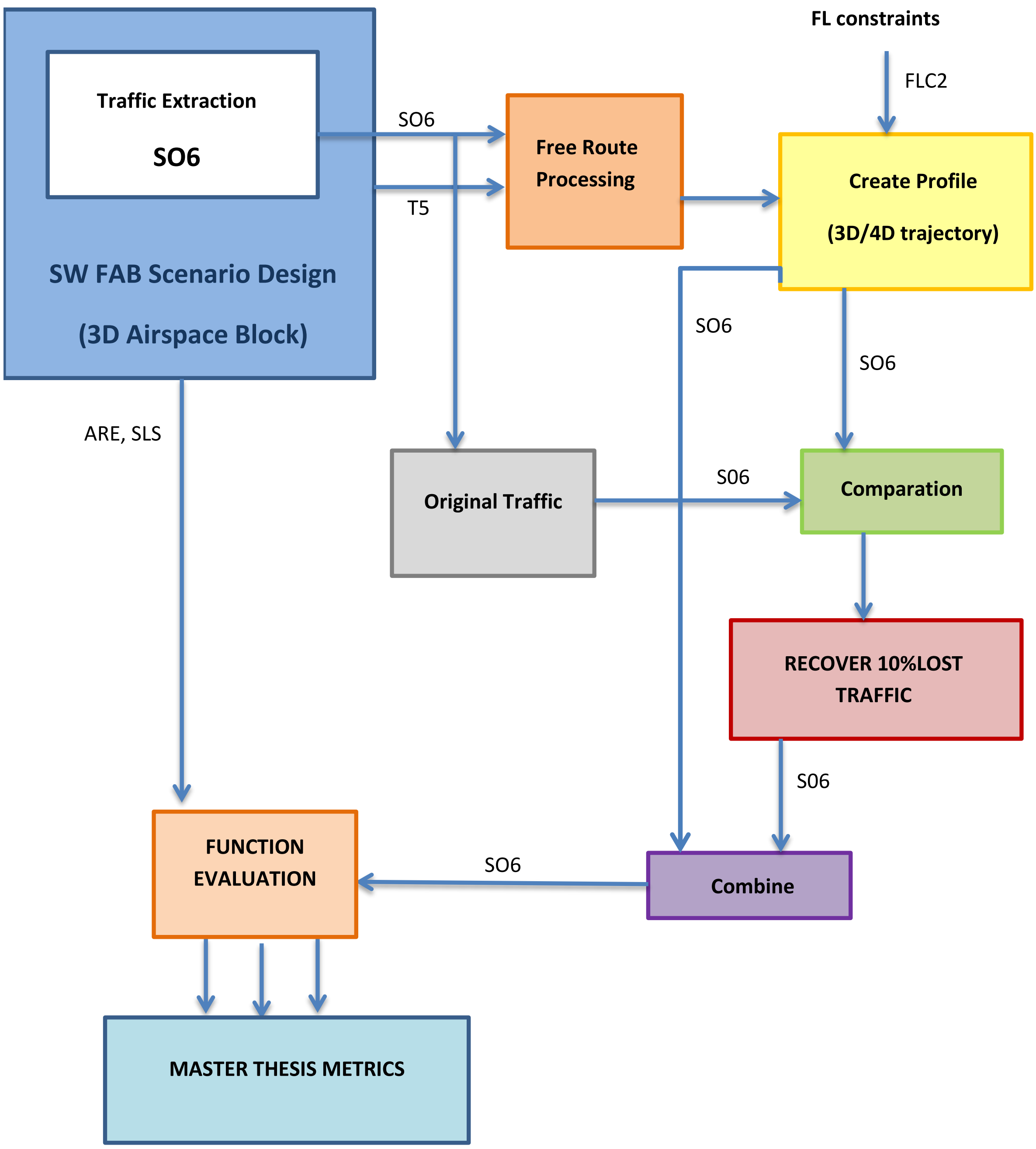
Executive controller 2019 Traffic Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	85.62	85.77	69.45	76.3	85.27	80.482
GCCCRE2	178.23	227.87	114.7	157.95	159.58	167.666
GCCCRW4	230.52	278.1	161.48	204.95	226.15	220.24
LECMASL	103.75	116.07	65.08	79.32	89.68	90.78
LECMASU	164.83	256.77	106.55	118.13	125.9	154.436
LECMSAN	311.15	317.75	166.93	175.63	210.47	236.386
LPPCCEL	260.52	303.37	140.12	145.1	174.27	204.676
LPPCCEU	264.43	387.82	164.73	178.93	192.78	237.738
LPPCWEST	232.03	251.93	160.17	168.87	174.12	197.424
LPPCMAD	105.7	115.47	68.53	83.63	99.12	94.49
LPPCNOL	247.88	249.72	145	149.62	183.07	195.058
LPPCNOU	291.65	396.75	173.32	176.55	197.6	247.174
LPPCSOUTH	298.12	369.35	185.55	201.53	241.03	259.116
LPPOALL	208.43	227.12	174.53	180.53	193.77	196.876

Executive controller 2019 Traffic Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	33.0833	27.29998
GCCCRE2	42.5	32.58888
GCCCRW4	46.1667	38.76666
LECMASL	21.7778	16.1278
LECMASU	53.6944	27.92222
LECMSAN	57.9722	38.67222
LPPCCEL	66	35.5
LPPCCEU	62.8889	37.84442
LPPCWEST	45.6111	31.85
LPPCMAD	27.3611	19.5222
LPPCNOL	61.8333	35.03334
LPPCNOU	71.8889	39.05558
LPPCSOUTH	63.1944	42.0222
LPPOALL	32.3056	27.30556

Planning controller 2019 Traffic Volume Taskload (Minutes)						
Sectors	Q3	Max	Min	Q1	Q2	Average
GCCCOCE	83.17	88.92	66.63	74.63	82.43	79.156
GCCCRE2	132.15	165.08	85.02	111.48	121.07	122.96
GCCCRW4	185.72	229.28	131.7	161.25	166.13	174.816
LECMASL	75.82	78.85	45.28	52.27	68.18	64.08
LECMASU	148.75	184.4	91.62	105.52	108.5	127.758
LECMSAN	231.68	277.42	147.2	153.43	188.68	199.682
LPPCCEL	189.65	204.05	103.68	107.57	129.4	146.87
LPPCCEU	223.38	255.12	143.55	151.42	168.27	188.348
LPPCWEST	194.17	235.15	152.8	161.02	168.57	182.342
LPPCMAD	84.62	99.47	62.45	74.3	84.37	81.042
LPPCNOL	161.55	192.8	109.68	112.95	141.22	143.64
LPPCNOU	253.82	268.45	150.5	152.9	175.55	200.244
LPPCSOUTH	260	268.7	157.5	172.18	214.98	214.672
LPPOALL	245.45	294.55	203.4	216.23	219.78	235.882

Planning controller 2019 Traffic Taskload Peak (%)		
Sectors	Max	Average
GCCCOCE	41.7778	30.25002
GCCCRE2	24.2778	21.22222
GCCCRW4	35.75	27.46666
LECMASL	13.9444	10.86666
LECMASU	32.5556	22.26666
LECMSAN	38.8333	31.8222
LPPCCEL	35.4444	23.82776
LPPCCEU	40.1667	30.3778
LPPCWEST	40.5278	28.91666
LPPCMAD	19.2778	15.96112
LPPCNOL	32.5833	23.43332
LPPCNOU	37.9722	29.65
LPPCSOUTH	39.3056	33.40002
LPPOALL	59.4444	44.96666

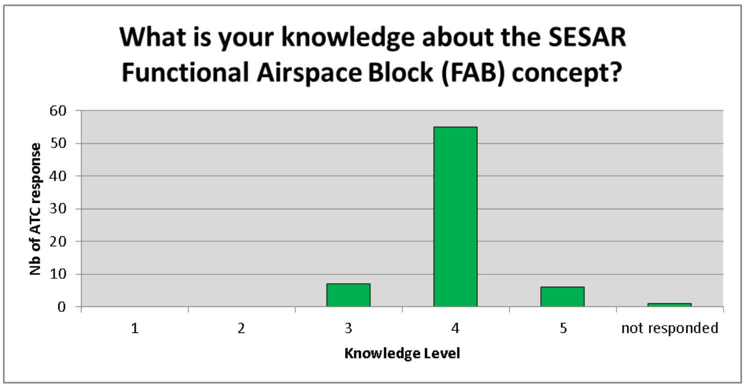
Annex 3 Simulation Scheme



Annex 4 Quiz Responses of ATC controllers

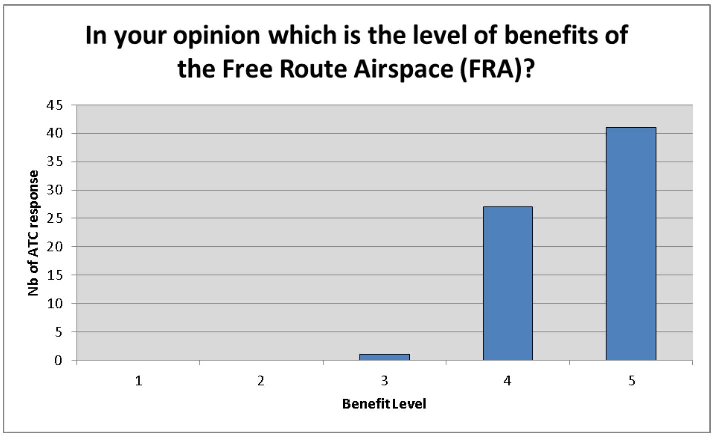
Lisbon Free route controller's responses

1



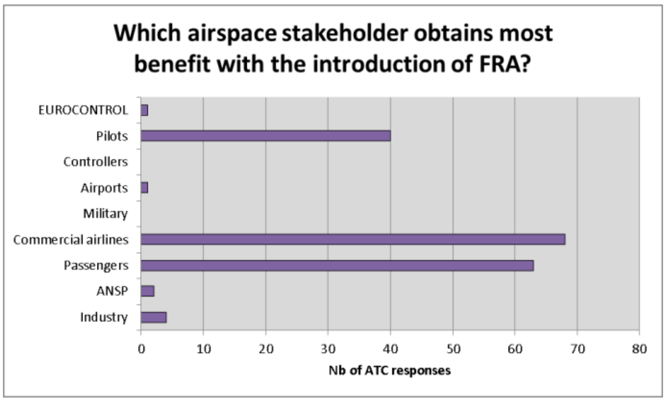
Knowledge Level	Nb of responses	
1	0	-
2	0	-
3	7	10%
4	55	80%
5	6	9%
not responded	1	1%
Total	69	100%

2



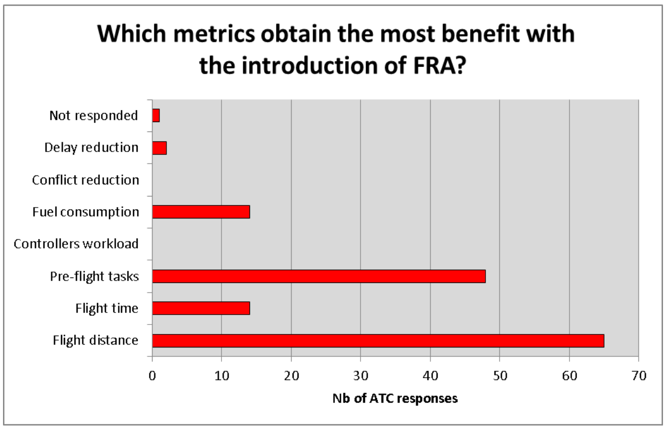
Benefit Level	Nb of ATC response	
1	0	-
2	0	-
3	1	1%
4	27	39%
5	41	59%
Total	69	100%

3



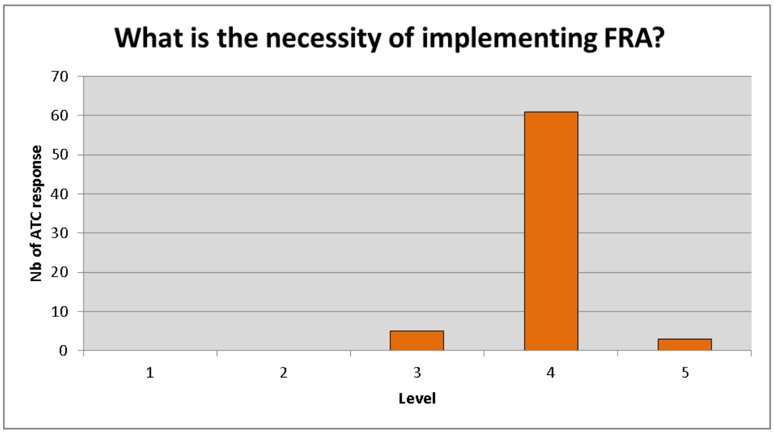
Stakeholders	ATC responses	
Industry	4	5.8%
ANSP	2	2.9%
Passengers	63	91.3%
Commercial airlines	68	98.6%
Military	0	-
Airports	1	1.4%
Controllers	0	-
Pilots	40	56%
EUROCONTROL	1	1.45%

4



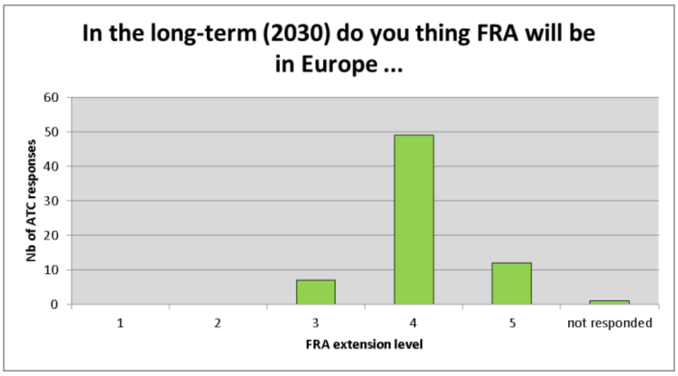
Metrics	ATC responses	
Flight distance	65	94.2%
Flight time	14	20.3%
Pre-flight tasks	48	69.6%
Controllers workload	0	-
Fuel consumption	14	20.3%
Conflict reduction	0	-
Delay reduction	2	2.9%
Not responded	1	1.45%

5



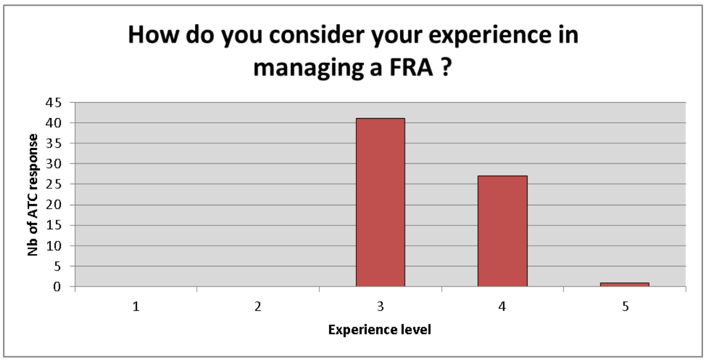
Necessity Level	Nb of ATC responses	
1	0	0%
2	0	0%
3	5	7%
4	61	88%
5	3	4%
Total	69	100%

6



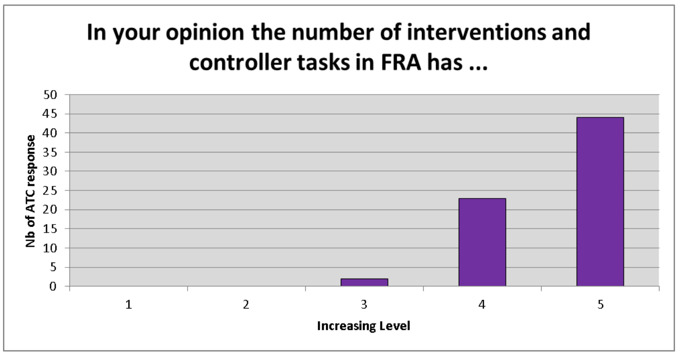
Extesion Level	Nb of ATC responses	
1	0	-
2	0	-
3	7	10%
4	49	71%
5	12	17%
not responded	1	1%
Total	69	100%

7



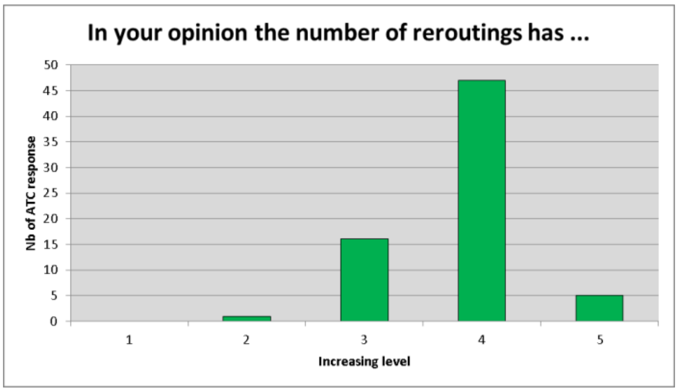
Experience level	Nb of ATC responses	-
1	0	-
2	0	-
3	41	59%
4	27	39%
5	1	1%
Total	69	100%

8



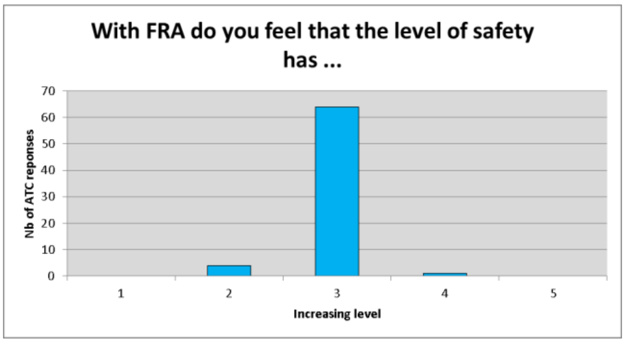
ATC interventions increasing level	Nb of ATC responses	-
1	0	-
2	0	-
3	2	3%
4	23	33%
5	44	64%
Total	69	100%

9



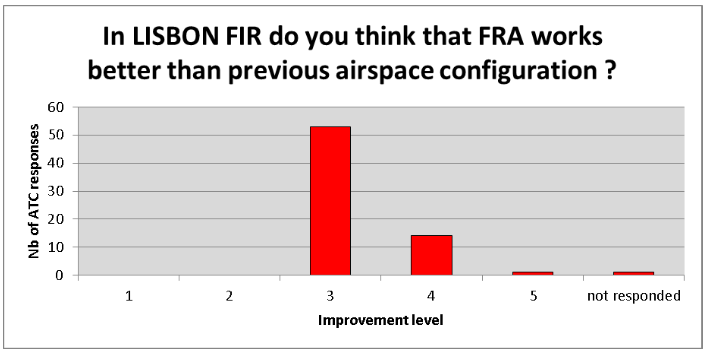
Rerouting increasing level		-
1	0	-
2	1	1%
3	16	23%
4	47	68%
5	5	7%
Total	69	100%

10



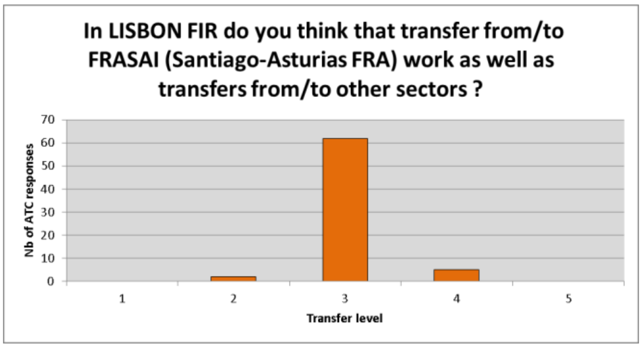
Safety increasing level	Nb of ATC responses	-
1	0	-
2	4	6%
3	64	93%
4	1	1%
5	0	-
Total	69	100%

11



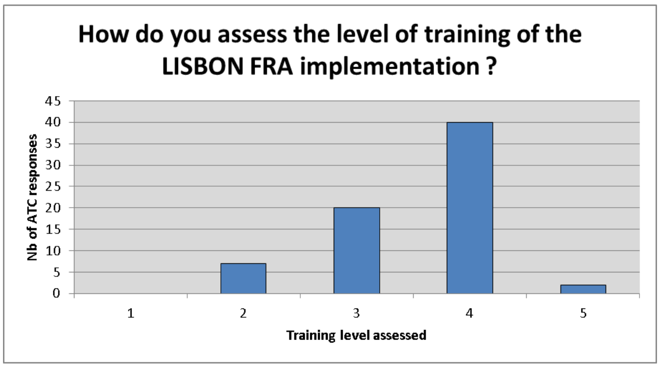
FRA improvement level	Nb of ATC responses	
1	**0**	**-**
2	**0**	**-**
3	**53**	**77%**
4	**14**	**20%**
5	**1**	**1%**
not responded	**1**	**1%**
Total	**69**	**100%**

12



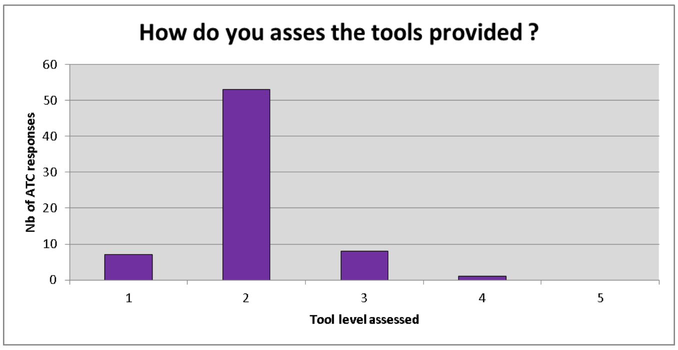
Transfer level	Nb of ATC responses	-
1	0	-
2	2	3%
3	62	90%
4	5	7%
5	0	-
Total	69	100%

13



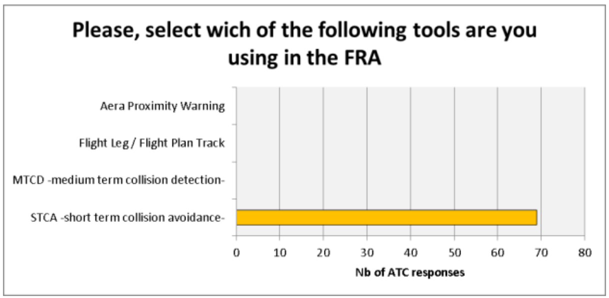
Training level assessed	Nb of ATC responses	-
1	0	-
2	7	10%
3	20	29%
4	40	58%
5	2	3%
Total	69	100%

14



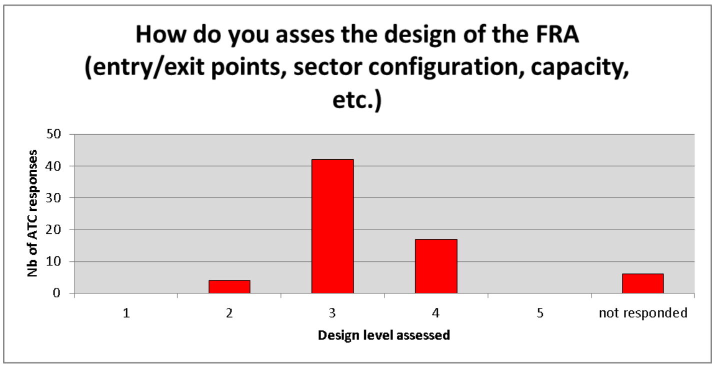
Tool level assessed	Nb of ATC responses	
1	7	10%
2	53	77%
3	8	12%
4	1	1%
5	0	-
Total	69	100%

15



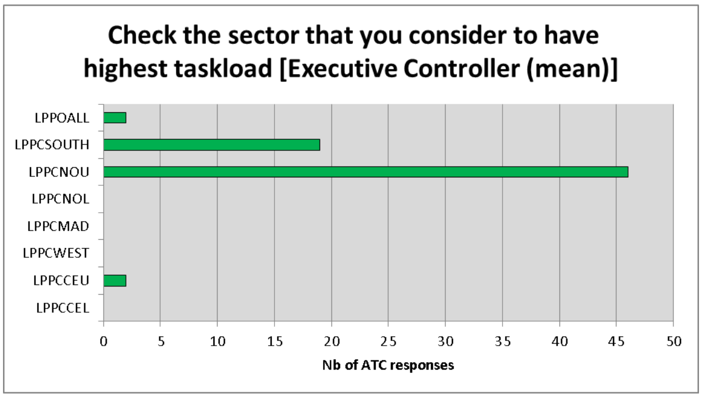
Tools	Nb of ATC responses	-
STCA -short term collision avoidance-	69	100%
MTCD -medium term collision detection-	0	-
Flight Leg / Flight Plan Track	0	-
Aera Proximity Warning	0	-

16



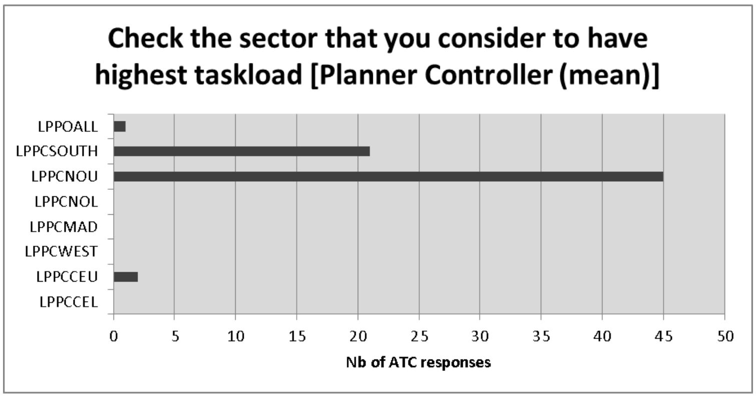
Design level assessed	Nb of ATC responses	
1	0	-
2	4	6%
3	42	61%
4	17	25%
5	0	-
not responded	6	9%
Total	69	100%

17



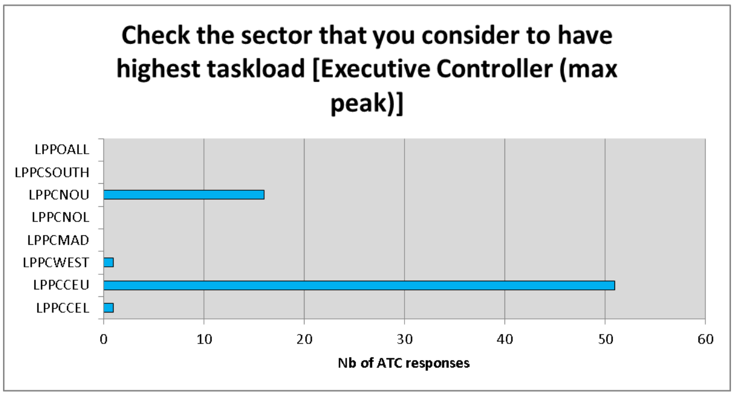
Sectors	Nb of ATC responses	-
LPPCCEL	0	-
LPPCCEU	2	3%
LPPCWEST	0	-
LPPCMAD	0	-
LPPCNOL	0	-
LPPCNOU	46	67%
LPPCSOUTH	19	28%
LPPOALL	2	3%
Total	69	100%

18



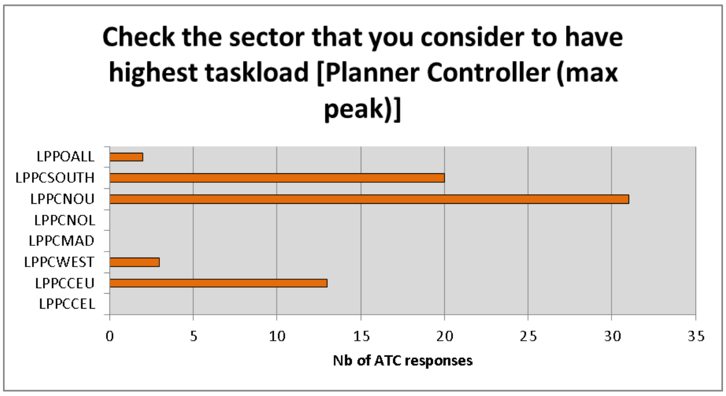
Sectors	Nb of ATC responses	
LPPCCEL	0	-
LPPCCEU	2	3%
LPPCWEST	0	-
LPPCMAD	0	-
LPPCNOL	0	-
LPPCNOU	45	65%
LPPCSOUTH	21	30%
LPPOALL	1	1%
Total	69	100%

19



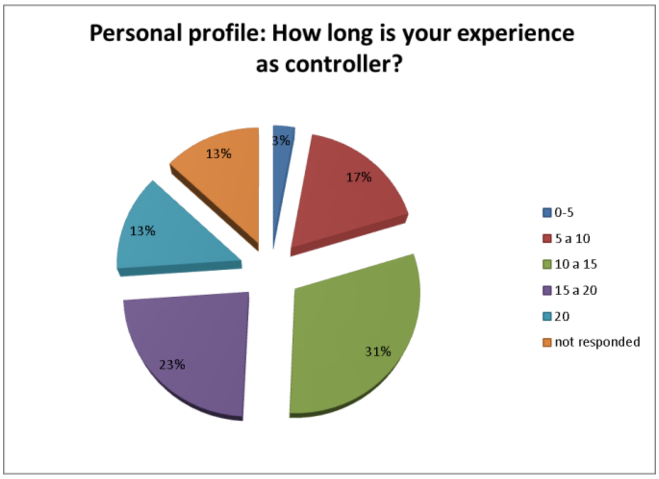
Sec tors	Nb of ATC reponses	
LPPCCEL	1	1%
LPPCCEU	51	74%
LPPCWEST	1	1%
LPPCMAD	0	-
LPPCNOL	0	-
LPPCNOU	16	23%
LPPCSOUTH	0	-
LPPOALL	0	-
Total	69	100%

20



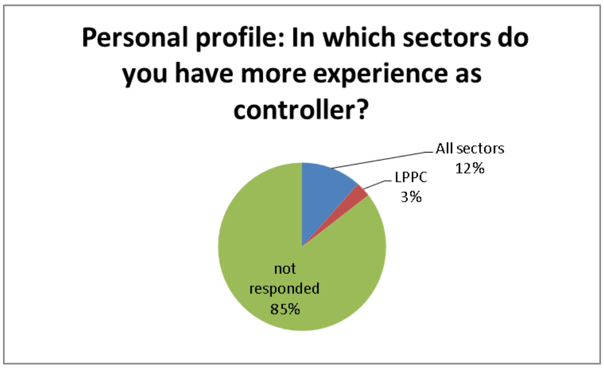
Sectors	Nb of ATC responses	
LPPCCEL	0	-
LPPCCEU	13	19%
LPPCWEST	3	4%
LPPCMAD	0	-
LPPCNOL	0	-
LPPCNOU	31	45%
LPPCSOUTH	20	29%
LPPOALL	2	3%
Total	69	100%

21



ATC experience (years)	ATCs	
0-5	2	3%
5 a 10	12	17%
10 a 15	21	30%
15 a 20	16	23%
20	9	13%
not responded	9	13%
Total	69	100%

22



Sectors	ATCs	
All sectors	8	12%
LPPC	2	3%
Not responded	59	86%
Total	69	100%