



# **Performance Metrics in Air Traffic Management Systems**

A Case Study of Isavia's  
Air Traffic Management System

by

Hulda Ástþórsdóttir

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Hulda Ástþórsdóttir

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Supervisors:

Þorgeir Pálsson, Professor, Reykjavik University  
Guðmundur Kristjánsson, Project Manager (R&D), Isavia

Examiner:

Runólfur Smári Steinþórsson, Professor, University of Iceland

## Abstract

Over several years there has been increasing demand world-wide for more capacity in Air Traffic Management Systems as air traffic has continued to grow. At the same time there is growing demand for quality of the service provided by the Air Navigation Service Providers as well as for lower charges. This has led to efforts by the European Union, through a major initiative called the Single European Sky, to increase the efficiency of Air Traffic Management in Europe. As a result of this development, much emphasis has been put on efforts to control cost and use financial resources in a more efficient way. An important development for this purpose has been the introduction of formal metrics for assessing service provider performance.

The airspace controlled by Iceland, the Reykjavík Control Area, spans approximately 5.4 million square kilometres and is mainly oceanic apart from the area over northern Greenland. Isavia is the Air Navigation Service Provider responsible for providing air navigation services in this area. This study is directed at the en-route Air Navigation Service provided in this area.

The aims of this thesis are to analyse and evaluate the metrics that are currently used to measure the performance of Air Navigation Service Providers and to develop a system of performance metrics for the Icelandic Air Traffic Management System. In this thesis, performance metrics which have been used in benchmarking Air Navigation Service Providers were studied as well as the factors affecting performance. Several performance metrics are calculated using data from Isavia. The results of the calculations are compared to other oceanic Air Navigation Service Providers. The productivity was also compared to the Maastricht Upper Area Control Centre since this centre provides only en-route Air Navigation Services similar to the oceanic en-route services provided by Isavia.

Isavia offers user-preferred tracks in most of its control area. Also radar surveillance is available in a large part of the area. This affords more flexibility to the user but increases the complexity of the air traffic and hence decreases the productivity of the ATM system. Several other factors affect the ATM system performance, such as traffic variability and the size of the Air Navigation Service Provider. All of these aspects are addressed and evaluated in this research. However a direct comparison is difficult as some of this information, apart from the volume of business, is not available for oceanic Air Navigation Service Providers which are used in the comparison.

It is concluded that in general the Air Traffic Services being provided by Isavia are very competitive compared with other Oceanic Air Navigation Service Providers. This is based on performance and financial metrics taking into account the effects of complexity and variability of air traffic in the area.

**Keywords:** *ATM, Performance, Metrics, Oceanic Airspace, Complexity.*

## Ágrip

Á undanförunum árum hefur flugumferð í heiminum aukist mikið sem hefur leitt af sér kröfur um meiri afköst í rekstri flugstjórnarkerfa. Á sama tíma eru gerðar auknar kröfur um gæði þeirra þjónustu sem veitt er og lækkun gjalda.

Við þessu hefur Evrópusambandið brugðist með því að koma á fót framtaksverkefni um samevrópskt loftrými (e. Single European Sky) til að auka skilvirkni í rekstri flugleiðsögukerfa í Evrópu. Þetta hefur leitt til þess að aukin áhersla hefur verið lögð á að takmarka kostnað og hagræða í rekstri. Mikilvægur þáttur í þessari þróun er innleiðing frammistöðumælikvarða.

Íslenska loftrýmið er um 5,4 milljónir ferkílómetra að stærð og er að miklu leyti yfir úthafinu, að undanskildu svæðinu yfir norðurhluta Grænlands. Isavia annast flugleiðsöguþjónustu í íslenska loftrýminu og beinist þetta verkefni að alþjóðaflugþjónustunni sem Isavia veitir.

Markmið þessa verkefnis er að greina og meta þá mælikvarða, sem nú eru notaðir til að mæla frammistöðu flugleiðsögukerfa ásamt því að þróa kerfi slíkra mælikvarða fyrir íslenska flugleiðsögukerfið. Í þessu verkefni eru skoðaðir frammistöðumælikvarðar sem hafa verið notaðir til að bera saman frammistöðu flugleiðsögukerfa ásamt því að skoða þá þætti sem hafa áhrif á samanburðinn.

Með gögnum frá Isavia eru reiknaðir nokkrir mælikvarðar fyrir íslenska flugleiðsögukerfið. Niðurstaðan úr þessum útreikningum er borin saman við útkomu hjá öðrum aðilum sem reka flugleiðsögukerfi á úthafssvæði. Framleiðnin var einnig borin saman við framleiðni Maastricht Upper Area Control Centre, þar sem þeir þjóna eingöngu flugleiðsögu í leiðarflugi, en það á einnig við um þá þjónustu sem veitt er á íslenska úthafssvæðinu.

Isavia býður upp á sveigjanleika fyrir flugrekendur í vali á flugleiðum innan stærsta hluta flugstjórnarsvæðisins. Ratsjárþjónusta er einnig veitt á stórum hluta svæðisins Þetta hefur í för með sér að flækjustig flugumferðarinnar eykst sem aftur á móti stuðlar að minni framleiðni

Nokkrir aðrir þættir hafa einnig áhrif á frammistöðuna, s.s. hversu breytileg flugumferðin er á svæðinu ásamt því hversu mikil flugumferð fer í gegnum svæðið. Í verkefninu er fjallað um þessa þætti og áhrif þeirra skoðuð. Ekki liggja fyrir nægar tölulegar upplýsingar um þessa þætti hjá þeim aðilum sem veita flugleiðsöguþjónustu á úthafssvæðum og því er erfitt að gera beinan samanburð milli þessara aðila.

Á grundvelli útreikninga á framleiðni- og fjárhagslegum mælikvörðumvar var lagt mat á frammistöðu íslenska flugleiðsögukerfisins. Almenna niðurstaðan er sú að flugleiðsögukerfi Isavia og sú þjónusta, sem veitt er á úthafinu, sé mjög samkeppnishæft við aðra aðila sem veita flugleiðsöguþjónustu á úthafssvæðum að teknu tilliti til þess hve umferðin er flókin og breytileiki hennar mikill frá degi til dags og milli árstíða.

**Lykilorð:** *Flugumferðarstjórn, Flugleiðsögukerfi, Frammistöðumælikvarðar, Framleiðni.*

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Rukólfur Smári Steinþórsson

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## Abbreviations

3Di Score	3-Dimensional Inefficiency Score
A/C	Aircraft
ACC	Area Control Centre
ACE	ATM Cost-Effectiveness
ACE Report	ATM Cost-Effectiveness Benchmarking Report
ADS-B	Automatic Dependent Surveillance–Broadcast
ADS-C	Automatic Dependent Surveillance–Contract
AFTN	Aeronautical Fixed Telecommunication Network
AIS	Aeronautical Information Service
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
APP	Approach Control Unit
ATM	Air Traffic Management
ATC	Air Traffic Control
ATCO	Air Traffic Controller/Air Traffic Control Officer
ATCO in OPS	Air Traffic Controller on operational duty
ATS	Air Traffic Service
ATFM	Air Traffic Flow Management
ATFCM	Air Traffic Flow and Capacity Management
ASM	Airspace Management
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation Services Organization
CFMU	Central Flow Management Unit
CNS	Communication, Navigation, Surveillance
COM	Communication
CPDLC	Controller Pilot Data Link Communication
CPL	Current Plan
CRC	Control and Reporting Centre
DLCS	Data Link Communication System
DLSP	Data Link Service Provider
EU	European Union
FAA	Federal Aviation Administration
FAB	Functional Airspace Block
FANS	Future Air Navigation System
FDPS	Flight Data Processing System
FIR	Flight Information Region
FIS	Flight Information Service
FL	Flight Level
FMS	Flight Management System
FPL	Flight Plan
FSFE	Fans Front End
FTE	Full Time Equivalent
GBWG	Global Benchmarking Workgroup
GPS	Global Positioning System

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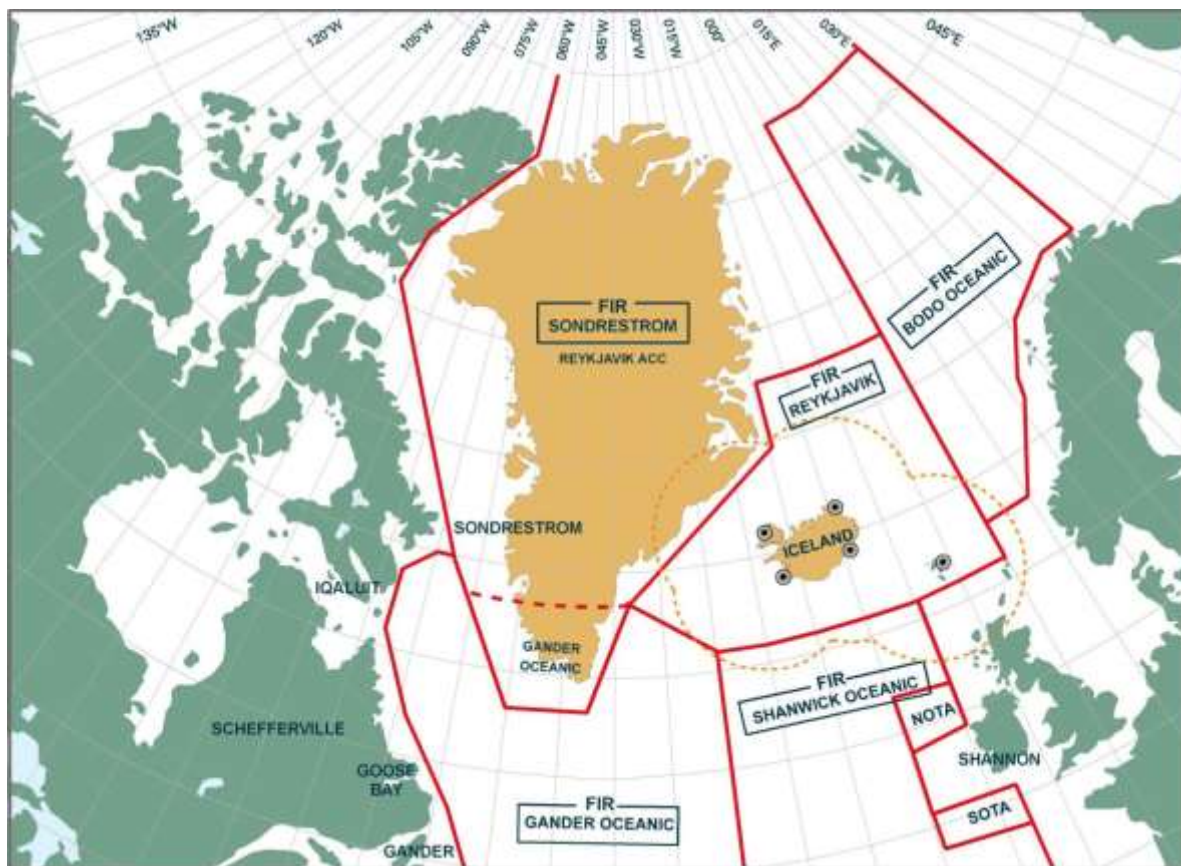
HF	High Frequency
HFDL	High Frequency Data Link
ICE	Integrated Controller Environment
IFR	Instrument Flight Rules
ICAO	International Civil Aviation Organisation
IPT	The FAA Oceanic and Offshore Integrated Product Team
INS	Inertial Navigation System
ISDS	Integrated Situation Display System
KPI	Key Performance Indicators
MET	Meteorological services
NAS	National Airspace System
NAT	North Atlantic
NAT OTS	North Atlantic Organized Track System
NATS	National Air Traffic Services
NM	Nautical Miles
NOTAM	Notices To Airman
OAC	Oceanic Area Control Centre
PPP	Purchasing Power Parity
PRC	The Performance Review Commission
PRR	Performance Review Report
PRU	The Performance Review Unit
SAR	Search and Rescue
SES	Single European Sky
SOR	Safety Occurrence Reporting
SESAR	Single European Sky ATM Research
SIGMET	Significant Meteorological Information
TMA	Terminal Manoeuvring Area
VFR	Visual Flight Rules

## 1. Introduction

The overall goal of this project is to develop a system of performance metrics that can be used to describe the performance of the Air Traffic Management System operated by Isavia for controlling air traffic in its area of responsibility in the North Atlantic Region. The project will be aimed at defining these metrics based on a thorough analysis and modelling of the Air Traffic Management system.

### 1.1 Background

The airspace above us is a limited resource which is under the jurisdiction of sovereign states or, in the case of international airspace, governed by the International Civil Aviation Organization (ICAO)<sup>1</sup> as far as civil aviation is concerned. Each state has full control over the airspace above its sovereign territory. Typically Air Navigation Services (ANS) in this airspace are delegated to an Air Navigation Service Provider (ANSP)<sup>2</sup>, which in most cases is a state agency or a state-owned organization. Isavia ohf. (Isavia), a state-owned limited liability company, is the designated ANSP for Iceland.



**Figure1.1: Geographical Boundaries of the Reykjavik Control Area. (Source: Isavia).**

<sup>1</sup> ICAO is an agency of the United Nations established to promote the safe and orderly development of international civil aviation throughout the world.

<sup>2</sup> See Glossary of Terms for further information.

The control of oceanic airspace outside the territory of member states is delegated by ICAO to certain member states. In the North Atlantic (NAT) Region ICAO has delegated the Air Navigation Services (ANS) to seven states including Iceland. The airspace controlled by Iceland, the Reykjavík Control Area (Reykjavik CTA), spans approximately 5.4 million square kilometres. The Reykjavik CTA comprises the Reykjavik Flight Information Region (FIR) and the Søndrestrom Flight Information Region, see figure 1.1 (Isavia, 2012a).<sup>3</sup> The Søndrestrom FIR is not under Icelandic territory and the control of the FIR by the Reykjavik Area Control Centre (ACC) stems from a joint agreement with Denmark.

In continental Europe the airspace has been divided into control areas in accordance with the borders between the states. However over Belgium, the Netherlands, Luxembourg and north-west Germany the upper airspace is controlled by the Maastricht Upper Area Control Centre (MUAC) operated by Eurocontrol. This means that when an aircraft is flying across Europe it passes through several control areas, each managed by a different ANSP. This way of managing the air traffic is the cause of major inefficiencies.<sup>4</sup>

The general rule with respect to the charges for the air navigation services provided by ANSPs is that it is calculated on the basis of the cost incurred in providing the service. The users of the services, i.e. airlines and private aircraft, are charged through a system of en-route charges and approach and/ or landing fees for their use of these services to recover the costs involved. It is in the interest of the airlines to decrease these charges and/or to improve the services being provided by the ANSPs in order to minimize their costs in a very competitive market.

The increasing demand for more capacity, higher quality and lower charges together with increasing air traffic has led to efforts by the European Union to increase efficiency in the Air Traffic Management in Europe without jeopardizing safety.

This effort has resulted in the concept called Single European Sky (SES)<sup>5</sup>. The European Union has passed two SES packages to create a legislative framework for European aviation.

The SES packages include five interrelated pillars : the performance-based regulatory framework, the safety pillar, the technological contribution, the human factor and the optimization of the airport infrastructure (European Commission, 2012).

With the SES came the initiative of organizing airspace into Functional Airspace Blocks (FAB)<sup>6</sup>, according to traffic flows rather than to national borders.

An important part of the means to obtain increased efficiency is set forth in the SES regulations in terms of performance measurements and performance targets. Eurocontrol<sup>7</sup> has

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<sup>3</sup> The Reykjavik Area Control Centre (ACC) provides Air Traffic Services within the Reykjavik FIR while in the Søndrestrom FIR Reykjavik ACC provides Area Control Service, Flight Information, Service and Alerting Service above FL 195 (Flugmálastjórn Íslands, 2011).

<sup>4</sup> When compared to US airspace where there is a single ANSP there are 13% fewer Air Traffic Controllers (ATCOs) in US than in Europe but they control 70% more flight hours (Eurocontrol & FAA, 2010).

<sup>5</sup> See Glossary of Terms for further information on SES.

<sup>6</sup> See Glossary of Terms for further information on FAB.

for several years gathered information from the ANSPs of member states and issues annually reports showing the result of several performance indicators which have been selected for this purpose.

Eurocontrol and the European Commission have prepared a European Air Traffic Management Master Plan (European Commission; Eurocontrol, 2009) for gradually implementing the SES. In this plan, a list of Key Performance Indicators has been defined. Another organization, CANSO<sup>8</sup>, has also suggested performance indicators for use in evaluating performance in the provision of air navigation services and annually issues a benchmarking report on Air Navigation Services Performance.

Even though Isavia is not part of the European Union, the SES regulations have been introduced in part in Iceland through the European Economic Area Agreement. EC 1070/2009 has however not been implemented in Iceland and hence the SES II requirements are not yet applicable in Iceland. As regards the Functional Airspace Blocks (FAB)<sup>9</sup>, Iceland withdraw from the NEFAB<sup>10</sup> project in 2011<sup>11</sup>. The implementation of SES II into the EEA agreement is under consideration. As mentioned before the largest part of the flight information regions under Icelandic control are delegated through agreements which have to be taken into account when entering a co-operation such as NEFAB.

When EC 1070/2009 has been fully implemented in Iceland, Isavia will have to provide the necessary information for the evaluation of its performance.

## 1.2 Statement of the problem

For every company it is necessary to measure the performance of its processes and business activities in order to be able to assess whether the company is achieving its goals and heading in the right direction towards its future vision for the company. In this context performance measurements are primarily for use within the company.

Performance measurements are also used to evaluate how a company is performing with respect to similar companies.

It is necessary for ANSPs to be able to know their strengths and weaknesses in comparison to other ANSPs. As for Isavia it is of great importance to be able to put a value to their service and to monitor their performance in general.

The delegation of oceanic airspace is at each time based on current situation. The oceanic airspace within the Reykjavik CTA has been under Icelandic control for a long period of time. The future delegation of this airspace depends on several factors; among them are the

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<sup>7</sup> European Organization for the Safety of Air Navigation is an intergovernmental organization made up of 39 Member States and the European Community.

<sup>8</sup> CANSO is an organization which represents the interests of Air Navigation Service Providers worldwide.

<sup>9</sup> See Glossary of Terms for further information on FAB.

<sup>10</sup> North European Functional Airspace Blocks, see Glossary of Terms for further information.

<sup>11</sup> For further information see: <http://www.eurocontrol.int/sites/default/files/content/documents/official-documents/reports/2012-ses2011-ic.pdf>

safety, quality and cost of the service provided by Reykjavik ACC. It is therefore important for Isavia to monitor their performance in this area and strive to increase it.

The airspace controlled by Isavia is shown in Figure 1.1. Compared to the average size<sup>12</sup> of the controlled airspaces in Eurocontrol member states the Reykjavik CTA of 5.4 million km<sup>2</sup> is very large. The oceanic airspace within the Reykjavik CTA is larger than any oceanic airspace under the control of Eurocontrol's members states (Performance Review Unit (PRU), 2012).

If the Reykjavik Control Area is compared with other oceanic control areas, Isavia provides more service by offering more flexibility in the choice of flight routes than is normally available. The main reason for this is that a part of the airspace has radar coverage. The radar coverage allows less separation between aircraft than possible when procedural separation is used, as is usual for oceanic airspace. This increases the possibility of adjusting flight routes in accordance with requests from airlines. Whereas most oceanic ANSPs offer fixed tracks for flight routes with little possibilities to change the route of the aircraft<sup>13</sup>, Isavia is able to offers flexible routes. The airlines will therefore have more possibility to choose their preferred route and to make changes of their cleared<sup>14</sup> routes. This also means that the traffic will become more complex to control when compared to traffic on fixed tracks.

If on the other hand the Reykjavik Control Area is compared with the airspace in continental Europe there is much more air traffic in continental Europe than in the North Atlantic and the complexity is also much greater.

All these factors will make benchmarking difficult, because some factors will not be directly comparable between control areas and service providers. When comparing two ANSPs with respect to cost the type and level of service provided and the complexity of the traffic must be taken into account.

## 1.3 Aim and objectives

The aims and objectives of this research were mainly defined through discussions with Isavia personnel and in cooperation with my supervisor. On the other hand some limitations had to be made to the initial scope of the project resulting in the following aims and objectives.

### 1.3.1 Research Aims

The aims of this research are:

- To analyse and evaluate the metrics that are currently used to measure the performance of ANSPs.

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<sup>12</sup> The average size of controlled airspace (including oceanic airspaces) in Eurocontrol member states is about 591 km<sup>2</sup>.

<sup>13</sup> For example to climb up to higher heights in order to decrease fuel consumption.

<sup>14</sup> For explanation see clearance in Glossary of Terms.

- To develop a system of performance metrics for the Icelandic Air Traffic Management (ATM) System operated by Isavia, based on an analysis and modelling of the ATM System.
- To identify the need for additional data, that may not be collected at this point in time and to define how such data could be collected.

### **1.3.2 Research Objectives**

The objectives of this research are to:

- Prepare a description of the ATM system at Isavia, focusing on the flow of information within the system.
- Gather data on existing performance measurements currently used or being suggested for use by ANSPs in Europe.
- Make a suggestion for a list of performance metrics to measure the performance of the ATM System operated by Isavia.
- Map out in details how these metrics are calculated from data available at Isavia and list any additional data that need to be gathered on a regular basis.
- Calculating the metrics using data from Isavia.
- Evaluate how the performance has changed over a time period
- Compare the performance metrics calculated for Isavia with metrics from other ANSPs.

## **1.4 Research methodology**

The research methodology of this thesis is a case study.

It involves gathering information on the ATM system at Isavia and drawing up a functional diagram showing the information flow between the various components of the Air Traffic Management System as well as preparing a written description of the system and its parts. This involves an explanatory case study where the information gathered in several meetings with Isavia's personnel and through material provided by Isavia is analysed. This part of the study was performed in cooperation with a fellow student (Unnur Þorleifsdóttir). The result of this study can be found in Annex I.

The research furthermore involved studying performance metrics which have been used by other ANSPs and gather information on how they are calculated. An evaluation of the applicability of these performance metrics for Isavia is based on this study.

## **1.5 Outline of the thesis**

The thesis starts with an introduction of Air Traffic Management in the Reykjavik Control Area in chapter 2, where emphasis is on the factors that are of importance to this study of performance measurements. A more detailed description of the Air Traffic Management

System at Isavia is found in Appendices I and II. In the following chapter no. 3 is an introduction of performance measurements in general.

The main study of performance metrics and the factors affecting performance in Air Traffic Management is presented in chapters 4 and 5. In these chapters the metrics are defined and evaluated with respect to their applicability for the evaluation of Air Traffic Management in the Reykjavik Control Area.

In chapter 6 a selection of performance metrics are calculated using data from Isavia followed by chapter 7 where the results are presented and discussed. Chapter 8 provides a discussion and summary of the results of the research performed and conclusions and recommendations for further research.

As the subject of the thesis is within a specialized area of Air Navigation Services there are many concepts which are new to the general reader. In order to facilitate the reading there is a Glossary of Terms at the end of the thesis in addition to the list of abbreviations which precedes this chapter.

## **2. Air Traffic Management in the Reykjavik Control Area**

One of the objects of this thesis was to study the Air Traffic Management (ATM) systems at Isavia to gain an understanding of the system which performance is under consideration.

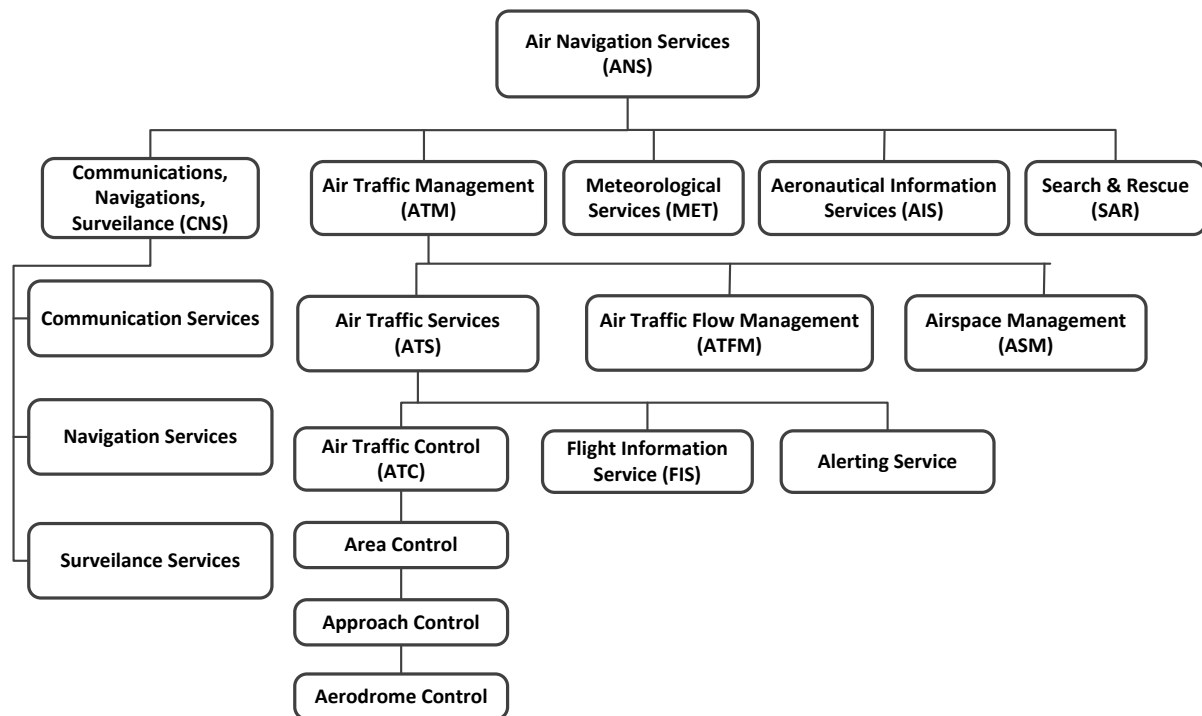
This study was performed in co-operation with a fellow student Unnur Þorleifsdóttir and the results can be found in Appendix I and II. We gathered information on the system from our mutual thesis advisor and from our meetings with personnel at Isavia.

In this chapter a brief description will be provided of how Air Traffic Management is implemented and carried out by Isavia with emphasis on those factors that affect the performance of the ATM System and especially those aspects which are different from other Air Navigations Service Providers (ANSP). For more detailed description of the Isavia ATM system reference is made to Appendices I and II.

### **2.1 Air Navigation Services**

Air Navigation Services (ANS) includes five broad categories of services provided to air traffic during all phases of operation (area control, approach control and aerodrome control). These services are: Air Traffic Management (ATM), Communication services, Navigation services and Surveillance services (CNS), Meteorological services for air navigation (MET), Aeronautical Information Services (AIS) and Search and Rescue (SAR) (ICAO, 2001).

Further division of these services is shown in Figure 2-1; an explanation of the terms in each box in the figure can be found in Glossary of Terms.



**Figure 2.1: The structure of Air Navigation Services. (Source: Performance Review Unit)**

Of the Air Navigation Services shown in Figure 2-1 Isavia provides most of the services except the Search and Rescue which is in the hands of the Icelandic Coast Guard and the Meteorological Service which is mainly provided by the Icelandic Met Office. Furthermore, Isavia does not perform all aspects of Air Traffic Flow Management as performed by the Central Flow Management Unit (CFMU)<sup>15</sup>, e.g. Isavia does not allocate slot time. However, the planning of the capacity within the Reykjavik Control Area (Reykjavík CTA) which is one aspect of Air Traffic Flow Management is performed by Isavia in the Reykjavik Area Control Centre (Reykjavik ACC) (see Flow Management in Appendix I).

The major part of the operation at Reykjavik Area Control Centre (Reykjavik ACC) lies however in the en-route Air Traffic Control (ATC) including CNS services. Furthermore the control of the international traffic is the dominant part of the ATC service provided by Reykjavik ACC. For this reason the main focus of this study is on these parts, i.e. the Area Control and CNS service. As in many companies there is not a clear cut between departments and it should therefore be noted that these services are an integral part of the whole ANS system and the boundaries are not as clear as indicated by the boxes in Figure 2-1.

## 2.2 The Reykjavik Control Area

In the Reykjavik ACC both domestic and international air traffic<sup>16</sup> is controlled. The approach control of international air traffic is at Keflavik airport.

<sup>15</sup> See Glossary of Terms for further information.

<sup>16</sup> Both over- flight traffic (i.e. traffic that transits through the CTA) and the en-route international traffic to and from Iceland.

The boundary between the international en-route airspace (the oceanic airspace) and the domestic airspace is defined in the AIP Iceland (Flugmálastjórn Íslands, 2011) and are as shown in figure 2.2. The upper limit of the domestic airspace is at flight level 245.



**Figure 2.2: Boundaries of the domestic airspace. (Source: Isavia)**

For the purpose of calculating charges in the Joint Financing Agreement, a flight is considered to have entered the domestic airspace at 220 kilometres from the Icelandic airport. Section III, point 10 of the agreement is as follows:

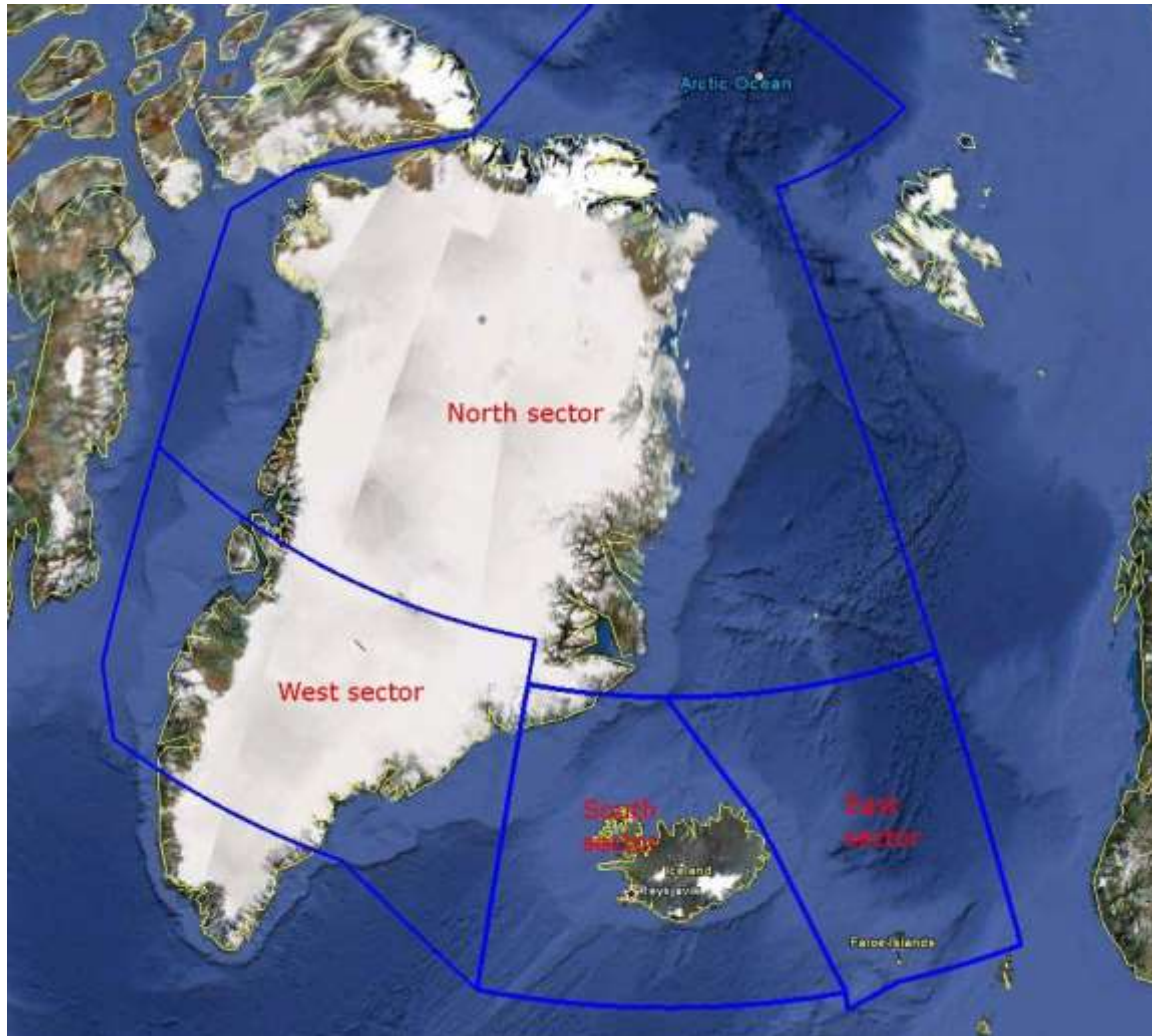
*“The distance factor ( $d$ ) is equal to one-hundredth of the great circle distance, expressed in kilometres, between the aerodrome of departure within, or the point of entry into, the airspace of the Reykjavik and Søndre Strømfjord FIRs and the aerodrome of first destination within, or the point of exit from, that airspace. The entry and exit points are the points at which the lateral limits of the airspace are crossed by the route of the aircraft. The distance to be taken into account is reduced by a notional 100 kilometres for each take-off and for each landing on the territory of the Søndre Strømfjord FIR and the Faroe Islands and 220 kilometres for each approach and each departure from airports in Iceland.” (ICAO, 2010)*

International air traffic to Iceland is therefore considered to have exited the international airspace at 220 kilometres (about 120 NM) from the Icelandic airport.

The airspace in the Reykjavík Control Area (Reykjavík CTA) is divided into geographical sectors as is necessary to divide the traffic load into smaller units that can be controlled by one or two Air Traffic Controllers (ATCOs). Four lateral sectors have been defined in the Reykjavík CTA: North sector, East sector, West sector and South sector as can be seen in Figure 2-2. When traffic load increases, further division of these sectors may be necessary.

The sectors are then further divided by flight levels in such a way that each Control Workstation (CWS) controls specified flight levels within the geographical sector.

There are five radars which service the Reykjavik CTA. Where there is radar coverage radar surveillance can be provided.



**Figure 2.3: Division of Reykjavik Control Area into geographical sectors. (Source: Isavia).**

The Reykjavik Control Area is free route airspace, i.e. air traffic is normally not required to follow predefined routes. There have however been defined fixed routes which are used under certain conditions such as the Blue Spruce routes<sup>17</sup>.

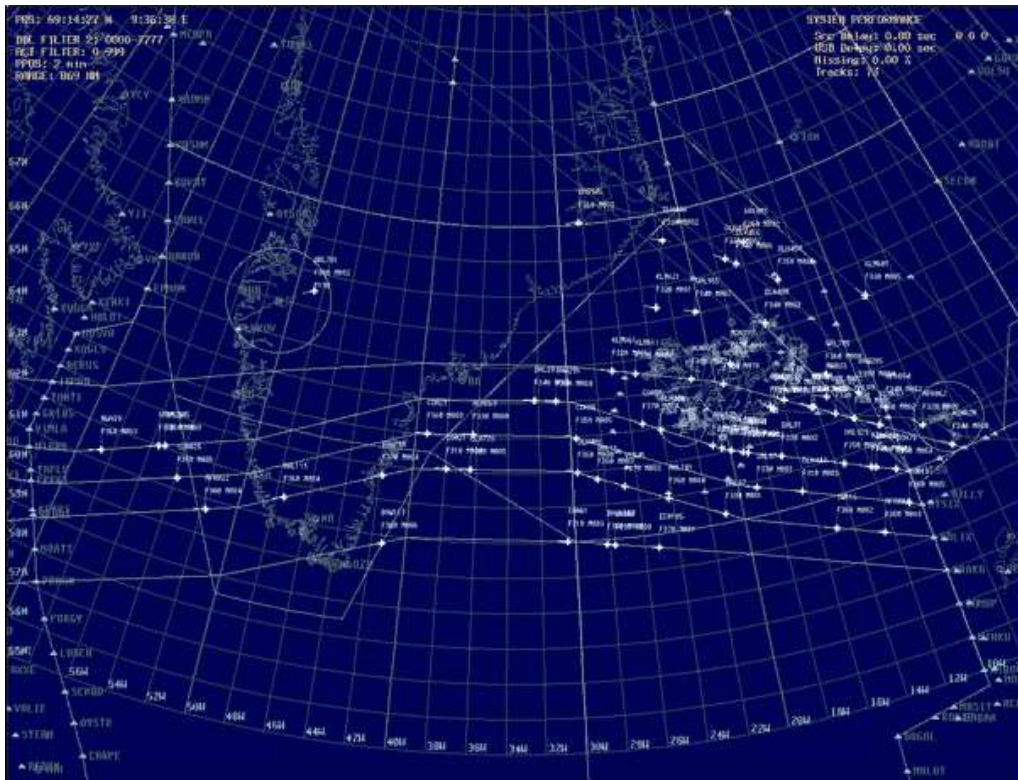
Large portion of the air traffic over the North Atlantic Ocean follows tracks which are defined every 12 hours. This track system is called North Atlantic Organized Track System (NAT OTS)(IVAO, 2012).

Over the North Atlantic Ocean strong westerly winds, often referred to as the jet stream, prevail. The jet stream affects the air traffic and the airlines plan their flight routes with the aim of maximizing tail winds and minimizing head winds. The position of the NAT tracks

<sup>17</sup> Routes where the aircraft is at all times within VHF range of a land station (Flugmálastjórn Íslands, 2011).

varies from day to day depending primarily on the location of the jet stream. Some days some or all of the OTS tracks enter the Reykjavik CTA. More frequently the OTS tracks are outside Reykjavik CTA. These fluctuations cause somewhat unpredictable variation in air traffic in the area. In 2010, the NAT tracks for traffic heading west entered the Reykjavik control area 111 days while the NAT tracks for traffic heading east entered the Reykjavik control area only 6 days (Isavia, 2012b).

Figure 2.4 shows the air traffic at noon on a day where the major part of the OTS tracks lies within the Reykjavik CTA. There are five OTS tracks issued; these are indicated with a line in the figure.



**Figure 2.4: NAT OTS tracks. (Source: Isavia)**

Airlines which plan to fly within the airspace where the tracks have been defined will be given flight routes which follow one of these tracks (unless they plan flights which are crossing the tracks). In other areas within the Reykjavík CTA aircraft routes can be planned in accordance with requests from airspace user, often called random routes<sup>18</sup>. The random meaning that the plans of the airspace user are generally not known until they file a flight plan. In free route airspace the flight routes are certainly not random since each request for a flight route must be considered with respect to other air traffic and other conditions before a flight plan is accepted.

By using fixed tracks the traffic control becomes more manageable by allowing a larger number of aircraft to be controlled by each ATCO. In control areas where the traffic is

<sup>18</sup> Random routes are routes which are not predefined and published; they are based on the requests from the airlines on a per flight basis.

controlled by using fixed tracks instead of allowing random routes the efficiency of the ATC operation will increase, i.e. larger number of aircraft can fly in the area without increasing the number of controllers. Although the fixed tracks solve the problem of excess demand they limit the possibilities of the airlines to choose their preferred route (which may be different from the track routes) and to make changes of their cleared<sup>19</sup> routes. This in turn will increase the fuel consumption and hence the cost and pollution.

## 2.3 Air Traffic Control

The main objectives of the Air Traffic Control (ATC) operation are to ensure separation of aircraft from each other and from objects on the ground as well as expediting and maintaining an orderly and efficient flow of air traffic.

Air Traffic Control is performed by a complex system where practically all decision making is made by air traffic controllers.

Isvia's ATC systems are mainly in-house systems which have been adapted to the special circumstances within the Reykjavik CTA.

The ATC systems include:

- Flight Data Processing System (FDPS)
- Radar Data Processing System (RDPS)
- Integrated Situation Display System and
- Voice Communication System

A further description of each of these systems and their interaction can be found in Appendix II.

By using the ATC systems the ATCO can monitor all aircraft in his/her sector with respect to separation minima based on surveillance data, position reports and estimated and projected aircraft position and velocity. The ATCO communicates with the pilot, receives requests for changes in the aircraft profile and provides instructions, clearances and advice regarding flight conditions (Subotic, 2007)(Flugmálastjórn Íslands, 2011).

In the area where radar coverage is available the ATCO can monitor aircraft with high accuracy<sup>20</sup>. Thus the minimum separation between two aircraft is significantly smaller while they are under radar control. This is the case because the state<sup>21</sup> of an aircraft is accurately determined by the radar surveillance system or by ADS-B when this service will be available<sup>22</sup>.

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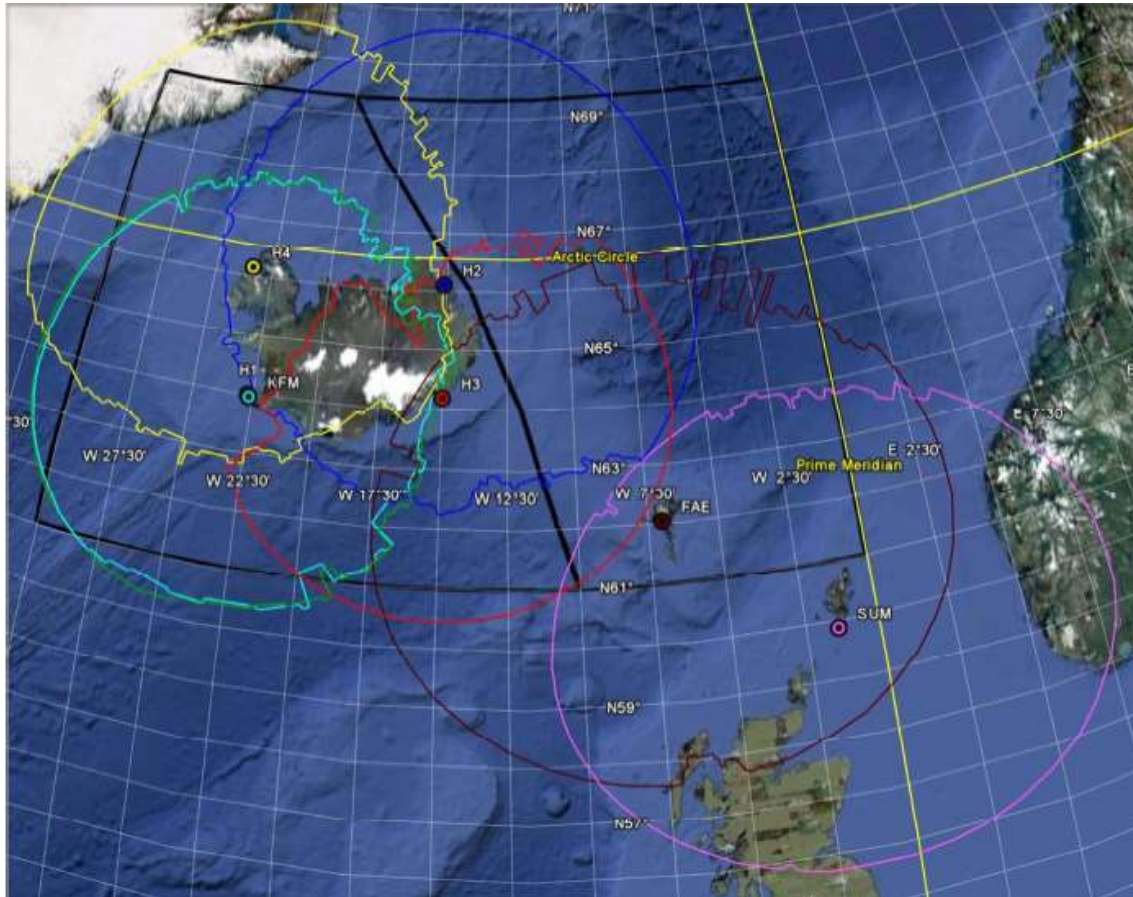
<sup>19</sup> For explanation see clearance in Glossary of Terms.

<sup>20</sup> The radar data arrives at 10 second intervals.

<sup>21</sup> The state of the aircraft includes its position, velocity (e.g. ground speed and course) and altitude.

<sup>22</sup> This new service is expected to be available in the end of 2013.

In areas where there is no radar coverage, pilots report their position with regular intervals through voice or data link communications often through a remote communications centre. In such cases the ATCO uses so-called procedural separation rules. The separation minimum for procedural separation is much greater than in radar separation<sup>23</sup>. The reason for this is that the procedural separation is based on less accurate position information. The response time for the ATCO and the pilot is also longer in procedural separation as they are normally not in direct voice contact with each other. When the aircraft is not within radar coverage the communication between the pilot and the ATCO goes through a Radio Operator at Iceland Radio at Gufunes who serves as an intermediary.<sup>24</sup>



**Figure 2.5: Radar stations and radar coverage in the Reykjavik Control Area at an altitude of 40,000 feet. (Source: Isavia)**

Figure 2.5 shows the radar coverage in the Reykjavik CTA. In the South and East sectors there is extensive radar coverage. Most of the air traffic through these sectors can take advantage of radar separation while in the West and North sectors procedural separation is maintained.

A more detailed description of the separation rules that apply in the Reykjavik CTA can be found in Annex I.

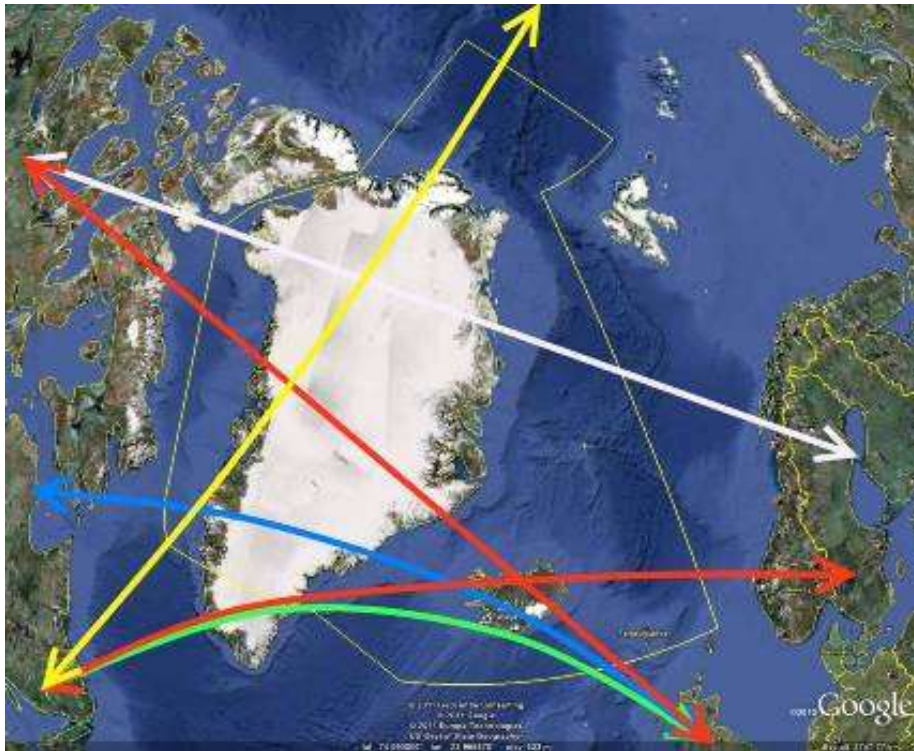
<sup>23</sup> See Separation Service in Appendix I.

<sup>24</sup> See Communication in Appendix II for further explanation.

The pilot may request changes to the cleared profile, such as altitude, route or speed changes. When the ATCO receives such requests he considers other traffic in the area and obtains acceptance of changes at the sector boundaries. Having taken this into account the ATCO will either reject the request or issue a clearance including based on the new profile.( route, flight level and speed).

The presence of the radars (and later ADS-B) in the busiest part of the Reykjavik Control Area makes it different from other oceanic Flight Information Regions (FIR). In most oceanic FIR's only procedural separation is available which does not offer much flexibility with respect to the flight routes or changes thereto. In many cases where there is procedural separation in oceanic airspace the flight route is cleared through the entire FIR. Any conflicts are resolved before the aircraft enters the oceanic airspace. In such cases the ATCO's work will mainly be to monitor the aircraft position throughout the flight. As the complexity of such work is not high, each ATCO can control a larger number of aircraft than would be possible in a more tactical operation. As opposed to this, in airspace where there is radar coverage the ATCO has more opportunities to respond to requests for changes in the flight route such as a request for increased altitude. This is possible because the separation between aircraft may be decreased and the update frequency is much higher than in the case of procedural control. This increases the possibility of providing service to the airlines which can choose more economical flight routes for their aircraft. This is of particular importance for long-haul flights where fuel consumption can be reduced by choosing a flight profile which is optimal with respect to wind and the weight of the aircraft throughout the flight. Providing radar services increases the workload on the ATCO as more complex tasks must be executed.

Figure 2.6 shows the pattern of traffic flow through the Reykjavik CTA. About 25% of the traffic is on its way to and from Iceland. The most substantial traffic however is proceeding between Europe and North-America. Due to the position of the jet stream mentioned above the westbound traffic is considerably greater than the east bound traffic (74% and 25% respectively in 2011).



**Figure 2.6: The traffic pattern in the Reykjavik Control Area. (Source: Isavia).**

A large part of the traffic over the North Atlantic Ocean is strongly dependent on the jet streams as mentioned before. Hence, the forecasted wind will influence the route chosen i.e. whether the route will lie within the Reykjavik CTA or not. The traffic within Reykjavik CTA can therefore vary a lot between days. Since this is based on the weather it is difficult to predict with more than several hours of lead-time what the traffic will be. Furthermore the traffic in the Reykjavik CTA is seasonal; there is clearly a significant increase in traffic during the summer months from June to September as compared to the winter months (Isavia, 2011a). Both of these factors increase the variability of the traffic and hence introduce a challenge in manning positions in order to ensure that the number of staff on duty is sufficient to control the traffic without having too many which will incur extra cost.

### 3. Measuring Performance

#### 3.1 Introduction

There are a large and increasing number of articles and books on how to run a business successfully. Of course they do not agree on a single road to follow towards that end. In *Strategy Safari* (Mintzberg, Lampel, & Ahlstrand, 1998) 10 different schools of strategy are listed which an organization can adopt in its pursuit towards better performance. Following one or the other of these strategies managers must develop performance metrics intended to measure how well the strategy is working.

Without going into details this chapter contains an introduction of performance measurements in general followed by a chapter on benchmarking since one of the objectives of this thesis is to look into the benchmarking efforts which have been made in the field of Air Traffic Management (ATM).

#### 3.2 Performance measurements

Measuring performance is an integral part of doing business. For profit-making organizations the ultimate performance metric is whether the business is returning a profit; without profit the business cannot continue in the long run. But measuring profit alone is not sufficient; there are several other considerations which should be taken into account in the long run. Perhaps the organization could do better, perhaps the business is too focused on present profit at the cost of future gain and/or resources are being misused.

Measurements can be used to induce better performance; the challenge is to find the right metrics, implement these and to develop the best means for using the results. Measuring the wrong parameters and using the results in an incentive system can have disastrous effects as has been learned from the last economic crisis. In this context it is appropriate to quote William Bruce Cameron : “not everything that counts can be counted, and not everything that can be counted counts” (Cameron, 1963).

The types of measures that are commonly used in business today can be divided into three main categories (Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel, 2006):

1. **Financial measures.** These are the traditional accounting measurements which organizations use for the evaluation of their financial performance. For most organizations these measures can be found in annual reports and describe absolute performance (revenues, costs, net income, profit), performance relative to asset utilization (accounting ratios like Return on Assets and Return on Investment) and financial strength (cash flow).
2. **External measures.** These measures focus on the market (how the organization is performing compared to competitors) and the customers (how to attract and retain

customers). Performance metrics in this category could be for example market share, customer satisfaction and customer loyalty.

**3. Internal measures.** These are intended for measuring the operational performance, how well the systems of the organization are performing. The operational metrics need to be linked to the financial and external metrics. These metrics can be very different from one organization to another. An example of internal performance metrics could be number of stock outs per year, which influence both the financial metrics (lost sale) and the external metrics (customer dissatisfaction). System performance metrics can in certain cases be defined in order to compare performance between similar systems as is done in benchmarking.

Performance measurements are often linked to the strategy of organizations. A well-known framework for performance measurements is the Balanced Scorecards (Kaplan & Norton, 1992) which suggests that organizations should translate their strategic goals into performance measurements and the measurements should be balanced. Following a research Kaplan and Norton found that using only financial performance metrics was not enough; these metrics should be balanced with other metrics which are drivers of future financial performance. The metrics which are drivers of future gain are in their opinion operational metrics of customer satisfaction, internal processes and the organization's innovation and improvement activities. In order to obtain balanced measurements Kaplan and Norton suggest that organizations use the following questions as guidance:

- How do we look to our shareholders (financial perspective)?
- What must we excel at (internal business perspective)?
- How do our customers see us (the customer perspective)?
- How can we continue to improve and create value (innovation and learning perspective)?

The Balanced Scorecard has been widely used but implementing a performance system of this type is not always straightforward and should be considered carefully. If it is to be successful several factors have to be considered. It is important that the metrics are carefully chosen, the implementation planned, the use of the measurements considered, etc. The main learning point from the Balanced Scorecard is that that you should not use financial metrics alone and that they should be balanced against other factors which are important to the success of the organization.

There are several studies and articles which give recommendation as to the design of performance measurements and performance frameworks. Neely, et. al. have in a literature review (Neely, Richards, Mills, Platts, & Bourne, 1997) gathered together some of the recommendations which have been given for the design of performance measurements, the recommendations are listed in table 3.1.

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**Recommendations for the design of performance measurements (Neely, Richards, Mills, Platts, & Bourne, 1997).**

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Performance measures should:

- be derived from strategy
  - be simple to understand
  - provide timely and accurate feedback
  - be based on quantities that can be influenced, or controlled, by the user alone or in co-operation with others
  - reflect the “business process” – i.e. both the supplier and customer should be involved in the definition of the measure
  - relate to specific goals (targets)
  - be relevant
  - be part of a closed management loop
  - be clearly defined
  - have visual impact
  - focus on improvement
  - be consistent (in that they maintain their significance as time goes by)
  - provide fast feedback
  - have an explicit purpose
  - be based on an explicitly defined formula and source of data
  - employ ratios rather than absolute numbers
  - use data which are automatically collected as part of a process whenever possible
  - be reported in a simple consistent format
  - be based on trends rather than snapshots
  - provide information
  - be precise – be exact about what is being measured
  - be objective – not based on opinion
- 

**Table 3.1: A list of recommendation for the design of performance measurements**

Furthermore Neely et. al. suggests that for each metric a data sheet is prepared containing the following information:

- **Title** (a title which explains what is measured)
- **Purpose** (the rationale behind the measure)
- **Relates to** (the business objectives which the measure relates to)
- **Target** (the goal for the measure and the time limit for achieving it)
- **Formula** (the data elements and how the metric is calculated)
- **Frequency of measurement** (how often the measure is performed and reported)
- **Frequency of review** (how often the metric is re-evaluated)
- **Who measures?** (the person who collects the data and reports the results)
- **Source of data** (specification of the raw data for each data element)
- **Who owns the measure?** (the person accountable for performance improvements)
- **What do they do?** (a description of how the measure will help to improve performance)

- **Who acts on the data?** (the person/team who reacts to a positive or negative results)
- **What do they do?** (define how to react to positive or negative results of the measure)
- **Notes and comments** (any additional information)

Several additional suggestions have been made since this article was published. Phelps prepared in his book (Phelps, 2004) a metrics audit where the metrics are evaluated against four headings. Performance metrics should:

- “clarify strategy”
- “capture real performance drivers”
- “promote joined-up management” (ensure that metrics do not conflict and do not lead to managers playing the system)
- “be useful for performance management” (used for reward and appraisal systems)

Under these headings Phelps has prepared 18 statements which the metrics should be measured against in order to evaluate their effectiveness.

Phelps emphasizes the need to distinguish between metrics which are drivers on one hand and outputs on the other hand and similarly between metrics which measure present value and metrics that measure future value.

Although it is very valuable information to know the profit of last year or last month, that information alone does not help organizations to increase its future profits. It is important that performance metrics provide information on the current status. However metrics which help the organization increase their performance next month and in the future should also be included. Managers should therefore ask themselves what factors will be driving future performance.

In order to address this issue, organizations need to find out what are the drivers behind the performance they wish to achieve. One way to do this is to use data mining, i.e. to line up several metrics which managers suspect will influence a certain output metric and to use regression or other data mining models to find which metrics are most significant. An example of this method can be found in Smart Business Metrics (Phelps, 2004, page 49-52).

While the above recommendations on how to design performance metrics were probably made considering for-profit organizations, operating in a competitive market, some of them will also apply to companies in a market where there is regulated monopoly.

There are however several factors which differ for these different types of working environments. Looking for example at the Air Navigation Service Providers (ANSPs), such as Isavia, the customers are the airlines which in most cases cannot choose between different service providers. The airlines can only on rare occasions bypass certain air traffic control areas in order to avoid high charges.

It is however not like the ANSPs can exploit their monopolistic position as there are several stakeholders which affect their operation. For Isavia the stakeholders are: Airlines, Aircraft owners, Airline passengers, The Icelandic Civil Aviation Administration, International Civil

Aviation Organization (ICAO), the Icelandic government, Eurocontrol and other service providers, especially those adjacent to the Reykjavík Control Area. On the other hand the ANSP's have obligations to service all aircraft in their control area and cannot choose to service only part of their customers or part of the control area. There are also several other obligations that are defined by laws and regulations which the ANSPs must adhere to and can be costly for smaller units to satisfy.

### **3.3 Benchmarking**

In benchmarking organizations compare their performance with their prior performance or with the performance of other organizations in the same industry.

Comparing own performance with performance within the same industry can be useful where there is a forum for sharing information on best practices. In that case you can learn better ways of operating your organization from the successful practices of others (Neely, 2002).

Many large companies, especially those that are made up of many business units use best-practice benchmarking for increasing their performance (Neely, 2002).

Benchmarking which are simply collecting indicators do not necessary help per se in enhancing performance, they do however give an indication of how one enterprise is performing in comparison to others and that is in itself valuable information. It would however be best if you could also learn why someone is doing better than the rest.

Companies in a competitive market are constantly comparing themselves to the rivals on the market and trying to do better. For organizations operating in a “market” where there is regulated monopoly the drive from the competition is lacking. In such cases benchmarking may be attractive.

If there is only a single monopoly in some given industry in the country or a region international benchmarking can be beneficial. However there may be additional factors which differ between countries and make the comparison difficult. Examples of such factors are the population, labour market, economic situation and geographical variables such as weather and geographical location.

There are however great opportunities of co-operation between monopoly organizations and sharing of best practices, even though direct comparison of numbers do not apply. Furthermore common performance indicators can be useful for regulators or supervisory bodies to monitor performance of monopolies especially where these have been agreed by independent benchmarking companies or organizations.

An example of such benchmarking is The International Transmission Operations & Maintenance Study (ITOMST<sup>TM</sup>) provided by UMS Group, an international management consulting firm. ITOMST<sup>TM</sup> is an association of international transmission companies that work together under guidance from UMS Group. The purpose of ITOMST<sup>TM</sup> is to compare performance and practices within the transmission industry worldwide and to identifying and

share best practices. One of the participants in ITOMS™ is the Icelandic company Landsnet which operates Iceland's electricity transmission system.

Benchmarking of performance indicators is also performed between ANSPs by two different organizations. As mentioned before Eurocontrol<sup>25</sup> has for several years gathered information from the ANSPs of member states and issues annually reports, the ATM Cost-Effectiveness (ACE) Benchmarking Report, showing the result of several performance indicators which have been selected for this purpose. Another organization, CANSO<sup>26</sup>, has also suggested performance indicators for use in evaluating performance in the provision of air navigation services and annually issues a benchmarking report on Air Navigation Services Performance.

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<sup>25</sup> European Organization for the Safety of Air Navigation is an intergovernmental organization made up of 39 Member States and the European Community.

<sup>26</sup> CANSO is an organization which represents the interests of Air Navigation Service Providers worldwide.

## 4. Performance Measurements in Air Traffic Management Systems

### 4.1 Introduction

This chapter serves the purpose of gathering together performance metrics which have been used or proposed for the evaluation of the performance of Air Traffic Management (ATM) systems and services.

European Organization for the Safety of Air Navigation (Eurocontrol)<sup>27</sup> is an intergovernmental organization made up of 39 member states and the European Community. Within Eurocontrol are several commissions, bodies and units; among them are the Performance Review Commission (PRC) and the Performance Review Unit (PRU)<sup>28</sup>. As indicated by their name the PRC and PRU objectives are to review performance of ATM systems within the member states. The PRU gathers information from member states and annually prepares a benchmarking report, the “ATM Cost-Effectiveness (ACE) Benchmarking Report” (ACE report), which shows several performance indicators of the Air Navigation Service Providers (ANSPs). Furthermore, PRC annually prepares a report which is an assessment of Air Traffic Management in Europe, the “Performance Review Report” (PRR).

The PRC, with the support of the PRU, has been designated by the European Commission as the Single European Sky (SES)<sup>29</sup> Performance Review Body and will as such take key responsibilities in the implementation of the SES Performance Scheme. In the SES Performance Scheme there are four performance areas where Key Performance Indicators have been defined for the first reference period (2012-2014).

Civil Air Navigation Services Organization (CANSO) is an organization which represents the interests of ANSPs worldwide. Within CANSO there is a Global Benchmarking Workgroup (GBWG), which has been gathering data from those CANSO member states participating in the benchmarking activity. GBWG has prepared annual reports for six years, the “Global Air Navigation Services Performance Report” (CANSO report).

The ACE report and the CANSO report are both benchmarking report with the purpose of harmonizing the performance metrics used within this area and comparing performance between ANSPs using these metrics. Both Eurocontrol and CANSO offer some kind of forum for best practice sharing.

The Federal Aviation Administration (FAA) Oceanic and Offshore Integrated Product Team (IPT) has studied performance metrics for oceanic Air Traffic Management (ATM) within the US National Airspace System (NAS). The results of that study and suggested performance

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<sup>27</sup> See also Glossary of Terms.

<sup>28</sup> See Glossary of Terms for further information on PRC and PRU.

<sup>29</sup> See Glossary of Terms for further information on SES.

metrics were reported in 2004 (Wu, Hamrick, Karakis, & Merkle, 2004). Some of the metrics suggested by IPT are mentioned in this chapter. Most of them can be defined as quality of service metrics.

The Danish ANSP, Naviair, has in the Business Plan for 2010-2014 made their Key Performance Indicators (KPIs) publicly available. These KPI's are an example of metrics not intended for benchmarking with other ANSPs but rather as means for achieving their strategic goals. Naviair has defined their mission and vision. In order to realize the mission and to implement the vision Naviair has defined 4 sub-strategies and 8 critical success factors. On this basis they have defined 26 KPIs. Naviair uses Balance Scorecard to define their KPIs (Naviair, 2010). In this chapter some of Naviair KPIs will be mentioned for comparison with the benchmarking indicators.

The ACE and CANSO reports are the main source documents for this study of metrics used for benchmarking performance in ATM.

There are several ways to categorize the metrics currently used into performance areas. In the SES Performance Scheme there are four areas defined for EU-wide targets, these are: Safety, Environment, Capacity and Cost-Efficiency. In the SESAR<sup>30</sup> Performance framework this has been expanded into seven areas: Capacity, Cost Effectiveness, Efficiency, Flexibility, Predictability, Safety and Environmental Sustainability.

CANSO defines four performance areas: Safety; Productivity; Cost-effectiveness; and Price, Revenue and Profitability. The GBWG has plans to add the following performance areas: Environment, Air Traffic Complexity, Density and Quality of Service and Human Resources (CANSO Global Benchmarking Workgroup, 2012).

In this thesis the performance areas are divided into: Safety, Productivity, Financial, Flight Efficiency and Environmental Impact, and Quality of Service. This division of areas is selected in order to include all areas from the CANSO report, although the Cost-effectiveness and Price, Revenue and Profitability are combined into one area, namely Financial.

In this chapter a brief description of each performance area will be provided and some of the performance metrics which have been suggested or used are described.

The data elements that are required for calculating the metrics are discussed in more details in Glossary of Terms. All data elements used to calculate the performance indicators represent data for a whole year.

## **4.2 Safety**

Safety is of utmost importance in aviation. For every change that is made in ATM systems, safety must always be considered as it cannot be jeopardized in the pursuit of greater efficiency or effectiveness.

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<sup>30</sup> SESAR stands for Single European Sky ATM Research, see Glossary of Term for further information on SESAR.

It is however not possible to optimize safety as such. If one seeks to ensure 100% safety in ATM that could only be achieved by grounding all aircraft. When considering the ATM system as a whole, safety can be considered as a constraint when optimizing the system performance with respect to other factors such as capacity, cost and efficiency. In order to ensure an acceptable level of safety, standards and regulations have been implemented. Although increasing safety is always on the agenda, any measures taken in that direction must be weighed against the effect that it has on costs, efficiency and the level of service provided to the airspace users.

#### 4.2.1 SES Performance Scheme

In the SES Performance Scheme<sup>31</sup>, Key Performance Indicators (KPIs) for Safety are introduced. These metrics were adopted prior to the first reference period, 2012-2014 (European Aviation Safety Agency, 2011):

1. Effectiveness of safety management.
2. Application of the harmonized severity classification of the Risk Analysis Tool<sup>32</sup> to allow harmonized reporting of severity assessment of:
  - a. Separation minima infringements
  - b. Runway incursions
  - c. ATM special technical events.
3. Reporting of just culture<sup>33</sup>.

According to the Performance Scheme, states have to monitor and publish these Safety KPIs during the first reference period (2012-2014). There are however no targets set for KPIs in this period. Figure 4.1 show the suggestions for safety indicators made by the Performance Review Body (PRB) for the second reference period (2015-2019) (Performance Review Body, 2012).

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<sup>31</sup> See Glossary of Term for more information on SES Performance Scheme.

<sup>32</sup> Risk Analysis Tool is a tool aimed to harmonize the way member states and ANSPs classify and analyze ATM safety occurrences. See also [https://www.eurocontrol.int/safety/gallery/content/public/library/Safrep/Risk\\_Analysis\\_Tool.pdf](https://www.eurocontrol.int/safety/gallery/content/public/library/Safrep/Risk_Analysis_Tool.pdf).

<sup>33</sup> See Glossary of Terms for further information on just culture.

KPA	ANS performance indicators	RP1	RP2	Comments
Safety	Effectiveness of safety management ('maturity')	Monitoring	EU target Perf. plan target	Possible update of elements of the SPI
	Application of severity classification scheme	Monitoring	EU target Perf. plan targets	Possible update of elements of the SPI
	Separation infringements	Monitoring	Monitoring	
	Runway incursions	Monitoring	Monitoring	
	ATM special technical events	Monitoring	Monitoring	
	Application of Just Culture	Monitoring	EU target Perf. plan target	Possible update of elements of the SPI
	Level of reporting		Monitoring	Quality check possible in RP1
	Quality of reports and analysis		Monitoring	Quality check possible in RP1
	Effectiveness of mitigation measures		Monitoring	
	Independent safety performance monitoring via use of TCAS-RA dataflow		EU monitoring	Feasibility study + indicator development
	Automatic runway incursion dataflow		EU monitoring	Feasibility study + indicator development
	Effectiveness of Runway Safety Programmes		Monitoring	Feasibility study + indicator development

**Figure 4.1: Overview of the proposals from PRB for Safety KPIs. (Source: PRB).**

### 4.2.2 CANSO report

In the CANSO 2012 report there are four safety KPI's listed (CANSO Global Benchmarking Workgroup, 2012):

1. IFR-IFR<sup>34</sup> losses of separation.
2. Runway incursions.
3. Safety Management System (SMS) maturity.
4. Safety culture.

CANSO gathers safety data from its members but these data are confidential and therefore not published.

### 4.2.3 The FAA's Oceanic and Offshore Integrated Product Team

In an article from 2004 the FAA Oceanic and Offshore Integrated Product Team (IPT) suggested several metrics directed at Oceanic ANS (Wu et al., 2004).

The following performance metrics may be classified as safety metrics:

1. Operational errors – the number of operational errors that occur in the oceanic center and the cause of errors.
2. Altitude change requests due to weather – the number of requests and the response time.
3. Deviation requests – the number of requests for lateral deviation from the cleared flight plan due to weather and the response time.

<sup>34</sup> IFR stands for Instrument Flight Rules, see Glossary of Terms.

This article is from 2004 but further information on results or development of these metrics could not be found.

#### **4.2.4 General comments on safety performance metrics**

Direct comparison of Safety KPI's between ANSP's is difficult and such comparison can have discouraging effect on the reporting of incidents. How incidents are defined and categorized with respect to severity affects the number of incidents reported.

The Safety Regulation Commission<sup>35</sup> estimates that only half of the incidents that occur are reported (Performance Review Commission, 2011).

The introduction of a Safety Management Systems, Just Culture<sup>36</sup> and harmonized severity classification has been established to address these factors. By harmonizing the severity classification and taking measures to induce reporting of incidents the comparison of safety metrics will become more realistic.

Another factor which affects the comparison of safety metrics is the time it takes to investigate the incidents. Even if reports of incidents are published the publication may be delayed, depending on the severity of the incident and the speed of investigation in each state. This can make the comparison between states difficult. Furthermore, safety metrics may be available later than other performance metrics. This is a disadvantage since in the evaluation of performance, different performance areas should be considered at the same time. It is important to know as soon as possible if a positive change in one performance metric has negative effect on safety.

Even though it may be difficult to accurately compare the safety KPIs between ANSPs they are still very important KPIs for comparison and guidance within each ANSP.

In chapter 6.2.1 the safety metrics for the ATM system within Isavia are listed.

### **4.3 Productivity**

When considering the ATM system as a whole the productivity of the system would, in the big picture, be the output of the system divided by all inputs to the system. There are several candidates to be considered as an output of an ATM system. The output could for example be considered as:

- The number of aircraft controlled.
- The number of controlled flight hours.
- The number of controlled kilometres.
- The number of directions/requests from the control centre.

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<sup>35</sup> The Safety Regulation Commission is an independent body to the EUROCONTROL, established for the multilateral development and harmonization of ATM safety regulations within the European Civil Aviation Conference (ECAC).

<sup>36</sup> See Glossary of Terms for further information on Just Culture.

The input can be defined as all the personnel, facilities, equipment and systems (software and hardware) in monetary or other terms which are provided in order to produce the output. Large part of these inputs such as facilities, equipment and systems are fixed, i.e. they do not change with the demand for more output in the short run. The main contributor to changes in productivity is therefore the variable input which is mainly the personnel required to produce the demanded service (the output). A large factor in the employment cost within the ATM systems is the employment cost of air traffic controllers (ATCOs). The number of ATCOs required on duty in Air Traffic Control (ATC) is dependent on the air traffic load, i.e. the demand for ATC. When looking at the input to the ATM system it is therefore logical to look at the contribution of work from the ATCOs. This contribution can be measured in number of ATCOs (in full time equivalence) or the working hours. It should be noted that some ATCOs also work on other duties and are therefore not always working in air traffic control. ATCOs are therefore divided into ATCOs in Operation (ATCO in OPS) and ATCOs on other duties.

With this in mind productivity can be defined in several ways, for example using either flight hours or flown kilometres as output and using either ATCO in OPS hours of duty or number of ATCO in OPS as input.

The productivity indicators from the ACE and CANSO reports and Naviar are listed in chapters 4.3.1 – 4.3.3.

### 4.3.1 ACE report

The following metrics are calculated for each ANSP in the ACE 2010 report:

$$1. \text{ ATCO-hour Productivity} = \frac{\text{Composite Flight Hours}}{\text{ATCO in OPS hours on Duty}} \quad (4.1)$$

$$2. \text{ ATCO-hours on Duty per ATCO per Year} = \frac{\text{ACC ATCO-hours on Duty}}{\text{ACC ATCOs in OPS}} \quad (4.2)$$

In *ATCO-hour Productivity* the Composite Flight Hours are defined as:

$$\text{Composite gate-to-gate flight-hours} = (\text{En-route Flight-Hours}) + (0,26 \times \text{IFR Airport Movements}) \quad (4.3)$$

(Performance Review Unit, 2011).

This is done to account for different definitions between ANSPs of when the en-route phase of the flight ends and the approach and landing starts, see also chapter 4.7.

As mentioned previously the focus of this study is on the international en-route flight within the Reykjavik Control Area (CTA). Airport movements are therefore not taken into account and the Composite Flight Hours will become equal to the En-route Flight Hours when calculating *ATCO-hour Productivity*. The En-route Flight Hours are found by taking the difference between the time when an aircraft enters the Reykjavik CTA and the time of exit from the Reykjavik CTA.

ATCO in OPS hours on Duty are defined as the total annual working hours of each ATCO working on operational duties (in ATC operations) both in Area Control Centers (ACC) and in Approach Control Units (APP). The number of hours can for example be found by using

the difference between the clock-in and clock-out time for each ATCO in OPS or other methods giving similar results.<sup>37</sup> When considering the en-route productivity only ATCOs working in ACC should be considered, not the ones working in APP.

The *ATCO-hour productivity* is measuring how many composite flight hours (the output) each ATCO working hour (the input) will produce and therefore the goal is to increase this indicator. Each ANSP has little influence on the number of flight hours flown in their territory and therefore need to control the ATCO hours in order to increase the productivity. There are two main factors which can be addressed in order to increase the productivity. One is directed at the work procedures of the ATCOs and the other is adjusting the number of ATCOs on duty to fluctuations in air traffic demand.

As the technology has advanced, ATC systems have been developed further to make the work of the ATCOs easier and to facilitate more efficient procedures. This has enabled each ATCO to monitor greater amount of air traffic, while maintaining or increasing safety of the procedures. This can greatly affect the productivity and should be under constant consideration together with general review of procedures in order to increase performance.

ATCOs are not a flexible workforce which can follow economic cycles. It is not possible to lay off ATCOs when there is a dip in the air traffic and then re-hire them when there is an increase in the traffic demand. ANSPs must use other means to adapt to fluctuation in air traffic. This can be done by using overtime and arranging shifts to adapt to the traffic pattern in each control unit. Using ATCOs on other projects is also possible in order meet fluctuation in air traffic demand. These measures to adapt to variation in traffic will however increase costs. ATCOs are expensive workforce and should therefore not be used excessively on other duties. Obtaining realistic air traffic forecasts is also a factor which is of importance when adjusting the workforce to the air traffic demand.

The metric *ATCO-hours on Duty per ATCO per Year* is calculated for the Area Control Centers (ACC). ACC ATCOs in OPS is the number of ATCOs working in Full Time Equivalent (FTE)<sup>38</sup> on operational duties in the area control centre. This metric gives the average annual working hours of each ATCO in OPS and hence the “utilization” of each ATCO in OPS. As there is a lot of cost involved in training and educating each ATCO in OPS, it is of importance to measure their contribution to the ATC operation. Clearly the ANSP would like to maximize this number. This is however only possible up to a point as too high work load for an extended period of time can have negative effect on health and general well-being of the staff. Too high a workload could result in increase in sick days and/or higher turnover of ATCOs. Therefore these factors must be considered as well. Different legislation in each country can also affect this metric, as there may be different rules on work-hours and overtime.

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<sup>37</sup> See definition of Air Traffic Controller in Operation in Glossary of Terms.

<sup>38</sup> See Glossary of Terms for further explanations.

In addition to this, sector productivity (flight-hours per sector-hour) and staffing per sector (ATCO-hours per sector-hour) are calculated in the report but will not be dwelt on in this thesis.

### 4.3.2 CANSO report

In the CANSO 2012 report, the following productivity metrics are listed:

1. Continental

$$\text{a. IFR Flight Hours per ATCO in OPS} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS}} \quad (4.4)$$

$$\text{b. IFR Flight Hours per ATCO in OPS hour} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS Hours}} \quad (4.5)$$

2. Oceanic

$$\text{a. IFR Flight Hours per ATCO in OPS} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS}} \quad (4.6)$$

3. Continental and Oceanic

$$\text{a. Average Annual Working Hours for ATCOs in OPS}$$

There is a difference between the definition of IFR hours defined in the ACE report and the IFR hours defined in the CANSO report, (see chapter 4.7 for explanations). In order to account for this difference one minute is added to the IFR Flight Hours according to the ACE report for each take-off and/or landing (a total of two minutes for the flights which starts and ends within the same control area) to be comparable with the IFR Flight Hours from the CANSO report.

In the CANSO report performance metrics are considered separately for continental and oceanic airspaces. Looking at the results of these productivity metrics in the CANSO report it turns out that for the same ANSP the productivity is much higher in the oceanic control areas than in continental control areas. The continental traffic is denser and more complex than the oceanic traffic. This is mainly due to the many airports and the complexity of the air traffic around them but also because of the many boundaries between different control areas. In contrast most of the oceanic air traffic is directed into parallel tracks throughout the flight which are more easily controlled. It should be noted here that within the Reykjavik CTA such track systems are under normal conditions only used for the NAT tracks, see chapter 2.2.

According to the CANSO report the metric *IFR Flight Hours per ATCO in OPS* for continental air traffic controlled by NATS (UK) was 922 in 2010, while the same metric for the oceanic air traffic controlled by NATS was 8.494. This means that one ATCO can control on average 922 flight hours of continental air traffic per year while in the oceanic air traffic the productivity is almost tenfold. For this reason it is reasonable to conclude that when comparing performance within the Reykjavik CTA to other control areas, one should consider performance in other oceanic areas.

The metric *IFR Flight Hours per ATCO in OPS* calculates how many IFR flight hours each ATCO can control on average per year. *IFR Flight Hours per ATCO in OPS hour* is similar to the metric *ATCO-hour productivity* used in the ACE report.

Comparing the metric *ATCO-hour productivity* used in the ACE report to *IFR Flight Hours per ATCO in OPS* it is clear that they are different although they are basically measuring the same thing (the ATCO's productivity). In the first one the denominator is ATCO hours but in the second the denominator is number of ATCOs. Mathematically the CANSO's metric *IFR Flight Hours per ATCO in OPS* is equal to the ACE report's metric *ATCO-hour productivity* times the *Average Annual Working Hour for ATCOs in OPS*. Looking at the two reports for the year 2009 the *ATCO-hour productivity* for NAVIAIR was 0,93 while the *IFR Flight Hours per ATCO in OPS* was 1.045 flight hours/year. Both metrics give valuable information but it is likely that the ATCO hours on duty is more accurate information than the number of ATCOs in operation per year. It can be difficult to find the exact number of ATCOs in OPS, especially where there are several ATCOs who work on other duties as well as in operation. The number of ATCOs in OPS is a mean for a whole year and is therefore less accurate number compared with ATCOs hours which in many cases can be obtained from time recording systems.

Both these metrics can be used to measure productivity and compare between years within the ANSP as well as comparing to other ANSPs. It is very important to monitor how changes in procedures will affect this metric to see how performance can be improved. It can also be useful for estimating the need for recruiting ATCOs on operational duties based on forecasted air traffic demand.

### 4.3.3 Naviair productivity indicators

Naviair, the Danish ANSP, published in 2010 its business plan for 2010 to 2014. The following indicators which relate to productivity are defined under the category Internal Processes in Naviair's Balanced Scorecard:

$$1. \text{Disposition efficiency – En-route (operations)} = \frac{\text{Number of En-route operations}}{\text{ATCO in OPS}} \quad (4.7)$$

$$2. \text{Disposition efficiency – Tower/Approach}^{39} \text{ (operations)} \\ = \frac{\text{Number of Tower/Approach operations}}{\text{ATCO in OPS}} \quad (4.8)$$

Naviair sets the targets for the en-route *Disposition efficiency* to be greater than 7.200 while the target for the Tower/Approach *Disposition efficiency* is set to be greater than 4.600. The term en-route operation refers to the number of flights while the term tower/approach operations refers to airport movements, i.e. take-off and landings (Naviair, 2010).

Although number of flights per year can be defined as an output of the ATC system and is often used when considering traffic demand, it could be preferable to use flight hours or

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<sup>39</sup> For Copenhagen airport.

kilometres flown when calculating the productivity. The reason is that the flying time in the control area is very different between flights. In 2011 the number of flights in the Reykjavik CTA was about 111.500, the time flown in each flight in the area was from less than a minute to several hours, and about 8.400 flights were less than 5 minutes in the Reykjavik CTA. If however the average flight hours per flight do not change between years then using number of flights instead of flight hours should lead to the same conclusion.

#### **4.3.4 Additional comments on productivity metrics**

The productivity metrics are of great importance as they affect the total ATCO in OPS employment costs which are a considerable part of the total cost.

It is a great challenge for the ANSP's to match the number of ATCO's employed and on duty to the traffic demand. In order to ensure safety the work load of each ATCO must be considered. The ATCO can spend only limited consecutive time at the controller workstation as the work demands much concentration. There is also a limit of how much traffic he/she can control at the same time. To address this, the airspace is divided into sectors which are manageable by one person or a team, depending on how this is organized in each ANSP. In the Reykjavik ACC the ATCO is under normal conditions in working position for a maximum 90 minutes, followed by a 30 minute break.

Variation in air traffic demand and the complexity of the air traffic are factors which can affect ANS performance, although researches have not shown a correlation between ANS performance and these factors (Performance Review Commission, 2011). The number of available ATCOs at the control centres must be able to meet the traffic peaks. If that is not the case the ANSP is forced to constrain the traffic flow into its control area. Comparing two ANSPs with same average air traffic but one with low variation in air traffic and the other with high variation in air traffic, it is clear that the ANSP with higher variation in air traffic is forced to employ greater number of ATCOs, other things being equal. Also, it is evident that an ATCO controlling air traffic through parallel tracks with procedural separation can control much larger number of aircraft than ATCO controlling free flight air traffic with radar separation (see also chapter 2.3.). As the number of ATCOs required for these different traffic patterns and situations are different, it will affect productivity. Further discussion on the factors affecting performance can be found in chapter 5.

In some areas, especially where traffic is dense the productivity of the ATM operation is increased by using fixed tracks as mentioned earlier. This should however be avoided where possible since this may result in less optimal routes from the point of view of the aircraft operation. Suboptimal routes increase fuel burn and therefore the cost for the user as well as CO<sub>2</sub> emission which has negative environmental effect. Whereas most oceanic ANSPs offer fixed tracks for flight routes with little possibilities to change the route of the aircraft<sup>40</sup>,

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<sup>40</sup> For example to climb up to higher heights in order to decrease fuel consumption.

Reykjavik ACC offers flexible routes. With flexibility in routing airlines will have more possibility to choose their preferred routes and to make changes to their cleared<sup>41</sup> routes.

#### 4.4 Financial

The increasing demand for lower charges together with increasing air traffic has led to efforts from the EU, via the SES regulations, to increase efficiency in the Air Traffic Management in Europe. As a result of this, much emphasis has been put on efforts to control cost and use funds in a more efficient way.

Generally the ANSP's revenues are received through charges for the Air Navigation Services they provide. These charges are normally calculated on the basis of the forecasted cost of providing the service (corrected with respect to actual cost of the previous year). The users of the service, mainly airline companies, are charged for their use to cover the cost involved.

Charging rules within the European Union are not the same as the rules which apply in the international airspace controlled by Reykjavik ACC. Air navigation service charges for the international civil air traffic controlled by Reykjavik ACC are decided in the Agreement on the Joint Financing of Certain Air Navigation Services in Iceland (Joint Financing Agreement).

The charges for the international route Air Navigation Services is split into two parts:

- A charge for each crossing. The charge depends on whether the crossing is defined as full crossing or not. Crossing between Europe and Canada or the United States is considered full crossing. In 2012 the charge for full crossing was 32,73 GBP. Charges for flights which are not considered a full crossing is lower and the rules relating thereto can be found in AIP Iceland (Flugmálastjórn Íslands, 2011).
- A charge based on distance flown in the Reykjavik CTA. This charge is equal to the product of a distance factor and a unit rate. The distance factor is equal to one-hundredth of the great circle distance between the entry and the exit point of the Reykjavik CTA, expressed in kilometres. More details of the distant factor can be found in the AIP Iceland. In 2012 the unit rate was 10,33 GBP. Flights flying below Flight Level 285 within the Reykjavik CTA and all flights in and out of airports located in Greenland are charged half the unit rate (Flugmálastjórn Íslands, 2011).

The charging rules within EU are defined in the Commission Regulation (EC) No 1794/2006 of 6 December 2006 laying down a common charging scheme for air navigation services. Without going into details of these charging rules it should be mentioned that the en-route charges are equal to the product of a unit rate and a service unit, where the service unit is a multiplication of an aircraft weight factor and a distance factor.

The main difference of the variables used in the en-route charges within EU and the Reykjavik CTA is the weight of the aircraft which is not included in the international en-route charges of the Reykjavik CTA (although it is a factor in the landing charges and the

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<sup>41</sup> For explanation see clearance in Glossary of Terms.

domestic en-route charges). Also the EU en-route charges do not include the fixed charge per flight and therefore the en-route revenues do not depend on the number of flights.

In this chapter the financial metrics are divided into Cost efficiency and Revenue and other financial metrics.

#### 4.4.1 Cost efficiency

When comparing costs between companies or between time periods within the same company it is preferable to express the cost in relative terms. Increase in total cost is not necessary a bad sign if the output (the goods and/or services) has also increased.

The main focus in this chapter is on the cost of providing a specific service per service unit. The service unit in this relation is variously air traffic (number of flights), flight hours or airport movements.

The term used for this metric is either cost efficiency or cost effectiveness. In the SES Performance Scheme cost efficiency is used while in the ACE and CANSO reports the corresponding metric is cost effectiveness.

##### 4.4.1.1 SES Performance Scheme

For the first reference period (2012-2014) a Cost-efficiency KPI is defined as:

$$\text{Cost-efficiency} = \frac{\text{En-route ANS Provision Cost}}{\text{Forecasted Traffic}} \quad (4.9)$$

The En-route ANS Provision Cost is defined in accordance with the Charging Schemes of SES. The Forecasted Traffic is given in Service Units<sup>42</sup> which are used for the calculation of route charges within the Eurocontrol Charging Area. The Service Unit is a multiplication of an aircraft weight factor and a distance factor.

In this metric the same output is used for reference as is used when calculating the en-route charges. It should however be noted that as for en-route traffic, the weight of the aircraft does not affect the air traffic control in any way. An increase in average aircraft weight would however result in a better cost-efficiency metric without any actual increase in efficiency.

##### 4.4.1.2 ACE report

The following metrics which can be categorized as cost efficiency indicators are calculated for each ANSP within Eurocontrol in the ACE 2010 report:

$$1. \text{ Financial Cost-effectiveness Indicator} = \frac{\text{Gate-to-Gate ATM/CNS Costs}}{\text{Composite Flight Hours}} \quad (4.10)$$

$$2. \text{ En-route Cost-effectiveness} = \frac{\text{En-route ATM/CNS Costs}}{\text{Total Flight Hours}} \quad (4.11)$$

$$3. \text{ Terminal Cost-effectiveness} = \frac{\text{Terminal ATM/CNS Costs}}{\text{IFR Airport Movements}} \quad (4.12)$$

<sup>42</sup> The service units are defined in accordance with the definition in Annex IV of the Commission Regulation (EC) No 1794/2006 of 6 December 2006 laying down a common charging scheme for air navigation services

$$4. \text{ ATCO Employment Cost per ATCO-hour} = \frac{\text{Employment Costs for ATCOs in OPS}}{\text{ATCO in OPS Hours on Duty}} \quad (4.13)$$

$$5. \text{ ATCO Employment Cost per unit of Output} = \frac{\text{Employment Costs for ATCOs in OPS}}{\text{Composite Flight Hours}} \quad (4.14)$$

$$6. \text{ Support Cost per unit of Output} = \frac{\text{Support Costs}}{\text{Composite Flight Hours}} \quad (4.15)$$

$$7. \text{ Support Cost Ratio} = \frac{\text{ATM/CNS Provision Costs}}{\text{Employment Costs for ATCOs in OPS}} \quad (4.16)$$

The definition of the data elements used in the above metrics can be found in Glossary of Terms. The costs are expressed in € in the ACE report and the employment costs are also expressed in Purchasing Power Parity<sup>43</sup> (PPP) in order to take into account the different standards of living between the states.

With the first metric effort is made to measure the cost effectiveness of the whole ATM and CNS<sup>44</sup> systems whereas in the second the cost effectiveness of the en-route part is measured and in the third metric the cost effectiveness of the terminal part is measured. The Gate-to-Gate ATM/CNS Costs is equal to the sum of the En-route ATM/CNS Costs and the Terminal ATM/CNS Costs. The Composite flight hour is derived from both the Total Flight Hours and Airport IFR Movements (see formula (4.3) above).

As this study is only considering the en-route traffic the *En-route Cost Effectiveness* is the most relevant of the first three metrics. It measures the average ATM/CNS cost per flight hour. This cost is linked to the en-route charges<sup>45</sup>, a decrease in this cost will, other things being equal, eventually lead to lower charges. It is therefore of importance to consider ways to decrease the outcome of this metric and to monitor the metric for changes in ATM/CNS operation.

In Europe staff cost is 62,9% of total ATM/CNS provision cost of which 50% is employment cost for ATCO's in OPS. The other 50% is the employment cost for support staff (Performance Review Unit, 2011).

It is therefore important to monitor the staff cost and the fourth, fifth and sixth metrics are intended for that. The ATCO in OPS employment cost is measured both as per ATCO hour giving the average cost per hour and per Composite Flight Hour (per output).

When the ATCO in OPS employment costs is monitored it is important to notice if a decrease in the costs results in an increase in other costs and therefore the Support Cost is monitored as well. In the Support Costs the Employment Costs for ATCO in OPS has been subtracted from the ATM/CNS Provision Costs.

The *Support Cost Ratio* has the advantage of giving a number which is not related to any currency and is therefore easier in comparison between countries. A decrease in support cost

<sup>43</sup>Purchasing Power Parity is an adjustment of the exchange rate so that a basket of the same goods in two different countries has the same price. See also Glossary of Terms.

<sup>44</sup> Communication, Navigation, Surveillance.

<sup>45</sup> The charges are dependent on flown kilometers which in turn are the product of the flight hours and speed.

ratio should indicate more cost-effectiveness, other things being equal. The support cost ratio should however not be considered alone since a low ratio could be caused by high ATCOs employment costs.

#### 4.4.1.3 CANSO report

The following metrics which can be categorized as cost efficiency indicators are calculated in the CANSO 2012 report:

##### 1. Continental

$$\text{a. Cost per IFR Flight Hour} = \frac{\text{Total Costs}}{\text{IFR Flight Hours}} \quad (4.17)$$

$$\begin{aligned} \text{b. Empl. Cost for ATCOs in OPS per IFR Flight Hour} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{IFR Flight Hours}} \end{aligned} \quad (4.18)$$

$$\begin{aligned} \text{c. Empl. Cost for ATCOs in OPS per ATCO in OPS} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCOs in OPS}} \end{aligned} \quad (4.19)$$

##### 2. Oceanic

$$\text{a. Cost per IFR Flight Hour} = \frac{\text{Total Costs}}{\text{IFR Flight Hours}} \quad (4.20)$$

$$\begin{aligned} \text{b. Empl. Cost for ATCOs in OPS per IFR Flight Hour} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{IFR Flight Hours}} \end{aligned} \quad (4.21)$$

$$\begin{aligned} \text{c. Empl. Cost for ATCOs in OPS per ATCO in OPS} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCOs in OPS}} \end{aligned} \quad (4.22)$$

##### 3. Continental and Oceanic

$$\text{a. Cost per IFR Flight Hour} = \frac{\text{Total Costs}}{\text{IFR Flight Hours}} \quad (4.23)$$

$$\begin{aligned} \text{b. Empl. Cost of ATCOs in OPS as a Percent of Operating Cost} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{Total Operating Cost}} \end{aligned} \quad (4.24)$$

$$\begin{aligned} \text{c. Empl. Cost of ATCOs in OPS as a Percent of Total Cost} \\ = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{Total Cost}} \end{aligned} \quad (4.25)$$

The oceanic metrics are calculated for six ANSPs in the CANSO report, namely FAA ATO (USA), NAV CANADA, NATS (UK), NAV Portugal, Airways New Zealand and ATNS (South Africa).

The CANSO's oceanic and continental metrics are identical except for the data used to calculate them.

The oceanic flight is by definition an en-route flight and the *Cost per IFR Flight Hour* is therefore similar to the *En-route Cost Effectiveness* metric from ACE report. The definition of cost<sup>46</sup> and IFR flight hours<sup>47</sup> is however not exactly the same and therefore these metrics cannot be directly compared but they are meant to capture the same performance element. Furthermore the *En-route Cost Effectiveness* metric from ACE report is not calculated for oceanic air traffic.

CANSO's *Empl. Cost for ATCOs in OPS per IFR Flight Hour* is also similar to the metric from the ACE report called *ATCO Employment Cost per unit of Output* (see formula 4.14), especially when only en-route traffic is considered and the Composite Flight Hours becomes equal to IFR Flight Hours.

The annual employment cost per ATCO in OPS is an interesting metric to compare between states. This cost is not easily controlled by the ANSPs although it may reflect the use of overtime in the operation. Overtime may however be caused by a variability in air traffic in the area.<sup>48</sup> Those ANSPs having high ATCO employment costs have more incentive to increase the ATCOs productivity to reduce the number of ATCO required for each controlled flight hour.

#### 4.4.2 Revenue and other financial metrics

This chapter covers some of the revenue and capital expenditures measures as well as financial ratios presented in the ACE and CANSO reports.

##### 4.4.2.1 ACE report

1. Gate-to-gate total revenues = En-route ANS revenues + Terminal ANS revenues (4.26)
2. Gate-to-gate ANS total capital expenditure (capex), (data from ANSP)

In the ACE report both the total revenues and costs are listed for each ANSP. Since most of the ANSPs are operating on the basis of cost recovery the difference of costs and revenues is usually little. That can however happen when the air traffic is different from forecasted traffic, but then the under or over recovery is adjusted two years later.

The total annual ANSP revenues may be considered as a measure of the size of the ANSP, as well as the annual IFR flight hours controlled by the ANSP, and is therefore useful when comparing the performance between different ANSPs.

The Gate-to-gate ANS total capital expenditures indicates the amount of investments made by the ANSP. In the ACE report the total capital expenditure is divided into capital expenditures for systems and equipment assets, land and building assets and intangible assets. If the investments are sound, capital expenditure can indicate future increase in performance.

<sup>46</sup> See Chapter 4.4.3. for further information on the difference in cost definitions.

<sup>47</sup> See Chapter 4.3.2. for further information on the difference in IFR Flight Hours definitions

<sup>48</sup> See Chapter 5.2. for more information on traffic variability.

Capital expenditures are often considered as a percentage of total revenues or costs since they should be in right proportion, not too high and not too low. When considering capital expenditures it may give wrong indication if considered only for one year as investments may vary between years and larger investments may take several years.

In the ACE 2010 report the planned cumulative capital expenditures for the period 2011-2015 is calculated as percentage of total ANS revenues in 2010. The total planned cumulative capital expenditures for the Eurocontrol states participating in the benchmarking was 69% of the 2010 total ANS revenues. For some ANSPs this percentage was over 100%, indicating plans for large investments (Performance Review Unit (PRU), 2012).

Continued low capital expenditures for several years may indicate stagnation as systems and buildings are not renovated and may become obsolescent. Continued low capital expenditures can lead to higher future costs and lost opportunities to improve performance. Too high capital expenditures may on the other hand indicate financial risk. At Isavia, all investments related to the international air traffic services must be approved by ICAO in accordance with the Joint Financing Agreement.

#### 4.4.2.2 CANSO report

##### 1. Continental

a. Example Consolidated Price per 1000 KM Flight for A320<sup>49</sup> = (data from ANSP)<sup>50</sup>

$$b. \text{ Total ANS Revenue per IFR Flight Hour} = \frac{\text{Total ANS Revenues}}{\text{IFR Flight Hours}} \quad (4.27)$$

##### 2. Oceanic

$$a. \text{ Total ANS Revenue per IFR Flight Hour} = \frac{\text{Total ANS Revenues}}{\text{IFR Flight Hours}} \quad (4.28)$$

##### 3. Continental and Oceanic

$$a. \text{ Return on Equity (ROE)}^{51} = \frac{\text{Net income}}{\text{Total equity (annual average)}} \quad (4.29)$$

$$b. \text{ Return on Assets (ROA)}^{52} = \frac{\text{Net income}}{\text{Total assets (annual average)}} \quad (4.30)$$

$$c. \text{ Cost of Capital and Depreciation as a Percent of Total Cost} = \frac{\text{Cost of Capital and Depreciation}}{\text{Total Costs}} \quad (4.31)$$

The CANSO oceanic metric *Total ANS Revenue per IFR Flight Hour* is similar to the metric *Cost per IFR Flight Hour* except that the cost is defined for ATC/ATFM<sup>53</sup> and CNS services whereas the revenues are defined for all ANS services. Also, there might be a difference in

<sup>49</sup> Here, A320 refers to the type of aircraft, A320 from Airbus.

<sup>50</sup> As this metric is intended for continental flight it is not relevant in this study. See definition in Glossary of Terms.

<sup>51</sup> Further information on ROE can be found in Glossary of Terms.

<sup>52</sup> Further information on ROA can be found in Glossary of Terms.

<sup>53</sup> Air Traffic Flow Management; see Glossary of Terms for further information.

ANS revenues and ANS costs even though for most of the ANSPs all cost is eventually recovered.

The metric *Cost of Capital and Depreciation as Percent of Total Cost* is representing the investments made by the ANSPs. Increase in investments will increase the cost of capital and the depreciation as well.

Cost of capital is the cost of debt and equity capital. ANSPs may finance new investments in different ways.

In the CANSO report the cost of capital is defined in the following way: “*The Cost of Capital falls into two categories. The first is the interest paid to the providers of debt capital. The second is the appropriate cost of capital applied to equity capital.*”

1. *For ANSPs with both categories, the cost of capital is the interest expense on debt capital plus the cost of capital on equity built into the ANSP charges.*
2. *For ANSPs with only debt capital, the cost of capital is the interest expense.*
3. *For ANSPs with only debt capital where the interest expense is born by the government and not reflected in the accounts of the ANSP, the cost of capital can be computed by applying the interest rate on overall government borrowing to the ANSP capital.” (CANSO Global Benchmarking Workgroup, 2012)*

It should be noted that the rate of return can be very different between states because of different risk and accessibility of funds. The available rate of return also varies between years within the same state due to effects of economic cycles within states. This will affect the cost of capital and distort comparison between ANSPs and between years within the same ANSP.

#### 4.4.3 Naviair financial metrics

The following metrics and their definition can be found under the category Financial in Naviair’s Balanced Scorecard:

1. En-route revenues: Operational revenues except revenues from the Danish Civil Aviation Administration and the Danish Meteorological Institute.
2. Revenues on fee for ATC at CPH<sup>54</sup>: Revenues on fee for ATC at CPH and Roskilde Airports.
3. Revenues on fee for ATC at Billund: Revenues on fee for ATC at Billund Airport.
4. Staff charges: Naviair’s staff charges.
5. Other operating expenses: Naviair’s other operating expenses.

Naviair has set targets for each of this metric (Naviair, 2010). For the three revenue metrics reference is made to comments here above on such metrics. When considering the *Staff charges* and the *Other operating expenses* it should be noted that they are not represented in relative terms (per output) such as per IFR flight hours. As mentioned earlier it would be

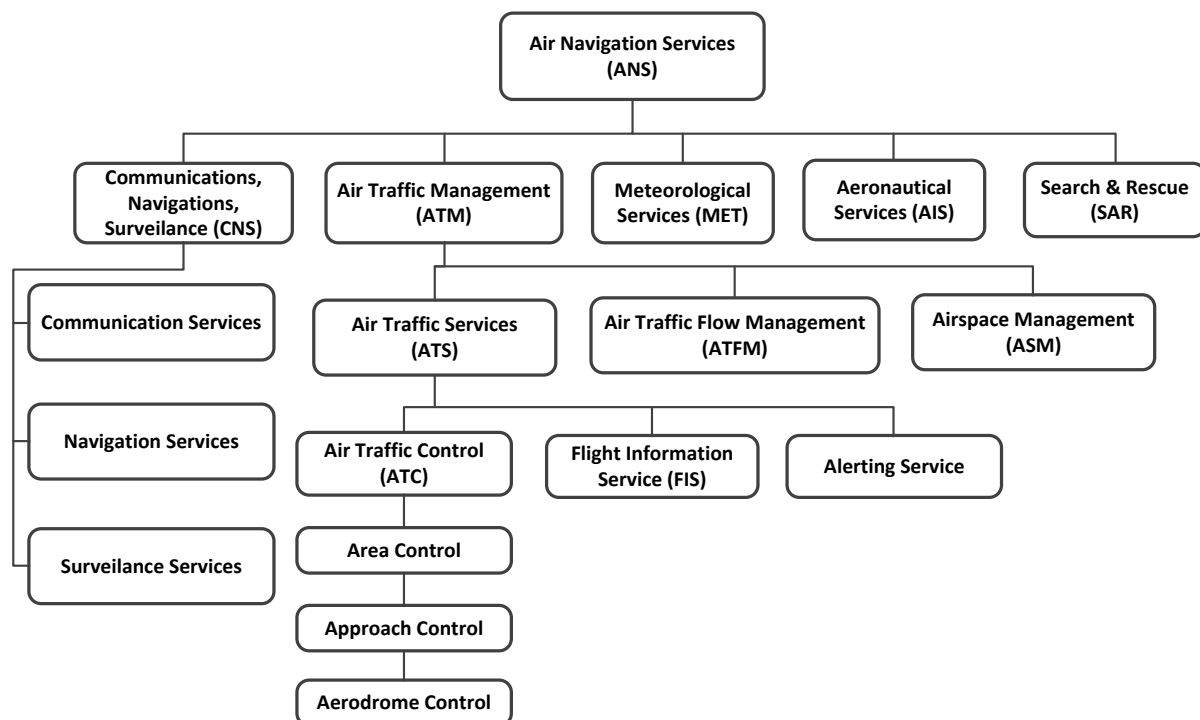
<sup>54</sup> Copenhagen Airport.

easier to compare between time intervals if they would be relative since increase in operating expenses is not necessary negative if they are direct result of increase in air traffic. It is interesting to note that Naviar does not distinguish ATCO employment cost from other staff charges. They have however set the target for ATCO on other duties to be less than 70 (in 2009 ATCOs in en-route operation were 7.260) in order to limit the use of such expensive workforce in other operation.

#### 4.4.4 Additional comments on the financial metrics

Although the definitions are similar between the ACE and CANSO reports there is some difference as to the service included when calculating the revenues and costs.

Figure 4.2 shows how ANS is divided into sub-categories according to a definition by Eurocontrol. This definition is provided as a guidance for the ANSPs within Eurocontrol when gathering data for the ACE report. In the ACE report the total costs refers to the costs of providing ATM and CNS services.



**Figure 4.2: Individual parts of Air Navigation Services as defined by Eurocontrol (Eurocontrol, 2008).**

In the ACE report ATM/CNS costs do not include:

- Costs for providing service relating to oceanic ANS, military operational air traffic and Aerodrome Flight Information Service at smaller regional aerodromes.
- MET costs.
- Regulatory and supervisory service costs.
- Eurocontrol costs.

- Payments to other ANSPs or states for delegated services.

In the CANSO report the costs are divided into Oceanic and Continental for those ANSP providing both services. In the report the cost is defined as ATC/ATFM provision cost but according to J. Paul Cripwell, a member of the GBWG, CNS costs are also included. As there is a variation between states how the MET cost is accounted for and whether the service is provided for within the ANSPs, MET cost is excluded in costs. Furthermore the cost does not include costs for providing service relating to Flight Service Stations which provide traffic advisories services.

Both reports define revenues for ANS, the revenues stated for a particular ANSP should therefore be the same in both reports.

In order to see whether these definitions of costs are comparable, ACE 2009 report and CANSO 2010 report were compared as they both cover data for the year 2009. Eight ANSPs which only provide continental ANS service were used in the comparison. The results can be found in table 4.1.

Revenues		Canso 2010		ACE 2009		Difference in M€
ANSP	IFR flight hours	Revenu per flight hour (USD)	Total revenues (USD)	Total revenues in € '000	Total revenues in € '000	
NAVIAIR (Denmark)	202.686	750	152.014.500	107.835	107.912	0
Finavia (Finland)	108.449	650	70.491.850	50.005	50.202	0
AENA (Spain)	1.300.611	1102	1.433.273.322	1.016.722	1.016.036	1
DSNA (France)	2.159.084	846	1.826.585.064	1.295.726	1.295.176	1
LFV (Sweden)	407.653	509	207.495.377	147.191	151.811	5
PANSA (Poland)	329.678	543	179.015.154	126.988	121.850	5
Romatsa (Romania)	266.528	937	249.736.736	177.156	166.960	10
LPS (Slovak Republic)	76.493	916	70.067.588	49.704	49.718	0

Costs		Canso 2010		ACE 2009		Difference in M€
ANSP	IFR flight hours	Cost per flight hour (USD)	Total Costs (USD)	Total Costs in € '000	ATM/CNS costs in € '000	
NAVIAIR (Denmark)	202.686	772	156.473.592	110.998	112.009	1
Finavia (Finland)	108.449	742	80.469.158	57.082	57.118	0
AENA (Spain)	1.300.611	1236	1.607.555.196	1.140.353	1.187.505	47
DSNA (France)	2.159.084	756	1.632.267.504	1.157.883	1.157.658	0
LFV (Sweden)	407.653	558	227.470.374	161.361	166.213	5
PANSA (Poland)	329.678	525	173.080.950	122.779	117.984	5
Romatsa (Romania)	266.528	781	208.158.368	147.661	147.767	0
LPS (Slovak Republic)	76.493	855	65.401.515	46.394	46.367	0

Exchange rate from Canso 2010 report: 1 USD = 1.4097 EUR

**Table 4.1 Comparison of the definition of revenues and costs in the ACE and CANSO reports.**

The Total Revenues in the table were calculated from IFR Flight Hours and Revenue per Flight Hour from the CANSO report and the result converted into Euros. Costs were

calculated in similar way using data from the CANSO report. From the table it is clear that the reporting of cost and revenue is not exactly the same for these reports, the difference is up to 47 million € which is about 6%. This should be kept in mind when making a comparison between ANSPs, it cannot be taken literally. It is likely that there will always be some variation because of errors and different interpretation in the definition of data elements.

## 4.5 Flight Efficiency and Environmental Factors

For each flight, a trajectory with as little deviation from the optimum trajectory is sought in order to optimize fuel burn and flight time which affect the cost to airspace users and pollution.

Optimum trajectory from the viewpoint of the flight operator is the trajectory where the cost is minimized with respect to wind, aircraft weight, route charges and perhaps other internal factors such as crew shifts and schedules of other flights. There are however also limiting factors which the operators must consider such as flight level capping and fixed tracks available. The flight plan filed by the flight operator might therefore not represent their optimal trajectory as it would be if their flight would be the only flight in the control area. In the flight efficiency metrics mentioned in this chapter the Great Circle<sup>55</sup> route has been used to represent the optimal trajectory, because of the calculation complexity of using wind optimal trajectories. The validity of this assumption will be considered in this chapter.

The flight efficiency metric aims to measure, for each flight, the deviation from the optimum trajectory. Decreasing this deviation will result in less fuel burn and the metric is therefore categorized as an environmental metric since less fuel burn means lower CO<sub>2</sub> emission to the atmosphere. It is also possible to categorize Flight efficiency as a quality of service metric for the airspace users because of the benefits from less fuel burn.

Noise in the terminal area and at airports is also an environmental factor but will not be dwelt on in this thesis as the focus is on oceanic en-route air traffic.

As fuel cost has increased over the years, fuel burn has become more important and much emphasis has been placed on finding solutions which decrease fuel burn of aircraft.

The flight efficiency has not been introduced as a metric for comparison between ANSPs. The ACE and CANSO reports do not include any flight efficiency metrics.

The PRC has however developed a metric to calculate vertical en-route flight efficiency called flight route extension and there is a flight efficiency metric in the SES Performance Scheme. Furthermore NATS UK has developed a fuel efficiency metric called 3DiScore. In chapters 4.5.2-4.5.4 these metrics will be explained but first a brief discussion on studies on flight efficiency will be provided in chapter 4.5.1.

### 4.5.1 Studies on flight efficiency

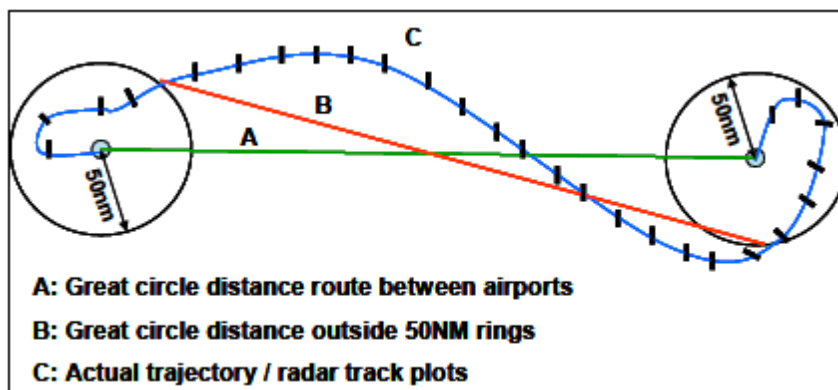
There are two main sources of flight inefficiency:

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<sup>55</sup> See Glossary of Terms for more information on the Great Circle.

- Horizontal inefficiency, where the trajectory flown is longer in kilometres than in optimal trajectory.
  - Vertical inefficiency, where the altitude flown at each time is not the optimum altitude. There are mainly two reasons for vertical inefficiency:
    - Flight level capping, e.g. the optimal cruising flight level is not available.
    - Suboptimal climb and descent. In the climb phase the aircraft is kept at suboptimal flight levels mainly for air traffic control operational reasons.
- (Performance Review Unit, 2008).

In a seminar paper from 2005 results of studies of flight efficiency carried out by Eurocontrol and the FAA were introduced and compared (Kettunen et al., 2005). Both these studies focused on the horizontal flight efficiency considering the difference in actual distance flown and the great circle distance<sup>56</sup>. The terminal area was defined as 50 NM circle from the airport in both studies, see figure 4.3.



**Figure 4.3: Parameters of the flight efficiency metrics. (Source: (Kettunen et al., 2005))**

The Eurocontrol study showed that the actual flown distances were about 10% greater than the great circle distances, whereas the FAA study showed 6-8% excess in distance of flight. Both studies indicated that large part of the inefficiency lies in the terminal areas, which can be explain by the restrictions set in terminal areas due to congestion around the airports.

It has been pointed out that using great circle distance as a reference route, may not give the correct results as it may not be the optimal route. This may especially apply for long distance hauls where the optimal route is calculated on the basis of several factors such as wind and the weight of the aircraft.

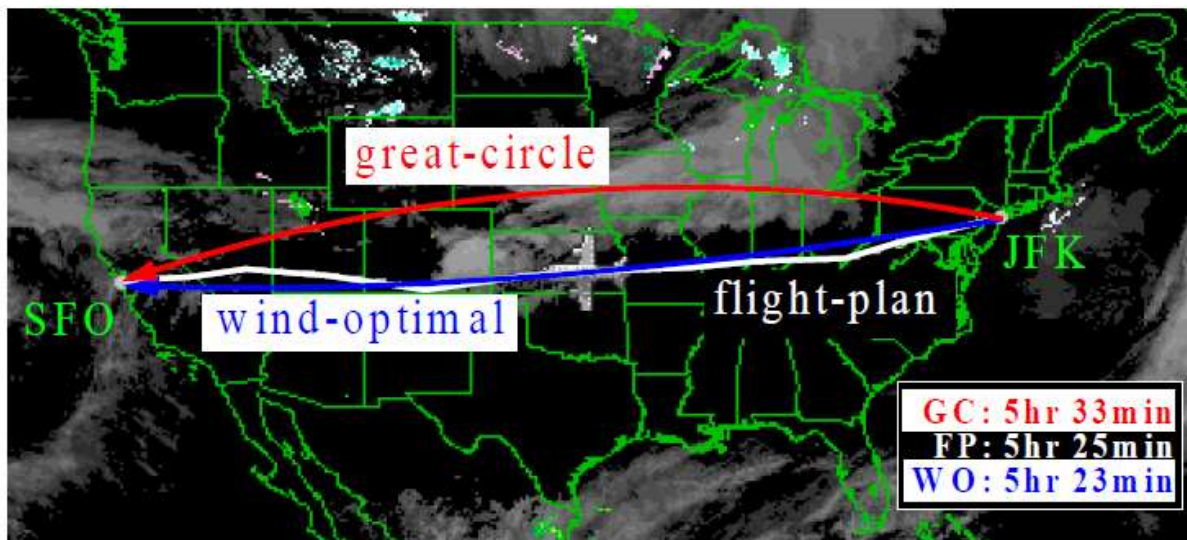
In the FAA study only flights in the range of 200 – 1.100 km were used. The reason for this, as stated in the paper, was that for longer flights, wind affects the choice of routes. For this reason the FAA study decided not to include flights longer than 1.100 km as that could result

<sup>56</sup> Great circle distance is the shortest distance between any two points on the surface of a sphere (Wikipedia contributors, 2012).

in difference in distance which is not related to inefficiency but rather the difference between the wind optimal route and the great circle route.

Using the wind optimal route when calculating flight efficiency instead of the great circle distance will increase the calculation complexity enormously which is the reason why the great circle route has been used to estimate the optimal route.

While this approximation may be justified for short distances, that is not the case for long distance flights. A study performed at Ames Research Center<sup>57</sup>, examining flights across the United States showed that the time difference between wind optimal routes and the great circle routes was on average 7 minutes (M. R. Jardin, 2004). During periods of strong jet stream this difference went up to an hour in flight time. An example of the difference can be seen in figure 4.4. Figure 4.4 shows three different routes of the flight between New York and San Francisco: the great circle route, the wind-optimal route and the route according to the flight plan. The wind optimal route is 10 minutes shorter in terms of flying time than the great circle route.



**Figure 4.4: Difference in great circle route and wind optimal route. Source: (M. Jardin, 2003)**

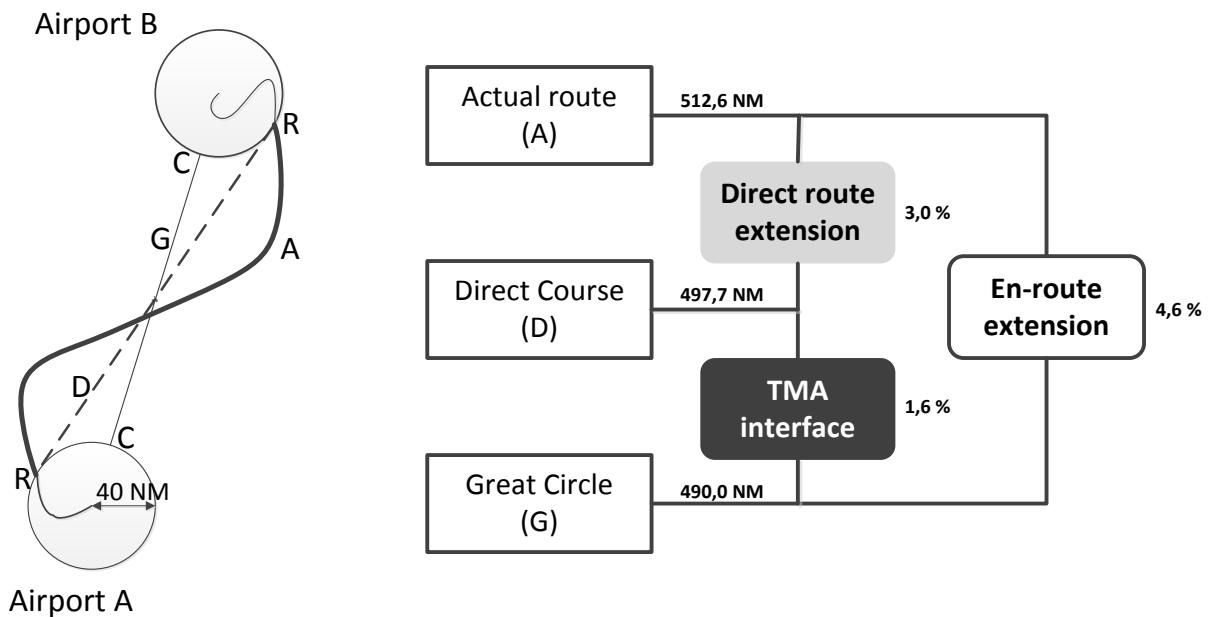
As can be seen from this figure the great circle distance is in this case far from being the optimal route and using that route as a reference for the Flight efficiency metric would give erroneous result.

In 2011 the average IFR flight hours in the Reykjavik CTA were about 1 hour and 43 minutes and the average kilometres flown were 1.440 km which is longer than the reference value of 1.100 km FAA used in their study mentioned above. The maximum IFR flight hours per flight in the Reykjavik CTA went up to 3 hours and 45 minutes in 2011. Because of the effect of the jet stream in the North Atlantic oceanic airspace and the long average distance flown in the Reykjavik CTA it can be concluded that the great circle route would not be a good proxy for optimal route through the Reykjavik CTA.

<sup>57</sup> The Ames Research Center is a NASA research center.

### 4.5.2 Performance Review Commission's En-route Extension

The En-route Extension as defined by the PRC is an indicator similar to Flight Efficiency calculated in the research described above in chapter 4.5.1. It calculates the difference in the distance between the Actual route (A) and the Great Circle route (G). The reference route (the great circle route) is calculated as if the aircraft were the only one in the system, without the usual restrictions applied. It therefore describes a theoretical performance which is unachievable in a real situation but can give guidance as to how performance can be improved (Performance Review Commission, 2012).



**Figure 4.5: En-route Extension as defined by PRC in the Performance Review Report.**

Figure 4.5 describes how the En-route Extension is calculated. A circle with a radius of 40 NM<sup>58</sup> from the airport centre is defined as a terminal area and is not included in the calculation.

The En-route extension is divided into two parts: Direct route extension and TMA interface.

The optimal flight, giving zero En-route Extension, would be the flight where the aircraft would depart from Airport A, go through point C, follow the Great Circle course (G) and enter the terminal area of Airport B at point C.

TMA interface (Terminal Manoeuvring Area interface) is the difference between Direct course (D) and Great circle (G) and describes the inefficiency of the terminal area. The TMA interface measures the effect of going through point R of the terminal area instead of point C. Without any detours in the terminal area the TMA interface would be contributing zero to the En-route extension. In that case R would coincide with C and the Direct Course (D) would be identical with the Great Circle course (G).

<sup>58</sup> In the 2011 Performance Report this was changed from 30 to 40 to harmonize performance indicator with the flight efficiency metric in the SES Performance scheme.

Direct route extension is the difference between Actual route (A) and the Direct course (D).

The Direct route extension was in 2011 the larger contributor to the En-route extension, 3%, while the TMA interface was 1,6%, giving total of 4,6% average En-route extension. This means that on average each flight was 4,6% longer (512,6 NM/949,3 km instead of 490,0 NM/907,5 km) than if it would have followed the Great Circle route.

By using the Great Circle as a reference in the En-route extension, it is presumed that the Great Circle route is the best route although it is acknowledged that it may not be the case when the route is optimized with respect to wind, route charges, aircraft weight etc. As mentioned in chapter 4.5.1 this assumption may not be valid especially in long distance haul. It is therefore noteworthy that the average flight distance in Europe mentioned here above is 949,3 km while the cut-off distance of 1.100 km was used by FAA in their studies mentioned in chapter 4.5.1. In PRR 2010 it is mentioned that the average Great Circle distance has been increasing over the years, in 2005 it was about 825 km (Performance Review Commission, 2011; page 67). This indicates that for increasing number of flights the Great Circle route may not be the optimal route and one would therefore find it appropriate that the error from this assumption would be evaluated in some way, but no such evaluation could be found in the PRR 2011.

### 4.5.3 Flight efficiency metric of SES Performance Scheme

The performance scheme of the Single European Sky (SES) is set forth in EU regulation no. 691/2010. In Annex I, Section 1, Item 2.1 it is stated that:

*“For the first reference period:*

*The first European Union-wide environment KPI shall be the average horizontal en route flight efficiency, defined as follows:*

- the average horizontal en route flight efficiency indicator is the difference between the length of the en route part of the actual trajectory and the optimum trajectory which, in average, is the great circle,*
- ‘en route’ is defined as the distance flown outside a circle of 40 NM around the airport,*
- the flights considered for the purpose of this indicator are:*
  - (a) all commercial IFR (Instrumental Flight Rules) flights within European airspace;*
  - (b) where a flight departs or arrives outside the European airspace, only that part inside the European airspace is considered,*
- circular flights and flights with a great circle distance shorter than 80NM between terminal areas are excluded.”* (The European Parliament and the Council of The European Union, 2010).

This flight efficiency indicator corresponds to the En-route extension which has been used by the PRC and is described in chapter 4.5.2. In the regulation it is stated that the reference trajectory (route) should be the optimum trajectory which in average is the great circle.

For the first reference period (2012-2014) of the Performance Scheme there is no mandatory Environmental KPI for the ANSPs or Functional Airspace Blocks (FAB)<sup>59</sup>.

A stakeholder survey was performed for the preparation for the second reference period of SES Performance Scheme, “SES II Performance Scheme Summary of Initial Stakeholder Views on RP2”. Here are some of the suggestions that were made of how this indicator might be improved (Eurocontrol, 2011a):

- Vertical dimension of the indicator to be considered.
- Use of Actual route rather than flight plan route.
- Taxi time (Taxi-out, Taxi-in)<sup>60</sup>.
- Holding time<sup>61</sup>.
- Wind optimal route rather than shortest route (great circle).

As a proposal of an alternative for measuring flight efficiency one suggestion was “Number of direct given by controller”. There are no further explanations of these suggestions in the survey.

According to Denis Huet, Head of Project Office within PRU, it is proposed to add a vertical flight efficiency indicator for the second reference period for monitoring purposes only. Proposals for the second reference period are however not finalized.

#### **4.5.4 NATS fuel efficiency metric**

NATS, the ANSP of the United Kingdom, has developed what they call the 3-Dimensional Inefficiency Score (3Di Score). The purpose of the 3Di Score is for NATS to be incentivized for improving fuel efficiency (Nutt, 2012).

In the 3Di Score, flight profiles are compared to optimal trajectories which follow the great circle route and cruise at requested level.

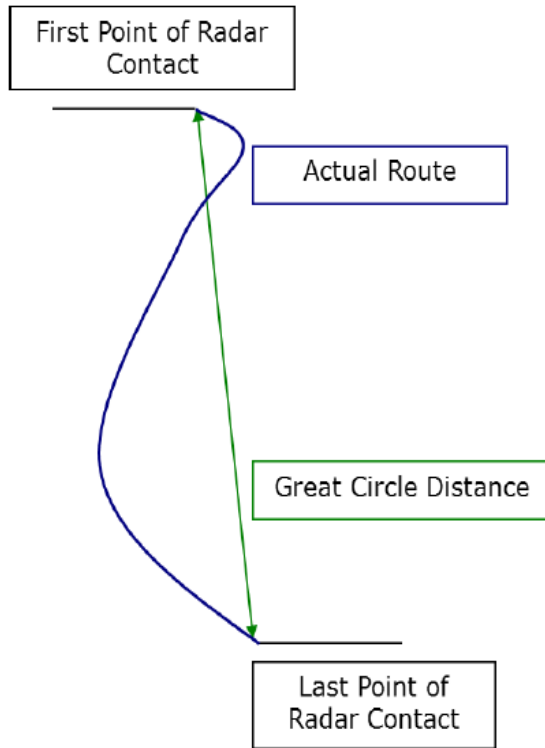
The 3Di Score has a horizontal component, similar to the En-route Extension (chapter 4.5.2.), called track extension (H). The track extension compares the Actual route to the Great Circle distance, see figure 4.6.

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<sup>59</sup> See further information on FAB in Glossary of Terms.

<sup>60</sup> See explanations in Glossary of Terms.

<sup>61</sup> See explanations in Glossary of Terms.



**Figure 4.6: The horizontal component of the 3 Di Score. (Source: (Nutt, 2012))**

There is however a difference between the track extension (H) and the En-route extension, as the track extension does not exclude a 40 NM radius at the airports and uses instead the first and last point of radar contact. Furthermore the track extension (H) is the excess distance flown as a portion of the Great Circle Distance:

$$H = \frac{\text{Actual Route} - \text{Great Circle Distance}}{\text{Great Circle Distance}} \quad (4.32)$$

The track extension is therefore a number without unit, the optimal value is zero.

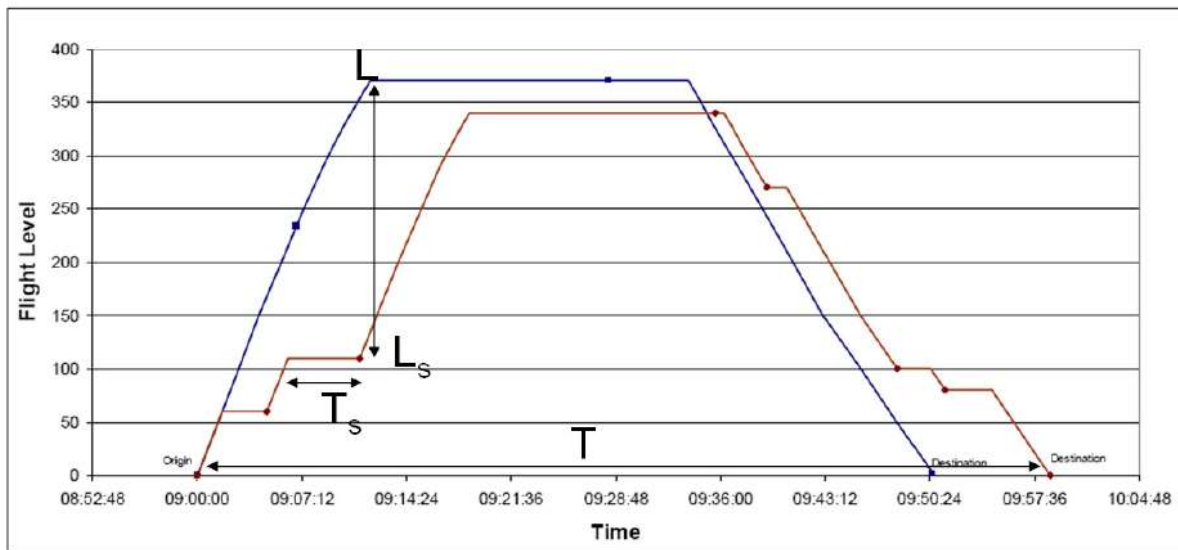
The 3Di Score also includes a vertical component, called vertical inefficiency (V). In the vertical inefficiency the vertical components of the trajectory flown is compared to an optimal trajectory which has unrestricted climb and descent phase and the requested flight level in cruise phase.

For each step,  $s$ , the vertical inefficiency,  $V_s$ , is calculated on the basis of the duration of the step, the flight level of the step, the total flight time and the reference flight level. The calculation of the vertical inefficiency is shown in figure 4.7. The figure is obtained from a published decisions of the British Civil Aviation Authority (CAA) regarding the Flight Efficiency Metric (Civil Aviation Authority, 2011).

The formula for the vertical flight inefficiency is:

$$V = \sum_s V_s = \sum_s \frac{T_s}{T} \left( \frac{L - L_s}{L} \right) \quad (4.33)$$

Where  $T$  = Total Flight Time,  $T_s$  = Duration of Step,  $L$  = Reference Level and  $L_s$  = Level of Step as defined in Fig 4.7.



**Figure 4.7: Vertical component of 3Di Score.**

In figure 4.7 the blue line represents the optimal trajectory and the red one represents the flight actual profile.

The vertical inefficiency is calculated for each phase of the flight, the climb, cruise and the descent.

As in track extension, vertical inefficiency is without unit with the optimal value of zero. Although vertical inefficiency for each step,  $V_s$ , is from zero to one the inefficiency for each phase of the flight is not necessary less than one since the inefficiencies of each step are added together.

Using a sample of 116.000 flights from 2009, a regression analysis was conducted to establish a model where the extra fuel consumption (because of inefficiency) was expressed in terms of the horizontal and vertical components (Civil Aviation Authority, 2011). The model was tested with a test sample of 58.000 flights.

The fuel burn was calculated for a flight with optimal trajectory, which follows the great circle route, cruise at requested level with uninterrupted climb and descent. This was compared with the fuel burn for the actual trajectory which was followed. The reference trajectories were modelled using standard BADA<sup>62</sup> aircraft performance data. The actual trajectory was simulated using the same aircraft performance data and atmospheric assumptions as the reference trajectory. The fuel burn calculations were performed using a model called KERMIT<sup>63</sup>.

The results of the analysis gave the following 3Di Score:

<sup>62</sup> BADA (Base of Aircraft Data), is an aircraft performance model developed and maintained by Eurocontrol.

<sup>63</sup> KERMIT (Kerosene Emissions Research Model) is a NATS model which uses data on aircraft performance from the Eurocontrol BADA 3.9 database.

$$\varphi = \beta_1 H + \beta_2 V_{CL} + \beta_3 V_{CR} + \beta_4 V_D + \beta_5 HV_{CL} + \beta_6 HV_{CR} + \beta_7 HV_D \quad (4.34)$$

Where  $\varphi$  is the 3 Di Score, H = Horizontal Inefficiency,  $V_{CL}$ = Vertical Inefficiency of the Climb,  $V_{CR}$ = Vertical Inefficiency of the Cruise,  $V_D$ = Vertical Inefficiency of the Descent and  $\beta$  are constants.

The constants, which were found by regression analysis, are given in table 4.2.

Parameter	Coefficient
$\beta_1$	0,8973
$\beta_2$	0,8233
$\beta_3$	1,1095
$\beta_4$	1,6788
$\beta_5$	0,4265
$\beta_6$	0,469
$\beta_7$	2,9618

**Table 4.2: The coefficients of the 3Di Score.**

The components of  $\varphi$  are additive,  $\varphi$  is therefore not limited from zero to one. As the 3Di Score calculates fuel inefficiency its optimal value would be zero.

Daily 3Di Scores were calculated in 2010 giving a range from 15 to 35 units. A trial flight was flown between Heathrow and Edinburgh where the flight route was meant to represent a “perfect flight”. The “perfect flight” concept involves an uninterrupted climb to cruise altitude, a direct route in cruise, followed by an uninterrupted descent. This was done to demonstrate that the 3Di could be reduced if you could follow your preferred route. The 3Di Score for the trial flight was 1,4 units (the average on the same route was 22,1) (Nutt, 2012).

It was suggested in the CAA decision that the coefficients of the model should be calculated annually by repeating the regression analysis with new flight data.

As with PRC’s En-route extension it has been criticized that the Great Circle route is used as the reference route instead of the wind optimal route in the 3Di Score (Tate, 2011).

This metric is calculated and modelled for flights in the UK airspace and can therefore not be used unchanged for other airspaces. The methodology could however be used for other airspace by using flight data from that airspace. This metric can be useful to assess changes in fuel efficiency between years within a certain control area but would hardly be suitable for benchmarking between countries since the formula for calculating the metric would not be the same.

The main difference of the 3DiScore as compared to other flight efficiency metrics are the addition of the vertical component and that it does not omit a circle of 40 NM around the terminal area.

#### 4.5.5 The applicability of the flight efficiency metrics in Reykjavik CTA

Considering the applicability of a similar metric for the Reykjavik CTA the use of great circle route as a reference would not be advisable, as mentioned before. Using wind optimal routes instead of great circle distance would however increase the calculation complexity. That does however not exclude the possibility of using wind optimal routes when calculating this metric in the future.

Also, when considering the vertical inefficiency it should be noted that when in cruise phase a single flight level is not necessary optimal. It is more efficient to start the cruise in one flight level and when the aircraft has lost weight to climb to another flight level(s). When considering only the oceanic international en-route flight in the Reykjavik CTA the vertical inefficiency will be reduced to the vertical inefficiency of the cruise phase.

This becomes the issue of obtaining the optimal flight level and the wind optimal horizontal route. A further study of a design of efficiency metric comparing actual routes with optimal route in Reykjavik CTA is warranted. Such metrics are of great value in large control areas where there are opportunities for fuel savings.

One might consider introducing a simplified metric which captures the issue of obtaining the optimal flight level as mentioned in chapter 4.6.2 below where the metric *Altitude Change Requests* is mentioned.

It is furthermore possible to make the assumption that the requested flight route as defined in the flight plan filed by the flight operator is the optimal route. A metric calculating the percentage of preferred flight routes granted versus flight routes filed would therefore indicate the flight efficiency.

There are however several drawbacks of such a metric.

- It does not calculate the fuel consumption and hence it cannot compare the optimal route to other sub-optimal routes. The flight operator might be granted second best route with little difference in fuel consumption.
- The flight operator might not request for the optimal route with respect to fuel consumption. Other factors might influence the requests for flight routes. There may be restrictions which limit the selection of flight routes such as predefined tracks or flight level caps. Prior experience of what is allowed/rejected may influence the choice. This may apply especially to requests for altitude change. If the pilot's experience is that such requests are normally rejected he/she may decide not to submit a request for altitude change even though such a change would decrease fuel consumption.

When comparing this kind of metric between ANSPs the last point mentioned above could lead to erroneous results. As an example the optimal flight route of a specific operator might differ significantly from the predefined tracks available.

The same applies for request of altitude changes. An ANSP which does not often allow changes to flight routes will probably have low number of such requests. If the flight operators/pilots have learnt under what circumstances such requests might be granted, this particular ANSP might have large percentage of altitude change requests granted. A measure of the percentage of altitude changes accepted versus altitude changes requested would therefore not necessarily measure efficiency in fuel consumption, as many aircraft might still fly in sub-optimal flight levels because of preconceptions of the pilots or the flight operator.

## 4.6 Quality of Service

Quality of service to the airspace users is a factor which must be taken into consideration while looking at the performance of ATM systems. It should be considered while taking measures to improve other performance metrics.

There are interdependencies between the service provided and cost effectiveness. It is possible to decrease cost by limiting the service provided by the ANSP. In the Reykjavik CTA an example of that could be to introduce fixed tracks resulting in less complex traffic which would require fewer ATCOs. That in turn would decrease the ATCO employment cost but the service to the airspace users would also deteriorate and would probably result in higher fuel cost<sup>64</sup>.

Demand-capacity balancing is a trade-off between quality of service and costs. If the capacity of the ATC system does not meet the air traffic demand, air traffic will be delayed or other restrictions introduced. That will have negative effect on the airspace users. If, on the other hand, the ATC capacity is higher than the air traffic demand, resources are not fully utilized which has negative effect on the cost efficiency.

Furthermore, route structure, handling of requests from pilots and how well equipped the ANS system is, are factors which affect the quality of service provided by ANSPs.

The main metrics representing quality of service which have been introduced are based on recorded flight delays and the flight efficiency metrics which were defined in chapter 4.5.

### 4.6.1 Delay/Capacity

When the capacity of ATC service does not meet the air traffic demand aircraft are delayed on ground at the departing airport until the capacity issue has been resolved. A metric capturing delay is therefore also an indicator for ATC capacity.

This metric does however hardly apply in the Reykjavik CTA. The reason is that there are not issued specific times (slot times) for entering Reykjavik CTA's airspace. There are several factors which affect the flight time through the oceanic airspace (such as wind and flight speed). An aircraft is usually not held at a departing airport because of air traffic in the oceanic area or at the destination airport across the ocean.

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<sup>64</sup> Using fixed tracks limits the possibility of the flight operator to use optimal flight route.

On the rare occasions when there is too much traffic load in the Reykjavik CTA which cannot be resolved through other means it is possible to decrease the traffic load by requesting limitations on incoming traffic for a specific period of time. Then the Central Flow Management Unit (CFMU)<sup>65</sup> will temporarily limit the traffic into the Reykjavík CTA. It is however only under exceptional conditions, that capacity limits are requested. In 2011 there were no such limitations and there were only few limitations in 2010 due to the eruption in Eyjafjallajökull which caused unprecedented increase in traffic load in the area.

In light of this there will be no calculations of delay in the Reykjavik CTA and hence the following metrics are only mentioned for information purposes without any further discussions.

#### **4.6.1.1 SES Performance Scheme**

In EU regulation no. 691/2010, Annex I, Section 2, Item 3.1 the national/FAB Capacity KPI is defined as:

Minutes of en-route ATFM delay per flight = the difference between the take-off time requested by the aircraft operator in the last submitted flight plan and the calculated take-off time allocated by the central unit of ATFM.

The Performance Scheme includes an EU-wide target for the Capacity KPI.

#### **4.6.1.2 ACE report**

In the ACE report the following capacity metric is indicated for each ANSP:

Minutes of ATFM delays > 15 minutes.

In the ACE report the cost of ground ATFM delay is estimated for each minute of delay and added to the cost of providing ATM/CNS services in a metric called Economic cost-effectiveness. In this way an effort is made to represent the trade-off between the quality of service and the cost.

#### **4.6.1.3 FAA Oceanic and Offshore Integrated Product Team**

The FAA Oceanic and Offshore Integrated Product Team suggested a measurement of delay in the following form:

1. Departure delay - the number of oceanic flights that have departure delays and the amount of time that they were delayed.
2. Arrival Delay – the number of oceanic flight that arrive late and the difference between the scheduled arrival time and the actual arrival time.(Wu et al., 2004).

Unfortunately available information on the work of the FAA Oceanic and Offshore Integrated Product Team are scarce and further information on these metrics was not found. There is also difference between procedures in US and Europe of how capacity problems are resolved.

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<sup>65</sup> CFMU is operated by EUROCONTROL, see also Glossary of Terms.

### 4.6.2 Other Quality of Service Metrics

The FAA Oceanic and Offshore Integrated Product Team (IPT) suggested several metrics directed at Oceanic ANS (Wu et al., 2004).

The following performance metrics may be classified as Quality of Service Metrics:

1. Altitude Change Requests - number of requests which are:
  - a. Granted
  - b. Modified
  - c. Not granted or deferred
2. Response Time – the difference in time from the receipt of a request and the transmission of the response to an altitude change request.
3. Entry Altitude Flown versus Filed Altitude (predictability) – The percentage of flights that entered the airspace where the altitude was:
  - a. Higher than the filed altitude
  - b. Lower than the filed altitude
  - c. As filed

These metrics were measured monthly and displayed on a dashboard of histograms to provide a picture of the overall performance of several metrics.

The metric *Altitude Change Requests* is in a way a vertical flight efficiency metric. When considering the oceanic control area (without departure and landing) NAT's vertical flight efficiency metric (see chapter 4.5.4.) reduces to the difference of the optimal flight level and the actual flight level. Here this is addressed in a different way, by counting altitude requests, rather than calculating the difference of fuel consumption between the optimal flight level and the actual flight level.

ANSPs might also consider adding other metrics which are not intended for benchmarking in order to evaluate the service they provide and the trends in these services for instance on an annual basis.

In the Balanced Scorecard, one of the guidelines for balanced system of performance measurement is the question (see chapter 3.2.):

How do our customers see us (the customer perspective)?

Metrics which focus on the client can be very useful in order to learn about their views with respect to the services available and any additional service they might appreciate.

It is also important to disseminate information about the services available and to make sure the airlines are aware of the value of the services offered.

## 4.7 Difference in definitions in the ACE and CANSO reports

Since Oceanic Air Navigation Services are the main part of the service provided by Isavia, it is important to observe that in the ACE report, data for the provision of service in oceanic areas are not included. The CANSO report divides the performance metrics into Oceanic and Continental. The CANSO 2012 report includes performance measurements from six ANSPs that manage traffic in oceanic airspace, namely FAA ATO (USA), NAV CANADA, NATS (UK), NAV Portugal, Airways New Zealand and ATNS (South Africa).

In the ACE report en-route flight-hours are calculated by the Central Flow Management Unit (CFMU) from the flight plans provided by airspace users using so-called “CFMU Model III”<sup>66</sup> (Performance Review Unit, 2011). En-route flight-hours are in a way comparable with the continental flight-hours as they both are intended to capture the hours controlled by Area Control Centers (ACC) and Approach Control Units (APP). However while in Europe the definition of flight time is the time from a point after take-off to a point before landing, the definition used in the CANSO report is from wheels-up to wheels-down since that is the definition used by many of the ANSP’s participating in the CANSO report. The difference has been estimated to be one minute for take-off and one minute for landing (Cripwell, 2012). As a result the flight hours are not comparable between the reports.

A document called “Eurocontrol Specification for Economic Information Disclosure” is a guidance for the ANSPs participating in the benchmarking disclosed in the ACE report. The definition of where the en-route service ends and terminal service starts should be in accordance with definitions used for charging purposes (Eurocontrol, 2008). It is however stated in the ACE report that the definition is different between ANSPs. In order to minimize errors resulting from this the ACE reports uses composite flight hours in their calculations. Composite flight hours are defined in the ACE 2010 report as:

Composite gate-to-gate flight-hours = (en-route flight-hours) + (0,26 x IFR airport movements) (Performance Review Unit, 2011).

In the ACE reports the financial elements are given in Euros. In the ACE 2011 report, which reports results from 2011, the financial elements used for the calculation of performance metrics are first obtained each year in national currencies. Then they are converted to 2011 prices in their national currency, taking into account the inflation in each country. Finally the elements are converted from national currency to Euros using the 2011 exchange rate.

CANSO reports are in US dollars. In the CANSO 2012 report, which reports results from 2011, the exchange rate for the end of 2011 is used for the comparison between ANSPs that year. In the trend analysis for the years 2007-2011 a dollar pegged to the 2007 end-of-the-year exchange rate is used.

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<sup>66</sup>The CFMU Model III gives an approximation to the actual trajectory flown on the basis of the flight plan and updates of the flight plan.

In both reports employment costs are also calculated using Purchasing Power Parity<sup>67</sup> exchange rate.

As will be described in more detail in chapter 4.5.3 there may be some difference in how the ANSPs report their revenue and costs between the ACE report and the CANSO report.

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<sup>67</sup>Purchasing Power Parity is an adjustment of the exchange rate so that a basket of the same goods in two different countries has the same price.

## 5. Factors affecting performance

### 5.1 Introduction

Air Navigation Service Providers (ANSP) have the common purpose of providing Air Navigation Services (ANS) in accordance with international standards and recommended procedures. Consequently, their operation is in many ways similar. However, their working environment may differ considerably. When deciding which performance metrics to use, one of the criteria is that the performance which is measured is controllable by the organization or individuals responsible for carrying out the specific activity. If a party has no control over the drivers affecting a metric, that metric cannot be used to measure the performance of this party, although it may provide valuable information. Often there are several drivers of performance, some of which may be beyond control of the ANSP. The metric *IFR flight hours per ATCO hours*<sup>68</sup> is for example influenced by several factors. Unexpected decrease in air traffic has great effect on the productivity and may be very difficult to adjust to. On the other hand improvements in working procedures and innovation which enhances ATCOs productivity are controlled by the ANSP.

In the ATM Cost-Effectiveness Benchmarking Report (ACE report), published annually by the Eurocontrol's Performance Review Unit, the factors affecting performance are divided into two categories: i.e. endogenous and exogenous factors. In this chapter the endogenous and exogenous factors are discussed and two factors, traffic variability and complexity, are considered further.

#### 5.1.1 Endogenous Factors

Endogenous factors are the factors affecting performance which ANSPs can control. The endogenous factors relate to how each ANSP has built up its air navigation services and how they are managed.

The effects of these factors on ATCO productivity vary and sometimes it may be difficult to establish which endogenous factors are affecting productivity and how they affect the productivity. Corporate culture may for instance have great effect on ATCO productivity, while it can be very difficult both to detect the cause-effect relationship and to change the culture in order to increase productivity. On the other hand when new features or procedures in the Air Traffic Management (ATM) systems and/or equipment are introduced it is possible to compare the productivity before and after its introduction, in order to estimate the effect on productivity.

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<sup>68</sup> Here IFR is an abbreviation of Instrument Flight Hours and ATCO is an abbreviation of Air Traffic Controller (or Air Traffic Control Officer).

The endogenous factors listed in the ACE 2009 report are (Performance Review Unit, 2011):

#### **Organizational factors**

- Internal organizational structure
  - Degree of centralization
  - Optimization of internal processes
  - Corporate culture
- Extent of in-house ownership and activities
  - Leasing, renting, owning assets
  - Research & development policy
  - Outsourcing non-core activities
- Human resources
  - Recruitment and training
  - Staff/management relationships
  - Internal communication
- Relationship with the customers
  - Arrangements for customer consultation
  - Disclosure of audited financial statements

#### **Managerial & financial aspects**

- ANSP management
  - Top-management leadership and actions
  - Performance oriented management
- Collective bargaining process
- Financial and accounting aspects
  - Business planning process
  - Investment policy
  - Balance sheet structure
  - Depreciation policy

#### **Operational & technical setup, including:**

- Operational organization
- Operational concepts and processes
  - Airspace and sector design
  - ASM, ATFM or ATFCM<sup>69</sup>
  - Civil/military arrangements
- Operational flexibility
  - ATM systems & equipment
  - Human/system interaction

Difference in performance between ANSPs with similar exogenous environment may be explained by varying degree of efficiencies arising from endogenous factors. However the endogenous factors may be affected by exogenous factors. Benchmarking, the comparison between two or more organizations, must therefore be considered in that light. Exogenous factor may for example affect how the ATM systems & equipment are designed. An example of this is the fact that the Reykjavik CTA is partly controlled with radar surveillance and partly by applying procedural separation. This results in a need for tailored solutions for the ATM system instead of commercial off-the-shelf solutions. This also affects the configuration and design of control sectors.

### **5.1.2 Exogenous factors**

When benchmarking performance the exogenous factors affecting performance of the ANSPs must be considered. Some of the exogenous factors are measurable and the ANSPs can be grouped on the basis of such measures and comparison performed within the groups. Other factors which may affect the ANSPs performance are not as obvious such as political and economic environment.

The exogenous factors listed in ACE 2009 report are:

<sup>69</sup> Airspace Management, Air Traffic Flow Management or Air Traffic Flow and Capacity Management.

**Legal & socio-economic conditions**

- Overall business & economic environment
  - Exchange & inflation rates
  - Cost of living & market wage rates
  - Political factors
  - Taxes on turnover or profit
  - Accounting standards
- General labour law and rules governing industrial relations
  - Working hours
  - Retirement age
  - Social security and pensions
- Value Added Tax application

**Operational condition**

- Size of the ANSP
- Traffic complexity
  - Density of traffic
  - Structural complexity
  - Traffic mix
- Spatial and temporal traffic variability
- Type of airspace under ANSP responsibility
- Weather

There are several factors on these lists which are of significance for Isavia as they are likely to differ from those of other ANSPs:

***Exchange & inflation rates***

Inflation rates have for several years been much higher in Iceland than in the US and in the Euro-zone. In January 2009 the inflation rate in Iceland went up to a peak of 18,6% on an annual basis. From 2007 to 2012 the average annual inflation rate was 7,4%. In this thesis, calculations are performed for the period 2009 to 2012. The average inflation rate for that period was 6,7%<sup>70</sup> while at the same time the average inflation rate in US and the Euro-zone was less than 2%.

The depreciation of the ISK versus the USD was 46% in the period 1.1.2007 – 31.12.2012<sup>71</sup>. The fluctuation of the USD – ISK exchange rate was great, the difference of maximum and minimum daily values from the average for this period were 39% and 45%, respectively. For the same period the change between the start and end date of the USD-EUR exchange rate was less than 1%. The difference of maximum and minimum daily values from the average for this period was 15% and 14%, respectively. However for the period between 1.1.2009 and 31.12.2012<sup>72</sup> the fluctuation of the USD - ISK exchange rate was much less and similar to the USD - EUR exchange rate.

The depreciation of the ISK vs. international currency increases the revenues for the air navigation service of Isavia in the local currency, as by far the largest part of the revenues are in foreign currency. A depreciation of the ISK increases the price of imported goods. As large part of consumer goods are imported or is made of imported raw material this will eventually affect the inflation rate. This may increase the cost of

<sup>70</sup> According to information from the Central Bank of Iceland's website.

<sup>71</sup> Using daily values from Seðlabanki Íslands and measured by the difference of first and last value of the period.

<sup>72</sup> Currency restrictions have been in place for the whole period.

the air navigation service, especially supplies and capital expenses. However, it should be noted that wages do not necessary increase with inflation, at least in the short run. As wages are large part of the ANS costs this may result in mismatch in revenues versus costs and hence cost-recovery. In the case of depreciation of the ISK the effect is over-recovery, while the strengthening of the ISK results in under-recovery.

### ***Size of the ANSP***

The size of an ANSP is usually measured in the number of annual IFR flight hours or, as in the ACE report, the composite flight hours (including part of the IFR airport movements). Total IFR flight hours in Reykjavik CTA in 2011 were 192.364, which is less than the flight hours of 18 out of 25 ANSPs in the CANSO 2012 report. Large part of costs is not dependant of the service output (i.e. the IFR Flight Hours) and is fixed. Hence the cost per IFR Flight Hours becomes high when the number of flight hours is low. The control area is also large in comparison with other ANSP which results in higher costs because of extra resources (such as communication equipment) required to service the larger area. Both these factors may affect the cost effectiveness at Isavia in comparison with other ANSPs of different size. High number of flight hours controlled should, under normal circumstances, increase the possibility of economies of scale as fixed cost will be spread over larger number of controlled flight hours. There are however little evidence showing that the larger ANSP have in fact utilized this possibility. That may however be explained by the lack of incentive to reduce cost under cost-recovery regime (Performance Review Unit (PRU), 2013).

### ***Type of airspace under ANSP responsibility***

There is radar surveillance available in a part of the Reykjavik CTA which is rather unusual in oceanic airspace. This affects equipment required, training of ATCOs, sector configuration etc. and will therefore increase costs as compared to control areas with no radar coverage. It also increases the possibilities to offer more service than in non-radar oceanic areas which is beneficial to the airspace users. With additional service, additional costs of providing the ANS service may be introduced although the benefits to the airspace users are likely to outweigh such additional costs.

In some control areas there are restrictions due to military operations which have negative effect on the civil air traffic. In the Reykjavik CTA the effect of military operations are minimal.<sup>73</sup>

### ***Weather***

Over the North Atlantic Ocean at high latitude, strong winds from west referred to as the Jet Stream have a dominant effect on the winds aloft.<sup>74</sup> This greatly influences the air traffic flow across the Atlantic Ocean and introduces spatial and temporal variability in air traffic in the Reykjavik CTA as explained further in chapter 5.2.

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<sup>73</sup> For further information see Appendix I and II.

<sup>74</sup> See Airspace Management in Appendix I.

As the complexity of air traffic is of great importance when comparing productivity between ANSPs a separate discussion on complexity is provided in chapter 5.3.

In the ACE 2011 report three exogenous factors are evaluated: the cost of living, traffic variability and traffic complexity.

The cost of living is taken into account by calculating the ATCO Employment Costs per ATCO-Hour adjusted using the so-called Purchasing Power Parity (PPP) parameter<sup>75</sup>. This method is also used in the CANSO 2012 report when calculating employment cost.

Eurocontrol has developed metrics for measuring traffic variability and traffic complexity. These metrics are described in sections 5.2 and 5.3.3.

## 5.2 Traffic Variability

The air traffic demand can vary between years, months, weeks, week-days and within a day. Providing enough personnel each day to ensure safety and a satisfactory level of service without an excessive number of personnel is therefore a challenging task.

In the Performance Review Report for 2012 (PRR 2012), traffic variability is calculated as the ratio between the peak traffic and average traffic measured by the number of flights. In 2012 the average variability of daily traffic in Europe (excluding Iceland) was 1,24, i.e. the number of flights on the busiest day was 24% higher than the average traffic. The variability of daily traffic in 2012 was 1,71 in the Reykjavik CTA, as will be further discussed in chapter 6.4.3.

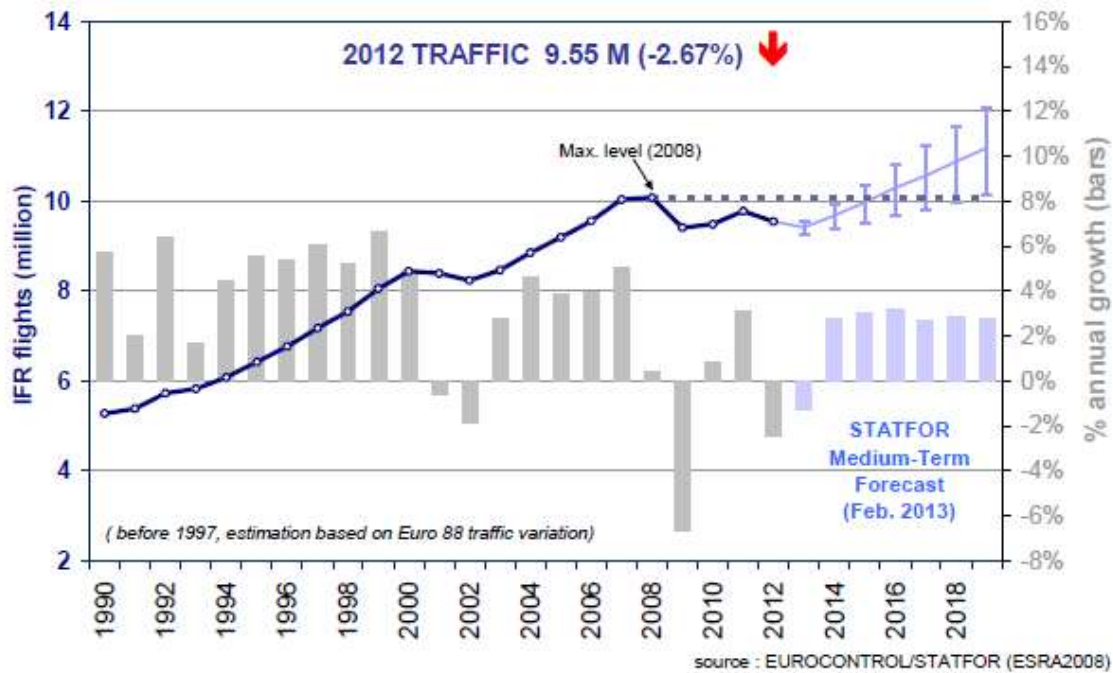
Seasonal variability is defined in the Performance Review Report as the ratio between the peak weekly traffic and the average weekly traffic. The average seasonal variability in 2012 was 1,15, with the highest value of 1,9 in Palma, Spain. The seasonal variability in 2012 was 1,36 in the Reykjavik CTA.

Annual air traffic in Europe has been increasing for several years apart from the downturn in 2001, 2002, 2009 and 2012, as can be seen figure 5.1 from the PRR 2012 (Performance Review Commission, 2013). These downturns are to a large part caused by the global recessions in 2001–2002 and 2008–2009<sup>76</sup>.

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<sup>75</sup> Purchasing Power Parity uses a defined basket of goods and services to compare the prices, in national currency, between different countries. Further information on PPP can be found in glossary of Terms.

<sup>76</sup> The recovery from 2008-2009 recession has been slow and the global GDP growth has been fluctuating. In 2011 and 2012 the GDP growth in advanced economies has been less than 3%, according to the IMF's World Economic Outlook Update of January 2013.



**Figure 5.1: Air traffic growth. (Source: PRC)**

The annual increase is however not evenly spread across Europe and each ANSP must consider the forecasted growth in their control airspace when planning how they will meet the traffic demand.

It is difficult to adjust to an unexpected downturn in annual demand for Air Traffic Control (ATC) service. ATCOs are not a flexible workforce, they need several years of training and the training must be maintained regularly to keep the ATC license. Furthermore the ANSP in each country is the only employer for ATCOs and fully trained ATCOs can therefore not be sought from the local employment market when there is sudden increase in air traffic. It is therefore not a realistic option to lay off ATCOs when there is an economic downturn and hire when the air traffic increases.<sup>77</sup>

Seasonal variations are different between countries. It is likely that seasonality affects the productivity but when this can be predicted it is possible to minimize the effect for example by using off season time for training and having ATCOs work on special projects during off season periods.

In some control areas as in the North Atlantic there is variability in the traffic due to variation in tracks which are defined according to weather conditions each day. In the Reykjavik control area 7,8% of the traffic in 2010 was in organized tracks but there is a great variability in this traffic between days (Isavia, 2011b). This variation is not regular as is the case with the summer traffic and is therefore more difficult to predict in advance. A prediction of the track traffic is made the day before the flight. Control centres in the North Atlantic airspace

<sup>77</sup> This is especially applicable in Iceland where it would require additional training because of special circumstances in the Reykjavik CTA. Also, it is likely that the workforce flows more easily between countries in continental Europe than to and from Iceland.

use Preferred Route Messages (PMR) from the larger airlines (such as British Airlines and Delta) to predict air traffic. The PRM messages are received on the day before flight<sup>78</sup>.

To address the variation between weekdays and within a day and its effect on productivity it is possible to use overtime and arrange the schedule of shifts in such a way that the working hours follow the demand for the ATC service. This may also be addressed by training ATCO for other operational duties while maintaining their license to operate as ATCO. However as the training of ATCOs is costly, the number of ATCOs on other duties should be kept at efficient minimum<sup>79</sup> if possible.

### 5.3 Complexity

A major limiting factor of current ATM systems to meet increasing air traffic is the workload of the ATCOs which is greatly influenced by the air traffic complexity.

When comparing the performance indicators such as productivity and cost effectiveness between ANSPs one of the factors that influence the performance of ATCOs is how complex their tasks are, which in turn determines how long it will take to complete each task.

#### 5.3.1 Definition of complexity

In general, complexity is considered to involve some level of difficulty.

Definition of complexity in air traffic control is related to the definition of the ATCO's workload, i.e. how different air traffic flows and ATM systems affect the level of difficulty of tasks performed by the ATCOs.

In a seminar paper by Meckiff et al. ATCO's workload is assumed to be a function of three elements: "firstly the geometrical nature of the air traffic; secondly the operational procedures and practices used to handle the traffic, and thirdly the characteristics and behaviour of individual controllers (experience, orderliness etc)" (Meckiff, Chone, & Nicolaon, 1998).

In the report "Complexity Metrics for ANSP Benchmarking Analysis", by the ACE working Group on Complexity (hereafter called ACE complexity report), the complexity is defined as "*a notion of additional controller workload beyond that directly associated with the number of flights*" (Performance Review Commission, 2006).

In this report further aspects of the complexity are introduced:

- "*ATC procedures-related complexity – additional controller workload arising from the concept of operation, ATC procedures in operation, airspace organisation, route structure, etc. Arguably these aspects are mostly internal to the ANSP;*"

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<sup>78</sup> See also further information on PRM in Airspace Management in Appendix I.

<sup>79</sup> The minimum number of ATCOs on other duties which give sufficient flexibility to adjust to fluctuation in air traffic.

- *Traffic characteristics complexity – additional controller workload arising from the concentration, type or interaction of traffic. Arguably these aspects are mostly external to the ANSP;*
- *External complexity – additional controller workload arising from the nature or structure of the airspace through which traffic is flying, also deemed to be mainly external to the ANSP” (Performance Review Commission, 2006).*

As the ACE complexity report’s main objective is to use the complexity metric for benchmarking purpose, the complexity has been defined narrowly in that context as the external factors affecting the workload.

### 5.3.2 Studies of ATCO workload

In order to resolve the foreseeable capacity issues stemming from the limits of ATCO workload, several solutions have been suggested to reduce their workload. These solutions include: self-separation (delegation of separation tasks from the air traffic control on ground to the aircraft), reconfiguring sectors in order to decrease complexity, redefining air traffic routes and modifying ATC systems and tools.

This has led to considerable amount of research on the factors affecting ATCO workload.

Factors affecting ATCO workload are numerous and may not be easy to detect. ATCOs can sense the same traffic pattern in different ways depending on their experience and nature. They may also use different strategies (to resolve foreseeable complex situation) which affect their workload.

The factors affecting ATCOs workload may be placed in two main categories. Factors which are controllable by the ANSP or the ATCOs such as sectorisation; working strategy and route structure on the one hand; and factors which are not controllable by ANSPs such as traffic density and traffic mix<sup>80</sup> on the other hand. Some factors may however be of both types, such as the number of crossing points between aircraft. Number of crossing points depends on the flight plans which are based on requests from airlines and are in that sense not controllable by the ANSP. However, in many control areas there are predefined routes which limit the number of crossing points. This limits the available routes and hence the routes specified in the flight plans filed. The crossing points in these control area are therefore indirectly controlled by the ANSP. Route structure is used to decrease air traffic complexity, which may be necessary in some circumstances i.e. when the traffic density and orientation of the traffic patterns exceed a certain level. This does however also limit the choices that airspace users have in order to define their optimal routes.

In this chapter the main focus is on research of external factors which in principle are not controllable by the ANSP and how these factors affect workload. Factors which are controllable by the ANSP are of course of importance and a study of those can lead to improvements of performance. Such improvements would probably have a positive effect on one or more of the performance metrics mentions in chapter 4. As the complexity metric for

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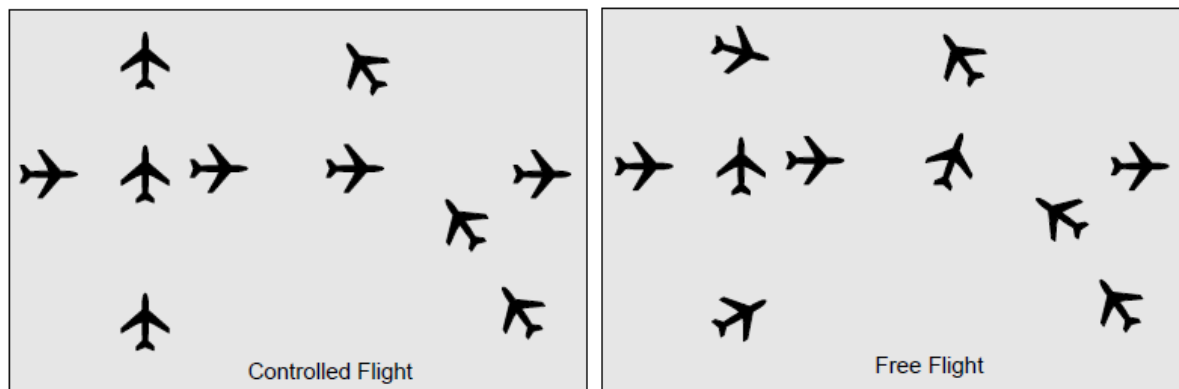
<sup>80</sup> Traffic mix can be different kind of aircraft, different flight rules (IFR/VFR), military versus civil traffic, etc.

benchmarking purposes is meant to account for the different environments that the ANSPs are facing, factors which are controllable by the ANSPs are in general not included.

In a report prepared by the Eurocontrol Experimental Centre, a literature review is given on cognitive complexity in air traffic control from 1963 to 2003 (Hilburn, 2004). From the research mentioned it is clear that there are many factors which affect complexity; there are several ways to measure complexity (workload) and various methods of linking these together. The researchers do not agree on a single set of factors linked to complexity and the relationship between factors changes from one sector to another and even within a sector over a period of time. In Annex III, 108 factors which were considered in these research projects are listed.

Traffic density is a factor which has been generally viewed as having the greatest influence on ATCO workload. Counting of air traffic has been used to predict ATCO workload and schedule shifts for many years. Several studies have confirmed that traffic density has great influence on ATCO workload. In a study by Hurst and Rose in 1978 it was found that 53% of the variance notable in activity and workload of ATCOs were attributed to traffic density (Hurst & Rose, 1978).

It has also been confirmed by several studies that traffic density alone is not a sufficient indicator of workload. This is evident just by considering figure 5.2 (Hilburn, 2004).



**Figure 5.2: Controlled flight versus free flight. (Source: Eurocontrol Experimental Centre)**

In figure 5.2 the difference between the structured flight patterns and the free flight patterns is evident. The traffic density is the same in both boxes. It is clear that it is more complicated to detect conflicts in the box to the right although the headings of only four aircraft out of ten have been changed.

Research indicates that the factors affecting workload are not necessary linear. In a study by Chatterji and Sridhar a neural network is used to predict low, medium or high workload based on sixteen factors. A simple model using only traffic count could be used to classify low workload accurately. However the accuracy dropped considerably for medium and high workload when only traffic count was used. The classification for the medium and high workload was improved considerably by adding complexity factors to the model. The following complexity factors were used in the model:

- Traffic density, proportional to the historical maximum for that airspace.
- Number of climbing aircraft, proportional to the historical maximum.
- Number of level aircraft, proportional to the historical maximum.
- Number of descending aircraft, proportional to the historical maximum.
- Average weighted horizontal distance between aircraft.
- Average weighted vertical distance between aircraft.
- Average minimum horizontal distance between aircraft.
- Average minimum vertical distance between aircraft.
- Minimum horizontal separation for an aircraft pair.
- Minimum horizontal separation for an aircraft pair.
- Number of aircraft within conflict timeframe.
- Average time-to-go to conflict.
- Smallest time-to-go to conflict.
- Groundspeed variation between aircraft.
- Groundspeed variation, proportionate to mean airspace groundspeed.
- The total conflict resolution difficulty based on time-to-go (Hilburn, 2004).

In another recent study by David Gianazza, neural networks are used for modelling workload (Gianazza, 2010). In this research the actual workload of the ATCOs is not considered but rather the sector status (merged, normal or split). The configuration of sectors is predefined on the basis of normal air traffic and workload. During the day, sectors may be split when the workload increases, and/or merged when the workload decreases. The air traffic greatly influences the decision to split or merge sectors but other factors affect this decision as well. If the ATCO feels the workload is too high despite a moderate increase in traffic he/she will request that the sector be split<sup>81</sup> up. This breaking point may be very different between individuals. Although this measure of workload is surely indicative it may not be very accurate. That is however also the problem with most other measurements of workload. This however does serve the objectives of the study which was to predict sector configuration on the basis of several complexity indicators. Gianazza selected 28 complexity factor candidates from older studies and found 6 factors to be the most relevant in predicting sector re-configuration:

- Sector volume.
- Number of aircraft within the sector.
- Average vertical speed.
- The incoming flows with time horizons of 15 minutes.
- The incoming flows with time horizons of 60 minutes.<sup>82</sup>
- The number of potential crossings with an angle greater than 20 degrees<sup>83</sup> (Gianazza, 2010).

<sup>81</sup> It should be noted here that in the Reykjavik ACC increased workload is either solved by splitting sectors or by adding another ATCO to the busy sector, resulting in two ATCOs working in the same sector instead of one.

<sup>82</sup> Incoming flow is the number of aircraft entering the control sector within a period of time (15 and 60 minutes).

When using actual traffic<sup>84</sup> to predict sector configuration the model was fairly accurate.<sup>85</sup> It is notable that of the 6 factors selected the only factor describing the structure of the traffic flow is the number of potential crossings of aircraft.

The complexity measures studied by Chatterji and Sridhar and Gianazza, mentioned above were not intended for comparison between ANSPs. These measurements were considered for specific control airspace, the volume of which differ between ANSPs. This is logical because in these cases the complexity measurements are intended to evaluate the complexity in that particular airspace and/or predict the complexity based on specific factors.

The purpose of complexity metrics used in benchmarking is on the other hand to evaluate external factors which are likely to influence ATCO workload and hence the performance of an ANSP.

Eurocontrol's Complexity Score was developed for this purpose and will be described in the next chapter.

### 5.3.3 Eurocontrol's Complexity Score

Following the studies performed by the Eurocontrol Experimental Centre, the ACE working Group on Complexity developed a complexity metric, called Complexity Score. This metric is reported in "Complexity Metrics for ANSP Benchmarking Analysis" and, as the name indicates, is intended for benchmarking analysis. This chapter is an extract from this report and is intended to explain the reasoning and calculations behind this metric.

As mentioned here above, it has been shown that it is not only the number of flight hours that increase workload. Performance metrics which are based on counting flight hours are therefore not necessarily comparable without considering the complexity of the air traffic controlled by the ANSP.

The focus of the working group was on external factors that induce extra workload for ATCO's. It was considered that improvements in internal air traffic control procedures, which reduce the workload of the ATCO and increase productivity, should not affect the complexity metric. Such improvements would therefore improve performance metrics but not affect the complexity metric.

The Complexity Score is intended to represent en-route complexity and is built from four indicators: adjusted density, vertical interactions, horizontal interactions and speed interactions. These indicators were selected from several candidate indicators taking into account the purpose of the metric. For benchmarking purpose the complexity metric was intended to reflect the traffic characteristics and external constraints but be independent of the route network and sector design. The complexity metric is calculated for ANSPs and Area

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<sup>83</sup> This is the complexity factor, called Potential horizontal interactions, which is used in the Complexity score, see chapter 5.3.3.

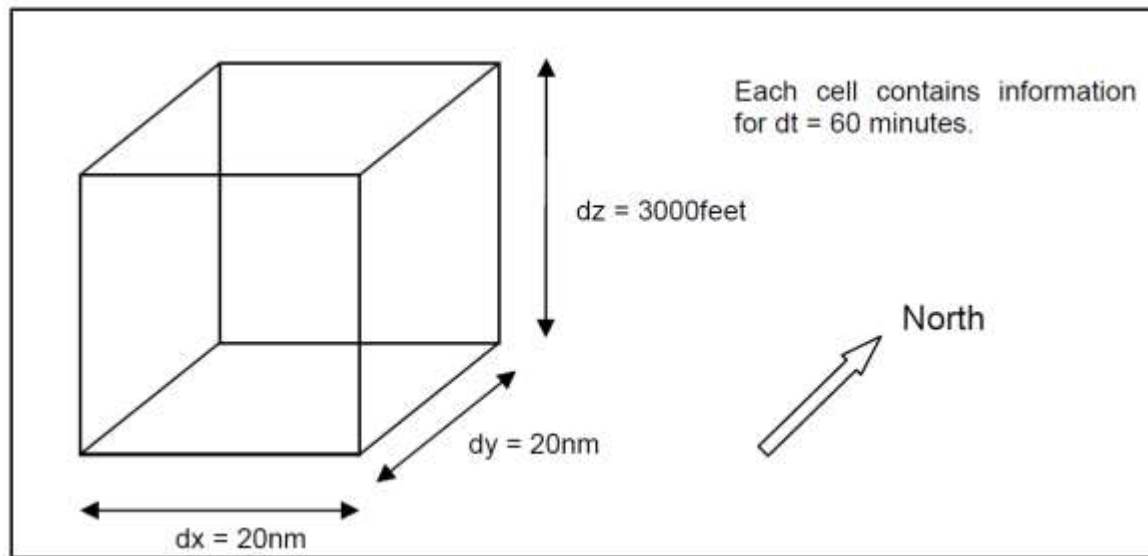
<sup>84</sup> The study also considered predicted traffic.

<sup>85</sup> The Pearson's correlation coefficient between the predicted and actual configuration was 0,91.

Control Centres (ACC's) in most of the states in the ECAC<sup>86</sup> area (Performance Review Commission, 2006). This metric is reported for each ANSP in the ACE and PRR reports.

### 5.3.3.1 Methodology

In order to calculate the four complexity indicators the whole area was divided into 3-dimensional (3D) cells, with an additional time dimension, as flight data are considered in each cell for 60 minutes time intervals. In order to minimize the distortion caused by the curvature of the earth Albers equal area projection<sup>87</sup> was used. With this projection all the cells are of equal size.



**Figure 5.3: Cell configuration.** (Source: ACE working group on Complexity)

Figure 5.3 shows the dimensions of the cells. The height of the cells is 3.000 feet and they are 20 NM<sup>88</sup> in length and width.

Flight data are collected for each cell for one hour at a time, giving 24 data sets for a single day. The traffic data which are of importance in the complexity calculation are the number of aircraft entering each cell within each hour, the number of minutes the aircraft is present in the cell<sup>89</sup>, the phase of flight of each aircraft (cruise, climb or descent), the heading of the aircraft (with respect to other aircraft) and the speed of the aircraft.

The complexity indicators are calculated for each ANSP, a cell belongs to an ANSP if the centre of the cell is within the control area of that ANSP.

<sup>86</sup> The European Civil Aviation Conference, an intergovernmental organisation.

<sup>87</sup> According to Wikipedia: "*The Albers equal-area conic projection or Albers projection (named after Heinrich C. Albers), is a conic, equal area map projection that uses two standard parallels. Although scale and shape are not preserved, distortion is minimal between the standard parallels.*"

<sup>88</sup> To have some perspective: it takes an aircraft at 800 km/hour, 2,8 minutes to cover the distance of 20 NM.

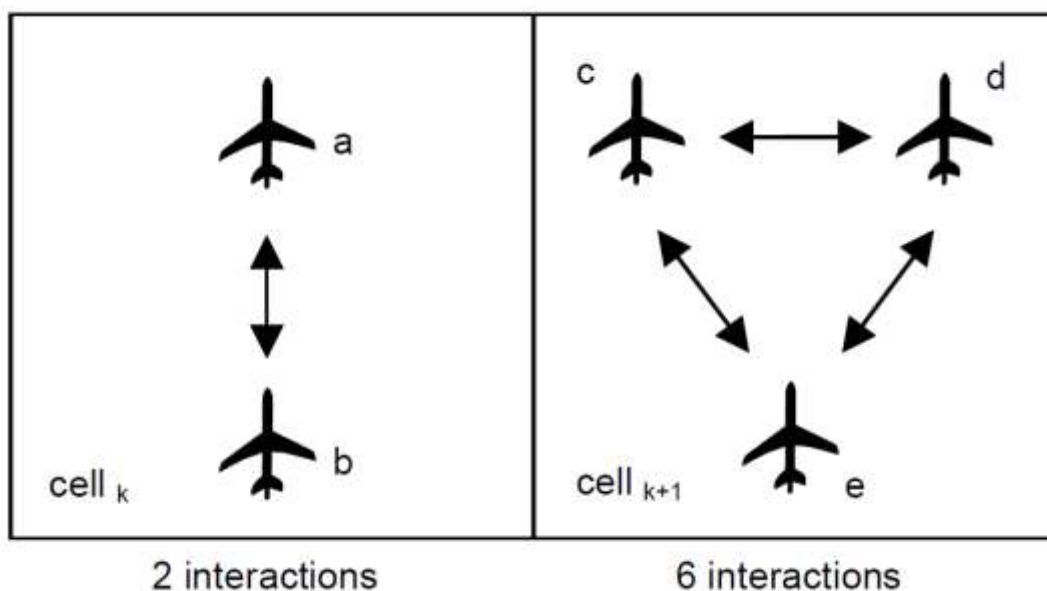
<sup>89</sup> The number of aircraft simultaneously present in the cell is calculated using the number of aircraft entering the cell.

In order to account for boundary effects<sup>90</sup> each cell is shifted laterally, longitudinally and vertically, resulting in 12 different positions for each cell. The complexity indicators for the cell are calculated for each position and the average from that calculation are the complexity indicators for that cell.<sup>91</sup>

### 5.3.3.2 Definition of interactions

In the calculation of the complexity indicators, the concept of interactions between aircraft is of great importance. It has been shown that the number of aircraft within the same area at the same time affects the workload of ATCOs. This is however not the only factor affecting the workload as the workload increases dramatically if the ATCO has to resolve possible interactions between aircraft at the same time. The complexity indicators are intended to capture the complexity caused by the interactions. However, the indicators only represent expected conflicts based on the number of aircraft and the air traffic pattern, rather than actual conflicts resolved by the ATCO.

The interaction in the ACE complexity report is defined as “*the simultaneous presence of two aircraft in the same cell viewed from each aircraft’s perspective*”.



**Figure 5.4: Definition of interactions.** (Source: ACE Working Group on Complexity)

Interactions are considered from each aircraft, aircraft **a** interacts with aircraft **b** and aircraft **b** interacts with aircraft **a**. There are therefore 2 interactions in a cell with 2 aircraft. In the same way aircraft **c** interacts with aircraft **d** and **e**, giving 2 interactions for aircraft **c**. This applies for also for aircraft **d** and **e**. There are therefore 6 interactions in a cell with 3 aircraft. For a cell with  $N$  aircraft the number of interactions is  $N \times (N-1)$ .

When evaluating the complexity it is considered how many minutes each aircraft is in the cell during the one hour interval. Each aircraft may enter the cell at any time within the hour. The

<sup>90</sup> Aircraft near the boundary of the cell will also influence other aircraft in adjacent cells.

<sup>91</sup> Each cell has 2 lateral and 2 longitudinal positions, 10 NM apart, giving 4 horizontal positions. For each of this position the cell has 3 vertical positions, 1.000 feet apart.

expected hours of interactions between aircraft **a** and aircraft **b** are calculated as the product of  $t_a$  and  $t_b$ . Here  $t_a$  and  $t_b$  are the measured duration of aircraft **a** and aircraft **b**, respectively, in the cell within the one hour time interval. If aircraft **a** spends 2 minutes and aircraft **b** spends 3 minutes in the cell the expected duration of the interaction between **a** and **b** is:

$$\left(\frac{1}{30} \times \frac{1}{20}\right) = \frac{1}{600} \text{ hours}$$

The probability of aircraft **a** being present in the cell at a time interval  $dt$  is  $1/30$  (2 minutes/60 minutes). The probability of both **a** and **b** being present in the cell at a time interval  $dt$  is  $1/30 \times 1/20$ . The expected time in the cell for an interval  $dt$  is  $1/30 \times 1/20 \times dt$ . For one hour interval the expected value becomes  $1/600$  hours.

This is calculated for each interaction (**a** with **b** and **b** with **a**) and the hours of interaction in this cell are therefore  $1/300$  hours.

The hours of interaction are calculated for each pair of aircraft and the result is summed up for each cell.

### 5.3.3.3 Adjusted density

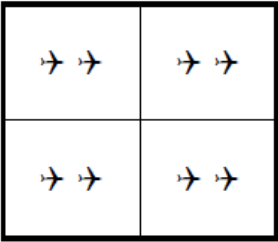
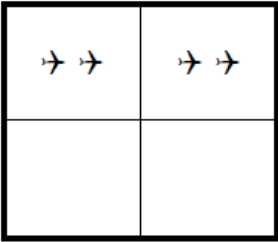
One of the four indicators of the complexity score is adjusted density. Studies have shown that complexity increases with traffic density. The traffic is however not evenly spread within the airspace. This is for example the case in the Reykjavik CTA, where the traffic is far from being evenly spread. The traffic in the north sector is very sparse compared to the east and south sectors.

In order to account for this effect, adjusted density is used as the traffic indicator in the complexity score. The adjusted density is calculated using the cells as defined in chapter 5.3.3.1 above. If there are no interactions in a cell, it does not contribute to the adjusted density.

The adjusted density is defined as the ratio of hours of interactions and flight hours over the period of consideration. The calculations performed by the ACE working group were for two separate weeks, week 3 and 36 in 2003. Hours of interactions are calculated for each cell for one hour at a time, giving 24 values for a single day and 168 for one week. The adjusted density is calculated for each ANSP by summing up the hours of interactions in each cell assigned to the ANSP over the measurement period and dividing by the total flight hours in the ANSP's control area over the same period.

$$\text{Adjusted density} = \frac{\text{Hours of interactions}}{\text{Flight hours}} \quad (5.1)$$

Figure 5.5 shows the calculations of adjusted density for two control centres.

 <p style="text-align: center;"><b>Centre 1</b></p>		 <p style="text-align: center;"><b>Centre 2</b></p>	
$2+2+2+2=8$	Number of interactions	$2+2=4$	
<p>To produce results in terms of expected duration, the time spent in the cell (three minutes in this example) must be taken into account.</p> <p style="text-align: center;">Adjusted density = Hours of interactions / Flight hours</p>			
$8 \times \frac{1}{400} = 0.02$	Hours of interactions	$4 \times \frac{1}{400} = 0.01$	
$8 \times \frac{1}{20} = 0.4$	Flight hours	$4 \times \frac{1}{20} = 0.2$	
$\frac{0.02}{0.4} = 0.05$	Adjusted Density	$\frac{0.01}{0.2} = 0.05$	

**Figure 5.5: Calculation of adjusted density<sup>92</sup>. (Source: ACE Working Group on Complexity)**

In the example in figure 5.5 the adjusted density is the same for both centres whereas standard calculation of density would give higher density in centre 1.

#### 5.3.3.4 Categories of interactions

The complexity score includes three indicators accounting for three kinds of interactions:

- Potential vertical interactions (Vertical Different Interacting Flows - VDIF)
- Potential horizontal interactions (Horizontal Different Interacting Flows - HDIF)
- Potential speed interactions (Speed Different Interacting Flows - SDIF)

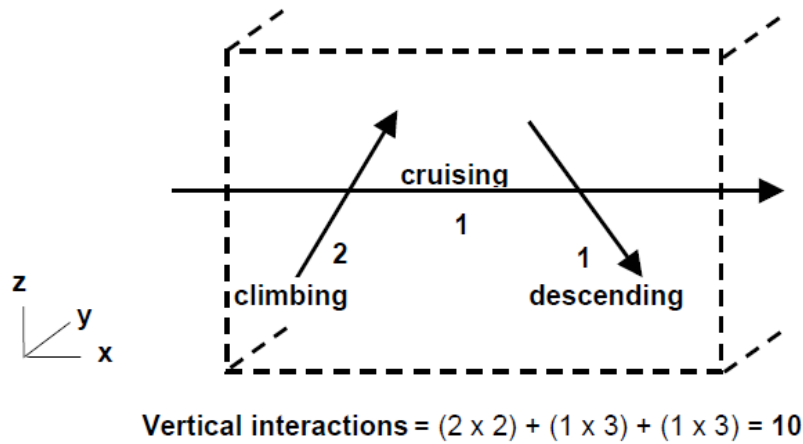
#### ***Vertical Different Interacting Flows – VDIF.***

The VDIF indicator is intended to capture the complexity which stems from the different kind of flight phase of aircraft. There are three phases of flight: climb, cruise and descent. Hours of vertical interactions are calculated for each cell. A vertical interaction is counted if two aircraft are present in a cell at the same time and they are in different flight phase (e.g. not both in cruise phase). If, for example, every aircraft within a cell is in cruise phase no interaction is counted.

<sup>92</sup> In these calculations it is presumed that each aircraft spends three minutes in the cell, giving 1/400 hours of interaction for each interaction.

The flight phase of the aircraft is decided upon entry into the cell. A flight is considered in climbing or descending phase if the rate of climb/descent is 500 feet per minute, or more. Else the flight is in cruise mode.

Figure 5.6 shows how the potential vertical interactions are counted.



**Figure 5.6: Vertical interactions.** (Source: ACE Working Group on Complexity)

In figure 5.6 there are four aircraft that enter the cell within the one hour interval, 2 in the climbing phase, 1 in the cruising phase and 1 in descending phase.

As the 2 aircraft in the climbing phase are in the same flight phase there is no vertical interaction between them but each of them interact with two other aircraft (the one cruising and the one descending). The cruising aircraft interacts vertically with 3 aircraft (two climbing and one descending) and the descending aircraft interacts vertically with 3 aircraft as well (two climbing and one cruising).

The hours of vertical interactions are calculated as described in section 5.3.3.2 for each pair of interacting aircraft based on the time spent in the cell. The VDIF indicator is defined as the ratio of hours of vertical interactions and flight hours:

$$VDIF = \frac{\text{Hours of vertical interactions}}{\text{Flight hours}} \quad (5.2)$$

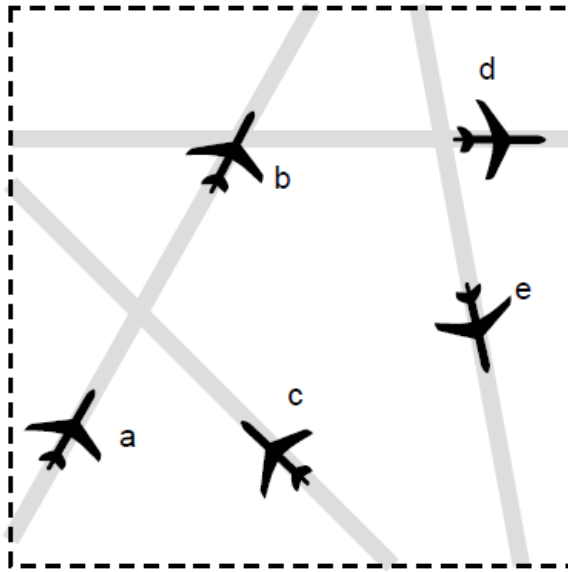
### **Horizontal Different Interacting Flows – HDIF.**

The HDIF indicator is intended to capture the complexity which stems from the interactions between flights with different headings.

Hours of horizontal interactions are calculated for each cell. A horizontal interaction is counted if two aircraft are present in a cell at the same time and they have different headings.

The heading of the aircraft is defined as the heading upon entry into the cell. An interaction is counted if the difference in heading of a pair of aircraft is greater than 20°.

Figure 5.7 shows how the potential horizontal interactions are counted.



**Figure 5.7: Horizontal interactions.** (Source: ACE Working Group on Complexity)

In figure 5.7 aircraft **a** and **b** do not interact horizontally with each other but they both interact horizontally with **c**, **d**, and **e**. Hence interactions counted for **a** and **b** are 6 in total. Each of the aircraft identified as **c**, **d**, and **e** interacts horizontally with 4 other aircraft and the counted horizontal interactions for these are 12 in total. Within the cell there are therefore 18 potential horizontal interactions.

The hours of horizontal interactions are calculated as described above for each pair of interacting aircraft depending on the time spent in the cell. The HDIF indicator is defined as the ratio of hours of horizontal interactions and flight hours:

$$HDIF = \frac{\text{Hours of horizontal interactions}}{\text{Flight hours}} \quad (5.3)$$

### ***Speed Different Interacting Flows – SDIF.***

The SDIF indicator is intended to capture the complexity which stems from the interactions between flights with different speeds.

Hours of speed interactions are calculated for each cell. A speed interaction is counted if two aircraft are present in a cell at the same time and they have different speed.

An interaction is counted if the difference in speed of a pair of aircraft is greater than 35 kts<sup>93</sup>. The speed used in these calculations is the speed indicated in the BADA<sup>94</sup> performance table, giving the speed for the aircraft type at the flight level of the cell centre.

The speed interactions are counted in a similar way as for the horizontal interactions, counting only the interactions where there is a difference in speed of a pair of aircraft.

<sup>93</sup> Knots, 35 knots is about 65 km/hour.

<sup>94</sup> BADA (Base of Aircraft Data) is an aircraft performance model developed and maintained by Eurocontrol.

The hours of speed interactions are calculated as described here above for each pair of interacting aircraft depending on the time spent in the cell. The SDIF indicator is defined as the ratio of hours of speed interactions and flight hours:

$$SDIF = \frac{\text{Hours of speed interactions}}{\text{Flight hours}} \quad (5.4)$$

### 5.3.3.5 The Complexity Score

While considering how to build complexity indicator(s) from the adjusted density, VDIF, HDIF and SDIF it was noted by the working group that the DIF indicators are highly correlated with adjusted density, i.e. there was dependency between the DIF indicators and the adjusted density. A further explanation of the rationale behind this can be found in the ACE complexity report (Performance Review Commission, 2006).

It was therefore decided to use relative indicators, r\_VDIF, r\_HDIF and r\_SDIF, which are calculated by dividing the interaction indicators for each ANSP/ACC by their adjusted density. By using this approach the flight hours are cancelled out and the relative interactions indicators show the percentage of interactions which are due to vertical, horizontal and speed interactions, respectively. It should be noted that one interaction can be counted in more than one category of interactions, such as both vertical and speed interactions. Therefore the three relative indicators do not necessarily add up to one.

To capture the effect of different structure of the air traffic, an indicator called Structural Index was created as the sum of the relative indicators:

$$\text{Structural Index} = r\_VDIF + r\_HDIF + r\_SDIF \quad (5.5)$$

This indicator represents the complexity arising from the structure of the traffic flow. Each of the components of the structural index gives information of the traffic structure:

- r\_VDIF indicates the percentage of interactions due to climb and descent.
- r\_HDIF indicates the percentage of interactions which are caused by different headings of aircraft.
- r\_SDIF indicates the percentage of interactions which are caused by difference in speed between two aircraft.

As an example of what these indicators might tell you, air traffic which is mostly parallel as is the case of the traffic on the NAT tracks would give very low r\_HDIF. If there are restriction of flight level changes, that would result in low r\_VDIF. Traffic above major airports is likely to give high structural index.

The complexity is also affected by the volume of traffic. The ACE Working Group on Complexity decided to create a complexity indicator which combines the two influencing factors, the traffic volume and the structure of the traffic flow. This Complexity Score is the product of the adjusted density and the structural index:

$$\text{Complexity Score} = \text{Adjusted Density} \times \text{Structural Index} \quad (5.6)$$

The Complexity Score can be considered as a whole or by considering each part which, as mentioned above, give information on the volume of the traffic and of each kind of structural factor. If the Complexity Score is considered as a single measure the formula becomes:

$$\text{Complexity Score} = \frac{\text{H.of Vertical Int.} + \text{H.of Horizontal Int.} + \text{H.of Speed Int.}}{\text{Flight Hours}} \quad (5.7)^{95}$$

This is also the sum of VDIF, HDIF and SDIF as defined in formulas 5.2, .5.3 and 5.4.

The Complexity Score was calculated for each ANSP and ACC using data for a whole week. Two calculations were performed for each ANSP/ACC, for week 3 (in winter) and week 36 (in summer). The Complexity Score for the ANSPs ranged from 0,005 to 0,210 in the winter and 0,008 to 0,222 in the summer.

The five ANSPs with the highest Complexity Score were from Belgium, Switzerland, United Kingdom, Germany and The Netherlands. This is not a very surprising as these states all include busy airports and are located in the core of the European airspace.

### 5.3.4 The applicability of the Complexity Score in Oceanic Control Areas

It would be of great value to define a similar complexity score for oceanic ANSPs. The complexity score was however designed for continental Europe. Thus there are several issues that must be considered regarding the applicability of this metric in other areas such as oceanic areas.

Considering the dimensions of the cells used to calculate the complexity score, it is necessary to compare these dimensions with the separation minima in each control area.

The Reduced Vertical Separation Minima (RVSM)<sup>96</sup> is 1.000 feet. The RVSM airspace is between flight levels 290 and 410 and is applied in Europe including the Reykjavik Control Area.

For en-route traffic, the minimum horizontal separation within radar coverage is from 5 NM (9,3 km) to 10 NM (18,5 km).

The minimum lateral separation outside radar coverage is from 50 NM up to 120 NM under certain conditions.

The longitudinal separation outside radar coverage is between 10 to 30 minutes, depending on the type of aircraft and separation technique used. The longitudinal separation between two aircraft can be reduced where the speed of the trailing aircraft is lower. Depending on the difference in speed the longitudinal separation minima can be reduced down to 5 minutes.

Oceanic airspace is usually outside radar range although the Reykjavik CTA has radar coverage in the busiest part of the airspace.

<sup>95</sup> H.of Vertical Int. is an abbreviation of Hours of Vertical Interactions.

<sup>96</sup> Airspace is referred to as RVSM airspace if it is allowed to use 1000 feet vertical separation instead of 2000 feet separation within the airspace. The aircraft must be equipped for RVSM in order to enter RVSM airspace.

A cell of horizontal dimensions 20 x 20 NM is probably too small to capture interactions between aircraft which are required to fulfil lateral separation minima of 50 NM and longitudinal separation of 10 minutes<sup>97</sup>.

Considering only one flight level a maximum of 6 aircraft could pass through a 20 x 20 NM cell in one hour (with 10 minute longitudinal separation) using procedural separation. If the same situation in radar separation is considered, presuming the average speed to be 830 km/hour, a maximum of 356 aircraft could pass through the cell in one hour<sup>98</sup>.

Using too small cell size in procedural separation could therefore lead to very few interactions captured, because of the separation minimum which applies in procedural separation.

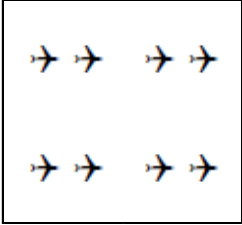

The size of the cell was selected by the ACE working group on Complexity because it mapped the boundaries better than larger cell. It would be possible to select larger cells for a study of complexity in oceanic areas. To capture similar portion of interactions, i.e. using the ratio of the difference in separation minima, the cell would have to be 200 x 200 NM. This could however be too large with respect to other factors such as the boundaries between control areas. When the complexity score was established, three sizes of cells were considered 20x20, 40x40 and 60x60 NM. The smallest was chosen because it was considered to map the boundaries of smaller control areas best. The oceanic control areas are large in comparison with the smaller areas in continental Europe and larger cell sizes might therefore be considered.

It should be noted that the selection of cell size has great effect on the calculations of the interactions and the adjusted density. Figure 5.5 showed how the adjusted density is calculated for a 20 x 20 NM cell, presuming that all aircraft are at the same speed and pass through the cell in 3 minutes. In figure 5.8 similar calculations are performed but here a comparison is made between two centres with identical air traffic (and identical size) but in one case there is one 40 x 40 NM cell while in the other there are four 20 x 20 NM cells.

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<sup>97</sup> If the speed of two aircraft is 830 km/hour, 10 minutes separation is about 74 NM.

<sup>98</sup> Presuming that the aircraft are 5 NM apart from each other and a line of 4 aircraft enters the cell every 0,669 minute (the time it takes to fly 5 NM).

 <p style="text-align: center;"><b>Centre 1</b></p>		 <p style="text-align: center;"><b>Centre 2</b></p>	
6 minutes = 1/10 hour	Time in cell	3 minutes = 1/20 hour	
$7 \times 8 = 56$	Number of Interactions	$2 + 2 + 2 + 2 = 8$	
$56 \times 1/100 = 0,56$	Hours of Interactions	$8 \times 1/400 = 0,02$	
$8 \times 1/10 = 0,8$	Flight hours	$8 \times 1/20 = 0,4$	
$0,56/0,8 = 0,7$	Adjusted density	$0,02/0,4 = 0,05$	

**Figure 5.8: Adjusted density calculated for different cell size (40x40 in Centre 1 and 20x20 in Centre 2).**

When the cell size is doubled, the time in the cell is also doubled, i.e. 6 minutes instead of 3 minutes. The number of interactions increases considerably by expanding the cell size. The results of these calculations show that the cell size affects the number of interactions and the adjusted density; hence, the complexity score is affected. If the cell size is too small, potential horizontal, vertical and speed interactions might not be captured,

It is therefore not possible to compare the complexity score between two ANSPs if the cell size used in the calculation is different.

A further concern regarding the cells is the use of Albers equal area projection; it should be considered whether this projection is applicable in the areas where comparison is to be made<sup>99</sup> or whether other kind of projection might be more suitable.

As mentioned previously there are several factors which make comparison between the performance of continental and oceanic ANSPs difficult. It would therefore be of great advantage if a similar complexity metric would be defined for oceanic airspace on the basis of the methodology used in the complexity score. The horizontal, vertical and speed interactions are all relevant in oceanic air traffic. There may be different strategies used in the control centres with respect to route structure. Where there are parallel tracks with few crossing points, the horizontal interactions may become close to zero. This may be done in order to increase the capacity. As a result adjusted density may be relatively high. It would therefore be very interesting to perform these calculations for the oceanic centres which are compared in the CANSO benchmarking report. Presently the ANSPs are classified only by the total IFR flight hours that are controlled over a given period.

### 5.3.5 Complexity within the Reykjavik Control Area

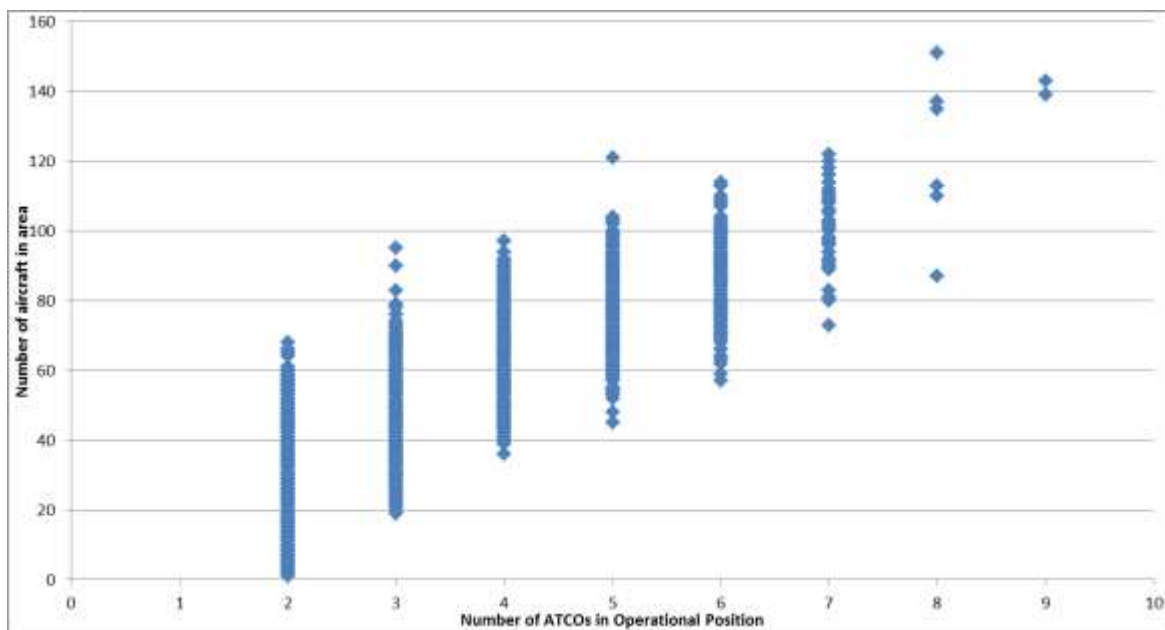
If the Reykjavik Control Area is compared with other oceanic control areas, Isavia is able to offer more flexibility in the choice of flight routes than is normally available. The main

<sup>99</sup> For example in the polar area.

reason for this is that a part of the airspace has radar coverage. The radar coverage allows less separation between aircraft than possible when procedural separation is used, as is usual for oceanic airspace. This increases the possibility of adjusting flight routes in accordance with requests from airlines but that will also introduce more complexity of the air traffic. Many oceanic ANSPs offer fixed tracks for flight routes with little possibilities to change the route of the aircraft<sup>100</sup>. Fixed tracks decrease the complexity of the air traffic.

The NAT tracks are an exception from the user preferred routes available in the Reykjavik CTA. Sometimes the NAT tracks lie within the Reykjavik CTA as discussed in chapter 2.2. The track traffic is per se not considered complex but when combined with random track air traffic it can affect the complexity in the control area. The complexity of the traffic within the Reykjavik CTA is likely to vary between days.

Figure 5.9 shows the number of aircraft in area and number of ATCOs in operational position for at the same time.



**Figure 5.9: A scatter diagram of the number of aircraft in the Reykjavik CTA within an hour interval versus the number of ATCOs in operating position. Each dot present one hour interval in 2012.**

The above numbers were calculated for domestic and oceanic flights in 2012. The number of aircraft in area for a one hour interval<sup>101</sup> was calculated. This was compared to the number of ATCOs in operational position (not all on duties just the ones at the operation desk) at the same time.

As expected the number of ATCOs in operating position increases with increasing traffic. However there is clearly a variation in the number of aircraft that trigger the opening of an additional operating position.

<sup>100</sup> For example to climb up to higher heights in order to decrease fuel consumption.

<sup>101</sup> An aircraft was considered in the area even though it exited the airspace just after the one hour interval started.

Two ATCOs can handle from 2 to 68 aircraft, three ATCOs can handle from 21 to 95 aircraft, four ATCOs can handle from 36 to 97 aircraft, etc. It is clear from the figure that it is very different how many aircraft each ATCO can control at the same time. This indicates that there are other factors than the number of aircraft in the control area as a whole that influence the workload, such as the variability in complexity.

## 6. Performance measurements using data from Isavia's Air Navigation Service

### 6.1 Introduction

In this chapter performance metrics for the Reykjavik Air Traffic Management (ATM) system are selected and the reason for the selection is explained. Factors affecting data integrity are considered and any assumptions and estimates introduced. The data used for computing these metrics are introduced and listed. Finally the metrics are calculated and the results are compared with outcomes from other oceanic Air Navigation Service Providers (ANSP).

### 6.2 Selection of the performance measurements to be used

In chapter 3 a discourse is provided on the design of performance metrics. Performance measurements are often linked to the strategy of an organization and defined with the purpose of reaching predefined goals. The focus of this thesis was however on evaluating performance metrics currently in use in Air Traffic Management and their applicability in the Reykjavik Control Area (CTA). Isavia's strategy and goals are therefore not the starting point in the selection of the performance measurements.

Isavia has expressed the following values:

<b>Safety</b>	With disciplined work methods, continual knowledge acquisition and purposeful oversight, we minimise risk and contribute to the safety of the public, our customers and our employees.
<b>Co-operation</b>	We work together as one team towards set goals to achieve results and provide good services. We respect each other's work and encourage initiative regarding improvements.
<b>Service</b>	We set clear service standards for ourselves and maintain a positive attitude and respect towards customers. We are economical and continually seek ways to maximise results (Isavia, 2013).

As for any ANSP, safety in providing Air Navigation Services (ANS) is a key success factor. Isavia has developed and measures several safety metrics which are listed in chapter 6.2.1.

When considering other performance metrics and improvements it is always in the context that safety is not jeopardised. When the ATM system as a whole is under consideration, safety can be considered as a constraint when optimizing the system performance with respect to other factors such as capacity, cost and efficiency.

Providing good service is clearly of great importance to Isavia as presented in the company values and it was also established from conversations with personnel within the ANS division

of Isavia. Service and costs must however be considered together. Additional services usually incur additional cost. The benefit from the additional service must therefore provide value to the customer which outweighs the added cost. Providing flexible flight routes, as an example, are likely to increase costs but they can result in lower cost of operation for the airspace users or other tangible benefits.

One of the objectives of this project, and an important one, is to compare the performance metrics calculated for Isavia with metrics from other ANSPs. In order to achieve this objective, information on available performance metrics for ANSPs were gathered and listed in chapter 4.

Most of the performance metrics listed there have not been introduced and calculated at Isavia. It was therefore logical to start with these metrics to be able to compare the performance of Isavia with other ANSPs.

In the “ATM Cost-Effectiveness (ACE) Benchmarking Report” (ACE report), data for the provision of service in oceanic areas are not included and all metrics calculated are based on continental flights. Many factors are different in oceanic versus continental air traffic services as explained in chapters 2.3 and 4.3.2. In the “Global Air Navigation Services Performance Report” published by CANSO (CANSO report) data for both oceanic and continental services are provided. NATS of the UK is one of the ANSPs which offer both these services. The metrics for NATS in the CANSO 2012 report reveal that the metric *IFR flight hours per ATCO in operation* in 2011 were 1.081 for continental flights against 8.839 for the oceanic flight. Furthermore, the cost per IFR flight hour in 2011 was \$ 1.000 for the continental flights versus \$ 92,- for oceanic flights. From this it is clear that these numbers differ by an order of magnitude. It is evident that these performance metrics for oceanic air navigation services are not comparable with corresponding metrics for continental service.

For this reason it was decided to concentrate on the CANSO report and calculate the metrics for oceanic services listed in that report.

### 6.2.1 Safety

In Isavia's operations handbook the following safety metrics are listed:

1. Serious air traffic incident caused by ATS<sup>102</sup>.
2. Loss of separation caused by ATS.
3. Incidents where separation is lost.
4. Radar system in the Control Center inactive.
5. FDPS<sup>103</sup> in the Control Center inactive.
6. Voice Communication System in the Control Center inactive.
7. Loss of separation caused by airport ATS.

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<sup>102</sup> Air Traffic Services

<sup>103</sup> Flight Data Processing Systems, see Flight Data in Appenix II.

8. Bird strikes reported by pilots.
9. Runway incursions at Reykjavik Airport (BIRK).
10. Runway incursions at Keflavik Airport (BIKF).
11. Number of SOR<sup>104</sup> reports at airports ATS.

There are 7 additional metrics for different incidents of downtime in equipment. For these metrics a schedule has been prepared of the purpose of the metric, how it shall be calculated/measured, who is responsible for the measurement, how often the measurements are performed, etc.

As mentioned in chapter 4 the following Key Performance Indicators (KPIs) for Safety are introduced in the SES Performance Scheme:

1. Effectiveness of safety management.
2. Application of the harmonized severity classification in reporting of:
  - a. Separation minima infringements.
  - b. Runway incursions.
  - c. ATM special technical events.
3. Reporting of just culture.

Comparing these metrics it is clear that Isavia has in their safety performance measures, addressed all the key features of the SES performance Scheme KPIs for safety. Isavia has implemented Just Culture and Safety Management System.

It is however out of the scope of this project to investigate the effectiveness of the Safety Management System or evaluate the application of these metrics.

### **6.2.2 Selected Performance Metrics**

There were mainly two factors which limited the choice of metrics calculated: the availability of data for comparison and the complexity of the metrics (and hence the available resources for the calculation, such as human and data processing resources).

In the benchmarking reports available, much emphasis has been put on the productivity and cost effectiveness and therefore these were the first choice of metrics to calculate.

The performance metrics calculated are listed in table 6.1. In addition to the performance metrics, variability was calculated both for weekly and daily traffic.

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<sup>104</sup> Safety Occurrence Reporting.

<b>Productivity metrics</b>	$\text{IFR Flight Hours per ATCO in OPS} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS}}$
	$\text{Average Annual Working Hours for ATCOs in OPS} = \frac{\text{ATCOs in OPS Hours}}{\text{ATCOs in OPS}}$
	$\text{IFR Flight Hours per ATCO in OPS hour} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS Hours}}$
<b>Financial metrics</b>	$\text{Cost per IFR Flight Hour} = \frac{\text{Total Costs}}{\text{IFR Flight Hours}}$
	$\text{Empl. Cost for ATCOs in OPS per IFR Flight Hour} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{IFR Flight Hours}}$
	$\text{Empl. Cost for ATCOs in OPS per ATCO in OPS} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCOs in OPS}}$
	$\text{Empl. Cost for ATCO in OPS per ATCO-hour} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCO in OPS Hours}}$
	$\text{Support Cost per IFR Flight Hours} = \frac{\text{Support Costs}}{\text{IFR Flight Hours}}$
	$\text{Cost of Capital and Depreciation as \% of Total Cost} = \frac{\text{Cost of Capital and Depreciation}}{\text{Total Costs}}$
	$\text{Support Cost Ratio} = \frac{\text{ATM/CNS Provision Costs}}{\text{Empl. Costs for ATCOs in OPS}}$
<b>Factors affecting performance</b>	$\text{Traffic Variability} = \frac{\text{Maximum Number of Flights}}{\text{Average Number of Flights}}$

**Table 6.1: Performance metrics calculated.**

Data were gathered from Isavia in order to calculate these metrics as will be further explained in chapter 6.4.

Some kind of fuel/flight efficiency metric as introduced in chapter 4.5 would be of great interest for Isavia, as a measure of the benefit from the services provided. The calculation of these metrics is however complex. The fact that the use of great circle distance is not recommended in the Reykjavik CTA, as explained in chapter 4.5, will only increase the degree of complexity of the calculations.

The same applies to the complexity metric mentioned in chapter 5.3.3, it involves complicated calculations. Furthermore, the complexity metric is intended to capture the difference in complexity between control areas to explain differences in performance by ANSPs. It is clear that the complexity of Reykjavik CTA would have to be compared to the complexity of other oceanic control areas. It is therefore of little value to calculate complexity in one oceanic control area if there is no comparison. A joint effort would be required to establish a single oceanic complexity metric.

It was decided not to gather data for the ANS revenue and calculate the revenue related metrics listed in the CANSO Report: *ANS Revenue per IFR Flight Hour*, *Return on Assets* and *Return on Equity*. *Return on Assets* and *Return on Equity* are metrics which are commonly considered in organizations and most likely this applies also to Isavia. These metrics were not available for comparison between oceanic centres and therefore they are excluded. The metric *ANS Revenue per IFR Flight Hour* does not add much information to the metric *Cost per IFR Flight Hour* when there is a cost recovery system, as is the case for most of the ANSPs. It might however be interesting to see whether there is much fluctuation over a period of time in over and under recovery but that information was not readily available from the report. It was therefore decided not to include this metric as well.

### 6.3 Data analysis and assumptions

The data were received directly from Isavia or from their website.

As Isavia has been going through mergers recently there were some changes in computer programs and databases which caused problems in gathering continuous and comparable data over 5 years as was the plan in the beginning. There was a change in the accounting procedures in 2008 with respect to the currency used. This made the cost in 2008 and 2009 incomparable without adjustment which would cause too much effort. As a result, data for 2009, 2010, 2011 and 2012 were gathered and used in the calculations of the metrics.

Some adjustments were made in order to fit the data to definitions of data elements in the CANSO and ACE reports.

In the CANSO report prices are reported in USD. In the 2012 CANSO report, metrics for the year 2011 are compared between ANSPs. There is also an analysis of the trend of the metrics over the period 2007-2011. The end-of-year exchange rate is used for comparison between ANSPs for the year 2011. In the trend analysis for the years 2007-2011, 2007 end-of-year exchange rate is used. Performance indicators including employment costs are also calculated using Purchasing Power Parity (PPP)<sup>105</sup>.

In the ACE report prices are reported in EUR. In the 2010 report, trend analysis for 2006-2010 is provided. In the trend analysis prices are converted to 2010 prices in national currency using national inflation rates. For comparison between ANSPs, the 2010 exchange rate is used to convert the national currency into EUR.

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<sup>105</sup> Purchasing Power Parity uses a defined basket of goods and services to compare the prices, in national currency, between different countries. Further information on PPP can be found in Glossary of Terms.

For a country like Iceland, with a high inflation rate and fluctuation of the exchange rate, the approach as presented in the ACE report is preferable. However as stated above the comparison will mostly be based on the CANSO report.

In light of this the comparison between ANSPs will be made for the year 2011 (the end year of the newest CANSO report) in 2011 prices converted to USD using the end-of year exchange rate for the year 2011. Usually it would be preferable to use the average exchange rate (for the whole year or the last quarter) instead of end-of year exchange rate<sup>106</sup>. However for this comparison it was decided to follow the CANSO report method. For the year 2011 the USD-ISK<sup>107</sup> average exchange rate was 116,07 while the end-of-year exchange rate was 122,71.

In the CANSO report, oceanic performance indicators are only reported in a trend analysis and hence the prices for 2011 are given using end-of-year 2007 exchange rate. In order to account for this the prices are converted into national currency using the end-of-year 2007 exchange rates given in the report. Then the prices are converted back to USD using end-of year 2011 exchange rates as listed in the CANSO report, see Appendix IV.

In trend analysis of Isavia's cost, in ISK, for the period 2009-2012, the prices are converted into 2012 prices using average consumer price indices. For comparison of trend with other countries the period 2009-2011 is available for comparison. However, for comparing cost between the countries, it makes no sense to convert the prices using end-of-year 2007 USD/ISK exchange rate of 62,0, as compared to 122,7 for 2011. It was therefore decided not to perform a trend analysis, but rather to compare difference in annual costs converted into USD using Purchasing Power Parity (PPP). The PPP as listed in the World Economic Outlook Database April 2011<sup>108</sup> from the International Monetary Fund was used. This is the same source as was used in the CANSO 2012 report.

### **6.3.1 IFR Flight Hours**

To calculate the IFR flight hours, flight data from Isavia's Flight Data Processing System were used. They contain the entry and exit times into and out of the Reykjavik CTA (including the date) as well as the destination and departing airports for each international flight. Data for 2011 and 2012 included also the calculated flown kilometres.

The flying time within the Reykjavik CTA is the difference between the entry and the exit time.

For international flights to and from Iceland, the entry and exit times are reported as the departure and arrival time, respectively, at the Icelandic airport. These flights include therefore the time flown in the domestic area. In order to include only flight hours in the

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<sup>106</sup> If there are fluctuations in the currency a single day exchange rate may give misleading information. Furthermore, costs are incurring during the whole year and may be dependent on the exchange rate at each time.

<sup>107</sup> Price of 1 USD in ISK.

<sup>108</sup> See <http://www.imf.org/external/ns/cs.aspx?id=28>.

oceanic area the flight hours are adjusted by subtracting the time it takes to fly to/from the domestic boundary from/to the Icelandic airport.

As mentioned in chapter 2.2 the boundary of the oceanic airspace is estimated to be at 220 kilometres (120 NM) from the airport when calculating fees in the Joint Financing Agreement. This approach of separating the domestic part of flights from the international part was used to correct the flight hours.

The flights departing and arriving through Icelandic airports can be identified by the Icelandic airport locator prefix BI (BIKF for Keflavik airport, BIRK for Reykjavik airport, etc.). Hence it is possible to make the adjustment only to the flying times of these flights.

Air Traffic Control supervisor at the Reykjavik CTA suggested that 18 minutes would be subtracted from the flight hour of each flight departing or arriving at Reykjavik airports. This is based on his experience.

The average aircraft speed was calculated for all flights in 2011 and 2012. When considering flights to and from Iceland the average speed is around 743 km/hour<sup>109</sup>. According to this, it would take aircraft about 18 minutes to fly the 220 kilometres. However, it may be presumed that the speed is below average the last/first part of the flight and hence that this is the minimum time.

Information on four flights (B757-200) were received from a pilot at Icelandair, two inbound and two outbound flights. For the outbound flights the time from departure to 220 kilometres were 18 and 19 minutes. For the inbound flights the time for the last 220 km were 20 and 21 minute. The average flying time for these flights is 19,5 minutes. The time can be expected to exceed 20 minutes as the average flight speed for this aircraft type was higher (812 km/hour) than the average speed for all flights to and from Iceland. Comparison of the speed of these flights for the last 220 km as a ratio of their average speed suggested up to 22 minutes flying time.

Considering these three sources it was decided to use 20 minutes correction of IFR flight hours for flights to and from Iceland.

Large sets of data gathered from operation are likely to contain some errors or include records that should for some reasons be excluded. When such anomalies were discovered they were either corrected or the record was deleted. Most of the “strange” results had some explanations and therefore there were only minor adjustments which had a negligible effect on the results.

Table 6.2 shows the results of the calculation of IFR flight hour for four years.

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<sup>109</sup> The average for all flights in 2011 and 2012 was 831 km/hour.

Data Element	2009	2010	2011	2012
<b>IFR Flight Hours controlled by Reykjavik ACC</b>	178.886	180.336	192.364	187.321
<b>IFR Flight Hours (Oceanic) corrected for 220 km</b>	170.652	171.804	182.838	177.165

**Table 6.2: IFR Flight Hours data as received and as corrected for use in the calculation of performance metrics.**

As can be seen from table 6.2 the air traffic increased from 2009 to 2011 (average 3,5% annual increase) but then there was a 3% drop in 2012. The drop in 2012 was unexpected. Forecasts for the year 2012, made by STATFOR in 2011, predicted continued growth in Europe. A revised forecast in February 2012 forecasted traffic decrease of 1,3% in Europe, while it turned out to be an average traffic decrease of 2,7% (Performance Review Commission, 2012).

### 6.3.2 ATCO in OPS and ATCO in OPS hours on duty

An Air Traffic Controller on operational duty (ATCO in OPS) is defined in the ACE report, in accordance with the following definition: „*An ATCO who is participating in an activity that is either directly related to the control of traffic or is a necessary requirement for an ATCO to be able to control traffic. Such activities include manning a position, refresher training and supervising on-the-job trainee controllers, but do not include participating in special projects, teaching at a training academy, or providing instruction in a simulator*“ (Eurocontrol, 2008). The CANSO report uses the same definition.

When establishing the number of ATCOs in OPS, Full Time Equivalents (FTE) are used. There are several ATCOs which maintain their licence but are only working part time in air traffic control. In such cases the percentage of full time is estimated. In 2012 there were 59 licenced controllers (who participated in air traffic control) employed at Isavia. Of this number 32 were full time in air traffic control, 9 were working part time and 18 were working as air traffic controllers as well as performing other duties (7,4 as ATCO in OPS and 10,6 as ATCO on other duties). In 2012 the number of ATCOs in OPS working full time was 47,2. When the number of ATCO in OPS in FTE was found the overtime was taken into account by calculating the average number of contractual hours per ATCO in OPS over the years. The number of FTEs was then established by dividing the total working hours in OPS by the contractual hours per ATCO in OPS.

ATCO in OPS hours on Duty is defined in the ACE report by the following definition: “*This is the number of hours “ATCOs in OPS” spend on duty in OPS, including breaks and overtime in OPS. This figure could be available from a time recording system (using for example first clock-in and last clock-out times); it could be computed from the roster plan; or it could be calculated by adding the average overtime worked in OPS to the contractual working hours and subtracting the average time an ATCO is not on duty in OPS.*” (Eurocontrol, 2008).

These data elements were received from Isavia. The ATCO in OPS hour included overtime but not refresher training. In order to account for the refresher training, 32 hours are added for each ATCO per year in accordance with suggestions from Isavia.

The number of ATCOs and their working hours apply to the operation in the Reykjavik Control Centre (CTA). The systems at Isavia do not distinguish between work relating to domestic and oceanic air traffic control in Reykjavik CTA. The total working hours and the number of ATCOs must therefore be corrected in order to obtain estimated values for the oceanic air traffic control.

When calculating the cost of providing ANS services for the international en-route air traffic it is estimated that 16%<sup>110</sup> of staff costs stem from the service to domestic air traffic. This ratio will be used when estimating the number of ATCOs in OPS and the ATCO hours. Using a fixed percentage has the disadvantage that the domestic traffic does not necessarily follow the same trend as the international traffic. However, when calculating the financial metrics it is reasonable to use the same ratio as is done in the cost calculations.

The results of the adjustments are shown in table 6.3.

Data Element	2009	2010	2011	2012
ATCOS in OPS (Oceanic and Domestic)	48,1	52,7	50,0	52,2
ATCOs in OPS (Oceanic)	<b>40,4</b>	<b>44,2</b>	<b>42,0</b>	<b>43,9</b>
ATCO in OPS hours on duty received from Isavia	61.653	65.129	67.000	63.800
Refresher training (32 hours per ATCO)	1.600	1.792	1.760	1.952
ATCO in OPS hours on duty (Oceanic and Domestic)	63.253	66.921	68.760	65.752
ATCO in OPS hours on duty (Domestic)	10.120	10.707	11.002	10.520
ATCO in OPS hours on duty (Oceanic)	<b>53.133</b>	<b>56.214</b>	<b>57.758</b>	<b>55.232</b>
Ratio of oceanic air traffic control	84%	84%	84%	84%

**Table 6.3: Data elements ATCOs in OPS (Oceanic) in FTE and ATCO in OPS hours on duty. Values used in further calculations are shown in bold.**

### 6.3.3 Costs

The costs used in the following data elements are gathered from the statement of costs for the Air Navigation Services (ANS) in Iceland, as provided to the International Civil Aviation Organization (ICAO) in accordance with the Joint Financing Agreement (JFA). These costs cover only the international flights; domestic services and approach control are therefore not included. The costs for 2012 are still unconfirmed and may be subjected to changes.

Isavia changed its accounting standards to International Financial Reporting Standards (IFRS) on January 1, 2010. This did not affect how the costs of the international air navigation service were reported and does therefore not influence the comparison between 2009 and 2010 (source: Isavia).

In table 6.4 the costs used in the calculations of performance metrics are reported in each year in thousands of ISK and transformed into equivalent 2012 costs by using the consumer price index from the Statistics Iceland.

<sup>110</sup> This percentage is an estimate which has been in use for several years.

<b>Data Element</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>
<b>Empl. Cost for ATCO in OPS (Oceanic)</b>	571	604	688	769
<b>Support Cost</b>	2.294	2.343	2.590	2.987
<b>Total Operating Cost</b>	2.438	2.543	2.904	3.397
<b>Depreciation and Interest payments</b>	428	405	373	359
<b>Total Costs (Oceanic)</b>	2.866	2.948	3.278	3.756
<b>Empl. Cost for ATCO in OPS (Oceanic) at 2012 price levels</b>	659	661	724	769
<b>Total Costs (Oceanic) at 2012 price levels</b>	3.304	3.225	3.448	3.756
<b>Consumer Price Index (year average)</b>	344,6	363,2	377,7	397,3

**Table 6.4: Costs related to the Oceanic ANS service. The costs are expressed in million ISK.**

#### **6.3.3.1 Employment cost for ATCOs in operation (ATCO in OPS).**

Employment Cost for ATCOs in OPS is defined in accordance with the definition of ATCO in OPS, see chapter 6.3.2 above for this definition.

The employment cost for ATCO in OPS was received from Isavia's finance department. The costs include refresher training cost and only cover the oceanic part of the service as defined by the Joint Financing Agreement.

#### **6.3.3.2 Support Cost**

Support Cost is defined in the Eurocontrol Specification for Economic Information as the staff costs other than those for ATCOs in OPS, non-staff operating costs and capital-related costs (Eurocontrol, 2008). In this case it is the difference of Total Cost and Employment Cost for ATCOs in OPS.

#### **6.3.3.3 Cost of capital and depreciation**

As new investments are financed solely by loans, the cost of capital is the interest payments of the loans. Interest payments and depreciation are indicated in the accounts for the international air traffic services.

#### **6.3.3.4 Total Operating Cost**

Total Operating Cost is defined in the CANSO benchmarking by the following: „*Operating costs include direct and indirect employment costs, non-staff operating expenses, and other costs incurred through the purchase of goods and services directly used to provide continental and oceanic ANS services. This should include outsourced services such as communications, IT, and external staff with short term assignments. Other items that are usually included in operating costs include materials; energy; rent; and facilities and maintenance. This excludes the cost of providing meteorological (MET) services, which should be counted under 'other unique costs'* “ (CANSO Global Benchmarking Workgroup, 2011).

Only the MET costs need to be excluded from the total operating cost and no further adjustments were made to the costs received from Isavia. If there are no exceptional items the total operating cost is equal to the total costs minus depreciation and capital costs.

### 6.3.3.5 Total Costs

The Total Costs (Oceanic) is defined in the CANSO benchmarking report as “*the sum of Oceanic Operating Costs, Depreciation/Amortization, and Cost of Capital related to providing Oceanic ATC/ATFM<sup>111</sup> Services*” (CANSO Global Benchmarking Workgroup, 2011). Costs related to Communication, Navigation and Surveillance (CNS) are also included but the total cost does not include costs for providing service relating to MET and Flight Services Stations that provide traffic advisories services.

Only the MET costs needed to be excluded from the total costs and no further adjustments were made.

## 6.4 Calculation of Performance metrics and Comparison between Oceanic ANSPs

The metrics as listed in table 6.1 were calculated for the period 2009-2012.

### 6.4.1 Productivity Metrics

The productivity performance indicators for oceanic flight in the CANSO report are:

$$\text{IFR Flight Hours per ATCO in OPS} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS}} \quad (6.1)$$

$$\text{Average Annual Working Hours for ATCOs in OPS} = \frac{\text{ATCOs in OPS Hours}}{\text{ATCOs in OPS}} \quad (6.2)$$

In the 2012 report the following continental metric was added:

$$\text{IFR Flight Hours per ATCO in OPS hour} = \frac{\text{IFR Flight Hours}}{\text{ATCOs in OPS Hours}} \quad (6.3)$$

This metric corresponds to the metric *ATCO-hour Productivity*<sup>112</sup> in the ACE report. Although this metric is not calculated for oceanic centres it is an important metric to monitor in addition to *IFR Flight Hours per ATCO in OPS*.

Productivity Metrics	2009	2010	2011	2012
IFR Flight Hours per ATCO in OPS	4.227	3.885	4.355	4.040
IFR Flight Hours per ATCO in OPS hour	3,21	3,06	3,17	3,21
Average Annual Working Hours for ATCOs in OPS	1.316	1.271	1.376	1.259

**Table 6.5: Isavia's productivity metrics in 2009-2012.**

It is interesting to note that while *IFR Flight Hours per ATCO in OPS* decreased between 2011 and 2012, the *IFR Flight Hours per ATCO in OPS hour* increased. This can be explained by the fact that while the number of ATCOs in OPS increased, their working hours

<sup>111</sup> Air Traffic Flow Management.

<sup>112</sup> ATCO-hour Productivity uses composite flight hours which are a combination of IFR flight hours and airport movements. As only the oceanic flight is under consideration there are no airport movements involved and composite flight hours becomes just IFR flight hours.

decreased as can also be seen in table 6.3 and in the decrease of the *Average Annual Working Hours for ATCOs in OPS* between 2011 and 2012. The overtime decreased over 17% between 2011 and 2012 and the standard working hours decreased about 3%. Using the ATCO hours gives a better picture of the input into the system than the number of ATCOs. It is a more accurate measurement than the number of ATCO in OPS where there may be errors, for example due to different reporting of sick and parental leaves. If there are many ATCOs which are working part-time on other projects the estimation of FTE may introduce errors.

The increase in *IFR Flight Hours per ATCO in OPS hour* between 2011 and 2012 is positive in light of the fact that in 2012 there was an unexpected decrease in air traffic.

It is very important to monitor how changes in procedures will affect this metric to see how performance can be improved.

As mentioned earlier, data on *IFR Flight Hours per ATCO in OPS hour (ATCO-hour Productivity)* are not available for oceanic ANSPs. It is however interesting to compare these numbers for Isavia with the Maastricht Upper Air Centre (MUAC) which controls only the upper airspace of Belgium, the Netherlands, Luxembourg and North-west Germany. MUAC controls only en-route traffic (not approach and landing) and is in that light comparable to the oceanic airspace of Reykjavik CTA especially that part where the traffic control is within radar surveillance. The flight hours controlled by MUAC are about 560 thousands per year which is more than twice the flight hours controlled by Isavia. Comparing Isavia's *IFR Flight Hours per ATCO in OPS hour* of 3,17 with MUAC's 1,95 in 2011 may indicate somewhat higher productivity at Isavia. However, it can be assumed that the complexity is significantly higher in the MUAC control airspace than in Reykjavik CTA and hence a direct comparison is not realistic without making some adjustments for this fact. However the values of this metric are in the same range for these two en-route centres which is encouraging (Performance Review Unit (PRU), 2013).

MUAC controls only en-route traffic (not approach and landing) and is in that light comparable to the oceanic airspace of Reykjavik CTA especially that part where the traffic control is within radar surveillance. Comparing Isavia's *IFR Flight Hours per ATCO in OPS hour* of 3,17 with MUAC's 1,95 in 2011 may indicate somewhat higher productivity at Isavia. However, it can be assumed that the complexity is significantly higher in the MUAC control airspace than in Reykjavik CTA and hence a direct comparison is not realistic without making some adjustments for this fact. However the values of this metric are in the same range for these two en-route centres which is encouraging.

The *IFR Flight Hours per ATCO in OPS* was compared to other oceanic ANSPs as reported in CANSO 2012 report and the result is shown in table 6.6. The report covers data up to 2011 and hence the comparison years are from 2009 to 2011.

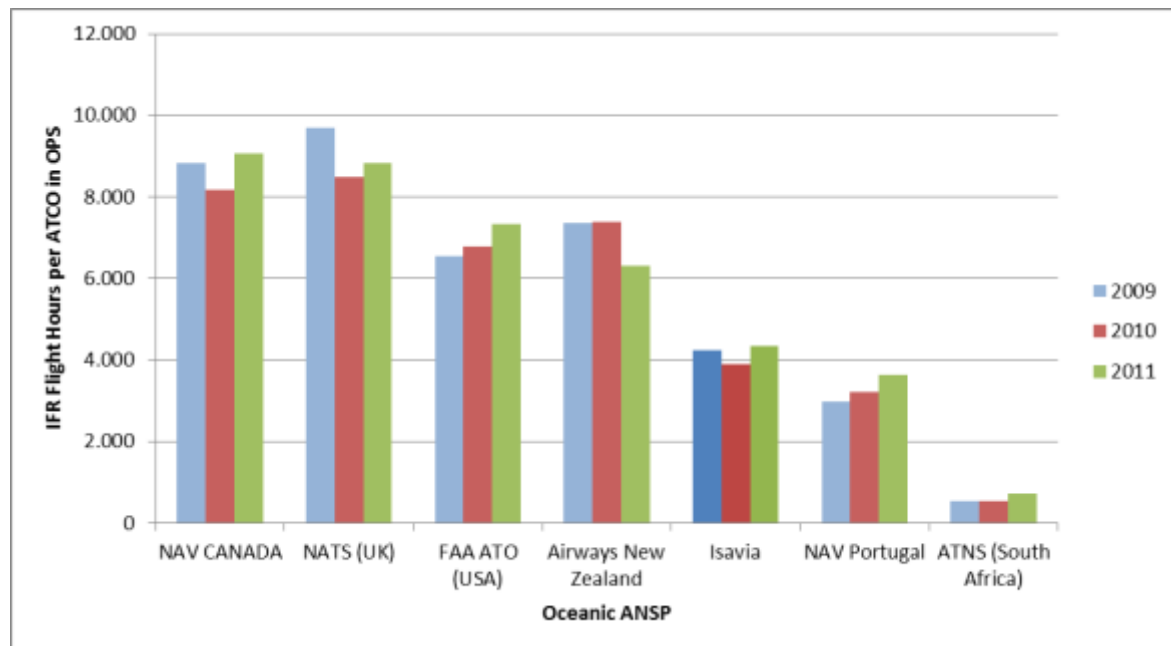
IFR Flight Hours per ATCO in Operations (Oceanic)	Flight Hour Group	2009	2010	2011
FAA ATO (USA)	A	6.548	6.787	7.323
NAV CANADA	A	8.816	8.164	9.059
NATS (UK)	A	9.706	8.494	8.839
NAV Portugal	B	2.987	3.211	3.641
Airways New Zealand	B	7.367	7.386	6.308
ATNS (South Africa)	B	530	532	722
Isavia	C	4.227	3.885	4.355

**Table 6.6: Comparison of IFR Flight Hours per ATCO in OPS between oceanic ANSPs for 2009-2011. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

The ANSPs are grouped by the number of annual flight hours (oceanic and continental). Isavia falls in group C with the lowest number of total IFR flight hours controlled per year among the oceanic centres. The number of IFR flight hours for the oceanic ANSPs are given in table 6.7.

There are two ANSPs with lower *IFR Flight Hours per ATCO in OPS* than Isavia: NAV Portugal and ATNS South- Africa.

Figure 6.1 shows the data from table 6.6. Isavia is 5<sup>th</sup> in the comparison over all the years.



**Figure 6.1: IFR Flight Hours per ATCO in Operation for the years 2009-2011. Comparison of oceanic ANSPs.**

The figure also shows that the trend for the years 2009-2011 are similar for Isavia, NATS and NAV Canada, with a decrease in 2010 and an increase in 2011. FAA ATO and NAV Portugal on the other hand show an increase between all the years.

This metric is useful to measure productivity and compare to other ANSPs until information on *IFR Flight Hours per ATCO in OPS hour* for oceanic ANSP becomes available. It can

also be useful for estimating the need for recruiting ATCOs on operational duties based on forecasted air traffic demand.

There are several factors which can explain the difference in this metric. As mentioned in chapter 5 some factors are not controlled by the ANSP (exogenous factors) and should be considered when comparing the performance metrics directly. The following factors are mentioned for consideration although a further study is warranted of this subject.

### *Size of the ANSPs*

In the CANSO report there are given contextual data for some of the ANSPs. Table 6.7 shows these data for the oceanic centres.

Contextual data for oceanic ANSPs	Oceanic IFR hour per km <sup>2</sup>	Oceanic airspace in km <sup>2</sup>	Radar coverage	Oceanic IFR flight hours	Total IFR flight hours	Source
FAA ATO (USA)	0,020000	65.000.000	N/A	1.300.000	25.106.283	Canso 2011
NAV CANADA	0,206520	3.070.462	100%	634.112	3.385.086	Canso 2012
NATS (UK)	N/A	2.120.000	0%	N/A	1.731.274	Canso 2011
NAV Portugal	0,040667	5.190.000	13%	211.060	518.247	Canso 2012
Airways New Zealand	0,005000	28.790.000	N/A	143.950	351.680	Canso 2011
ATNS (South Africa)	0,000851	12.720.920	0%	10.830	290.971	Canso 2012
Isavia	0,034035	5.400.000	23%	183.789	218.796	Isavia

**Table 6.7: Contextual data for oceanic ANSPs.<sup>113</sup>**

It should be noted that the Oceanic IFR flight hours in the table are not reported in the CANSO report; these are calculated from Oceanic IFR hour per km<sup>2</sup> and the area of the oceanic airspace (except for Isavia).

The ANSP with Oceanic IFR hour per km<sup>2</sup> of a similar order of magnitude are the NAV Portugal and FAA ATO (USA). The flight hours and the size of the oceanic airspace controlled by FAA ATO are however much larger.

Considering both the size of the airspace and the oceanic IFR flight hours, NAV Portugal is in the same category as Isavia<sup>114</sup>. In that light Isavia is performing better than NAV Portugal

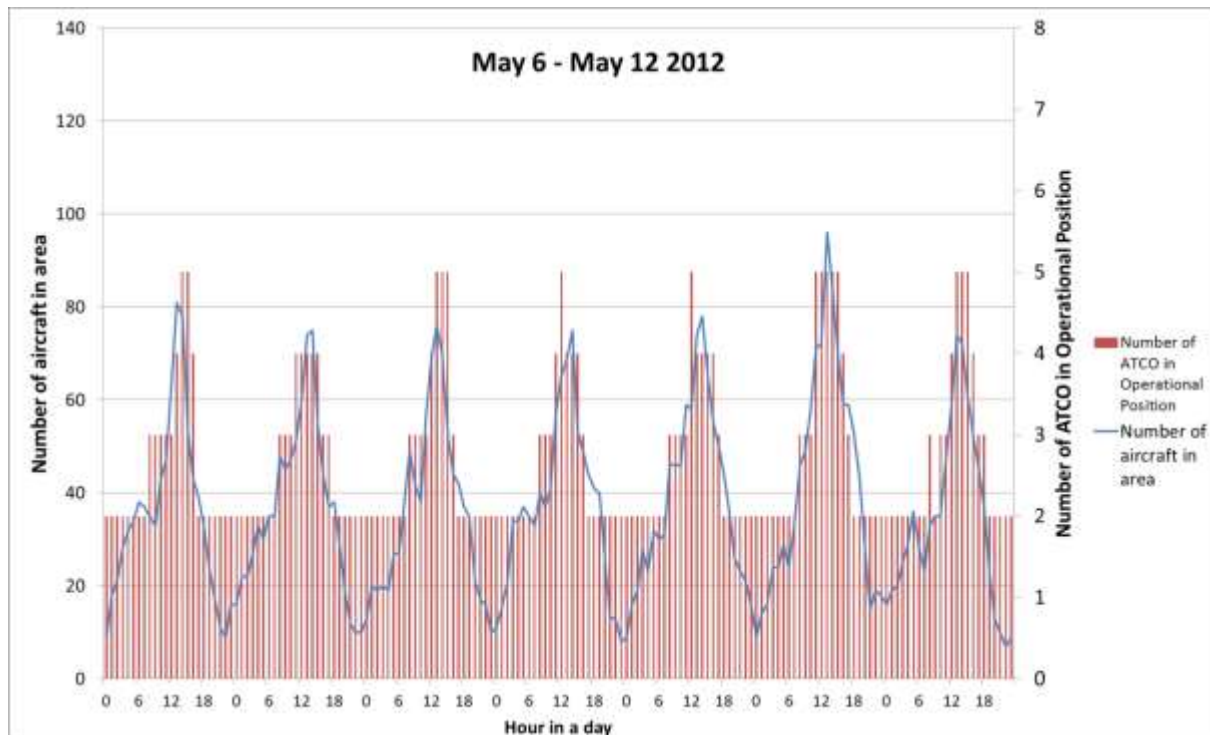
In the Reykjavik CTA the minimum number of ATCOs in operational position (the number of sectors open)<sup>115</sup> is two. When the traffic is very low and theoretically only one ATCO (or even half an ATCO, if such an ATCO existed) could handle the traffic, the minimum number of two ATCOs is required for safety reasons.

<sup>113</sup> N/A means that data are not available. Comparing ACE 2011 report with CANSO 2012 report for the year 2011 show that NATS oceanic flight hours are about 463 thousand.

<sup>114</sup> In addition to this, the number of ATCOs in oceanic operation in area control centres at NAV Portugal in 2011 was 40 compared to 37 at Isavia.

In order to study this further the time distribution of flights in the CTA in 2012 was considered by determining their number for one hour intervals<sup>116</sup>. This was compared to the number of ATCOs in operational positions at the same time.

Figure 6.2 shows the number of aircraft in the area and the number of ATCOs in operational position for each one hour interval from May 6<sup>th</sup> until May 12<sup>th</sup> of 2012. This particular week was selected as the number of flights during this week was close to the weekly average for the year.



**Figure 6.2: The number of aircraft in the area and the number of ATCOs in operational positions per hour of the day. This figure is based on flight data for both domestic and oceanic flights.**

Figure 6.2 indicates that although the number of ATCOs in operational position do not always follow the traffic pattern directly (as explained in chapter 5.3.5) there is clearly a strong dependency. It furthermore indicates the inefficiency caused by low traffic volume during the night when there is minimum number of ATCOs in operational position.

It is however likely that many ANSPs are faced with this situation as the traffic is usually low at nights.

#### ***Complexity and the type of airspace under ANSP responsibility***

If the Reykjavik Control Area is compared with other oceanic control areas, Isavia is able to offer more flexibility in the choice of flight routes than is normally available. The main reason for this is that a part of the airspace has radar coverage. The radar coverage allows less separation between aircraft than possible when procedural separation is used, as is usual for oceanic airspace. This increases the possibility of adjusting flight routes in

<sup>116</sup> An aircraft was considered in the area even though it exited the airspace just after the hour interval started.

accordance with requests from airlines. Whereas many oceanic ANSPs offer fixed tracks for flight routes with little possibilities to change the route of the aircraft<sup>117</sup>, Isavia offers flexible routes. The airlines will therefore have an increased possibility to choose their preferred route and to make changes of their cleared<sup>118</sup> routes. This also means that the traffic will become more complex to control when compared to traffic on fixed tracks and hence the productivity will be affected.

At Isavia the major part of the air navigation service provided by the Reykjavik ACC is for oceanic air traffic, nominally estimated at 84%. This is different from all the other ANSPs in the comparison. At NAV Portugal and Airways New Zealand the oceanic flight hours are 41% of total flight hours. For the other ANSPs this percentage is less<sup>119</sup>. Thus there may be great differences between ANSP's as to how cost and work effort for oceanic air navigation services are distinguished from other air navigation services. The allocation of the strategic and pre-tactical part of the work<sup>120</sup> to oceanic air navigation services may for example differ between the ANSPs. Where the oceanic part of the service is small the tendency might be to exclude this part of the service from the oceanic air navigation services. However, the methods used by the ANSPs of dividing costs and work between oceanic and continental services are not included in the CANSO report. Hence the effect this has on the comparison cannot be evaluated.

### ***Traffic variability***

As can be seen in chapter 6.4.2 traffic variability is high in the Reykjavik CTA, compared to traffic in Europe. This is likely to lead to underutilization of resources as the productivity must be balanced against safety (ensuring necessary ATC resources under uncertainty), resulting in lower productivity.

Comparison between years within each ANSP is however valid but for that comparison one should also be careful. As seen in table 6.5 *IFR Flight Hours per ATCO in OPS* is decreasing from 2009 to 2012 while the total change in *IFR Flight Hours per ATCO in OPS* hour between 2009 and 2012 is negligible. The reason for this difference is explained in *Average Annual Working Hours for ATCOs in OPS* which varies with the *IFR Flight Hours per ATCO in OPS*.

There are several factors which the ANSPs can consider in order to increase the productivity, for example optimization of processes and better staff utilization.

A good co-operation between ATCOs in OPS and ATM system developers can lead to new procedures which increase productivity by enabling each ATCO to handle an increased volume of traffic.

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<sup>117</sup> For example to climb up to higher heights in order to decrease fuel consumption.

<sup>118</sup> For explanation see clearance in Glossary of Terms.

<sup>119</sup> The information for NATS is missing in the CANSO reports. According to NATS Annual Report 2012 the oceanic flights are about 18% of all flights (<http://www.nats.co.uk/wp-content/uploads/2012/07/NATS-AnnualReport2012.pdf>).

<sup>120</sup> See Air Traffic Management in Appendix I.

The utilization of ATCOs could be considered, i.e. the number of ATCOs in OPS on duty versus the number of ATCOs in OPS at the operational ATC workstation (or working position). It would be interesting to compare these numbers on an hourly basis over a long time period to see what possibilities there are for improvements. This is also linked to the reliability of forecasts; if it would be possible to improve forecasts it would most likely result in better shift plans and hence higher productivity. This applies especially in areas where there is high variability in the air traffic.

It is important to monitor the productivity metric when any improvements are made to systems and processes in order to see how the changes affect productivity. The period 2009 - 2012 did not show much change in this metric. It would be interesting to evaluate the productivity over a longer period.

### 6.4.2 Financial Metrics

The financial performance indicators for oceanic flights in the CANSO report are:

$$\text{Cost per IFR Flight Hour} = \frac{\text{Total Costs}}{\text{IFR Flight Hours}} \quad (6.4)$$

$$\text{Empl. Cost for ATCOs in OPS per IFR Flight Hour} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{IFR Flight Hours}} \quad (6.5)$$

$$\text{Empl. Cost for ATCOs in OPS per ATCO in OPS} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCOs in OPS}} \quad (6.6)$$

$$\begin{aligned} &\text{Cost of Capital and Depreciation as a Percentage of Total Cost} = \\ &\frac{\text{Cost of Capital and Depreciation}}{\text{Total Costs}} \end{aligned} \quad (6.7)$$

These metrics all have a corresponding metric in the ACE report. The ACE report also includes the following metrics:

$$\text{Empl. Cost for ATCO in OPS per ATCO-hour} = \frac{\text{Empl. Costs for ATCOs in OPS}}{\text{ATCO in OPS Hours}} \quad (6.8)$$

$$\text{Support Cost per IFR Flight Hours} = \frac{\text{Support Costs}}{\text{IFR Flight Hours}} \quad (6.9)$$

$$\text{Support Cost Ratio} = \frac{\text{Total Costs}}{\text{Empl. Costs for ATCOs in OPS}} \quad (6.10)$$

Here the name of the metric *ATCO Employment Cost per ATCO-hour* has been adjusted to CANSO's terminology and is therefore named *Empl. Cost for ATCO in OPS per ATCO-hour*. *Support Cost per IFR Flight Hours* has been adjusted to en-route traffic, including only IFR flight hours but no airport movements, as in the composite flight hours. For the Support Cost Ratio the ATM/CNS Provision Costs has been replaced with Total Costs as defined in Glossary of Terms and listed in table 6.4.

These metrics were calculated using data from Isavia. The results, which are presented in table 6.8 are expressed in ISK and converted to 2012 price levels.

<b>Financial Metrics at 2012 price levels</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>
Cost per IFR Flight Hour	19.362	18.770	18.856	21.201
Support Cost per IFR Flight Hours	15.501	14.922	14.898	16.862
Empl. Cost for ATCOs in OPS per IFR Flight Hour	3.861	3.847	3.958	4.339
Empl. Cost for ATCOs in OPS per ATCO in OPS	16.322.078	14.944.907	17.235.509	17.527.613
Empl. Cost for ATCOs in OPS per ATCO-hour	12.401	11.758	12.528	13.917
Cost of Capital and Depreciation as a Percentage of Total Cost	15%	14%	11%	10%
Support Cost Ratio	5,01	4,88	4,76	4,89

**Table 6.8: Financial metrics for Isavia in ISK at 2012 price levels.**

*Cost per IFR Flight Hour* is equal to the sum of *Empl. Cost for ATCOs in OPS per IFR Flight Hour* and *Support Cost per IFR Flight Hours*. When there is a change in the *Cost per IFR Flight Hour* it is therefore easy to see whether it stems from either or both of the other two metrics.

ATCO in OPS employment cost is 20 to 21% of total costs over this period. According to the ACE report the average ATCO in OPS employment cost is around 30%. For the oceanic ANSP participating in the CANSO benchmark, the average ATCO in OPS employment cost is around 28% of total costs over the years 2009-2011 (ranging from 21-41%). The average ATCO in OPS employment cost as a percentage of total cost is therefore unusually low at Isavia. It is possible that this is caused by the fact that the support cost is in large part independent of the number of IFR flight hours controlled (i.e. mainly fixed cost) while the employments cost for ATCO in OPS is more dependent on the number of flight hours controlled. The number of flight hours controlled by Isavia is low in comparison with other ANSPs which could be the reason for high support cost and hence this low employment cost for ATCO in OPS as a percentage of total cost.

Three metrics in table 6.8 can be compared to other oceanic ANSPs from the CANSO report for the year 2011:

- *Cost per IFR Flight Hour*,
- *Employment Cost for ATCO in OPS per IFR Flight Hour*,
- *Employment Cost for ATCOs in OPS per ATCO in OPS* and
- *Support Cost Ratio*.

#### **6.4.2.1 Cost per IFR Flight Hour**

*Cost per IFR Flight Hour* increased about 9% from 2009 to 2012<sup>121</sup>. Most of the increase was from 2011 to 2012, about 12%.

The comparison of *Cost per IFR Flight Hour* between oceanic ANSPs is shown in table 6.9.

<sup>121</sup> In 2012 price levels.

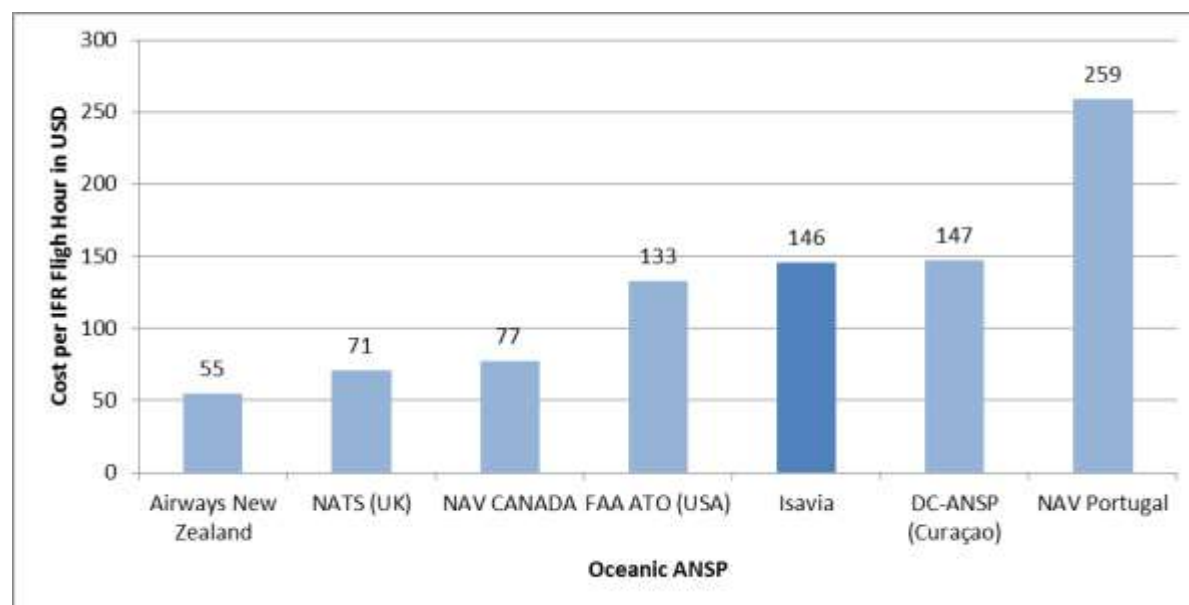
Cost (USD) per IFR Flight Hour (Oceanic)	Flight Hour Group	2011
FAA ATO (USA)	A	133
NAV CANADA	A	77
NATS (UK)	A	71
NAV Portugal	B	259
Airways New Zealand	B	55
DC-ANSP (Curaçao)	C	147
Isavia	C	146

**Table 6.9: Comparison of Cost per IFR Flight Hours in oceanic control areas. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

The cost was converted from USD based on end-of-year 2007 exchange rate, as indicated in the CANSO report, to USD using the end-of-year 2011 exchange rate. Isavia's cost was converted to USD using the end-of-year 2011 exchange rate.

In the 2012 CANSO report the Dutch Caribbean Air Navigation Service Provider (DC-ANSP) is included in the comparison of Cost per IFR Flight Hours but none of the other oceanic metrics. On the other hand ATNS (South Africa) is not included in this comparison, but is included in the comparison of all other oceanic metrics.

Figure 6.3 shows the data from table 6.9.



**Figure 6.3: Cost per IFR Flight Hour for the year 2011 in USD. Comparison between oceanic ANSPs.**

As shown in figure 6.3 Isavia is the 5<sup>th</sup>, with DC-ANSP and NAV Portugal showing higher cost. The same five ANSPs that showed higher productivity also show lower total cost, although the ANSPs are not in the same order for both of these metrics.

### 6.4.2.2 Employment Cost for ATCO in OPS per IFR Flight Hour

*Employment Cost for ATCO in OPS per IFR Flight Hour* increased about 9% from 2009 to 2012<sup>122</sup>. Most of the increase was from 2011 to 2012, about 13%.

The comparison of *Employment Cost for ATCO in OPS per IFR Flight Hour* is shown in tables 6.10 and 6.11.

<b>Employment Cost for ATCOs in Operations (USD) per IFR Flight Hour (Oceanic)</b>	<b>Flight Hour Group</b>	<b>2011</b>
FAA ATO (USA)	A	32
NAV CANADA	A	18
NATS (UK)	A	21
NAV Portugal	B	93
Airways New Zealand	B	20
ATNS (South Africa)	B	36
Isavia	C	31

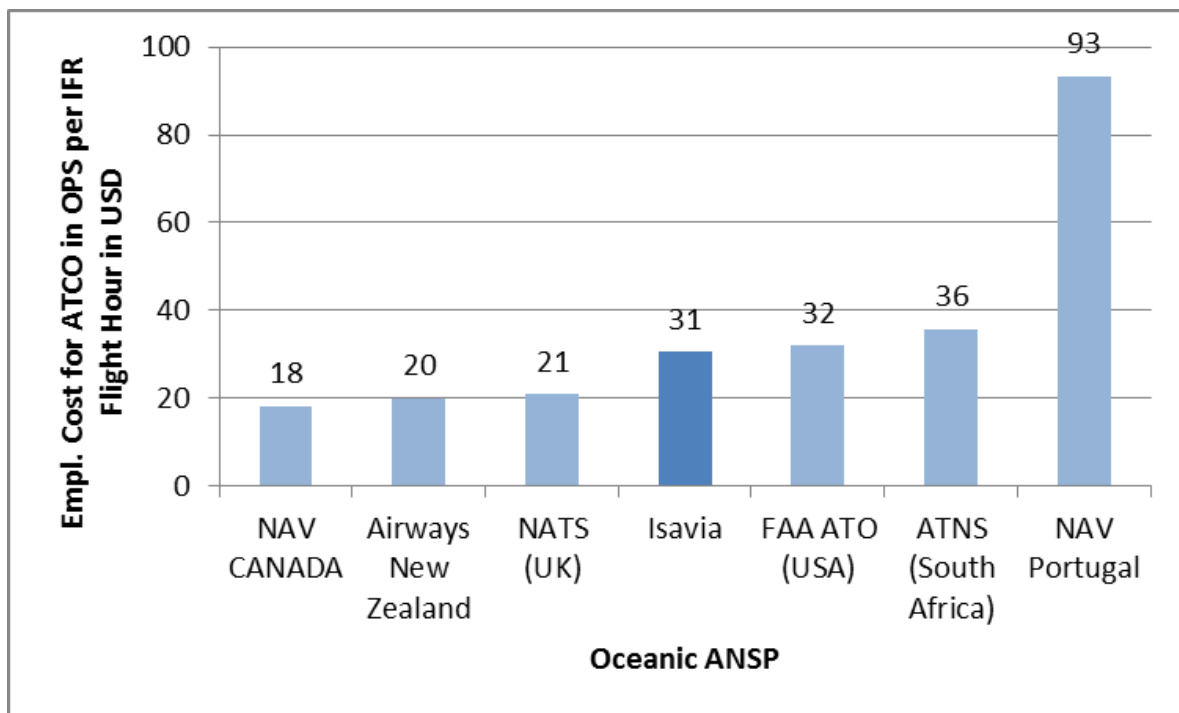
**Table 6.10: Employment Cost for ATCOs in Operations per IFR flight hour. For each oceanic ANSP this is expressed in USD using end-of-year 2011 exchange rates. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

<b>Employment Cost for ATCOs in Operations (USD) per IFR Flight Hour (Oceanic) - PPP</b>	<b>Flight Hour Group</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>
FAA ATO (USA)	A	29	29	32
NAV CANADA	A	15	16	15
NATS (UK)	A	30	29	20
NAV Portugal	B	96	81	104
Airways New Zealand	B	12	12	16
ATNS (South Africa)	B	191	83	55
Isavia	C	27	27	29

**Table 6.11: Employment Cost for ATCOs in OPS per IFR Flight Hour. For each oceanic ANSP this is expressed in USD using PPP. Conversion rates are given in Appendix V. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

Figure 6.4 shows the data from table 6.10.

<sup>122</sup> In 2012 price levels.



**Figure 6.4: Employment Cost for ATCO in OPS per IFR Flight Hour in USD for the year 2011. Comparison between oceanic ANSPs.**

As seen in figure 6.4 if the ANSPs are ordered from lowest to highest cost in 2011, Isavia is the 4<sup>th</sup>, with FAA ATO, DC-ANSP and NAV Portugal showing higher employment cost.

This order is the same whether the usual USD conversion or the PPP conversion is used for the year 2011. However, if 2009 and 2010 are considered in table 6.11., Isavia has the 3<sup>rd</sup> lowest employment cost, after Airways and NAV Canada. As mentioned earlier Isavia has rather low ATCO employment cost as a percentage of total costs, which can explain why they rank higher (3<sup>rd</sup> and 4<sup>th</sup> compared to 5<sup>th</sup>) in comparison with the other ANSPs for the employment cost as compared to the total costs.

#### 6.4.2.3 Employment Cost for ATCOs in OPS per ATCO in OPS

The comparison of *Empl. Cost for ATCOs in OPS per ATCO in OPS* is shown in tables 6.12 and 6.13.

Employment Cost for ATCOs in Operations (USD) per ATCO in Operations (Oceanic)	Flight Hour Group	2011
FAA ATO (USA)	A	236.260
NAV CANADA	A	167.486
NATS (UK)	A	183.867
NAV Portugal	B	338.685
Airways New Zealand	B	128.506
ATNS (South Africa)	B	25.916
Isavia	C	133.531

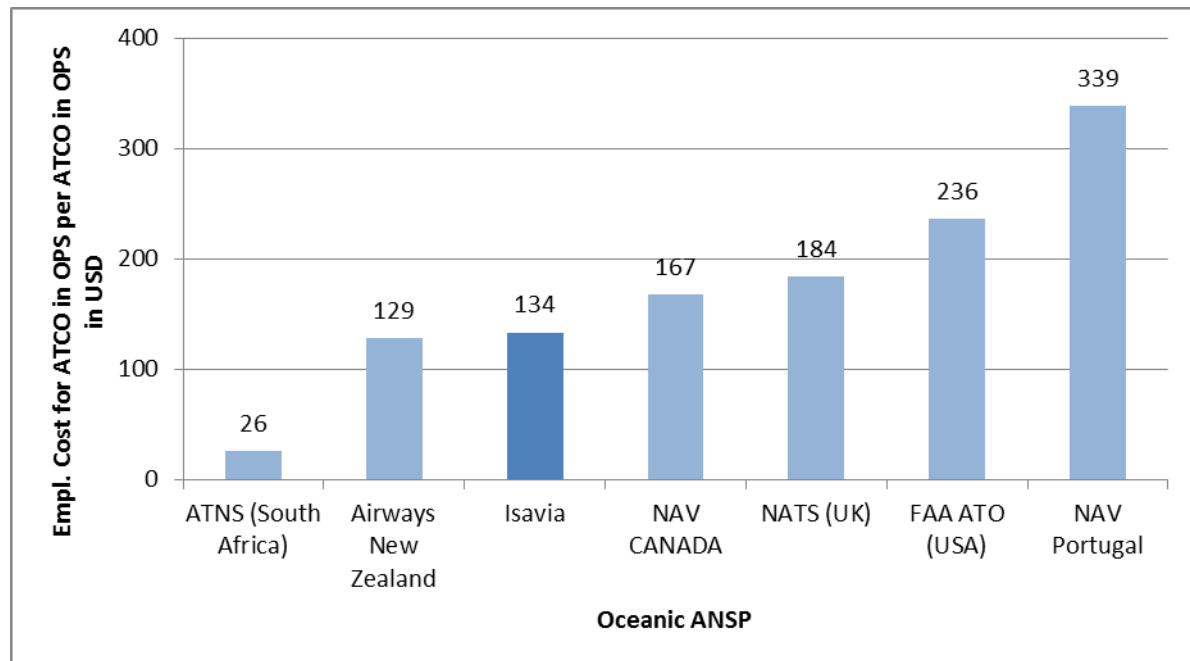
**Table 6.12: Employment cost for ATCO in OPS per ATCO in OPS. For each oceanic ANSP this is expressed in USD using end-of-year 2011 exchange rates. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

Employment Cost for ATCOs in Operations (USD) per ATCO in Operations (Oceanic) - PPP	Flight Hour Group	2009	2010	2011
FAA ATO (USA)	A	186.870	195.723	236.260
NAV CANADA	A	134.485	134.267	138.734
NATS (UK)	A	294.749	243.831	178.353
NAV Portugal	B	287.885	260.581	379.034
Airways New Zealand	B	91.096	90.775	99.142
ATNS (South Africa)	B	101.282	44.352	39.452
Isavia	C	114.976	104.980	124.734

**Table 6.13: Employment Cost for ATCOs in OPS per ATCO in OPS. For each oceanic ANSP this is expressed in USD using PPP. Conversion rates are given in Appendix V. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

Tables 6.12 and 6.13 show similar results for Isavia with respect to rank from lowest to highest *Empl. Cost for ATCOs in OPS per IFR Flight Hour*.

Figure 6.5 shows the data from table 6.12.



**Figure 6.5: Employment cost for ATCO in OPS per ATCO in OPS in thousand USD. Oceanic ANSPs.**

As can be seen in figure 6.5 Isavia has the 3<sup>rd</sup> lowest employment cost per ATCO in OPS. In table 6.13 it is 3<sup>rd</sup> and 4<sup>th</sup> lowest depending on the year of comparison. As mentioned above the number of ATCO in OPS may be subject to errors, for example due to differences in the reporting of sick and parental leaves as well as in estimating the Full Time Equivalent for the ATCOs which are also involved in other duties.

Both NAV CANADA and NATS have higher employment cost per controller than Isavia but lower employment cost per IFR flight hour. This is because of higher productivity (*IFR Flight Hours per ATCO in OPS*) at NAV CANADA and NATS than Isavia. *Employment cost*

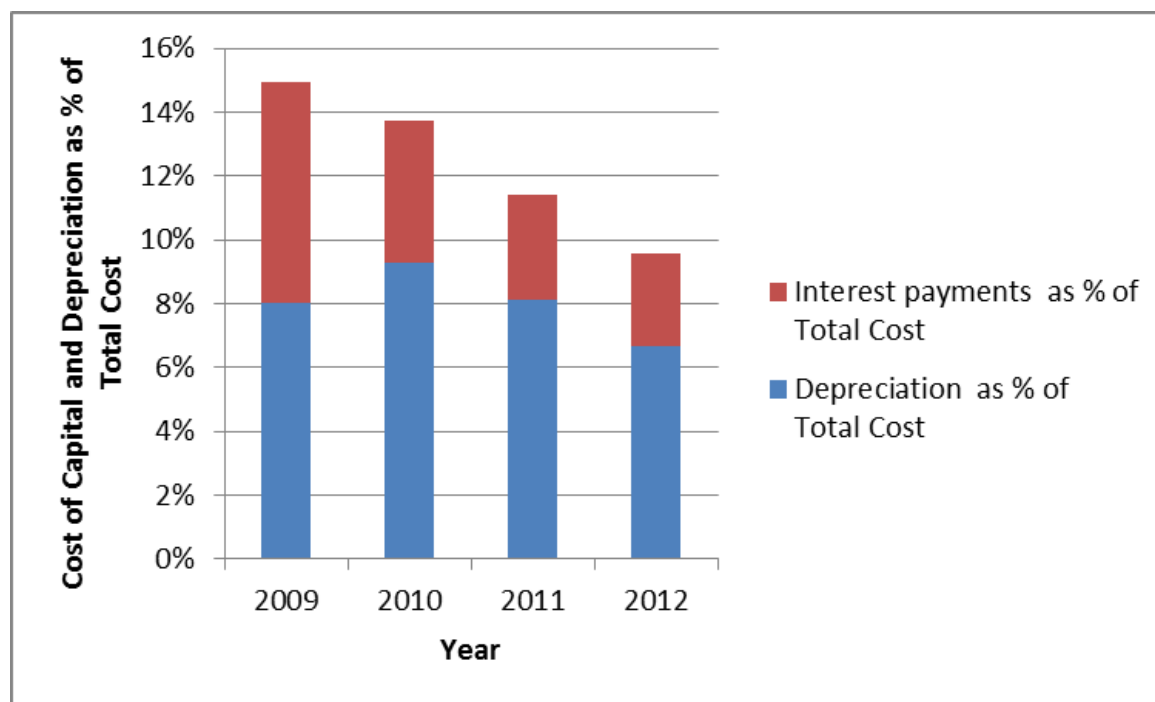
*for ATCO in OPS per ATCO in OPS is equal to the product of IFR Flight Hours per ATCO in OPS and Employment Cost for ATCO in OPS per IFR Flight Hour.*

It should be noted that the PPP conversion is not intended for time series analysis, but rather for comparison between ANSPs each year. It is therefore not possible to draw any conclusion with respect to the development of costs for each ANSP, such as increase or decrease in costs.

#### **6.4.2.4 Cost of Capital and Depreciation as a Percentage of Total Cost**

*Cost of Capital and Depreciation as a Percentage of Total Cost* is calculated in the CANSO report for oceanic and continental service. In the year 2011 the average percentage for all the ANSPs in the report was about 20% for both continental and oceanic air navigation services, ranging from 8,2% - 35,6%.

Figure 6.6 shows this metric for Isavia over the years 2009-2012 for the oceanic air navigation service.



**Figure 6.6: Cost of Capital and Depreciation as a Percentage of Total Cost for Isavia over the years 2009-2012.**

*Cost of Capital and Depreciation as a Percentage of Total Cost* is lower than the CANSO average and has been decreasing from 2009. Large part of the decrease is because interest payments have decreased considerably.

The interest payments in 2012 were 52% lower than in 2009. Depreciation decreased about 6% over this period while the total cost increased about 14%.

#### 6.4.2.5 Support Cost Ratio

Support Cost Ratio was calculated on the basis of *Cost per IFR Flight Hour* and *Empl.Cost for ATCOs in OPS per IFR Flight Hour* for the year 2011.<sup>123</sup>

Support Cost Ratio	Flight Hour Group	2011
FAA ATO (USA)	A	4,2
NAV CANADA	A	4,2
NATS (UK)	A	3,4
NAV Portugal	B	2,8
Airways New Zealand	B	2,8
Isavia	C	4,8

**Table 6.14: Support Cost Ratio for oceanic ANSPs. ANSPs are listed in order of total IFR Flight Hours controlled per year.**

Isavia's support cost of 4,8 means that for each 1 ISK spent on employing an ATCO in OPS 3,8 ISK are spent on other costs. Isavia shows high Support Cost Ratio in comparison with other ANSPs. This is not surprising in light of the fact that the percentage of employment cost for ATCOs in OPS to total cost is low compared to other ANSPs, and hence the support cost high, as discussed here above. This is probably caused by the fact that the support cost is in large part independent of the number of IFR flight hours controlled (i.e. mainly fixed cost) while the employments cost for ATCO in OPS is more dependent on the number of flight hours controlled.

#### 6.4.3 Traffic Variability

In the Performance Review Report traffic variability is calculated as the ratio between the peak traffic and average traffic, measured in number of flights.

$$\text{Traffic Variability} = \frac{\text{Maximum Number of Flights}}{\text{Average Number of Flights}} \quad (6.11)$$

This can be calculated for different periods of time. Using air traffic data traffic variability was calculated for time periods of one day and one week.

Traffic Variability	2009	2010		2011	2012
		All flights	Corrected		
Average Daily Traffic	278	280	272	305	295
Peak Daily Traffic	546	1.019	531	548	505
<b>Traffic Variability</b>	<b>1,96</b>	<b>3,64</b>	<b>1,95</b>	<b>1,79</b>	<b>1,71</b>
Average Weekly Traffic	1.915	1.930	1.875	2.104	2.038
Peak Weekly Traffic	3.130	4.329	2.784	2.945	2.764
<b>Traffic Variability</b>	<b>1,63</b>	<b>2,24</b>	<b>1,48</b>	<b>1,40</b>	<b>1,36</b>

**Table 6.15: Traffic variability, considering air traffic per day and per week.**

<sup>123</sup> It should be noted here that ATM/CNS Provision Costs which are used in Eurocontrol's definition of the support cost ratio is in most cases the same as the Total Cost as defined by CANSO.

The eruption of Eyjafjallajökull from April 14<sup>th</sup> 2010 to May 23<sup>rd</sup> 2010 had a great influence on air traffic in Europe and the North Atlantic. The effect in the Reykjavik CTA was somewhat different than in other areas. During the period 8<sup>th</sup> – 12<sup>th</sup> of May 2010 there were unprecedented air traffic peaks in the Reykjavik CTA as air traffic was diverted north of the volcanic crater. On May 11<sup>th</sup> the number of flights went up to 1.019 which is about three times the average of a normal year and about two times the maximum number over a single day for the other years considered. It was therefore decided to correct for this abnormal event in the calculation of the traffic variability for the year 2010.

In 2012 the average variability of daily traffic in Europe (excluding Iceland) was 1,24, i.e. the number of flights on the peak day was 24% higher than the average daily traffic. Seasonal variability is defined in the Performance Review Report as the ratio between the peak weekly traffic and the average weekly traffic. The average seasonal variability in 2012 was 1,15, with the highest value of 1,9 in Palma, Spain (Performance Review Commission, 2013).

It is clear from table 6.15 that variability is high in the Reykjavik CTA, both when considering air traffic per day and per week. The variability of the daily traffic is well above the average in Europe and is probably caused at least partially by the NAT tracks. It turned out that on the peak days there were from 3 to 5 tracks in the Reykjavik CTA. It is more difficult to adapt to the daily variability of traffic than the seasonal variability, as it is more difficult to predict the spatial variations of the winds aloft than seasonal variations in the timetable of airlines.

## 7. Results and Discussions

In this chapter the results of this study and calculations are presented together with a short discussion.

### 7.1 Summary of Results

Several metrics have been considered for measuring performance in this research. In the following table the metrics which were calculated are listed as well as the results of the calculations performed for 2009 -2012 based on data obtained from Isavia.

Performance Area	Performance Metric	2009	2010	2011	2012
<b>Productivity</b>	IFR Flight Hours per ATCO in OPS	4.227	3.885	4.355	4.040
	IFR Flight Hours per ATCO in OPS hour	3,21	3,06	3,17	3,21
	Average Annual Working Hours for ATCOs in OPS	1.316	1.271	1.376	1.259
<b>Financial</b>	Cost per IFR Flight Hour	19.362	18.770	18.856	21.201
	Support Cost per IFR Flight Hours	15.501	14.922	14.898	16.862
	Empl.Cost for ATCOs in OPS per IFR Flight Hour	3.861	3.847	3.958	4.339
	Empl.Cost for ATCOs in OPS per ATCO in OPS	16.322.078	14.944.907	17.235.509	17.527.613
	Empl.Cost for ATCO in OPS per ATCO-hour	12.401	11.758	12.528	13.917
	Cost of Capital and Depreciation as a Percentage of Total Cost	15%	14%	11%	10%
	Support Cost Ratio	5,01	4,88	4,76	4,89

**Table 7.1: Results of the performance measurements for Isavia in hours and ISK at 2012 price levels.**<sup>124</sup>

Factors affecting performance were considered and traffic variability metrics were calculated with respect to daily traffic and weekly traffic. The results of these calculations are presented in table 7.2.

Factors affecting performance		2009	2010	2011	2012
<b>Traffic Variability</b>	Traffic Variability of Daily Traffic	1,96	1,95	1,79	1,71
	Traffic Variability of Weekly Traffic	1,63	1,48	1,40	1,36

**Table 7.2: Traffic variability in the Reykjavik Control Area (CTA).**<sup>125</sup>

<sup>124</sup> ATCO in OPS is an abbreviation of Air Traffic Controller on operational duty. IFR is an abbreviation of Instrument Flight Rules.

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The results of these calculated metrics will now be discussed in more detail.

## 7.2 Productivity metrics

Three metrics were calculated in this category:

- *IFR Flight Hours per ATCO in OPS hour*,
- *IFR Flight Hours per ATCO in OPS* and
- *Average Annual Working Hours for ATCOs in OPS*.

*IFR Flight Hours per ATCO in OPS hour* varied little in the period 2009 - 2012 and was almost the same for 2009 and 2012. There were however more variations in *IFR Flight Hours per ATCO in OPS* over the period, there was 4% decrease in *IFR Flight Hours per ATCO in OPS* from 2009 to 2012.

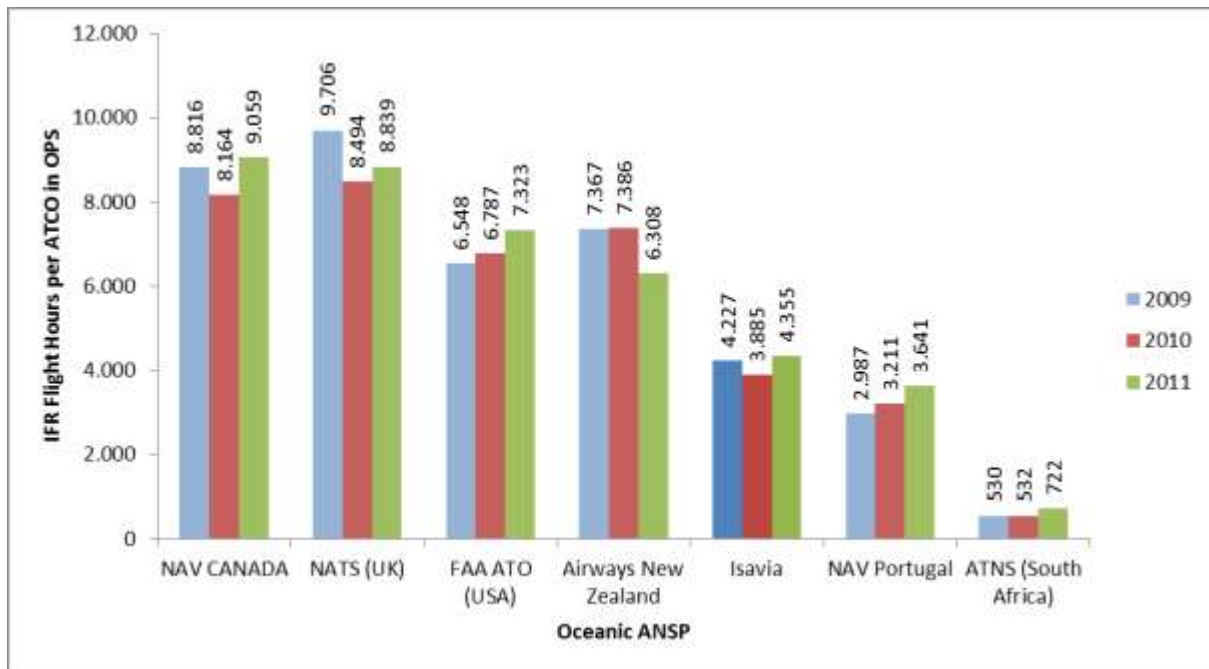
It turned out that the variations in the number of ATCO in OPS do not follow the variations in ATCO in OPS hours. As ATCO in OPS hours is a more accurate input, the *IFR Flight Hours per ATCO in OPS hour* is preferable to the *IFR Flight Hours per ATCO in OPS* as a productivity metric. The former metric is used in Eurocontrol's ATM Cost-Effectiveness Benchmarking Report (ACE report) in their annual benchmarking report, but unfortunately they are not calculated for the oceanic part of the air navigation services. This metric was however compared with the Maastricht Upper Air Centre (MUAC) which controls the upper airspace of Belgium, the Netherlands, Luxembourg and North-west Germany. MUAC controls only en-route traffic (not approach and landing) and is in that light comparable to the oceanic airspace of Reykjavik CTA especially that part where the traffic control is within radar surveillance. Comparing Isavia's *IFR Flight Hours per ATCO in OPS hour* of 3,17 with MUAC's 1,95 in 2011 may indicate somewhat higher productivity at Isavia. However, it can be assumed that the complexity is significantly higher in the MUAC control airspace than in Reykjavik CTA and hence a direct comparison is not realistic without making some adjustments for this fact. However the values of this metric are in the same range for these two en-route centres which is encouraging.

*IFR Flight Hours per ATCO in OPS*, from CANSO's Global Air Navigation Services Performance Report (CANSO report), was the only productivity metric where there were available results for oceanic ANSPs.

Isavia's *IFR Flight Hours per ATCO in OPS* was compared with six other oceanic ANSPs. Isavia ranked number five in the comparison, as shown in figure 7.1.

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<sup>125</sup> Traffic variability in 2010 was in fact much higher, which was caused by unprecedented air traffic peaks in the Reykjavik CTA due to the eruption of Eyjafjallajökull. Corrections were made to account for this anomaly.



**Figure 7.1: IFR Flight Hours per ATCO in Operation for the years 2009-2011. Comparison of oceanic ANSPs.**

It should be pointed out here that even though all these ANSPs are providing oceanic Air Navigation Services, there are several factors which must be taken into account as explained in chapter 5. Direct comparison without considering these factors is therefore not realistic. Complexity of the air traffic is a good example of such factor.

The oceanic centres showing highest productivity are NAV CANADA and NATS. In both of these centres most of the traffic is controlled on organized tracks which reduces the complexity considerably allowing more aircraft to be handled by each operational air traffic controller.

In the ACE and the CANSO reports ANSPs are grouped by size (annual IFR Flight Hours) and complexity (only ACE report) for this purpose. Since a complexity metric is not available for oceanic ANSPs the size was considered. In order to find the most comparable ANSP, both the size of the airspace and the oceanic IFR flight hours were considered. NAV Portugal turned out to be in the same category as Isavia in this respect. In that light Isavia is performing better than NAV Portugal.

### 7.3 Financial metrics

The average ATCO in OPS employment costs at Isavia as a percentage of total costs is about 20%. This is low in comparison with an average of 30% in Eurocontrol's member states and an average of 28% for the oceanic ANSP considered in the comparison. This means that support cost is relatively high at Isavia. It is likely that this is caused by the fact that the support costs are in large part independent of the number of the IFR flight hours controlled (i.e. mainly fixed cost) while the employments cost for ATCO in OPS is more dependent on the number of flight hours controlled. The number of flight hours controlled by Isavia is low

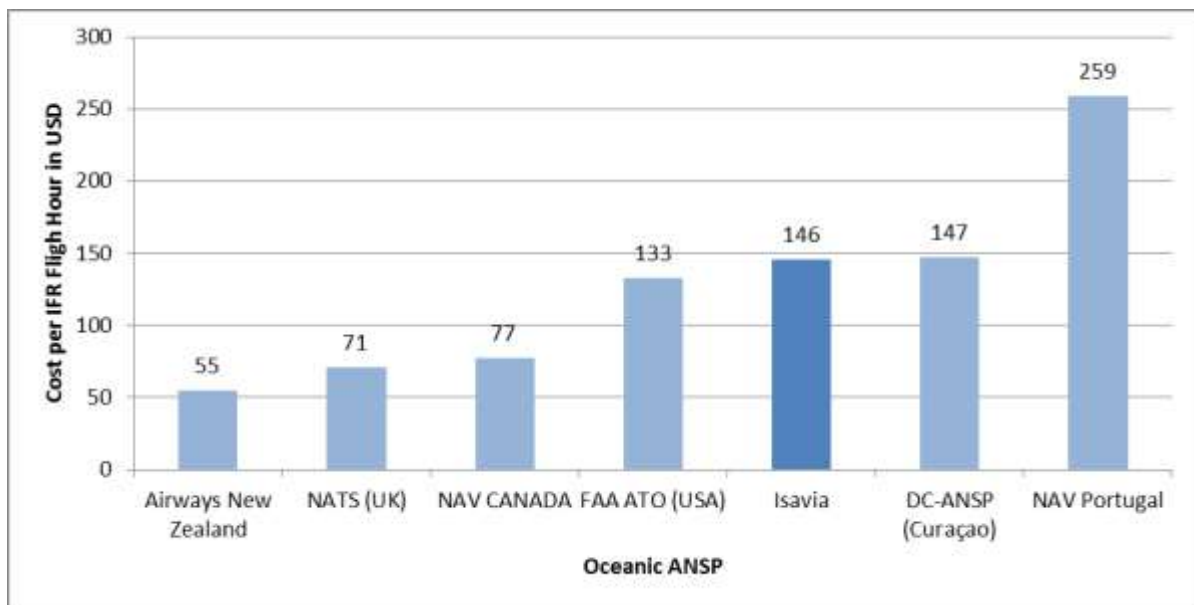
in comparison with other ANSPs (especially the oceanic ANSPs) which could explain, at least partly, high support cost.

Seven financial metrics were calculated, as listed in table 7.1. Information for comparison with other ANSPs was available for four of these metrics. Further discussion of the outcome of these metrics can be found in chapter 6.4.2. The two metrics which are of most importance are the *Cost per IFR Flight Hour* and *Employment Cost for ATCO in OPS per IFR Flight Hour*. It is also interesting to consider the *Empl.Cost for ATCOs in OPS per ATCO in OPS* in order to better understand how the financial metrics and productivity metrics work together.

### ***Cost per IFR Flight Hour***

*Cost per IFR Flight Hour* increased about 9% from 2009 to 2012 in ISK<sup>126</sup>. Most of the increase was from 2011 to 2012, about 12%.

Isavia's *Cost per IFR Flight Hour* in 2011<sup>127</sup> was compared with six other oceanic ANSPs, the result is shown in figure 7.2.



**Figure 7.2: Cost per IFR Flight Hour for the year 2011 in USD. Comparison between oceanic ANSPs.**

Isavia ranked number five in the comparison after Airways New Zealand, NATS (UK), NAV CANADA and FAA ATO (USA). Airways New Zealand showed the lowest *Cost per IFR Flight Hour*.

As productivity influences the cost the ANSPs with lower complexity are likely to have lower costs. The numbers of IFR flight hours controlled annually by the ANSP will probably also affect the support costs as mentioned above and hence the *Cost per IFR flight Hour*.

NAV Portugal has many similarities with Isavia, such as annual IFR Flight Hours controlled, size of the airspace, percentage of radar coverage and number of air traffic controller in

<sup>126</sup> In 2012 price levels.

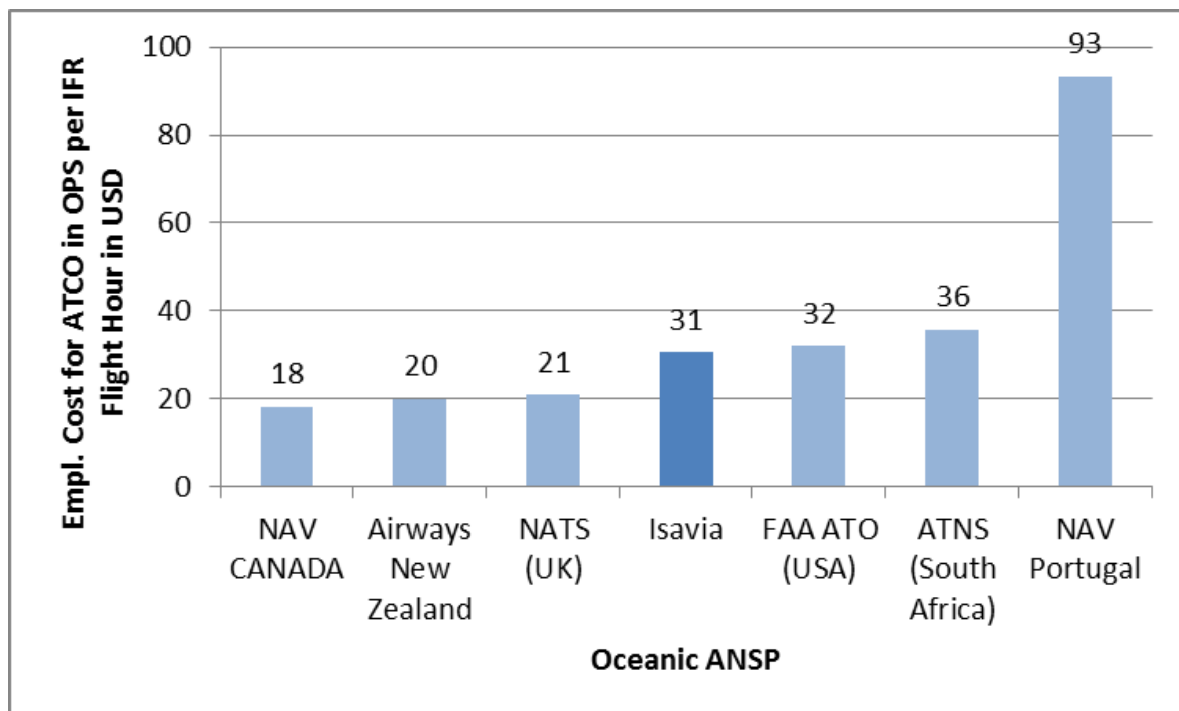
<sup>127</sup> The most recent CANSO report was used for the comparison.

oceanic operation (see table 6.7). Isavia is however showing much lower cost. This great difference is explained by the high ATCO in OPS employment cost at NAV Portugal, as seen in figure 7.3.

### ***Employment Cost for ATCO in OPS per IFR Flight Hour***

*Employment Cost for ATCO in OPS per IFR Flight Hour* increased about 12% from 2009 to 2012 in ISK<sup>128</sup>. Most of the increase was from 2011 to 2012, about 10%.

Isavia's *Employment Cost for ATCO in OPS per IFR Flight Hour* in 2011 was compared with six other oceanic ANSPs, the results are shown in figure 7.3.



**Figure 7.3: Employment Cost for ATCO in OPS per IFR Flight Hour in USD for the year 2011. Comparison between oceanic ANSPs.**

Isavia ranked number four in the comparison after NAV CANADA, Airways New Zealand and NATS (UK). NAV CANADA showed the lowest *Employment Cost for ATCO in OPS per IFR Flight Hour*. If figure 7.3. is compared to figure 7.2 it is clear that the ratio of Isavia's cost to the lowest cost is different. This ratio is lower when the employment cost of ATCOs in OPS is considered. This is because of the relatively high support cost at Isavia. It should however be pointed out that despite this relatively high support cost, Isavia's support cost per IFR Flight Hour is lower than the support cost at NAV Portugal.

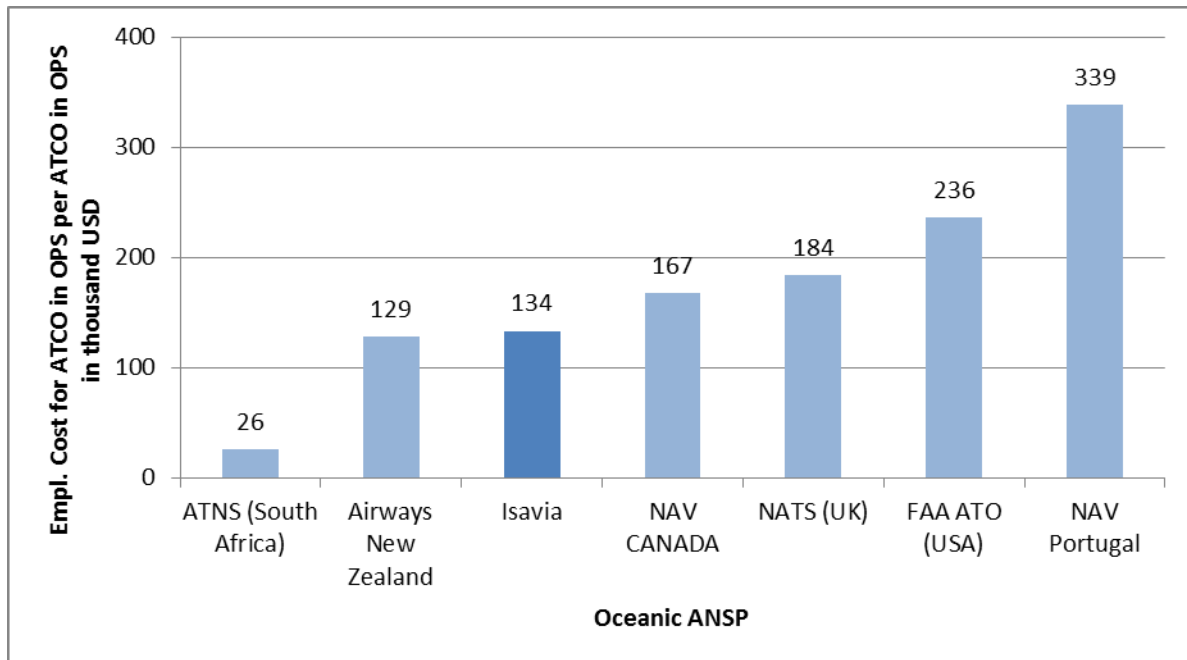
There is much less variation in the ATCO in OPS employment cost between the oceanic ANSPs than in the total cost, except for NAV Portugal which show much higher ATCO in OPS employment cost.

<sup>128</sup> In 2012 price levels.

### ***Empl. Cost for ATCOs in OPS per ATCO in OPS***

*Empl. Cost for ATCOs in OPS per ATCO in OPS* increased about 7% from 2009 to 2012 in ISK<sup>129</sup>. Most of the increase was from 2010 to 2011, about 15%.

Isavia's *Employment Cost for ATCO in OPS per IFR Flight Hour* in 2011 was compared with six other oceanic ANSPs, the results are shown in figure 7.4.



**Figure 7.4: Employment cost for ATCO in OPS per ATCO in OPS in thousand USD. Oceanic ANSPs.**

Both NAV CANADA and NATS have higher employment cost per operational controller than Isavia but lower employment cost per IFR flight hour. This is because of higher productivity (*IFR Flight Hours per ATCO in OPS*) at NAV CANADA and NATS than Isavia.

*Employment cost for ATCO in OPS per ATCO in OPS* is equal to the product of *IFR Flight Hours per ATCO in OPS* and *Employment Cost for ATCO in OPS per IFR Flight Hour*.

## **7.4 Flight efficiency metrics**

The flight efficiency metrics aims to measure, for each flight, the deviation from the optimum trajectory. Decreasing this deviation will result in less fuel burn and the metric is therefore categorized as an environmental metric since less fuel burn means lower CO<sub>2</sub> emission to the atmosphere. It is also possible to categorize Flight efficiency as a quality of service metric for the airspace users because of the benefits from less fuel burn.

Performance Review Commission's has defined a flight efficiency metric called En-route Extension. NATS, the ANSP of the United Kingdom, has defined a flight efficiency metric called the 3-Dimensional Inefficiency Score (3Di Score).

<sup>129</sup> In 2012 price levels.

Both these metrics use the great circle distance in the calculation of the shortest route. In former studies it has been shown that using great circle routes as an estimation of the optimal route can lead to erroneous results for longer distances. Considering the applicability of a similar metric for the Reykjavik Control Area (CTA) the use of great circle route as a reference could introduce errors because of the size of the control area and variable and sometimes extreme weather conditions. Using wind optimal routes instead of great circle distance would on the other hand increase the calculation complexity. However, this does not exclude the possibility of using wind optimal routes for calculating flight efficiency metrics in the future.

The 3Di Score considers both horizontal and vertical flight efficiency whereas the En-route Extension only considers the horizontal flight efficiency.<sup>130</sup> For long haul flights the vertical efficiency becomes more relevant than in shorter routes and should therefore be taken into account in larger control areas.

Considering the 3Di Score for en-route traffic in Reykjavik CTA, the metric can be simplified. It can be reduced to the issue of obtaining the optimal flight level and the wind optimal horizontal route. A further study of the design of an efficiency metric based on comparing actual routes with the optimal routes in Reykjavik CTA is warranted. Such a metric is especially important in large control areas, like the Reykjavik CTA, where there are more opportunities for fuel savings. To be able to put a number, in terms of fuel savings, on the benefits the airlines achieve from the flexibility in route selection would be of great value to Isavia.

## 7.5 Complexity metrics

The purpose of complexity metrics used in benchmarking is to evaluate external factors which are likely to influence ATCO workload and hence the performance of an ANSP.

It is clear that there is a great difference in complexity of continental air traffic which is controlled using radar separation and oceanic traffic which is controlled using procedural separation. The air traffic in the Reykjavik CTA is controlled using both these separation methods and it is therefore somewhere in between with respect to complexity. The traffic in Reykjavik CTA is less complex than the air traffic in continental Europe but more complex than in typical oceanic airspace where there is no radar surveillance available.

The ACE working Group on Complexity developed a complexity metric for benchmarking purposes, called Complexity Score. A description of this metric was provided in chapter 5.3.3.

The Complexity score was designed for continental Europe. The suitability of the metric in oceanic airspace was considered and it was concluded that further research would be necessary in order to adapt this metric for oceanic control areas.

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<sup>130</sup> See chapter 4.5 for explanations of horizontal and vertical flight efficiency.

The complexity metric is intended to capture the difference in complexity between control areas to explain differences in performance by ANSPs. If the complexity of Reykjavik CTA is calculated using a new complexity metric it would have to be compared to the complexity of other oceanic control areas. It is therefore of little value to calculate complexity in one oceanic control area if there is no comparison. A joint effort is therefore required to establish a single oceanic complexity metric.

## **7.6 Traffic variability**

Variability is calculated as the ratio between the peak traffic and average traffic, measured in number of flights. The results are shown in table 7.2. A correction was made to exclude anomalies caused by the Eyjafjallajökull eruption in the spring of 2010.

It is clear from table 7.2 that the traffic variability has been decreasing from 2009 to 2012. An explanation of this decrease has not been found. This may be caused by changes in weather, affecting the routes selected or by new routes and airline schedules which could result in less variation in the traffic.

In 2012 the average variability of daily traffic in Europe (excluding Iceland) was 1,24, i.e. the number of flights on the busiest day was 24% higher than the average traffic. The variability of daily traffic in 2012 was 1,71 in the Reykjavik CTA, in 2009 the variability was 1,91. This is considerably higher than the average.

Seasonal variability is defined in the Performance Review Report as the ratio between the peak weekly traffic and the average weekly traffic. In 2012 the average seasonal variability in Europe was 1,15, with the highest value of 1,9 in Palma, Spain. The seasonal variability in 2012 was 1,36 in the Reykjavik CTA.

## 8. Conclusions and Recommendation

In this chapter the aims set in the beginning will be considered and how, and to what extent, these aims have been fulfilled. A summary of the conclusions which were drawn from this study is provided and recommendations offered on further work or research to be performed on the basis of this study.

### 8.1 Revisiting the research aims

The aims of this research were listed in chapter 1.3. These were to:

- Analyse and evaluate the metrics that are currently used to evaluate the performance of Air Navigation Service Providers (ANSP) in managing, developing and operating their services.
- Develop a system of performance metrics suitable for the Icelandic Air Traffic Management (ATM) System operated by Isavia, based on an analysis and modelling of the ATM System.
- Identify the need for additional data, that may not be collected at this point in time and to define how such data could be collected.

In order to fulfil these aims the following steps were taken:

- Information on the ATM system at Isavia was gathered in order to study the core features of system and ATM in general and define a functional block diagram for the system as a whole. This was performed in cooperation with a fellow student (Unnur Þorleifsdóttir). The results of these studies can be found in chapter 2, and Appendix I and II.
- Performance metrics which have been used in benchmarking ANSPs were extensively studied. In particular the system that was developed by the Eurocontrol Performance Review Unit were scrutinised as well as the metrics listed in the Performance Report of CANSO<sup>131</sup>'s Global Benchmarking Workgroup. Further sources of performance metrics were considered but these two were the main sources when selecting metrics to measure productivity and financial efficiency. Other performance metrics in the area of flight efficiency and quality of service were considered and their applicability in the Reykjavik Control Area evaluated. Further study is required in order to design suitable performance metrics in these performance areas. The results of this study can be found in chapter 4.
- The factors affecting performance and the available metrics for evaluating these factors were studied. Two metrics, Complexity Score and Traffic Variability, have been introduced in this area and are calculated by the Eurocontrol Performance Review Unit. The variability of the air traffic in the Reykjavik Control Area was calculated, but further study on a Complexity metric for oceanic airspace is necessary. The results of these studies can be found in chapter 5.

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<sup>131</sup> Civil Air Navigation Services Organization

- Metrics to be used in calculation were defined and selected. The choice of metrics was limited by the available data on comparable oceanic ANSPs. Oceanic metrics introduced by CANSO's Global Benchmarking Workgroup were selected. To that selection were added some metrics developed by the Performance Review Unit. The results of these studies are provided in chapter 6.2.
- Data were gathered from Isavia in accordance with the definitions of the data elements required for the calculation of the selected metrics. Some adjustments and calculations were required in order fulfil the definitions of the data elements. These steps are described in chapter 6.3.
- The values of the selected metrics were calculated. The results of the calculations were evaluated and compared to other oceanic ANSPs. The ANSPs used for comparison were FAA ATO (USA), NAV CANADA, NATS (UK), NAV Portugal, Airways New Zealand, ATNS (South Africa) and DC-ANSP (Curaçao). The results of this study can be found in chapter 6.4.

The development of a new system of performance metric is a difficult task. For large organisations the system it is likely to be in many layers, from top management down to the people in operation. Such systems should be linked to the goals of the organization as defined in accordance with the strategy, values and vision of the organization.

As such the performance metrics presented in this study do not form a complete system but may be considered as important building blocks of such a system for the Reykjavik ATM System. Every step of the process of calculating the selected performance metrics have been described in the thesis.

There are many interesting aspects of performance in Air Traffic Management which have been discussed in some detail in this thesis but require further research.

## **8.2 Conclusions**

The performance metrics which were introduced in this thesis have all been designed for use in benchmarking. Before they were selected for that purpose they were extensively studied by Eurocontrol and CANSO for their suitability as measurements of performance. Isavia can benefit from this work and adopt these metrics to evaluate their performance in ATM. The calculation of the productivity and financial metrics introduced in this thesis are not complicated and could therefore be easily adopted into Isavia's working procedures. The results of the calculation of Isavia's performance metrics were compared to other oceanic Air Navigation Service Providers (ANSP).

The productivity metric used in CANSO's benchmarking report was calculated for Isavia's Oceanic Air Navigation Services and the results were compared to other oceanic ANSPs. The oceanic centres showing highest productivity are NAV CANADA and NATS. In both these centres the bulk of the air traffic is controlled on organized tracks which reduce the complexity considerably. NAV Portugal's operations has many similarities with Isavia, such as annual IFR Flight Hours controlled, size of the airspace and number of air traffic controller in oceanic operation (see table 6.7). It was therefore interesting to see that Isavia's

productivity of 4.355 annual IFR Flight Hours per ATCO in OPS measured higher than the productivity at NAV Portugal, which was 3.641 annual IFR Flight Hours per ATCO in OPS.

The productivity metric used in the ATM Cost-Effectiveness Benchmarking Report was also compared to the Maastricht Upper Air Centre (MUAC) which controls only the upper airspace of Belgium, the Netherlands, Luxembourg and north-west Germany. MUAC controls only en-route traffic (not approach and landing) and is in that light comparable to the oceanic airspace of Reykjavik CTA especially that part where the traffic control is within radar surveillance. Comparing Isavia's *IFR Flight Hours per ATCO in OPS hour* of 3,17 with MUAC's 1,95 in 2011 may indicate somewhat higher productivity at Isavia. However, it can be assumed that the complexity is significantly higher in the MUAC control airspace than in Reykjavik CTA and hence a direct comparison is not realistic without making some adjustments for this fact. However the values of this metric are in the same range for these two en-route centres which is encouraging.

High traffic variability in the Reykjavik CTA was confirmed, when compared to European average. In 2012 the average variability of daily traffic in Europe (excluding Iceland) was 1,24, i.e. the number of flights on the busiest day was 24% higher than the average traffic. The variability of daily traffic in 2012 was 1,71 in the Reykjavik CTA, in 2009 the variability was 1,91. This is considerably higher than the average. Information on the traffic variability in the control areas of the oceanic ANSPs used in the comparison were however not available. There is an interesting trend in the variability in Reykjavik CTA as it has decreased each year from 2009 to 2012, after corrections were made to account for the eruption of Eyjafjallajökull.

A complexity metric called Complexity Score designed by the ACE working Group on Complexity (within Eurocontrol) was considered. It was concluded that the Complexity Score cannot be applied directly in oceanic airspaces without adaptations. Further studies are required on this subject as this metric is of great importance when accessing productivity between different control areas. It is however of little value to calculate complexity in one oceanic control area if there is no comparison. A joint effort is therefore required to establish a single oceanic complexity metric.

Flight efficiency metrics were considered. Flight efficiency metric similar to NATS fuel efficiency metric, called 3Di-Score, could be of value to Isavia. This is a metric which calculates efficiency in fuel consumption and must be adapted to each control area. Some adaptations will be required for the use of this metric in the Reykjavik CTA and further studies are therefore required on this subject. A metric like this is especially important in large control areas, such as the Reykjavik Control Area, where there are more opportunities for fuel savings. To be able to calculate, in terms of fuel savings, the benefits the airlines achieve from the flexibility in route selection would be of great value to Isavia.

In general it is concluded that the Oceanic Air Traffic Services being provided by Isavia are competitive compared with other Oceanic Air Navigation Service Providers. This is based on the overall outcome of the performance and financial metrics taking into account the effects

of complexity and variability of air traffic in the area. However, more work on the definition of performance metrics are required in order to enable a more accurate benchmarking comparison of oceanic air traffic services. This includes adding new indices to measure additional aspects of ATM system performance.

### **8.3 Suggestions for further work**

The metrics introduced in this thesis are used for benchmarking and are all based on past performance. These metrics should be supplemented with metrics which act as drivers for future performance. A research of the factors affecting the productivity and financial metrics could be beneficial. The factors which Isavia can actually control should be considered in order to introduce methods for improving performance.

In chapter 3 the design of performance metrics is discussed. According to Kaplan and Norton it is necessary to introduce metrics which are drivers of future performance. The metrics which are drivers of future gain are in their opinion operational metrics of customer satisfaction, internal processes and the organization's innovation and improvement activities (Kaplan & Norton, 1992). For Isavia such metrics could for example be directed to the development of better working processes or new features in the ATM system which could shorten the time it takes to perform certain tasks in Air Traffic Control.

In chapter 5.1.1 there are listed endogenous factors which affect the performance of ANSPs. It would be a logical step for Isavia to look at these factors when considering how future performance can be improved.

When considering the factors affecting the productivity, balancing the workforce with the air traffic demand is of importance. It would be interesting to study the number of ATCOs in OPS on duty versus the number of aircraft in the control area at the same time. If these numbers would be considered on an hourly basis over a long time period it could reveal whether this balance is in place or whether there are possibilities for improvements. This is also linked to the reliability of forecasts. If it is possible to improve forecasts for example on the basis of flight schedules of airlines, it would most likely result in better balancing of workforce with the air traffic and hence higher productivity.

Performance metrics to measure the quality of the Air Navigation Service were studied in this thesis. One way of evaluating the service provided, is from some kind of fuel efficiency metric as explained in chapter 4.5. The 3Di Score for en-route traffic in Reykjavik CTA the metric can be simplified. It can be reduced to the issue of obtaining the optimal flight level and the wind optimal horizontal route. A further study of the design of an efficiency metric based on comparing actual routes with the optimal routes in Reykjavik CTA is warranted.

A metric which focuses on the client can also be very useful in order to learn about the views of the airspace users with respect to the services available and any additional service that the

client might appreciate. It is important to disseminate information about the services available and to make sure the airlines are aware of the value of the services offer. The benefits from the extra service provided (for example in fuel savings) may not be as clear as the extra cost incurred when providing the service.

As mentioned above, further studies of complexity are required. If there will be designed a complexity score for oceanic ANSPs, it is important that the special circumstances in the Reykjavik Control Area are taken into account. Hence it is important for Isavia to participate in any co-operation which might take place on the subject or even initiate such work.

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## Appendices

### Appendix I Air Traffic Management system

In this chapter and next chapter an overview of the Air Traffic Management (ATM) systems will be provided. In Appendix I an information flow between four different operational functions of the ATM system is presented. In Appendix II the technical side of the system will be described where the main building blocks are equipment and software used in the system. The overview of the system is focused on normal operational modes and does not consider information flow under hazardous and unforeseen circumstances.

This chapter and next chapter were prepared on the basis of information from Professor Þorgeir Pálsson and the following specialists at Isavia: Arnar Þórarinnsson, Arnór Bergur Kristinnsson, Guðmundur Karl Einarsson, Guðmundur Kristjánsson, Hjalti Pálsson, Jón Gunnlaugsson, Kristján Torfason, Magnús Ásbjörnsson, Steingrímur Hálfðánarson and Steinunn Arna Arnardóttir.

### Air Traffic Management

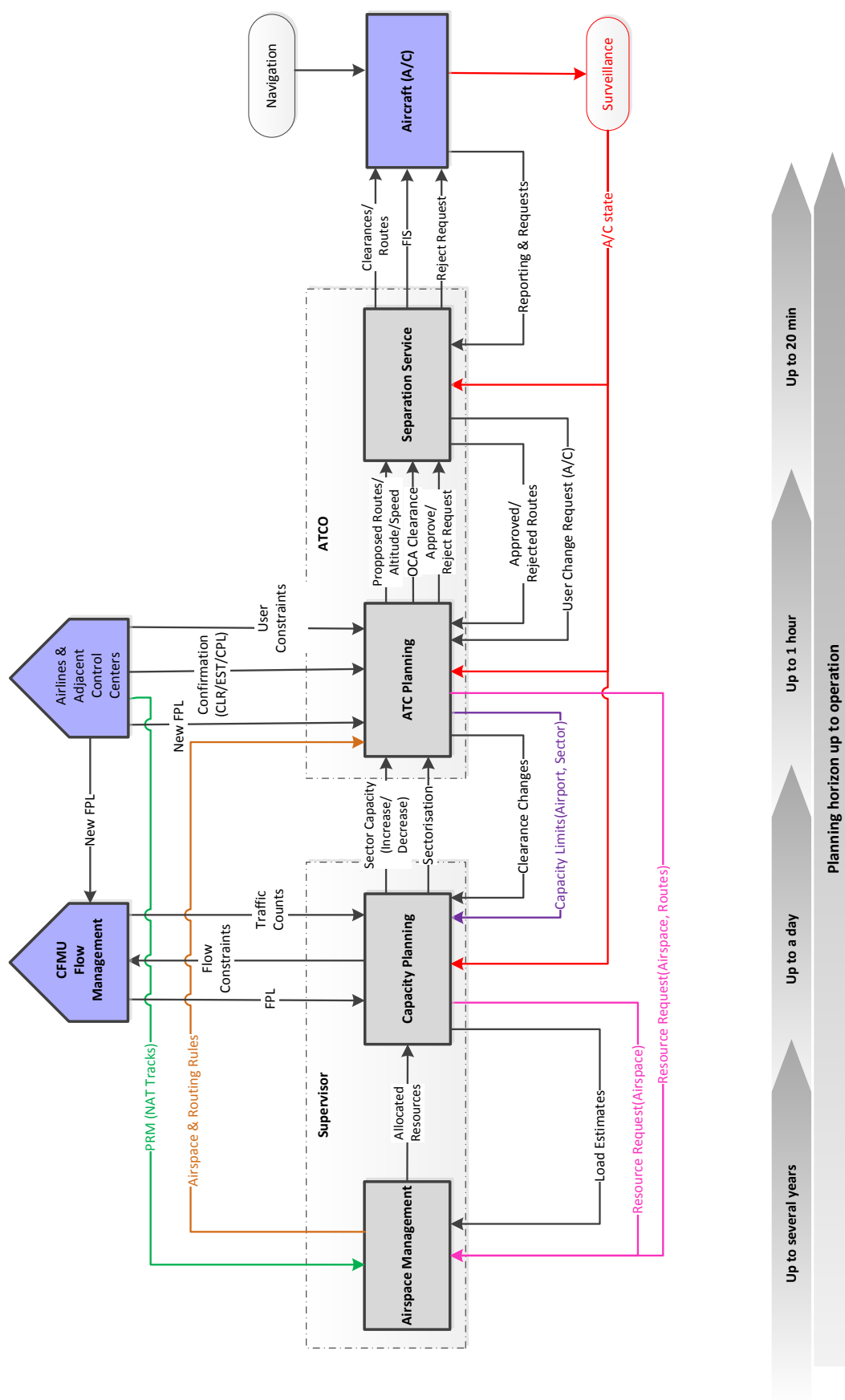
The main objective of Air Traffic Management is to ensure the safety of an aircraft from gate to gate. This is done by assuring safe separation between the aircraft and other objects, including other aircraft, on the ground and in the air.

ATM is defined by the International Civil Aviation Organization<sup>132</sup> (ICAO) as the aggregation of the airborne functions and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations. Included in this is: Airspace Management (ASM), Air Traffic Flow Management (ATFM) and Air Traffic Services (ATS), where Air Traffic Service is a generic term meaning variously, Flight Information Service (FIS), Alerting service, Air Traffic Advisory Service and Air Traffic Control service (ICAO, 2007a).

Figure I.1 shows an overview of the main parts of the ATM system, how each part of the system interacts and the flow of information within the system. The figure is adapted from a figure prepared by Haraldsdóttir et. al., as presented in a paper issued in the 5th US/Europe Air Traffic Management R&D Seminar (Haraldsdóttir et al., 2003).

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<sup>132</sup> ICAO is an agency of the United Nations established to promote the safe and orderly development of international civil aviation throughout the world.



**Figure I.1: Flow of operational data between Airspace Management, Flow Management, ATC Planning, Separation Service and Aircraft.** Adapted from a paper issued in the 5th US/Europe Air Traffic Management R&D Seminar (Haraldsdottir et al., 2003).

Of all the Air Traffic Services the major part of the operation lies in the Air Traffic Control (ATC) function. For this reason the focus of this research will be on that part. In figure I.1 the ATC is divided into **ATC Planning** and **Separation Service**, where the **ATC Planning** is the pre-tactical planning of the air traffic by looking at each flight before they enter into the Reykjavik control area and the **Separation Service** is the tactical operation when the aircraft have entered the controlled airspace and are monitored and controlled in order to ensure safe separation between other aircraft and objects. The gray boxes represent main ATM functions within Isavia and references in the text to those functions are indicated with bold format. The arrows represent information flow and references in the text to that information are indicated with *Italic* format. The main responsibilities which currently are in the hands of the supervisor<sup>133</sup> and the ATCO are defined by dash-lined boxes but this definition is not accurate, the supervisor is for example only partly responsible for the **Airspace Management**. The external parties involved, i.e. **CFMU**, **Airlines & Adjacent Control Centres**, are represented in the figure as house-like boxes and in the text they are represented in bold format.

### *Airspace Management*

**Airspace Management** is defined by The European Union in the Single European Sky regulation no. 549/2004:

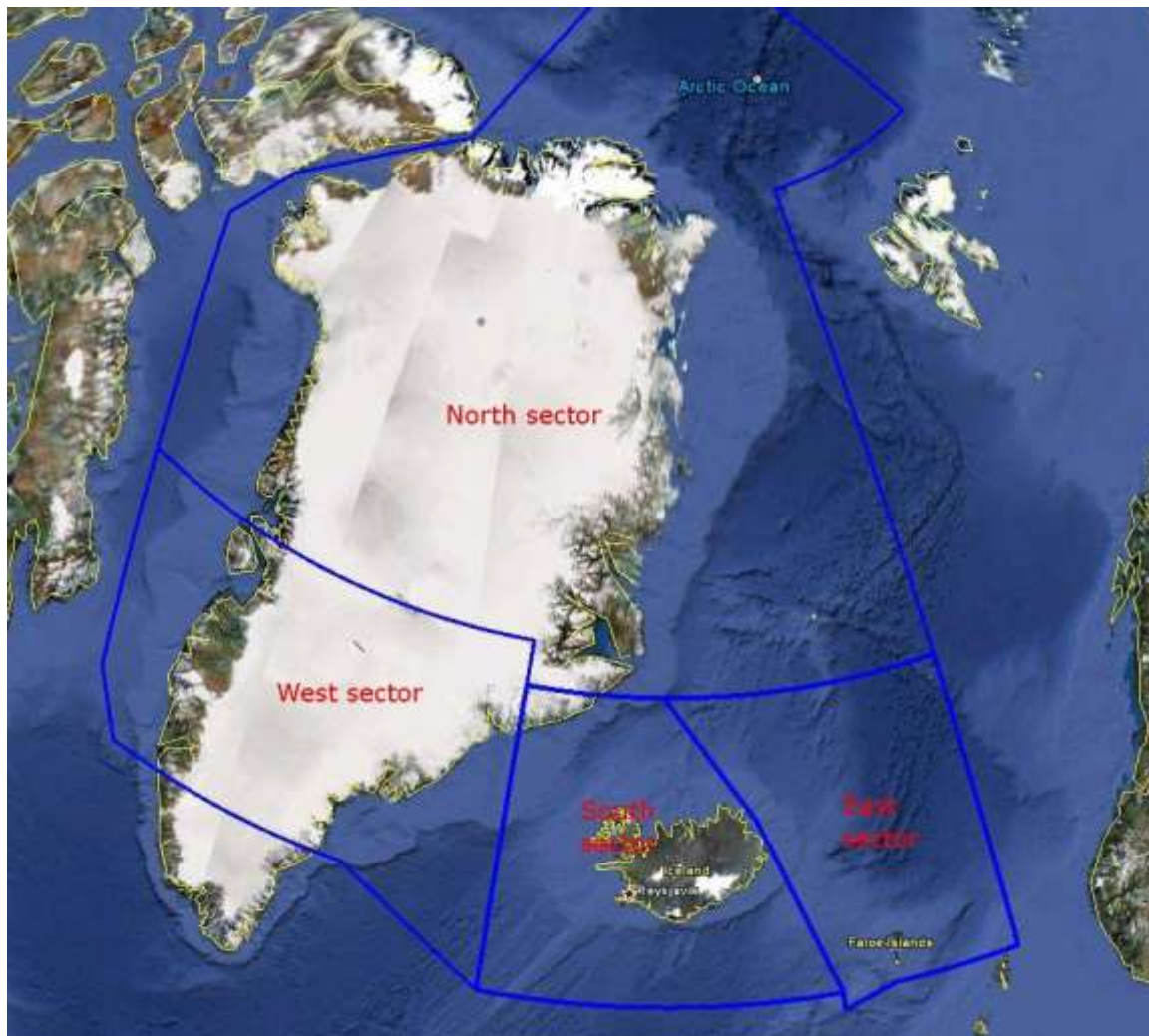
“ ‘airspace management’ means a planning function with the primary objective of maximizing the utilization of available airspace by dynamic time-sharing and, at times, the segregation of airspace among various categories of airspace users on the basis of short-term needs” (The European Parliament and the Council of The European Union, 2010).

The main function of the **Airspace Management** within Isavia is the allocation of the airspace under the control of Iceland. Most of the work in **Airspace Management** is done on a strategic and pre-tactical level, i.e. before the day of operation up to several years before.

The airspace is divided into geographical sectors to divide the traffic load into smaller units that can be controlled by one or two ATCOs. Four lateral sectors have been defined in the Reykjavík control area: North sector, East sector, West sector and South sector as can be seen in figure I.2. This definition of the sectors is done on a strategic level, i.e. the lateral definition of the sectors is usually not changed for many years. When workload load increases, further division of the sectors may be necessary. The sectors are then further divided by flight levels in such a way that one or two ATCOs control certain altitudes within that lateral sector. The decision to divide one of the four sectors further is made by the **Capacity Planning** on the basis of daily traffic and workload of the ATCOs.

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<sup>133</sup> At Isavia there is always one supervisor on shift, his responsibilities are described later in the chapter.



**Figure I.2: Division of Reykjavík control area into sectors (“Reykjavik Control Area,” 2012).**

Although Iceland is a member of NATO it is one of few countries without armed forces. The airspace controlled by Iceland is therefore generally open to international air traffic since no airspace is reserved for military use. However, as a member of NATO, Iceland hosts NATO military exercises. On such occasions, which are about 4 times per year, blocks of airspace are set aside for the military units and are meanwhile closed for other air traffic. There are predefined blocks of airspace planned for this purpose, selected to cause as little disruption of other air traffic as possible and the time of reservation for the military units is limited to the actual use. This is what is referred to as “time-sharing” in the definition of **Airspace Management** here above; allocation of airspace to the military shall have as little effect on the civil air traffic as possible. These defined blocks of military airspace are therefore only closed for a limited period of time.

In the Reykjavík Control Area there are generally no fixed routes issued. However a large portion of the air traffic over the North Atlantic Ocean follows tracks which are defined every 12 hours. This track system is called North Atlantic Organized Track System (NAT OTS)(IVAO, 2012).

Over the North Atlantic Ocean lies jet stream directing strong wind from west to east. The jet stream affects the air traffic and the airlines plan their flight routes with the aim to maximize tail winds and minimize head winds. Depending on the location of the jet stream the position of the NAT tracks varies from day to day and the track do not always enter the Reykjavik control area. In 2010, the NAT tracks for traffic heading west entered the Reykjavik control area 111 days while the NAT tracks for traffic heading east entered the Reykjavik control area only 6 days (Isavia, 2012b).

Control centres in the North Atlantic airspace receive, on the day before the flight, Preferred Route Messages (*PMR*) from the larger airlines (such as British Airlines and Delta) indicating which routes they would like to fly having taken into account the weather forecast. These *PRM* messages are then used to prepare the North Atlantic (NAT) tracks. Isavia receives suggestions for *NAT tracks* prepared by either Gander or Shanwick control units (European and North Atlantic Office of ICAO, 2005). The suggested tracks are evaluated and in most cases accepted unless there are certain conditions where Isavia would like to add tracks further north due too high traffic load. On rare occasions the tracks are moved further south in order to limit the traffic in the Reykjavík control area. After the tracks have been accepted by the control units involved, the *NAT tracks* are published. Aircraft that fly within the airspace where the tracks have been defined have to follow one of these tracks but in other areas within the Reykjavík control area there are random routes<sup>134</sup>. By using tracks the traffic control in that area becomes more manageable allowing a larger number of aircraft to be controlled by each ATCO. In areas where the traffic is controlled by using tracks the efficiency will increase and larger number of aircraft can fly in the area. Although the tracks solve the problem of excess demand they limit the possibilities of the airlines to choose their preferred route which may be different from the track routes.

As can be seen in figure I.1 **Airspace Management** provides resources for the **Capacity Planning**, i.e. the information of available airspace and NAT tracks. **Airspace Management** receives *Load Estimates* (estimated traffic load) from **Capacity Planning** in order to evaluate the NAT tracks and for the allocation of airspace to military use. If the **Capacity Planning** detects capacity problems while there are some limitations of available airspace they may request more airspace, such as opening of military airspace sooner than planned. Too much traffic load can in a similar way induce a request from **ATC planning** for more airspace. As mentioned before the airspace controlled by Iceland is only closed for military purposes on rare occasions and therefore capacity and demand imbalances are seldom solved in this manner.

The ATCO informs **Airspace Management** if the traffic load becomes too high, **Airspace Management** can then provide more resources. When an ATCO informs the supervisor that the traffic load is too high, the supervisor can provide more resources such as dividing the sector and/or providing assistance for the ATCO to manage the traffic.

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<sup>134</sup> Random routes means that the route flown is based on a request for a flight route from the airlines on a per flight basis; they are not predefined or published as fixed routes.

At Isavia the responsibility of **Airspace Management** is currently in the hands of the supervisor with support from the ATC Procedure Manager. The supervisor is also responsible for the **Capacity Planning**.

### ***Flow Management***

Since capacity of the resources is limited, the flow of air traffic must be controlled to ensure safety. The resources of concern to Flow Management include airspace sector capacities, and airport arrival/ departure rates (Subotic, 2007). Flow management has overview over multi-sector airspace, monitoring capacity and demand imbalances up to a day before operation.

Eurocontrol<sup>135</sup> defines Flow Management as follows:

“Flow management is a function established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extent possible, and that the traffic volume is compatible with the capacities declared by the appropriate air traffic service providers” (Eurocontrol, 2011e)

In Europe the Air Traffic Flow Management is performed by the Central Flow Management Unit (CFMU) which is operated by EUROCONTROL (Eurocontrol, 2011b). Isavia is not a member of the CFMU but there is close cooperation between the two.

Isavia does not perform all aspects of Flow Management as performed by **CFMU**, e.g. Isavia does not allocate slot time. However, the focus within Isavia is on one main aspect of Flow Management; the **Capacity Planning**.

In Isavia there are primarily two levels of **Capacity Planning**; pre-tactical and tactical levels. The pre-tactical level includes route and personnel allocation, producing a traffic forecast and a daily capacity plan. Traffic forecast is based on Preferred Route Messages and on statistical traffic data. The tactical level involves capacity monitoring and updating the daily plan according to the actual traffic and capacity at the day of operation.

### ***Capacity Planning***

The **CFMU** receives flight plans from **Airlines & Adjacent Control Centres**<sup>136</sup> which represent the demand for the resources available. **CFMU** accepts the flight plans or suggests amendments to them. Then the **CFMU** forwards the flight plan to Isavia's **Capacity Planning** anywhere from 30 minutes up to a few hours before the operation. In addition to the flight plan **CFMU** forwards pending *Traffic Counts* i.e. number of aircraft per sector per

<sup>135</sup> Eurocontrol, also known as the European Organization for the Safety of Air Navigation, is an intergovernmental organization made up of 39 member states and the European community

<sup>136</sup> Adjacent Control Centres to Reykjavík control area are Stavanger, Scottish, Shanwick and Gander.

time unit. The *Traffic Counts* are based on flight plans and are presented in a histogram showing number of aircraft expected to enter each sector on hourly basis.

The **Capacity Planning** unit detects any capacity and ATC demand imbalances and reacts accordingly. **Capacity Planning** receives information about aircraft in each sector (*A/C state*) from the surveillance systems to monitor the air traffic.

**Capacity Planning**'s main operation is monitoring and forecasting traffic capacity and responding to capacity issues that come up. **Capacity Planning** actions are restrained by the availability of resources. Thus there are specified limits to the number of aircraft passing through a sector within a certain time span without more resources. If the traffic load is too high and capacity cannot be increased, **Capacity Planning** can decrease the load by requesting limitations on incoming traffic. Then the **CFMU** will temporarily limit the traffic into the Reykjavík control area. It is however only under exceptional conditions, that capacity limits are requested in the Reykjavík control area. In 2011 there were no such limitations and there were only few limitations in 2010 due to the eruption in Eyjafjallajökull which caused unprecedented increase in traffic load in the area.

Airspace allocation, qualified personnel and systems infrastructure are needed to be able to provide Air Traffic Services. Short term shortages of these elements call for actions by the **Capacity Planning** that make the best use of the available resources.

**Capacity Planning** determines *Sector Capacity* and sets the *capacity limits*. Under normal circumstances the *Sector Capacity* in the Reykjavík control area is around 35 aircraft per hour per sector. However, it depends on the application of fixed tracks and general traffic patterns. **Capacity Planning** provides reports on *Sector Capacity* to **ATC Planning**. *Sector Capacity* problems occur for example when ATCOs ability to handle the traffic load is diminished. Under normal conditions the ATCO is in working position for a maximum 90 minutes, followed by a 30 minutes break. A minimum of six ATCOs are therefore required to man four sectors and when sectors are divided one or two additional ATCOs are required in each new sector. In some cases instead of opening a new sector, the sectors with much traffic load are manned with two ATCOs that cooperate closely to control traffic within that sector. Thus personnel are closely connected to *Sectorization* and traffic demand. The **Capacity Planning** prepares demand forecasts on the basis of the preferred route messages and these forecasts are used to plan the number of ATCOs working each day. Furthermore, on weekdays there are several ATCOs on other duties which can be reached if required.

In case of excess demand capacity may be increased by limiting the service provided, e.g. by declining requests for changes in flight levels and other route changes.

**Capacity Planning** decides in cooperation with ATCOs if two sectors should be merged into one due to reduced load or vice-versa if a sector needs to be split during increasing load.

In case of equipment malfunction, **Capacity Planning** checks if it is sufficient to add personnel or decrease service in order to increase capacity. If not **Capacity Planning** may ask the **CFMU** to put up *Flow Constraints*.

To sum up **Capacity Planning** aligns information from the **CFMU, Airlines & Adjacent Control Centres** with the available resources. **Capacity Planning** produces a traffic flow forecast for the next day, provides *Load Estimates* based on the traffic forecasts and determines *Sector Capacity*. **Capacity Planning** monitors the flow a few hours before operation, arrival and departure rates and compares actual traffic flow to forecasted traffic flow. In case of capacity problems **Capacity Planning** proposes resolutions such as allocating personnel<sup>137</sup>, defining routes and dividing sectors (*Sectorization*).

### ***Air Traffic Control***

The main objectives of the Air Traffic Control are the separation of the aircraft from each other and from objects on the ground. Maintaining an orderly flow of air traffic, notifying search and rescue if needed and providing advice and information allowing safe and efficient conduct of flights are also important parts of ATC (Flugmálastjórn Íslands, 2011).

Air Traffic Control is performed by a system where ATCOs play key role in decision making.

In figure I.1, Air Traffic Control is divided into **ATC Planning** and **Separation Service**. At Isavia the tasks of both the ATC Planning and the Separation Service are usually in the hands of one ATCO, although these tasks are commonly performed by two ATCOs with a different kind of training.

#### **ATC Planning**

**ATC planning** is in many ways similar to **Capacity Planning**. The main difference between the two is that **Capacity Planning** focuses on total traffic flow whereas **ATC planning** focuses on individual aircraft.

A *New Flight plan* is received from **Airlines & Adjacent Control Centres** or from **CFMU**. Then about 15-60 minutes before the aircraft arrives into the sector a clearance<sup>138</sup>, estimate<sup>139</sup>, or current plan<sup>140</sup> (CLR/EST/CPL) is received.

The flight plans enters the Flight Data Processing System (FDPS)<sup>141</sup> at Isavia and are examined for errors, which the data specialist corrects before they are reviewed by the ATCO.

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<sup>137</sup> Necessity for Personnel is assessed based on tracks, CFMUs Traffic Counts, traffic forecast and need for sectorization.

<sup>138</sup> A clearance is an abbreviation of Air Traffic Control Clearance. The clearance authorizes a pilot to proceed according to a specific request. To indicate the type of request the clearance may be prefixed by the words "taxi", "take-off", "departure", "en route", "approach" or "landing". Oceanic clearance is issued for every aircraft entering an oceanic airspace in the North Atlantic (NAT) Region. The oceanic clearance includes a specific route, flight levels and speed from the arrival of the aircraft into a controlled oceanic airspace and until it exits the airspace.

<sup>139</sup> Estimated flight plan

<sup>140</sup> Actual flight plan

<sup>141</sup> Definition and discussion of FDPS can be seen in Appendix II.

If an ATCO agrees with the flight plan he forwards the *Proposed Routes, Altitude and Speed* to the **Separation Service**. **Separation Service** will then make sure that the aircraft follows that plan. If the ATCO does not agree with the plan, clearance changes are made.

When an aircraft arrives in an oceanic sector (like the one controlled by Isavia) the ATCO provides oceanic clearance to ensure a specific route, flight levels and speed throughout the airspace.

In addition to sending *New Flight plan*, airlines sometimes have *User Constraints* such as restrictions due to types of aircraft or the equipment on board i.e. it can only fly up to a certain speed and cannot go higher than a certain altitude etc. This can impact **ATC planning** especially if the constraints would result in changes that are inconvenient or not possible due to traffic load. Blue Spruce Routes<sup>142</sup> have been defined for aircraft with limited navigation capabilities.

If the ATCO deems there is too much traffic load he informs the **Capacity Planning** which can take the necessary steps to increase the capacity or, on rare occasions, decrease the load by requesting limitations on incoming traffic for a specific period of time.

To sum up **ATC planning** focuses on individual aircraft, issues clearances, suggests alternative routes and/or levels and alerts **Airspace Management** and/or **Capacity Planning** if the traffic load is becoming unmanageable.

### *Separation Service*

**Separation service** is provided on a tactical level, when the aircraft enters the Reykjavík control area. The ATCO manning the controller workstation monitors the aircraft within his sector to ensure that separation between aircraft are in accordance with the prescribed separation minima and that the actual route of the aircraft is in accordance with the cleared route.

Separation criteria are the rules which specify the separation minima between aircraft within the airspace. The North Atlantic System Planning Group (NAT SPG) defines the separation criteria for the Reykjavík control area and how it changes in each area if equipment such as individual radars becomes unavailable. These separation criteria are listed in operation manuals.

The ATCO communicates with the pilot and provides instructions, clearances and advice regarding flight conditions (Subotic, 2007)(Flugmálastjórn Íslands, 2011). The advisory service is called Flight Information Service (FIS) and contains weather information, including Significant Meteorological Information (SIGMET), traffic information and information issued in Notices To Airman (NOTAM). NOTAMs include a variety of messages concerning aeronautical facilities, such as changes in services, non-standard conditions or hazard (ICAO, 2007a). The messages are in standard format.

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<sup>142</sup> Routes where the aircraft is at all times within VHF range of a land station (Flugmálastjórn Íslands, 2011).

The state<sup>143</sup> of the aircraft is detected by the radar surveillance system (or by ADS-B when the ADS-B service will be available). In the area where there is radar coverage the ATCO can monitor aircraft with high accuracy. Therefore there are specific rules that apply to the minimum separation between aircraft while they are located in a radar area and under radar control. In areas where there is no radar coverage, pilots report their position with regular intervals through voice or data link communication. In such cases the ATCO uses so-called procedural separation rules. The separation minima for procedural separation is much greater than in radar separation since the former is based on less accurate position and the response time for the ATCO and the pilot is longer as they are not necessarily in direct voice contact with each other.

The main separation rules<sup>144</sup> which apply in the Reykjavik control area while the aircraft is in cruising are (Flugmálastjórn Íslands, 2011):

1. Procedural separation

- a. The vertical separation minimum is 1000 feet in flight levels up to 410 inclusive and 2000 feet above that. Between flight levels 290 and 410 there is Reduced Vertical Separation Minimum (RVSM) airspace<sup>145</sup>.
- b. The minimum lateral separation outside radar coverage is from 50 NM (93 km) but can be up to 120 NM (223 km) under certain conditions. Between flight levels 290 and 410 there is Minimum Navigation Performance Specification (MNPS) airspace<sup>146</sup>.
- c. The longitudinal separation is from 10 to 30 minutes, depending on the type of aircraft and separation technique used. The longitudinal separation between two aircraft can be reduced where the aircraft's speed of the second aircraft is lower. Depending on the difference in speed the longitudinal separation minima can be reduced down to 5 minutes.

2. Radar separation

- a. The minimum horizontal separation within radar coverage is from 5 NM (9,3 km) to 10 NM (18,5 km) depending on flight levels. The minimum horizontal separation is reduced to 3NM (5,6 km)<sup>147</sup> when the distance from Keflavik airport is 30 NM (55,6 km) or less.

The pilot may request changes to the cleared profile, such as altitude, route or speed changes. When the ATCO receives such requests he considers other traffic and obtains acceptance of changes at the sector boundaries. Having taken this into account the ATCO will either reject the request or issue a clearance including the new profile, flight level or speed.

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<sup>143</sup> The state of the aircraft includes its position, velocity (e.g. ground speed and course) and altitude.

<sup>144</sup> The separations rules within the domestic area are not included.

<sup>145</sup> RVSM airspace is airspace where it is allowed to use 1000 feet vertical separation instead of 2000 feet separation if the aircraft is equipped for RVSM.

<sup>146</sup> MNPS airspace is airspace where there are only allowed aircraft which meet certain lateral navigation performance capabilities.

<sup>147</sup> A further condition for the reduction of the separation minima to 3 NM is that primary surveillance radar is in range.

When the aircraft reaches the boundary between two sectors the FDPS performs hand-off<sup>148</sup> by automatically changing the controlling sector of the aircraft.

To sum up, within the **Separation Service** the ATCO monitors all aircraft in its airspace with respect to separation minima based on surveillance data and/or position reports. The ATCO also receives requests for changes in flight profiles from aircraft and approves or rejects these requests if necessary. **Separation Services** also provides general Flight Information Services.

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<sup>148</sup>Hand-off is the act of passing control of an aircraft from one ATCO to another in an adjacent sector.

## **Appendix II The Air Traffic Control System at Isavia**

In this chapter the focus is on the equipment and systems used for the Air Traffic Control. ATC is generally divided into en-route Air Traffic Control, Approach Control and Aerodrome Control. Approach Control and Aerodrome control are mainly operated in towers at each airport. Approach control focuses on flights arriving/departing from airport Terminal Areas that typically can extend to 60 NM from the airport. Aerodrome control directs air traffic in the vicinity of the airport and on the ground. Thus, Approach and Aerodrome controllers work closely together (Subotic, 2007). En-route ATC on the other hand concentrates on the traffic control while the aircraft is in the air and is operated by en-route Area Control Centres (ACCs). Since the thesis is concentrated on en-route air traffic control the focus of this chapter will be on the Reykjavik en-route ACC. En-route control is divided into Air Traffic Management, Communication, Navigation and Surveillance i.e. ATM/CNS. Figure II.1 shows systems and equipment used in Reykjavik ACC.

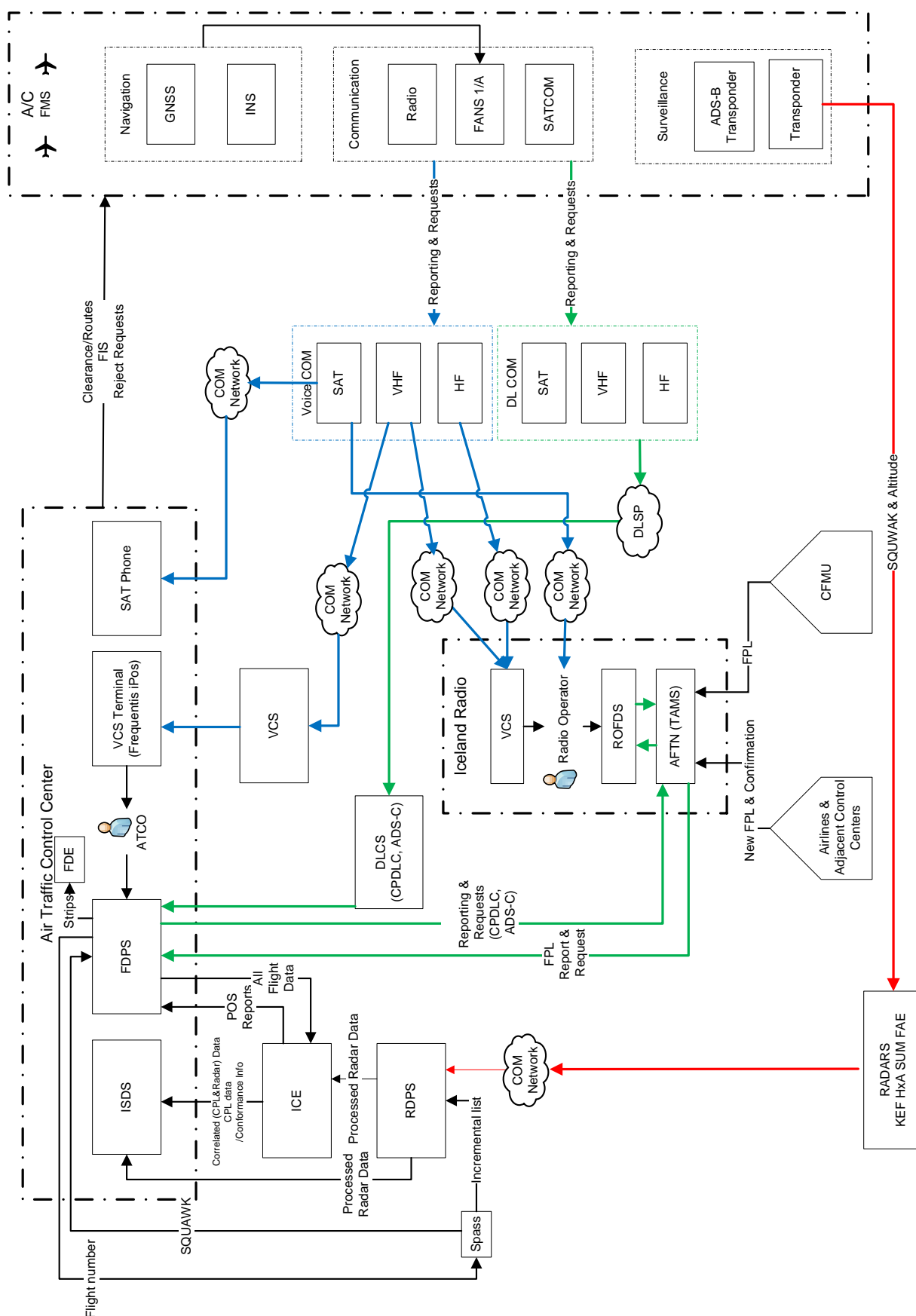


Figure II.1: Information systems and equipment used in Reykjavik ACC.

In figure II.1 the arrows represent the input/output from each system/equipment. The aircraft (A/C) is displayed on the right hand side whereas the systems/equipment used by ATCOs at the Air Traffic Control Centre are displayed in a dashed box at the top left corner. In order to simplify the figure the voice and data (the arrow containing: Clearance/Routes, FIS, Reject Requests) from the Air Traffic Control Centre to the aircraft is shown as a single arrow from the Air Traffic Control Centre to the aircraft, although the actual route is in most cases through the same channels as the information flow from the aircraft to the Air Traffic Control Centre.

## Surveillance

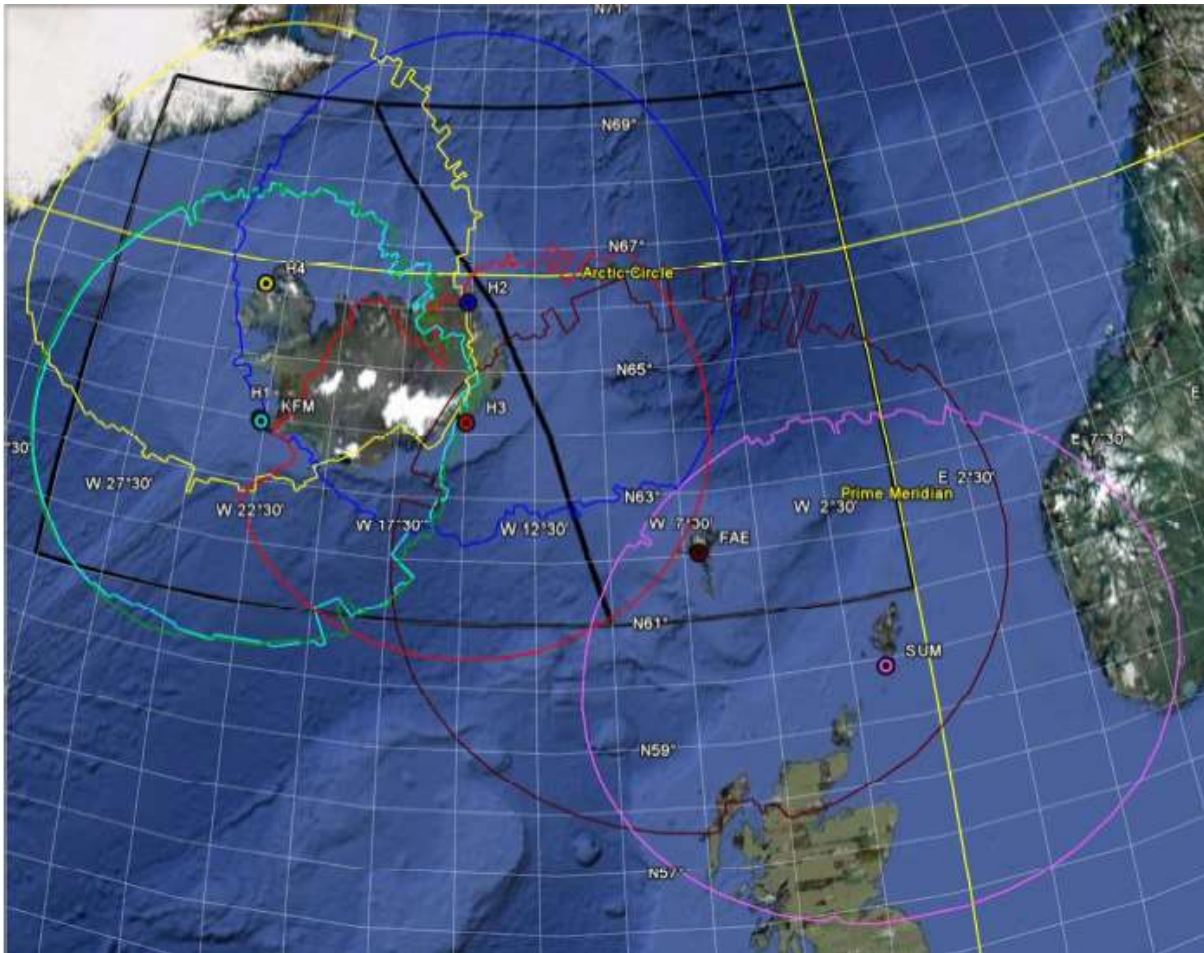
Surveillance systems are used to monitor flights and compare them to confirmed flight plans. The Surveillance system at Reykjavik Area Control Centre consists of radars, communication network, Radar Data Processing System and a Squawk Allocation System (SPASS<sup>149</sup>).

### *Radars*

The ATC centre is connected via a communications network to 7 radars; in Keflavik (two radars –KFM and H-1), Bolafjall, Gunnólfsvíkurfjall, Stokksnes, Faroe Islands and Sumburgh in the Shetland Islands (Scotland). In the area where there is radar coverage, radars provide near continuous surveillance of aircraft with identity (squawk) and altitude, the radar data arrives at 10 second intervals. Figure II.2 shows the radar stations as well as the overall radar coverage area. At each radar site there are both primary and secondary radars except in the Faroes and Shetland, which provide secondary data only.

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<sup>149</sup> SPASS stands for Strip Printing and Squawk Allocation System, however the strip printing is no longer a part of the system.



**Figure II.2: Radar stations and radar coverage in the Reykjavik control area at 40 thousand feet.**

### ***Primary radar***

Primary radar provides precise knowledge of the position of aircraft but does not identify them. The radar provides independent surveillance of aircraft and can report the position of anything that reflects transmitted electromagnetic signals including, aircraft, birds, weather etc. Even though its information is more limited than in Secondary Surveillance Radar primary radar is used at Isavia mainly for backup purposes. Primary radar is not used directly during air traffic control at Isavia, however it does provide augmentation of the secondary radar measurements of position (Nolan, 2011).

### ***Secondary Surveillance Radar (SSR)***

SSR is more sophisticated than primary radar as it provides additional information such as identity and altitude in addition to the position of the aircraft. Unlike primary radar systems, SSR is dependent on aircraft being equipped with a radar transponder (Nolan, 2011). The transponder replies to the signal from the SSR by transmitting a transponder code which is a four digit octal code called squawk.

### ***Transponder (Transmitter- responder)***

A transponder is an electronic device located in aircraft, used to receive secondary radar signals and automatically respond to them. The transponder code is assigned by air traffic control centre to uniquely identify an aircraft. This allows easy identification of the aircraft on radar and on other aircraft's collision avoidance systems.

### ***Squawk Allocation System (SPASS)***

SPASS (also known as ADT) assigns a squawk code to a call sign upon a request from the Flight Data Processing System (FDPS) i.e. FDPS says "I have ICE520, what squawk code should I assign to it?" to which SPASS replies "ICE520 has been assigned squawk code 3321". SPASS also informs RDPS what call sign (e.g. ICE520) matches a squawk code (e.g. 3321).

When the RDPS requests data from the SPASS, the SPASS provides an “incremental” list. The incremental list holds all squawk codes that were assigned from the last request and when the codes will expire.

### ***Automatic Dependent Surveillance Broadcast (ADS-B)***

ADS-B is a surveillance technique that broadcasts identification, position, altitude, velocity and other data automatically from the aircraft at a high rate (once pr. second). As the signal is broadcasted the originating source has no knowledge of who receives it. To operate the ADS-B needs ground-based receiving stations, a transponder within the aircraft as well as the on-board systems providing the data to be transmitted. ADS-B is expected to be operational at the Reykjavik ACC in the near future. ADS-B expands and augments the more traditional SSR networks and may eventually replace the radars used today. ADS-B which is sometimes referred to as pseudo-radar provides more accurate and comprehensive information than conventional radar (Australian Government & Civil Aviation Safety Authority, 2012).

### ***Automatic Dependent Surveillance - Contract (ADS-C)***

This is a surveillance equipment which automatically transmits information from other systems in the aircraft, such as identification, position and speed to the ATCO through data link. In ADS-C the data is only sent between the ground system and the aircraft as opposed to ADS-B (Automatic Dependent Surveillance – Broadcast) where the data is broadcasted constantly to all possible recipients (ICAO, 2007a).

### ***COM Network - Communication network***

The Reykjavik ACC communications network in Iceland is provided by the telecommunication company Míla<sup>150</sup>. The building blocks of the network are a copper system, optical fibre network and microwave system (Míla ehf., 2012).

Radar signals arrive into a central unit called Control and Reporting Centre (CRC; Nato facility) at Keflavík and from there they are transmitted through optical fibre/microwave to the Radar Data Processing System at Isavia's ACC in Reykjavik.

<sup>150</sup> In Figure 3 COM Network represents Míla except for in satellite communication which is transmitted through Radiomiðlun.

### ***Radar Data Processing System (RDPS)***

The RDPS system provides simultaneous data processing from radar data while performing real-time monitoring and data extrapolation.

RDPS merges the radar data from seven secondary surveillance radars, processes the data by using extrapolation and filtration to generate a single „system track“. This provides velocity, direction and identification call-sign of every individual aircraft flying through the area on a 2D ATC situation display which is updated every 3 seconds. This display provides core information on the traffic to the radar air traffic controller. The system also provides a range of supporting functions i.e. distance measures, separation measures, velocity measures, time plans etc. RDPS also includes a Short Term Conflict Alert (STCA) which alerts the ATCOs in case of impending or actual separation minimum violations.

## **Flight Data**

In this chapter the main focus is on how equipment and systems contain and process flight data<sup>151</sup>. The systems that handle flight related data at Isavia are Flight Data Processing System (FDPS), Integrated Controller Environment (ICE), Integrated Situation Display System (ISDS) and Flight Data Entry (FDE).

### ***Flight Data Processing System (FDPS)***

The FDPS is one of the most important systems used by ATCOs at Isavia and is in continuous development. FDPS is a complicated system that consists of many processes working together and receives all flight information other than radar data.

FDPS is a message driven system which automatically processes all the information related to the flight and aircraft relative position (*A/C state*) into electronic progress strips<sup>152</sup>. These strips are vital for operation and should always contain the newest known information. FDPS uses a weather model to calculate the progress of the flight. The system alerts ATCO if some changes could result in minimum separation violation.

The system automatically distributes information between ATCOs within the ATC centre and also outside of the ATC centre, such as Reykjavik and Keflavik tower, CRC and adjacent ANSPs. Other functions include creating basis for clearance, receiving and processing all flight plans and updating *A/C state* according to position (POS) reports etc.

FDE continuously receives flight data strips from the FDPS for storage and is therefore a backup for the most important information provided by the system. The strips can be printed out as last resort backup if the FDPS backup fails.

### ***Integrated Controller Environment (ICE)***

Main function of the ICE system is to provide a standby database backup of FDPS data. If there is a problem with the primary FDPS system then the backup FDPS system can be

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<sup>151</sup> All data used to track a flight in ATC, generally contains all information related to position of the aircraft e.g. aircraft identification (e.g. a flight number), aircraft type (e.g. B744 for a Boeing 747-400), flight level (assigned altitude), departure, destination and time.

<sup>152</sup> A strip contains updated information from the flight plan displayed in a specific format

started with data from the ICE system. The data is also used to send current flight plan (CPL) information to Integrated Situation Display System.

ICE also communicates with the RDPS to supply the FDPS system with more accurate POS reports<sup>153</sup> and does a correlation between CPL and radar data. The result is sent to ISDS. ICE data is also used to perform conformance monitoring i.e. to compare actual position of the aircraft with the cleared routes and reports discrepancy to ISDS.

### ***Integrated Situation Display System (ISDS)***

ISDS is a display system that provides a visual representation of flight profiles, flight estimates, crossing times etc. ISDS integrates two fundamental systems in the Reykjavik Oceanic Area Control; the RDPS and FDPS. ISDS combines information from the different systems into one situation display for the ATCO which enhances the ATCO's situation awareness. The ISDS displays useful information showing both radar and CPL tracks in convenient and timely manner. The system uses Processed Radar Data from RDPS. ISDS also uses Correlated CPL and Radar Data from ICE as well as conformance information.

The system provides lateral- and vertical conformance monitoring against the cleared oceanic flight profile. ATCOs use the information displayed on the screen and data from FDPS to maintain separation and control traffic.

## **Communication**

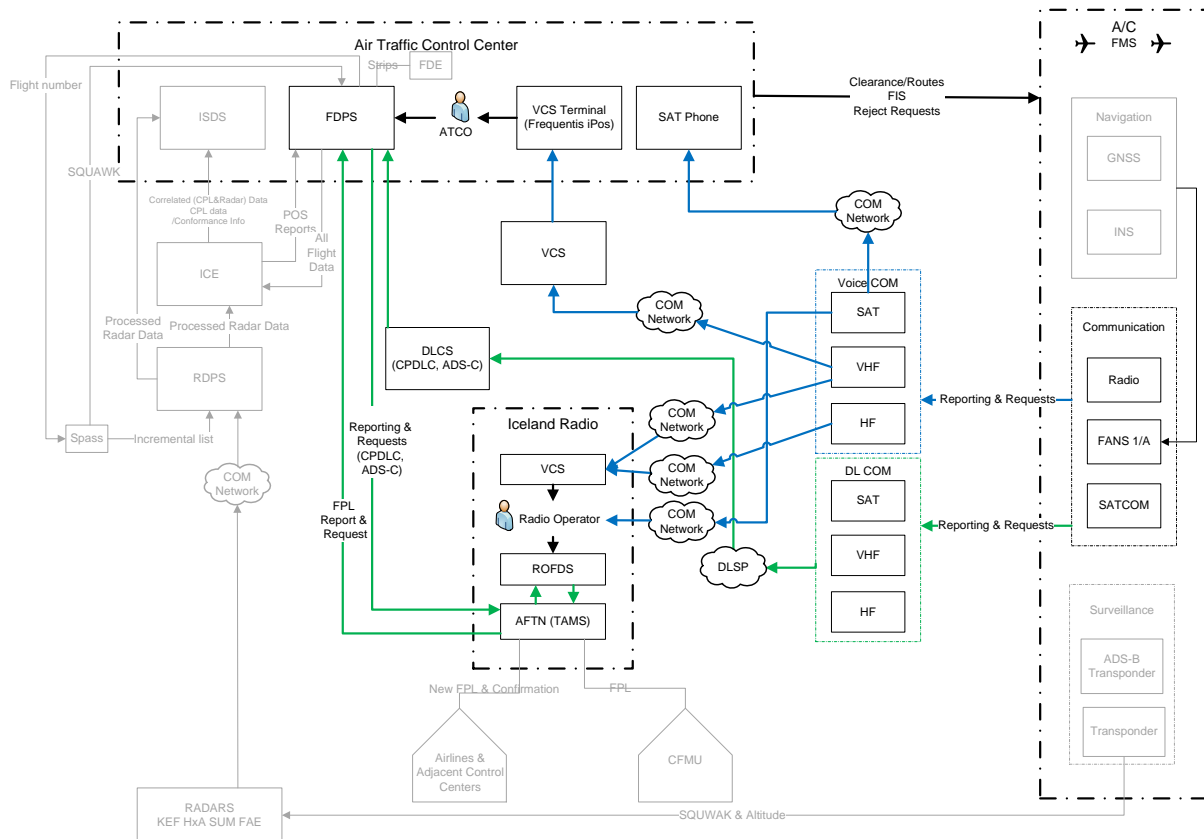
There are three ways for communication between the pilot and ATCO:

1. Direct voice communication between pilot and ATCO through VHF radio or satellite phone.
2. Data communication through data link between pilot and ATCO, such as CPDLC.
3. Communication through a radio operator at Iceland Radio<sup>154</sup> using VHF radio, HF radio or satellite phone.

Figure II.3 shows the communication part of the system, voice communication is shown in green and data communication is shown in blue.

<sup>153</sup> POS report is a position report usually communicated through Iceland Radio. These reports are needed in certain places when there is no radar coverage. Position reports replace radar or ADS.

<sup>154</sup> Iceland Radio, which is a part of the Air Navigation Division at Isavia, is a communication centre located in Gufunes that provides aeronautical telecommunication service.



**Figure II.3: The communication between the ATCC and the Aircraft. The path of the voice communication is shown in green colour and the path of data communication is shown in blue.**

Figure II.3 shows the equipment and systems used in the communication between the ATCO and the pilot. It also shows what kind of information is communicated. Although the information flow from ATCO to the pilot is shown in one arrow directly between the control centre and the aircraft the actual way of communication is through the channels shown for the communication from the communication system of the aircraft to the control centre. This is done to simplify the drawing.

The direct voice communication path between the pilot and the ATCO is shown in blue in figure II.3 i.e. from the communication equipment in the aircraft, through VHF radio and communication network to a Voice Communication System (VCS) in the control centre. A terminal for VCS is located at the ATCO's workstation. The ATCO can also communicate with the pilot directly through satellite phone.

The data communication path is shown in green in Figure 6 i.e. from the communication equipment in the aircraft, through data link communication provided by Data Link Service Providers (DLSP) to the Data Link Communication System in the control centre. The information communicated this way appears in FDPS where the ATCO can see it on the screen.

The communication path through Iceland Radio is shown in Figure 6. It begins in communication equipment in the aircraft, through satellite phone, VHF or HF radio and

communication network to VCS or a radio operator in Iceland Radio. There the radio operator converts voice communication to data which are then transferred to FDPS where the ATCO receives the data.

### ***High Frequency Radio (HF Radio)***

Used for voice communication between the pilot and a radio operator. HF is also used by Data Link Service Providers<sup>155</sup> (DLSP) as a data link, HF DL. Iceland Radio runs seven HF ground stations. HF radio signals cover larger area than VHF and can therefore be used when other communication technology is out of range, for example in the polar area. It is however subject to noise and disturbances from other equipment.

### ***Very High Frequency Radio (VHF Radio)***

Used for voice communication between the pilot and a radio operator or ATCO. VHF is also used by DLSPs as a data link, it is for example used by ARINC<sup>156</sup> in CPDLC. Isavia runs twelve VHF stations in Iceland and two in the Faroe Islands. Iceland Radio runs six stations in Iceland, two in Greenland and two in the Faroe Islands. As there is VHF radio coverage within the radar areas the ATCOs at the Reykjavík ACC can communicate through VHF radio while the aircraft is in radar coverage.

### ***Satellite Communication (SATCOM)***

Voice or data communication through satellites. The satellite communication is today mainly a data link communication through Data Link Service Providers as intermediates. The Reykjavík ACC and Iceland radio are also equipped with satellite phones for voice communication with the pilot.

### ***Controller Pilot Data Link Communication (CPDLC)***

CPDLC is a means for communication between ATCO and pilot through a data link. The data links are mainly through either VHF or satellite. DLSP, such as SITA<sup>157</sup> and ARINC are intermediates for this service.

The CPDLC application provides air-ground data communication of messages such as *Clearances/Routes*, requests, *FIS*, and reports in a format which corresponds to phraseologies used in the radiotelephony environment. There is also an option to send messages in a free format (ICAO, 2007a).

### ***Future Air Navigation System (FANS I/A)***

FANS-1/A is a system (hardware, software and communication networks) for data communication between ATCO and pilot, located in the aircraft as a part of the Flight Management System (FMS). The communication may be in the form of clearances, requests and position reporting. Both ADS-C messages and CPDLC communication are services provided through the FANS-1/A system. FANS-1/A is mainly used in oceanic airspace.

<sup>155</sup> DLSP are Companies that provide air-ground communication service via data link.

<sup>156</sup> ARINC is a Data Link Service Provider

<sup>157</sup> SITA is a Data Link Service Provider

### ***Voice Communication System (VCS)***

VCS is a telecommunication control system. VCS from Frequentis is located in the Air Traffic Control Centre. This system is used by ATCOs for most of their air-to-ground and ground-to-ground voice communication. With this system, radio contact is made with the aircraft through ground stations located around Iceland and in the Faroe Islands. Telephone communications with adjacent control units, towers, etc. go through this system as well. Each ATCO's workstation is equipped with a VCS terminal, called IPOS.

### ***Aeronautical Fixed Telecommunication Network (AFTN)***

AFTN is a ground-to-ground communication system for transmitting flight data messages. The system is a part of a worldwide network for transmitting messages between ANSPs, the CFMU, airlines, etc. The format of the messages is according to standards prepared by ICAO. The system that manages the messages at Iceland Radio was created by Tern Systems and is called TAMS.

### ***Radio Operator Flight Data System (ROFDS)***

A system that handles and keeps track of messages between aircraft and the radio operator. The radio operator at Iceland Radio communicates with the pilots through satellite phone, VHF or HF radio and enters the communication into ROFDS which creates AFTN messages that are transmitted to TAMS and then from TAMS to FDPS.

## **Navigation**

Navigation systems are located in the aircraft enabling the pilot to ascertain the position of the aircraft. Navigation equipment feeds information to FMS. Common navigation equipment include Automatic direction finder (ADF), Distance measuring equipment (DME), altitude sensors, speed sensors, Global Navigation Satellite System (GNSS), Inertial Navigation System (INS) and so on. GNSS and INS are frequently used for navigation on board aircraft and will be discussed in further detail here below.

### ***Global Navigation Satellite System (GNSS)***

GNSS is a system that uses satellites for three dimensional positioning. GNSS operations are based on triangulation from a group of satellites reference points in space that provide mainly three dimensional positioning, velocity and time (Nolan, 2011).

European Geostationary Navigation Overlay Service (EGNOS) is a space based augmentation system (SBAS) that increases the accuracy and integrity of GNSS signals for safety-of-life navigation reliability for aviation. Isavia participates in the EGNOS program by deploying and servicing EGNOS ranging and integrity monitoring stations (RIMS) in Iceland in cooperation with the European GNSS Agency (GSA). Position of aircraft relative to the satellite can affect GNSS signals making them inaccurate or blocked. Other signals, area surroundings e.g. mountains and so on, can also influence the GNSS signals (source: Isavia).

***Inertial Navigation System (INS)***

This navigation system can be independent of ground-based radio navigation stations and GNSS for a limited period of time and thus INS can be suitable for navigation when GNSS is not a viable solution (Christensen & Fogh, 2008).

INS can measure the slightest change in an aircraft's speed or direction of flight. Using this information, the INS can calculate the altitude, velocity, position, course to be flown and the estimated time of arrival (Nolan, 2011). When used correctly, the INS is highly accurate; however, the accuracy of the INS deteriorates with distance flown due to measurement inaccuracies. (Christensen & Fogh, 2008).

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## Appendix III List of complexity factors

In a literature review from Eurocontrol Experimental Centre called Cognitive Complexity in Air Traffic Control researches from 1963 to 2003 is considered and the following list is given in that report. The list represents the factors which have been considered to have influence on complexity.

1. Aerodromes, number of airline hubs
2. Aerodromes, total number in airspace
3. Aircraft mix climbing and descending
4. Airspace, number of sector sides
5. Airspace, presence/proximity of restricted airspace
6. Airspace, proximity of sector boundary
7. Airspace, sector area
8. Airspace, sector boundary proximity
9. Airspace, sector shape
10. Airspace, total number of nav aids
11. Conflicts, average flight path convergence angle
12. Conflicts, degree of flight path convergence
13. Conflicts, number of aircraft in conflict
14. Conflicts, number of along track
15. Conflicts, number of crossing
16. Conflicts, number of opposite heading
17. Conflicts, total time-to-go until conflict, across all aircraft
18. Convergence, presence of small angle convergence routes
19. Coordination, frequency of coordination with other controllers
20. Coordination, hand-off mean acceptance time
21. Coordination, hand-offs inbound, total number
22. Coordination, hand-offs outbound, total number
23. Coordination, number aircraft requiring hand-off to tower/approach

24. Coordination, number aircraft requiring vertical handoff
25. Coordination, number flights entering from another ATC unit
26. Coordination, number flights entering from same ATC unit
27. Coordination, number flights exiting to another ATC unit
28. Coordination, number flights exiting to same ATC unit
29. Coordination, number of communications with other sectors
30. Coordination, number of other ATC units accepting hand-offs
31. Coordination, number of other ATC units handing off aircraft
32. Coordination, total number LOAs
33. Coordination, total number of handoffs
34. Coordination, total number required
35. Equipment status
36. Flight entries, number aircraft entering in climb
37. Flight entries, number aircraft entering in cruise
38. Flight entries, number aircraft entering in descent
39. Flight entries, number entering per unit time
40. Flight exits, number aircraft exiting in climb
41. Flight exits, number aircraft exiting in cruise
42. Flight exits, number aircraft exiting in descent
43. Flight Levels, average FL per aircraft
44. Flight Levels, difference between upper and lower
45. Flight Levels, number available within sector
46. Flight time, mean per aircraft
47. Flight time, total
48. Flight time, total time in climb
49. Flight time, total time in cruise
50. Flight time, total time in descent

51. Flight type, emergency / special flight operations, number
52. Flow organisation, altitude, number of altitudes used
53. Flow organisation, average flight speed
54. Flow organisation, complex routing required
55. Flow organisation, distribution of Closest Point of Approach
56. Flow organisation, flow entropy/structure
57. Flow organisation, geographical concentration of flights
58. Flow organisation, multiple crossing points
59. Flow organisation, number of altitude transitions
60. Flow organisation, number of current climbing aircraft proportional to historical maximum
61. Flow organisation, number of current descending aircraft proportional to historical maximum
62. Flow organisation, number of current level aircraft proportional to historical maximum
63. Flow organisation, number of intersecting airways
64. Flow organisation, number of path changes total
65. Flow organisation, routes through sector, total number
66. Flow organisation, vertical concentration
67. Other, controller experience
68. Other, level of aircraft intent knowledge
69. Other, pilot language difficulties
70. Other, radar coverage
71. Other, resolution degrees of freedom
72. Procedural requirements, number of required procedures
73. Radio Telephony, average duration of Air-Ground communications
74. Radio Telephony, call sign confusion potential
75. Radio Telephony, frequency congestion
76. Radio Telephony, frequency of hold messages sent to aircraft

77. Radio Telephony, total number of Air-Ground communications
78. Separation standards (separation/spacing/standards)
79. Staffing
80. Time, total climb
81. Time, total cruise
82. Time, total descent
83. Traffic density, aircraft per unit volume
84. Traffic density, average instantaneous count
85. Traffic density, average sector flight time
86. Traffic density, localised traffic density / clustering
87. Traffic density, mean distance travelled
88. Traffic density, number flights during busiest 3 hours
89. Traffic density, number flights during busiest 30 minutes
90. Traffic density, number flights per hour
91. Traffic density, number of arrivals
92. Traffic density, number of current aircraft proportional to historical maximum
93. Traffic density, number of departures
94. Traffic density, total fuel burn per unit time
95. Traffic density, total number aircraft
96. Traffic distribution/dispersion
97. Traffic mix, aircraft type, jets vs props
98. Traffic mix, aircraft type, slow vs fast aircraft
99. Traffic mix, climbing vs descending
100. Traffic mix, military activity
101. Traffic mix, number of special flights (med, local traffic)
102. Traffic mix, proportion of arrivals, departures and over flights
103. Traffic mix, proportion of VFR to IFR pop up aircraft

- 104. Weather
- 105. Weather, at or below minimums (for aerodrome)
- 106. Weather, inclement (winds, convective activity)
- 107. Weather, proportion of airspace closed by weather
- 108. Weather, reduced visibility

## Appendix IV Exchange rates from CANSO's Global Air Navigation Services Performance Report 2012. Oceanic ANSPs.

ANSP	Country	Currency	End-of-year exchange rate	
			2007	2011
FAA ATO	United States	USD	1,0000	1,0000
NAV CANADA	Canada	CAD	1,0194	0,9807
NATS	United Kingdom	GBP	1,9973	1,5456
NAV Portugal	Portugal	EUR	1,4728	1,2950
Airways	New Zealand	NZD	0,7752	0,7743
ATNS	South Africa	ZAR	0,1480	0,1232
DC-ANSP	Curaçao	ANG	0,5714	0,5618
Isavia	Iceland	ISK	0,0161	0,0081

In the table is as reported in the Appendix E of the CANSO report but the ISK/USD rate has been added. The corresponding USD/ISK rates are 62 at the 2007 year end and 122,71 at the 2011 year end.

## Appendix IV Purchasing Power Parity exchange rates.

The Purchasing Power Parity rates are from World Economic Outlook Database April 2011 prepared by the International Monetary Fund.

ANSP	Country	Currency	IMF Purchasing Power Parity		
			2009	2010	2011
FAA ATO	United States	USD	1,000	1,000	1,000
NAV CANADA	Canada	CAD	1,197	1,218	1,231
NATS	United Kingdom	GBP	0,655	0,666	0,667
NAV Portugal	Portugal	EUR	0,698	0,698	0,690
Airways	New Zealand	NZD	1,612	1,654	1,674
ATNS	South Africa	ZAR	4,736	5,051	5,332
DC-ANSP	Curaçao	ANG	0,863	0,864	0,858
Isavia	Iceland	ISK	123,128	130,127	131,365

## Glossary of Terms

**Aerodrome Control** is the control of the aircraft on the ground after the aircraft has landed.

**Aeronautical Information Services (AIS)** main objective is to ensure the flow of information necessary for the safety, regularity and efficiency of international civil aviation. Member states of ICAO are required to provide this service (ICAO, 2002).

**Alerting Service** is „*a service provided to notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required*“ (ICAO, 2005).

**Air Navigation Services (ANS)** includes five broad categories of services provided to air traffic during all phases of operations (area control, approach control and aerodrome control). These services are: Air Traffic Management (ATM), Communication services, Navigation services and Surveillance services (CNS), Meteorological services for air navigation (MET), Aeronautical Information Services (AIS) and Search and Rescue (SAR) (ICAO, 2001).

**Air Navigation Service Provider (ANSP)** is an organization, which in most cases are state owned. Each member state of the ICAO has sovereignty over the airspace above its territory and the air traffic management of the airspace has been delegated to Air Navigation Service Providers (ANSP).

**Air Navigation Service Revenue (ANS Revenue)** is a data element from CANSO's benchmarking report, with the following definition: „*ANS revenue is ANS revenue (before adjustments from previous years) from the provision of oceanic ANS services*“ (CANSO Global Benchmarking Workgroup, 2011).

**Airspace Management (ASM)** is defined in a SES regulation as „*a planning function with the primary objective of maximizing the utilization of available airspace by dynamic time-sharing and, at times, the segregation of airspace among various categories of airspace users on the basis of short-term needs*“ (The European Parliament and the Council of The European Union, 2004). The functions of Airspace Management are described in more details in *Airspace Management* in Appendix I.

**Air Traffic Control (ATC)** The main objectives of the Air Traffic Control (ATC) are the separation of the aircraft from each other and from objects on the ground as well as expediting and maintaining an orderly flow of air traffic (ICAO, 2005).

**Air Traffic Controller (ATCO)** is the holder of a valid ATC license which permits the individual to control traffic at a specific operational unit. Executive controllers, planning controllers, and supervisors are ATCOs. For the purpose of performance assessment, the total

number of ATCOs that hold a valid license can be broken down into two subcategories: ATCOs in OPS and ATCOs on other duties (Eurocontrol, 2008).

**Air Traffic Controller on operational duty (ATCO in OPS)** is a definition from the ACE benchmarking report, according to the following: *„An ATCO who is participating in an activity that is either directly related to the control of traffic or is a necessary requirement for an ATCO to be able to control traffic. Such activities include manning a position, refresher training and supervising on-the-job trainee controllers, but do not include participating in special projects, teaching at a training academy, or providing instruction in a simulator“* (Eurocontrol, 2008). In the CANSO report the same definition is used for ATCOs in Operation.

**ATCO in OPS hours on Duty** is a data element from the ACE benchmarking report, according to the following definition: *“This is the number of hours “ATCOs in OPS” spend on duty in OPS, including breaks and overtime in OPS. This figure could be available from a time recording system (using for example first clock-in and last clock-out times); it could be computed from the roster plan; or it could be calculated by adding the average overtime worked in OPS to the contractual working hours and subtracting the average time an ATCO is not on duty in OPS.”* (Eurocontrol, 2008).

**ATCO in Operations Hour** is a data element from the CANSO report, according to the following definition: *“Average Annual Working Hours for ATCOs in Operations times the number of ATCOs in Operations”* (CANSO Global Benchmarking Workgroup, 2012)

**Air Traffic Controller on other duties (ATCO on other duties)** is a data element from the ACE benchmarking report, according to the following definition: *“An ATCO who is participating in an activity outside OPS such as special projects, teaching at a training academy, providing instruction in a simulator, working in a full time management position, etc.”* (Eurocontrol, 2008).

**Air Traffic Flow Management (ATFM)** is according to the AIP Iceland *“a service established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring ACC capacity is utilized to the maximum extent possible and the traffic volume is compatible with the capacities declared by the appropriate ATC authority”* (Flugmálastjórn Íslands, 2011).

**Air Traffic Management (ATM)** is according to Eurocontrol Specification for Economic Information *„a system approach with the objective of enabling aircraft operators to meet their planned times of departure and arrival and adhere to their preferred flight profiles with minimum constraints, without compromising agreed levels of safety. It comprises ground elements and airborne elements which, when functionally integrated, form a total ATM system. The airborne part consists of the elements necessary to allow functional integration with the ground part. The ground part comprises air traffic services (ATS), air traffic flow*

*management (ATFM) and airspace management (ASM), where ATS is the primary component“ (Eurocontrol, 2008).*

**Air Traffic Service (ATS)** is defined in the Eurocontrol Specification for Economic Information in the following way: *“consists of the air traffic control service (area control service, approach control service, or aerodrome control service), flight information service (including air traffic advisory service), and alerting service. Typical systems for ATS include: flight data processing systems (FDP), surveillance radar data processing systems (RDP), and the human-machine interface systems (HMI)” (Eurocontrol, 2008).*

**Approach Control** is defined in the Eurocontrol Specification for Economic Information in the following way: *“Air Traffic Control services to arriving, departing and over-flying flights within the airspace in the vicinity of an aerodrome” (Eurocontrol, 2008).*

**Approach Control Unit (APP)** is defined in the Eurocontrol Specification for Economic Information in the following way: *“The ATC unit provides Air Traffic Control services to arriving, departing and over-flying flights within the airspace in the vicinity of an aerodrome. The APP is generally located in the tower building or co-located with an Area Control Center” (Eurocontrol, 2008).*

**Area Control** is the Air Traffic Control services for en-route traffic.

**Area Control Centre (ACC)** is defined in the Eurocontrol Specification for Economic Information in the following way: *“The Air Traffic Control unit providing Air Traffic Control services to en-route traffic in control areas under its jurisdiction. Part of an ACC might also supply approach services” (Eurocontrol, 2008).*

**Average Annual Working Hours for ATCOs in Operations** is a data element from CANSO’s benchmarking report, according to the following definition: *„The number of hours ATCOs in operations spend on duty in operations, including breaks and overtime in operations. This figure could be available from a time recording system (using for example first clock-in and last clock-out times); it could be computed from the roster plan; or it could be calculated by adding the average overtime worked in operations to the contractual working hours and subtracting the average time an ATCO is not on duty in operations“ (CANSO Global Benchmarking Workgroup, 2011).*

**Central Flow Management Unit (CFMU)** refers to a unit under Eurocontrol which has the responsibility to manage traffic flow within airspaces controlled by Eurocontrol member states. In the United State there is a similar unit, the Air Traffic Control System Command Centre, for managing the traffic flow in US airspace.

**Civil Aviation Authority (CAA)** is the authority in each country which carries out the civil aviation regulatory tasks, in particular in the area of flight safety. The Icelandic CAA is The Icelandic Civil Aviation Administration (Flugmálastjórn Íslands).

**Civil Air Navigation Services Organization (CANSO)** is an organization which represents the interests of Air Navigation Service Providers worldwide. CANSO issues annually the Global Air Navigation Services Performance Report.

**Communication Services** refers to the service provided in order to maintain communication between the parties involved when providing Air Navigation Service. The main part of this service is the provision of communication between the ATCO and the pilot as well as the communication between adjacent ANSPs. Vital parts of the communication systems at Isavia are HF and VHF radio, satellite communication, data link communication, voice communication and telecommunication network. Further information can be found under *Communication* in Appendix II.

**Composite Flight Hours** is a term used in the ACE-report to represent both flight hours and airport movements. It is calculated according to the formula:

Composite gate-to-gate flight-hours = (en-route flight-hours) + (0,26 x IFR airport movements)

According to the “Eurocontrol Specification for Economic Information Disclosure”, the definition of where the en-route service ends and terminal service starts should be in accordance with definitions used for charging purposes (Eurocontrol, 2008). It is however stated in the ACE report that the definition is different between ANSPs. In order to minimize errors resulting from this the ACE reports uses composite flight hours in their calculations.

**Cost of Capital and Depreciation** is a data element used to calculate Cost of Capital and Depreciation as a Percent of Total Cost in the CANSO report. It is defined in the following way: *“The Cost of Capital falls into two categories. The first is the interest paid to the providers of debt capital. The second is the appropriate cost of capital applied to equity capital.”*

1. *For ANSPs with both categories, the cost of capital is the interest expense on debt capital plus the cost of capital on equity built into the ANSP charges.*
2. *For ANSPs with only debt capital, the cost of capital is the interest expense.*
3. *For ANSPs with only debt capital where the interest expense is born by the government and not reflected in the accounts of the ANSP, the cost of capital can be computed by applying the interest rate on overall government borrowing to the ANSP capital.”* (CANSO Global Benchmarking Workgroup, 2012)

**Current Plan (CPL)** is the latest flight plan which has been accepted.

**Employment Cost for ATCOs in Operations** is a data element from CANSO’s benchmarking report, according to the following definition: *„Total continental employment costs including gross wages and salaries, payments for overtime and other bonuses, employer contribution to social security scheme and taxes, pension contributions, and other benefits for ATCOs in operations. This should exclude mission-related expenditures, including travel*

*expenditures and training fees, as these should be considered operating costs“ (CANSO Global Benchmarking Workgroup, 2011).*

**En-route** is the phase of the flight where the aircraft is cruising and controlled by an ACC unit. It is the phase after the aircraft has taken off and is no longer controlled by the APP and until it starts to descend and the APP of the destination has taken over the control from the ACC.

**En-route ANS Provision Cost** is a data element used in calculating the Cost-efficiency KPI in the SES Performance Scheme.

**En-route ATM/CNS Costs** is the cost of providing the ATM/CNS service for the en-route phase of the flight. Gate-to-Gate ATM/CNS Costs is the sum of En-route ATM/CNS Costs and Terminal ATM/CNS Costs.

**Eurocontrol** is the European Organization for the Safety of Air Navigation, an intergovernmental organization made up of 39 Member States and the European Community. According to Eurocontrol’s website the role of Eurocontrol is stated as follows:

*“Eurocontrol supports its Member States to achieve safe, efficient and environmentally-friendly air traffic operations across the whole of the European region. We play a pivotal role in Europe by working together with all aviation partners to deliver a Single European Sky that will help to meet the safety, capacity and performance challenges of European aviation in the 21st century” (Eurocontrol, 2011c).*

In this research a reference is made to several reports issued by Eurocontrol such as the ACE Benchmarking Report and the Performance Review Report.

**Example Consolidated Price per 1000 KM Flight for A320** is a data element in the CANSO report according to the following definition: *“The sum of en route, approach, and terminal navigation charges for a theoretical continental flight of 1000 km (i.e. distance between two airports is 1000 km). ANSP with location-specific pricing will apply pricing related to highest IFR traffic (high demand) city-pair; ANSPs with national pricing regime will apply these charges to the theoretical continental flight. Amount excludes taxes, such as VAT” (CANSO Global Benchmarking Workgroup, 2012).* Here, A320 refers to the type of aircraft, A320 from Airbus.

**Federal Aviation Administration (FAA)** is the national aviation authority of the United States of America. FAA is an agency of the United States Department of Transportation which objects are to provide for the safe and efficient use of national airspace.

**Flight Data Processing System (FDPS):** The FDPS is a system used by ATCOs at Isavia. FDPS consists of many processes working together and receives all flight information other than radar data. It is a message driven system which automatically processes all the information related to the flight and aircraft relative position (A/C state) into electronic

progress strips<sup>158</sup>. These strips are vital for operation and should always contain the newest known information. FDPS uses a weather model to calculate the progress of the flight. The system alerts ATCO if some changes could result in minimum separation violation.

The system automatically distributes information between ATCOs within the ATC centre and also outside of the ATC centre, such as Reykjavik and Keflavik tower, CRC and adjacent ANSPs.

**Flight Information Region (FIR)** is defined in the Eurocontrol Specification for Economic Information in the following way: *“An airspace of defined dimensions within which flight information service and alerting service are provided”* (Eurocontrol, 2008).

**Flight Information Services (FIS)** is *“a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights”* (ICAO, 2005).

**Flight Level (FL)** is according to definition in Rules of the Air *“a surface of constant atmospheric pressure which is related to a specific pressure datum, 1.013,2 hectopascals (hPa), and is separated from other such surfaces by specific pressure intervals”* (ICAO, 2005). According to this flight level zero is at the atmospheric pressure level of 1.013.2 hPa. The flight level is expressed as a nominal altitude in hundreds of feet, for example a FL 300 means 30.000 feet. A pilot must calibrate the altimeter according to the local air pressure at sea level in order to display the altitude above sea level.

**Functional Airspace Block (FAB):** Introduced in the Single European Sky regulations, by definition it *“Functional Airspace Block means an airspace block based on operational requirements and established regardless of State boundaries, where the provision of air navigation services and related functions are performance-driven and optimized with a view to introducing, in each functional airspace block, enhanced cooperation among air navigation service providers or, where appropriate, an integrated provider”* (The European Parliament and of the Council of the European Union, 2009).

**Full Time Equivalent (FTE):** Data element from the ACE benchmarking report, according to the following definition: *„The equivalent of a single person carrying out a particular job or activity working on a full time basis during a year. A part time employee working half time would be counted as a 0.5 FTE. A full time ATCO working two thirds of his time on duty in OPS and one third of his time on teaching at a training academy would be counted as a 0.67 FTE ATCO in OPS and a 0.33 FTE ATCO on other duties“* (Eurocontrol, 2008).

**Gate-to-Gate ATM/CNS Costs** is a data element in the ACE report used when calculating Financial Cost-effectiveness Indicator.

**Global Benchmarking Workgroup (GBWG)** is a working group within CANSO which aim is to develop appropriate global measures for ANSPs performance. The Global Air

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<sup>158</sup> A strip contains updated information from the flight plan displayed in a specific format

Navigation Services Performance Report, which has been issued annually for some years, is the result of this work.

**Great circle** is “*a circle on the surface of the earth, the plane of which passes through the center of the earth*” (ICAO, 2007b).

**Great circle distance** is “*the length of the shorter arc of the great circle joining two points*” (ICAO, 2007b).

**Holding time** is any delay, usually caused by other air traffic, of an aircraft from the gate of the departing airport to the gate of the arriving airport. The delay may occur for example at a runway holding position where the pilot awaits clearance to take-off, or when an aircraft is approaching the destination airport and is kept on holding fix until it may proceed to landing.

**Iceland Radio also called Gufunes Communications Centre** is a part of the Air Navigation Division at Isavia. It is a communication centre located at Gufunes that provides aeronautical telecommunication service. The role of Iceland Radio in the communication system at Isavia can be seen in Figure AII.1.

**IFR Flight Hours (Oceanic)** is a data element from CANSO’s benchmarking report, according to the following definition: “*The sum of oceanic IFR flight hours controlled by an ANSP’s En Route Centres (ACCs). For any given flight, the flight hours controlled are derived from the difference between the entry time and the exit time (as derived from the last flight plan received) in the oceanic controlled airspace*” (CANSO Global Benchmarking Workgroup, 2011).

**Instrument Flight Rules (IFR)** are the rules and regulations which applies for flights when it is not safe to fly by using outside visual reference. In IFR flight the pilot depends upon the instruments within the aircraft for the flight and navigation is accomplished by reference to electronic signals (FAA, 2012).

**International Civil Aviation Organization (ICAO)** is an agency of the United Nations established to promote the safe and orderly development of international civil aviation throughout the world. Iceland is a member of ICAO.

**Joint Financing Agreement** is the “Agreement on the Joint Financing of Certain Air Navigation Services in Iceland” (as of March 2010). It is an international agreement between 24 states on the joint financing of the air navigation service provided by Isavia in the international airspace controlled by Iceland. The implementation of the agreement is supervised by ICAO, the development of the service provided according to the agreement and the cost involved is reviewed regularly (ICAO, 2010).

**Just Culture** is defined in EC regulation no. 691/2010 as “*a culture in which front line operators or others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful*

*violations and destructive acts are not tolerated*” (The European Parliament and the Council of The European Union, 2010).

**Meteorological services (MET)** means, according to the Eurocontrol Specification for Economic Information, *“those facilities and services that provide aircraft with meteorological forecast, briefs and observations as well as any other meteorological information and data provided by States for aeronautical use”* (Eurocontrol, 2008).

**National Airspace System (NAS)** is the aviation system for the US airspace governed by the FAA.

**National Air Traffic Services (NATS)** is the Air Navigation Service Provider in UK.

**NAV CANADA** is the Air Navigation Service Provider in Canada.

**Notices To Airman (NOTAM)** is according to ICAO definition *“A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations”* (ICAO, 2007a).

**Performance Review Commission (PRC)** is a body within Eurocontrol, established in 1998. The PRC supports the management of European Air Navigation Service through target-setting and the establishment of a performance review system. The PRC is responsible for enforcing implementation of the performance and target-setting system throughout Eurocontrol’s Member States and issues annual Performance Review Report. The PRC is supported in its work by the Performance Review Unit (PRU) of Eurocontrol (Eurocontrol, 2013).

**Performance Review Report (PRR)** is a report prepared annually by PRC with an analysis of the performance of the European Air Traffic Management system.

**Performance Review Unit (PRU)** is a supporting unit of the PRC and the Performance Review Body of SES (PRB). The PRU is responsible for monitoring and reviewing the performance of the European ANS System and issues annually the ATM Cost-Effectiveness (ACE) Benchmarking Report.

**Procedural separation:** In areas where there is no radar coverage, such as in oceanic airspaces, pilots report their position and speed with regular intervals through voice or data link communication. This information about the aircraft is entered into the FDPS for the ATCO to monitor the aircraft. Procedural separation rules (see Separation Service in Appendix I) define the separation minima where there is no radar coverage. The separation minima for procedural separation is much greater than in radar separation since the former is based on less accurate position and the response time for the ATCO and the pilot is longer as they are not necessarily in direct voice contact with each other. When the aircraft is not in

radar area the communication between the pilot and the ATCO goes through Iceland Radio where a Radio Operator is an intermediate.

**Purchasing Power Parity (PPP)** is, according to Wikipedia, *“an economic theory and a technique used to determine the relative value of currencies, estimating the amount of adjustment needed on the exchange rate between countries in order for the exchange to be equivalent to (or on par with) each currency's purchasing power. It asks how much money would be needed to purchase the same goods and services in two countries, and uses that to calculate an implicit foreign exchange rate. Using that PPP rate, an amount of money thus has the same purchasing power in different countries. Among other uses, PPP rates facilitate international comparisons of income, as market exchange rates are often volatile, are affected by political and financial factors that do not lead to immediate changes in income and tend to systematically understate the standard of living in poor countries, due to the Balassa–Samuelson effect.”*

**Random routes** refer to the routes flown which are based on the request (via flight plan) for flight route from the airlines on a per flight basis. Random routes as the name indicates are not predefined or published as is the case for fixed routes.

**Return on Assets (ROA)** is a financial ratio. It indicates the company's profitability with respect to its assets. The formula for calculating ROA is as follows:

$$ROA = \frac{\text{Net income}}{\text{Total assets (annual average)}}$$

**Return on Equity (ROE)** is a financial ratio. It is a “measure of how well a company used reinvested earnings to generate additional earnings” (Performance Review Commission, 2011). The formula for calculating ROE is as follows:

$$ROE = \frac{\text{Net income}}{\text{Total equity (annual average)}}$$

**Search and Rescue (SAR)** is the organizational body which is responsible for search and rescue. The Icelandic Coast Guard has this responsibility in the Reykjavik control area.

**SESAR (Single European Sky ATM Research):** SESAR is a program which is directed towards the technological and operational dimension of the Single European Sky (SES) initiative (Eurocontrol, 2012).

**Service Units** are used for the calculation of route charges within the Eurocontrol Charging Area. The Service Unit is a multiplication of an aircraft weight factor and a distance factor in accordance with the definition in Annex IV of the Commission Regulation (EC) No 1794/2006 of 6 December 2006 laying down a common charging scheme for air navigation services.

**Single European Sky (SES)** is an initiative within the European Union to improve overall ATM performance in Europe at the same time as the air traffic flow is increasing. The initiative has resulted in two legislative packages in order to meet this objective with common rules and procedures at European level. The SES regulations suggest that the European airspace is divided into functional blocks, according to traffic flows rather than to national borders. The first regulation package consisted of EC regulations nos. 549/2004, 550/2004, 551/2004 and 552/2004. The Single European Sky second package (SES II) was introduced in EC regulation no. 1070/2009 amending the SES regulations to introduce targets in key areas of safety, network capacity, effectiveness and environmental impact (Eurocontrol, 2011d).

**Single European Sky Performance Scheme** was introduced in the Single European Sky regulations second package (SES II). The objective of the performance scheme is to improve the performance of air navigation services and network functions in the single European sky. a performance scheme for air navigation services and network functions shall be set up (The European Parliament and of the Council of the European Union, 2009).

**Surveillance Services (SUR)** according to Eurocontrol's definition "*means those facilities and services used to determine the respective positions of aircraft to allow safe separation*" (Eurocontrol, 2008).

**Support Cost** is defined in the Eurocontrol Specification for Economic Information as the staff costs other than those for ATCOs in OPS, non-staff operating costs and capital-related costs (Eurocontrol, 2008).

**Taxi time** is the time while the aircraft is moving on the surface of an aerodrome under its own power, excluding take-off and landing (ICAO, 2005).

**Terminal ATM/CNS Costs** is the cost of providing the ATM/CNS service for the part of the flight from the gate until the aircraft is in en-route phase. Gate-to-Gate ATM/CNS Costs is the sum of En-route ATM/CNS Costs and Terminal ATM/CNS Costs.

**Terminal Manoeuvring Area (TMA)**, also called Terminal Control Area, is "*a control area normally established at the confluence of ATS routes in the vicinity of one or more major aerodromes*" (ICAO, 2005).

**The Federal Aviation Administration Oceanic and Offshore Integrated Product Team (IPT)** is a team formed by the FAA to improve its ATM system performance measurement capabilities.

**Total Costs (Oceanic)** is a data element from the CANSO Report and is defined as "*the sum of Oceanic Operating Costs, Depreciation/Amortization, and Cost of Capital related to providing Oceanic ATC/ATFM Services*" (CANSO Global Benchmarking Workgroup, 2011). CNS costs are also included but the total cost does not include costs for providing service relating to MET and Flight Services Stations that provide traffic advisories services. Total

Costs as defined by CANSO is similar to the ATM/CNS provision cost as defined by Eurocontrol.

**Total Operating Cost** is a data element from CANSO's benchmarking report, according to the following definition: „*Operating costs include direct and indirect employment costs, non-staff operating expenses, and other costs incurred through the purchase of goods and services directly used to provide continental and oceanic ANS services. This should include outsourced services such as communications, IT, and external staff with short term assignments. Other items that are usually included in operating costs include materials; energy; rent; and facilities and maintenance. This excludes the cost of providing meteorological (MET) services, which should be counted under 'other unique costs'* “ (CANSO Global Benchmarking Workgroup, 2011).

**Visual flight rules (VFR)** are the flight rules governing aircraft flight using visual references. When the weather conditions are such that the pilot cannot operate according to VFR, instrument flight rules (IFR) must be used (FAA, 2012).