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FOR THE SAFETY OF AIR NAVIGATION

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EUROCONTROL EXPERIMENTAL CENTRE

DMEAN
(Dynamic Management of the European Airspace Network)

Benefit Assessment Of Operational Use Case 3

EEC Note No. XX/xx

FAP
Future ATM Profile

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DMEAN - Benefit Assessment of Operational Use Case 3

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Abstract :

Objective: This study, conducted during the last quarter of 2005, was aiming at developing a methodology to assess expected benefits of a better use of CDRs, in the framework of DMEAN.

The results, in terms of distance flown and ATFM delay, are intended to be used as input in a Cost Benefit Analysis, using EMOSIA.

Results: A methodology to assess the expected benefits of a better use of CDRs has been developed. It particular, the use of COCA to evaluate sector capacity variations provided interesting results which could have been translated in forecast delay variations, using PACT and GASEL.

The results in terms of delay reduction are conservative. Therefore, the use of these results can be used initially as input in a CBA.

It is proposed to conduct an other study with the following improvements:

- Various enhancements of the methodology.
- Use of optimised traffic samples.
- Update of the ACC capacity figures.

Table of Contents

Abbreviations

AMC	Airspace Management Cell
ANSPs	Air Navigation Service Providers
AO's	Aircraft Operators
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
CAMES	Co-operative ATM Measures for a European Single Sky
CATM	Capacity and Air Traffic Management
CFMU	Central Flow Management Unit
CDM	Collaborative Decision Making
CM(s)	CAMES Measure(s)
COCA	Complexity and Capacity
DARTS	Decision Aid for Real Time Synchronisation
DCAM	Data Collection and Analysis Methods
DMs	DMEAN measures
DMEAN	Dynamic Management of European Airspace Network
EEC	EUROCONTROL Experimental Centre
EMOSIA	European Model for Strategic ATM Investment Analysis
EUROCONTROL	European Organisation for the Safety of Air Navigation
ETFMS	Enhanced Tactical Flow Management System
FAM	Future ATFM Measures
FAP	Future ATM Profile
FMPs	Flow Management Positions
FPL	Flight Plan
FS	Facility Specifications
FUA	Flexible Use of Airspace
GASEL	Generic ATFM Simulation Engine and Library
LCIP	Local Convergence and Implementation Plan
MIL	Military
NCD	Network Capacity and Demand management (EEC business research area)
NOP	Network Operational
OUC3	Operational Use Case number 3
PACT	Portable ACC capacity Tool
RTD	Real-Time Demonstration
RTS	Real-time Simulation
SAAM	System for Assignment and Analysis at a Macroscopic level
STATFOR	Specialist Panel on Air Traffic Statistics and Forecast
TACOT	TACtical Operational Tool
TACT	CFMU Tactical System
TSA	Temporary Segregated Area

1. Introduction

1.1 Objective

This study, conducted during the last quarter of 2005, was aiming at developing a methodology to assess expected benefits of a better use of CDRs, in the framework of DMEAN.

The results, in terms of distance flown and ATFM delay, are intended to be used as input in a Cost Benefit Analysis, using EMOSIA.

1.2 DMEAN – OUC3

DMEAN (Dynamic Management of the European Airspace Network) aims to release hidden ATM system capacity as a means to meeting capacity demand in the short-term, until operational improvements from initiatives such as SESAR materialise. This pan-European programme will consolidate a number of current ATM developments and improve information exchange processes to allow the ATM system to cope with demand and capacity situations in a more dynamic manner. It relies on maximum operational co-operation between the European ATM partners.

The first set of operational improvements will be delivered in 2006 leading to a full implementation of the DMEAN concept of operations by 2009.

A number (6) of Operational Use Cases (OUCs) have been described. This study was made in support of the third OUC: "Planned military training activities cancelled and a new area allocated later on the same day".

1.3 Cost Benefit Analysis

The results of this study will be input into the European Model for Strategic ATM Investment Analysis.

EMOSIA consists of three main elements:
- dialogue with stakeholders and decision-makers to define the questions and assumptions for the economic evaluation;
- five stakeholder models and an overall model to evaluate the economic viability of an ATM improvement;
- standard inputs and baseline.

The five stakeholder models are for airlines, airports, air navigation service providers, general aviation and the military. Each model captures the incremental costs and benefits of the ATM improvement to each stakeholder segment.
The main outputs of EMOSIA, for stakeholder segment and overall, are:
- economic and financial indicators, namely NPV, benefit to cost ratio (B/C ratio), IRR, breakeven point and payback period;

- sensitivity analysis identifying the most critical variables to the economic success of the ATM improvement;
- risk analysis showing the likelihood of the ATM improvement delivering a certain net present value;
- recommendations for the ATM improvement including focus for further research;
- overall change in the cost per unit of aircraft operations.

1.4 Benefit Assessment

To assess the expected benefits in 2009 of a better use of CDRs, several tools were used and linked together :

1.4.1 SAAM - System for air traffic Assignment and Analysis at a Macroscopic level

To assess the future demand, simulations are performed to show how the traffic currently handled by the CFMU would be distributed over the future route network (e.g. the Air Route Network-Version 5, ARN.V5), with different assumptions of CDRs utilisation

The simulations of the new route network are made using SAAM whose role is to determine flight profiles for re-routed traffic corresponding to the future network.

1.4.2 FIPS - Flight Increase Process Software

The future air traffic demand is assessed by the FIPS tool, using as inputs:

- Traffic re-routed by SAAM.
- The overall traffic growth rates per origin-destination zones, established by the STATFOR (EUROCONTROL Statistic and Forecast Service) process.
- Airports capacities from the EUROCONTROL Airports Database.

1.4.3 COCA (Complexity and Capacity Analysis)

The principle goal of COCA is to provide some relevant, measurable, and meaningful indicators to evaluate the intrinsic difficulty of the ATM tasks in the context of the airspace concerned.

The approach is to analyse the relationship between complexity, controller workload, sector type and capacity. Practical examples of these analyses are through elaboration of indicators and comparisons of their values between different European states, centres of control or between USA and Europe.

For complexity evaluation a number of generally accepted traffic criteria have been identified. The sectors are then classified into groups and the traffic criteria are then linked to workload of the task associated with the flight types. This evaluation is further refined by applying a weighting factor added to the task(s) that is related to the sector type. The sector types are obtained by statistical classification. To evaluate capacity, the concept of when a controller is occupied at a level representing a maximum workload threshold is retained.

The COCA outputs are traffic complexity, controller workload and sector capacities.

1.4.4 PACT

The ACC was found to be the most appropriate level of granularity for en-route medium and long-term capacity plans and delay prediction.

This might be also useful for assessing future ATM improvements.
But sector capacities are declared to CFMU, ACC capacities have no operational meaning. FAP has developed different indicators. The PACT indicator, based on sector configurations and capacities, has been used in this study.

1.4.5 GASEL(Generic ATFM Simulator & Library)

At the heart of the analytic environment is an ATFM simulator that simulates the slot allocation process of the CFMU. The model therefore takes as input both ‘supply-side’ (capacity) and demand-side (individual flight plans) data and allocates departure slots in the same way as the CFMU. These tools represent the only such European-wide analytical environment capable of faithfully replicating the operations of the CFMU and resultant network interaction.
Outputs are delay and trajectory length for each flight.

The way these various tools have been used are explained in detail in the following sections and shown on the diagram in Annex 3.

2. Delay Forecast - Methodology

The purpose of this study is to give an overview of the expected benefits of the DMEAN deployment in 2009 over the ATM network.

This overview is based on established capacity plans prior to the summer 2005 and expected traffic sample, build using DMEAN assumptions (15%, 33% and 66% utilisation of CDRs).

This delay forecast is the result of simulations performed with the tools used in the capacity planning process (FAP methodology) and contains an identification of potential bottlenecks areas for the year 2009 in the DMEAN deployment context.

The following paragraphs present an overview of the FAP (Future ATM Profile) methodology and the delay forecast results.

2.1 Global methodology

Each day, the delay is calculated based on regulations at the sector level by the CFMU with a tool called CASA. This tool is doing the slot allocation for each aircraft entering the ECAC area. The CASA simulation reflects what the CFMU is doing in real time. It calculates the delay based on traffic and regulation entries (see following figure).

However, two differences between the real CASA and CASA simulations can be highlighted:

- Dynamic versus static
  CASA takes into account last minute changes, whereas the simulation is based on the latest flight plans available.

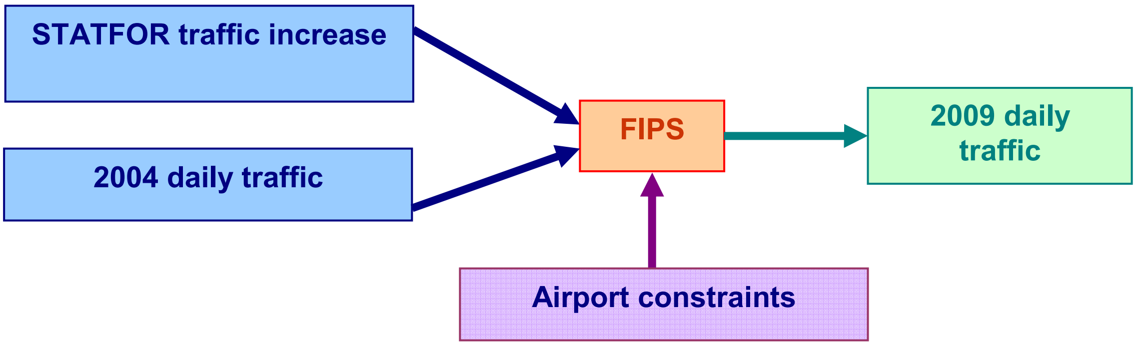
- Sector versus ACC level
  The regulations in the CFMU are defined at the sector level. In the case of FAP studies, many simulations (like the delay forecast) are done at the ACC level.

The main interest of using this methodology is that the network effect is taken into account in the simulations. The most penalizing regulation (the one producing the most delay for a flight) is the one that is responsible for all the delay of a flight, so that other regulations producing less delay will not appear as delay producers. This way of counting delays can lead to some ACCs protecting other ACCs, and this effect is reflected in CASA simulations.

2.2 Traffic input

For the delay forecast, a future traffic sample is needed. STATFOR provides predictions of traffic growth over Europe in three different hypotheses, low, medium and high. These forecasts take into account yearly airport constraints, as well as different sets of assumptions, e.g. economic growth, airline productivity, and competition from other means of transport. STATFOR forecasts are based on traffic flow growths between Origin Destination Zones in Europe (ODZ, which corresponds to a major airport or a group of airports).

The tool used to increase the traffic is called FIPS, and is a module of GASEL ATFM simulator.



For each day, FIPS is cloning flights from 2004 traffic on different city pairs based on STATFOR traffic growth assumptions. The traffic distribution during the day is respected by the FIPS cloning process: A flight to clone is taken randomly on a city pair (so that there are more chances to take a flight during the busiest hours), and it is cloned around its original departure time.

FIPS also takes into account hourly airport constraints, so that the increase can not be processed at the busiest times in a congested airport. A 2009 day by day traffic sample is obtained with this methodology.

In the 2009 DMEAN assessment context, the original 2004 traffic was re-routed on ARNV5 network with partial usage of CDRs. Three scenarios were retained for the assessment:

- Traffic with 15% use of CDRs (this scenario is considered as the DMEAN baseline in 2009),
- Traffic with 33% use of CDRs,
- Traffic with 66% use of CDRs.

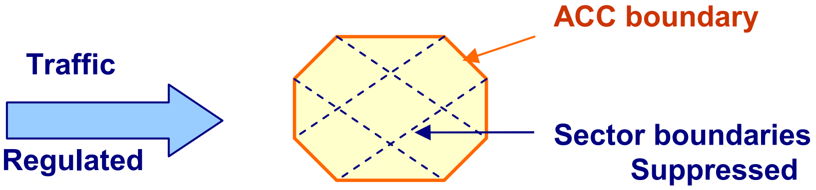
The SAAM tool has been used to perform re-routings and then, FIPS was applied on those traffic samples in order to produce the 2009 traffic.

2.3 Regulation input

The regulation inputs in the delay forecast process are based on 2009 capacity values used to perform the "EUROPEAN MEDIUM TERM ATM NETWORK CAPACITY PLAN 2006-2009"[1] (i.e. 2009 LCIPs capacity values). For each DMEAN hypothesis (15, 33 and 66 percent use of CDRs),

Centre capacity have been elaborated using the PACT tool and sector complexity variations determined by the COCA tool.

A regulation is set 24 hours a day, with a rate equal to the determined level of capacity each day. All the traffic entering the ACC is regulated.



In addition to these regulations per ACC, the airport regulations defined in 2004 are kept in 2009. The aim is to preserve the network effect, especially if some airports protect some ACCs.

The regulation inputs are the same in the three simulation sets (low, medium and high traffic growth)

2.4 Period studied

The simulations have been run on 14 days (from AIRAC cycle 258), from the 19th of July to 1st of August 2004. For each day, the delay has been computed, based on the FAP methodology explained in the previous sections.

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[1] 2009 capacity values are extracted from capacity plans prior to the summer 2005.

3. COCA methodology to assess sector capacity

3.1 Introduction

The purpose of the COCA Study was to estimate the capacity for the traffic samples S15%, S33% and S66% in each sector of the ECAC area and to compare these capacities with respect to the different traffic samples. The COCA methodology and tools, described hereafter, were used.
In order to meet the tight deadlines, the COCA Study has been realised on one day extracted from the 14 days traffic.

The COCA project approach is to analyse the relationship between complexity, controller workload, sector type and capacity.

3.2 How to define sector capacity?

The determination of sector capacity is realised by the determination of the sector workload.
The Workload formula will be defined later. Just consider the workload formula to be a linear relationship which aims at assessing, at sector level, a workload value (WL) from different input complexity indicators amongst which the number of aircraft per hour (AC/h).
Let us consider the graphical example represented in Figure 1. Each value of traffic demand (AC/h represented on x-axis) corresponds to one or many values of controller workload (WL represented on y-axis). When plotting these values, we obtain the blue cloud shown in Figure 1. Then, we draw a regression curve between traffic demand and controller workload (yellow curve in Figure 1). The capacity sector value corresponds to the abscissa of the intersection point between the regression curve and the predefined workload threshold (red line), that is to say 42 in this example.

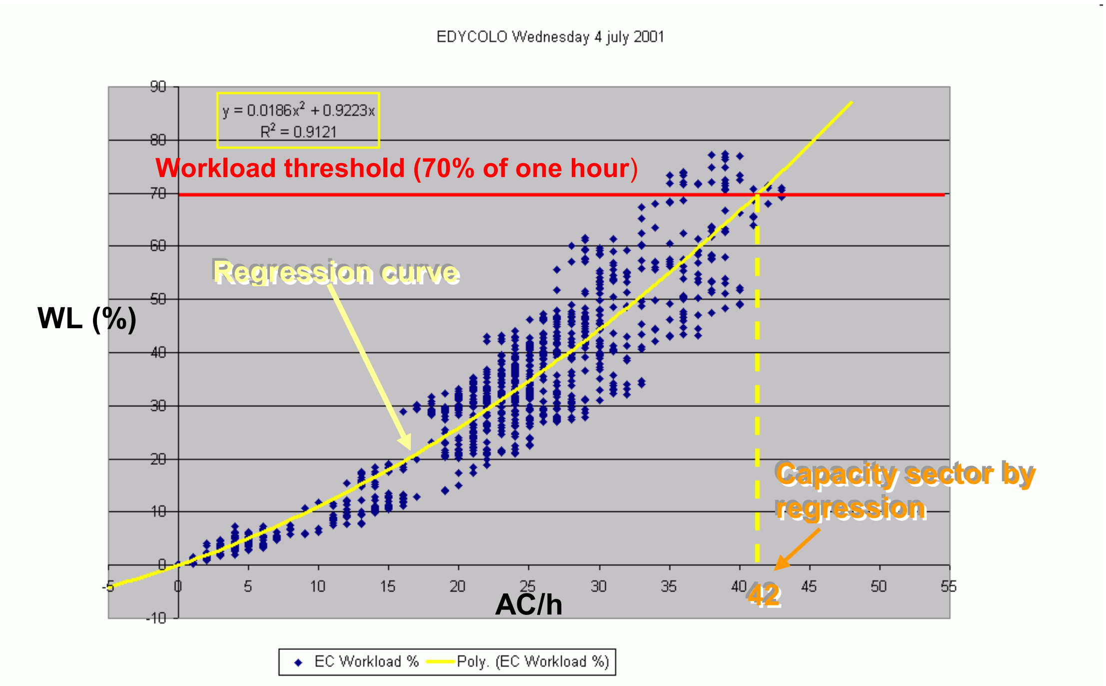


Figure 1: Capacity estimation by regression.

So, the sector capacity is derived from the workload estimation. The way the regression curve is obtained and the validation of this method will not be detailed in this document but are fully documented in [1].

3.3 How to evaluate workload per sector?

For this study, the executive controller's task workload was computed using the Adapted Macroscopic Workload Model (AMWM) developed by the COCA project. This model relies on the Macroscopic Workload Model (MWM) which is fully described in [2]. As its name indicates, the workload evaluation is performed at a macroscopic level. That is to say, only a few controllers' tasks are considered. Adapted (in AMWM) refers to a classification process to evaluate workload in relation to the complexity factors of the sector.

The MWM has been built to evaluate ACC workload, and is based on the workload used in the RAMS fast time simulator. This model is fully described in references [3] and [4]. The MWM states that every controller task can be placed in one of three **macro** tasks categories:

- routine task (AC);
- level change monitoring task (LC);
- conflict monitoring task (CNF).

The list of tasks associated with the 3 macro task categories are those as defined in the RAMS but some examples of these tasks include: Routine tasks – R/T tasks to and by the pilot for first and last call on frequency, flight progress data management tasks, route clearances, etc. Level change monitoring tasks include controller radar monitoring (or aircraft report) of flight leaving current level and reaching assigned and associated flight data management tasks; and conflict monitoring tasks that include identification, resolution and monitoring conflicts.

Thus, an estimate of workload can be obtained from the following formula:

$$\mathbf{MWM} = \omega_{AC} * n_{AC} + \omega_{LC} * n_{LC} + \omega_{CNF} * n_{CNF}.$$

Equation 1: Macroscopic Workload Formula.

Where

ω_{AC}, ω_{LC} and ω_{CNF} are respectively the times (expressed in seconds) needed to execute routine tasks, level change tasks, and conflict resolution and

n_{AC}, n_{LC} and n_{CNF} are respectively the number of occurrences of routine tasks, flight levels crossed and the conflict research/resolutions.

The parameters n are estimated at sector level using the COCA fast-time simulator named COLA.

It is recognised that controller tasks (and associated durations) may not be the same in every circumstance, or in different sector types: hence, controller task workload is context related. The AMWM is an endeavour to take account of the context of sector types by applying different weights to the same task dependant upon the sector type. To do this, sectors were first grouped into clusters sharing similar complexity properties. Following classification, an optimisation process (named CALIB) is applied to weight the controller tasks according to the sector type (so as to evaluate the ω_{AC}, ω_{LC} and ω_{CNF} weights).

Table 1 summarizes the workload evaluation process.

Adapted Macroscopic Workload Model (2003)	
Indicators?	Aircraft, Proximate Pairs, Level Changes + other complexity indicators (for classification): avg transit time, traffic mix, volume, traffic attitude…
Input?	CFMU reference capacities, traffic and configuration files.
Preliminary step	Classification (DIVAF) of the sectors using complexity indicators.
Method?	Workload evaluation via an optimisation process.
Output?	Workload value per sector.

Table 1: COCA methodology for Workload evaluation

3.4 How to classify the sectors?

As explained in the last paragraph, the workload evaluation depends on the sectors complexity. A preliminary step (see Table 1) which consists in classifying the sectors according to their complexity properties is necessary.

To classify the sectors into complexity clusters we used the DIVAF technique. DIVAF is a hierarchical method which gives, at the end, a decision tree. This method (DIVAF) has already been used by the COCA team for several studies and is documented in reference [5]. The method can be briefly summarised. At the beginning, all the sectors are considered belonging to a unique cluster (root of the tree). During the hierarchy building process, each single cluster is divided into two sub-clusters. The division is obtained by the selection of a complexity indicator. A corresponding question (binary type) is associated to the selected indicator which makes it possible to distribute the elements of the cluster into the two sub-clusters. By repeating this process until getting a satisfactory final number of clusters (leaves), a decision tree is worked out. The advantage of this method is not only to be easily interpreted but also to allow an operational “advice” for the selection the discriminating indicator.

Four steps are necessary to carry out the classification

1. Extract a representative sample of sectors to build the decision tree;
2. Normalise and aggregate the complexity values of the selected sample;
3. Build the decision tree from the sample: identify the complexity indicator which best divide the sample into two sub-clusters and repeat the process until the suitable number of clusters has been obtained;
4. Classify the remaining sectors according to branches of the tree (after having normalised their complexity values as in step 2.).

3.5 How to compute the complexity indicators?

The analysis was performed using the COCA fast-time complexity simulator named COLA.

The inputs to the simulations were the:

- Flight plan data describing individual aircraft trajectories (IFR flights) – for all ECAC sectors – covering a 24 hour period;
- Sector configurations for the traffic sample chosen taken from the corresponding Aeronautical Information Regulation And Cycle (AIRAC) notice;

The output complexity indicators thought to be most relevant to this study were selected:

- Sector volume;
- Occurrences of proximate pairs;
- Number of flight levels crossed;
- Mixture of aircraft types and performance;
- Numbers of flights per hour and per 10 min period (avg);
- Traffic mixture in relation to flights in climb, cruise and descent.

The resulting values can be assessed at any spatial/temporal steps level.

3.6 Summary of the whole COCA process

Figure 2 shows the COCA methodology to assess sector capacity.

The input data are coloured in blue, the toolboxes in orange and the output in green.

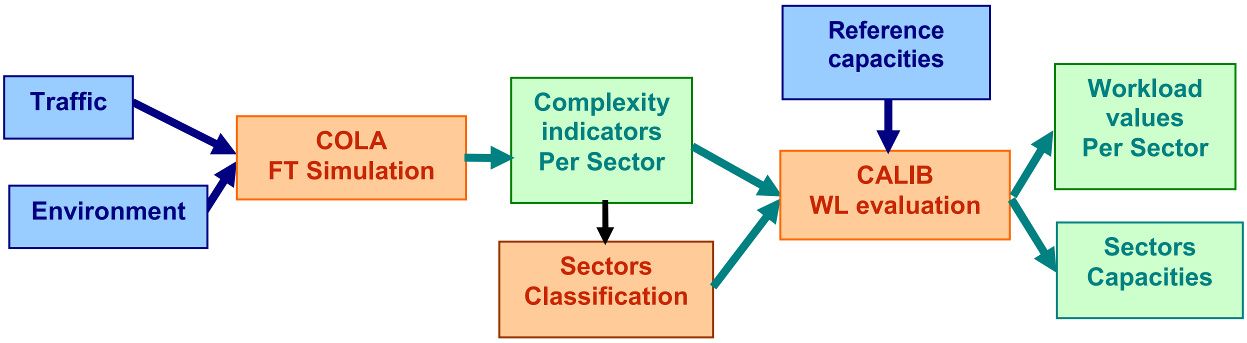


Figure 2: COCA process for Sector Capacity Assessment.

4. COCA Results

4.1 Input Data

For tight schedule reasons, the sector capacity evaluation has been limited to one day of traffic.

Date chosen: 22nd July 2004. After a variability analysis on the 14 day sample, this day has been identified as being the busiest day over the 14 days sample.

Number of Sectors to be studied: 641 (whole ECAC).

4.2 Data collection

FAP/SAAM provided COCA with data:
- **3 types of traffic** (baseline traffic: S15%, S33% and S66%);
- **Environment definition**;
- **Reference sector capacity values** (for the baseline).

The classification process and the weight calibrations (for workload evaluation) respectively described in paragraph 3.4 and 3.3 have been applied to the baseline traffic. Then, with taking into account the results found on the baseline (clusters and weights in the workload formula), the sector capacities (only) have been assessed for the 2 remaining traffic samples S33% and S66%.

4.3 COCA Fast Time Simulations: Complexity Indicators evaluation

Computation of 7 high level complexity indicators for the 3 types of traffic at day level for the 641 sectors considered:

- Volume (NM^2*100feet)
- Avg Transit Time (min)
- Proximate Pairs
  - Along Track Proximate Pairs (-)
  - Crossing Proximate Pairs (-)
  - Opposite Track Proximate Pairs (-)
- Nb of Level Changes (-)
- Avg Speed (knots)
  - Std Deviation Speed (knots)
- Nb of Aircraft (-)
- Traffic Attitudes
  - Percentage of aircraft in cruise (%)
  - Percentage of aircraft in climb (%)
  - Percentage of aircraft in descent (%)

A statistical study of the indicators has been lead for the baseline traffic, which helped in reducing the list of complexity indicators (some of them are highly correlated).

Indicators removed:

- *Proximate Pairs Along Track* and *Proximate Pairs Crossing* highly correlated with total number of Proximate Pairs;
- *Volume* correlated with Avg Transit Time.

4.4 Classification Process

For the classification process, a selected sample (about 33% of the total number of sectors) has been randomly extracted (corresponding to 173 sectors).

Principal Component Analysis (PCA):
It is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analysing data.

A principal component analysis enables us to reduce (again) the list of candidate indicators for the DIVAF classification. Only five indicators, listed hereafter, have been kept.

DIVAF Classification
List of indicators kept for the classification:

- Avg Transit Time
- Total nb of Proximate Pairs
- Avg Speed
- Nb of Aircraft
- Traffic Attitudes: Percentage of aircraft in climb

The complexity characteristics of the selected sample are given in Table 2.

	Avg Transit Time (decimal min)	Total nb of Proximate Pairs (-)	AvgSpeed (knots)	Nb of Aircraft (-)	Percentage of aircraft in climb (%)
Min	1.797	0.00000	276.3	0.2867	0.0000
1st Quartile	6.785	0.02902	375.8	1.4196	0.1182
Median	9.164	0.05088	409.3	2.1469	0.2636
Mean	10.317	0.06630	401.6	2.2828	0.2689
3rd Quartile	12.799	0.07927	435.1	2.9161	0.3948
Max	26.936	0.42574	455.5	10.1818	0.7119

Table 2: Selected indicators properties (non normalised values)

Figure 3 shows the representation of the selected sample of sectors in the two first principal components axes. The red arrows labelled with indicator names show the distribution of the sample according to the complexity properties. For example, sectors with high average transit time are more located on the right part of the figure; sectors with high number of flights are more located in the bottom left part of the figure. The PCA enables us to avoid the "duplication" of complexity information. Indeed, the red arrows are well "separated" and each considered complexity indicator is meaningful for this sample.

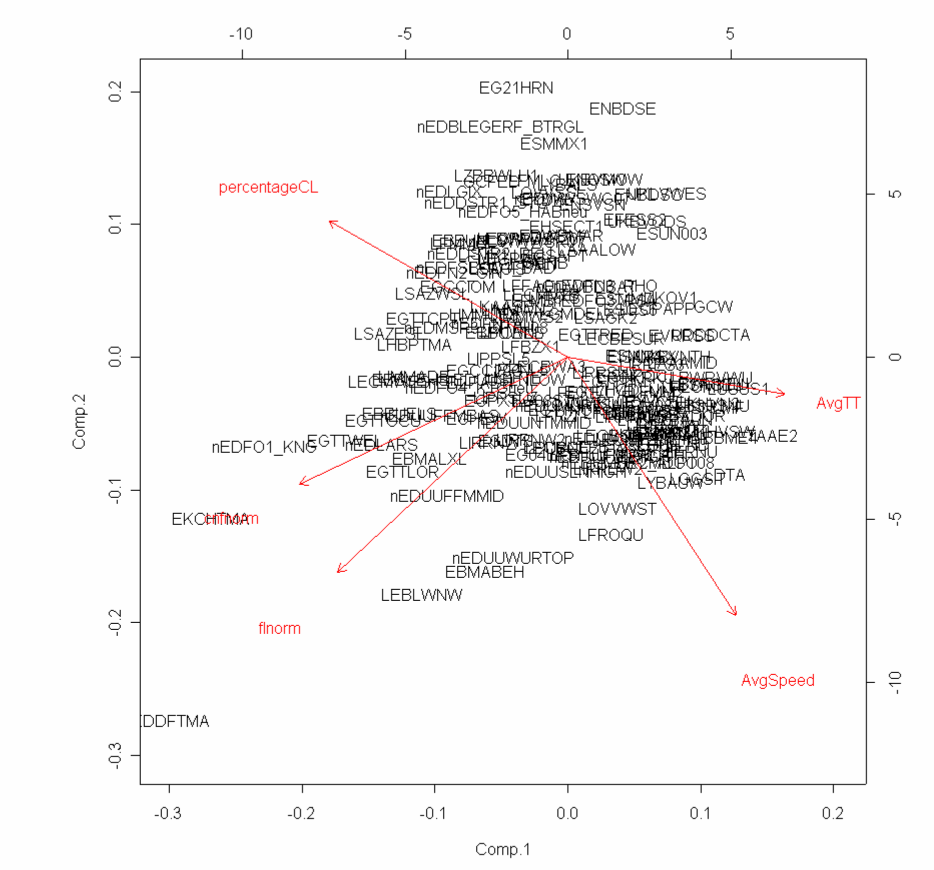


Figure 3: Principal Component Analysis on the sample.

Divisive Analysis process:

When applying the DIVAF method to the selected sample, the indicator to consider for the division of the sample was twice Proximate Pairs.
Figure 4 shows the levels of division. In each “leaf”, the indicator to consider for dividing the sample and the number of elements (sectors) are mentioned.

Several attempts have been made to find the ideal number of clusters. Ultimately, a classification made of 3 clusters was judged to be satisfactory. The three final leaves are shaded in pink in Figure 4.

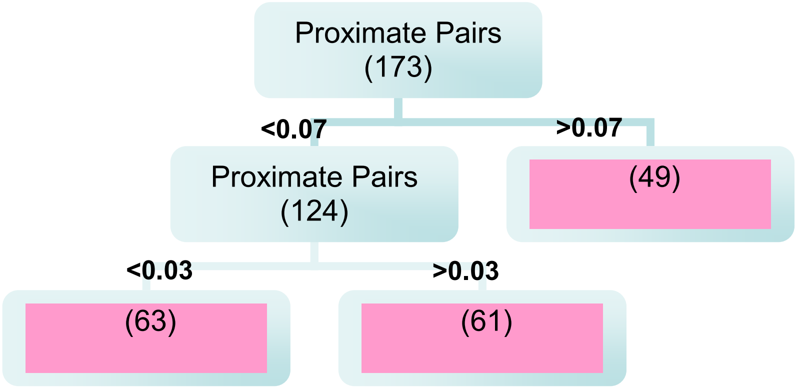


Figure 4: Divisive tree for the 3 clusters.

We can represent the cluster found in the PCA axes, as shown in Figure 5

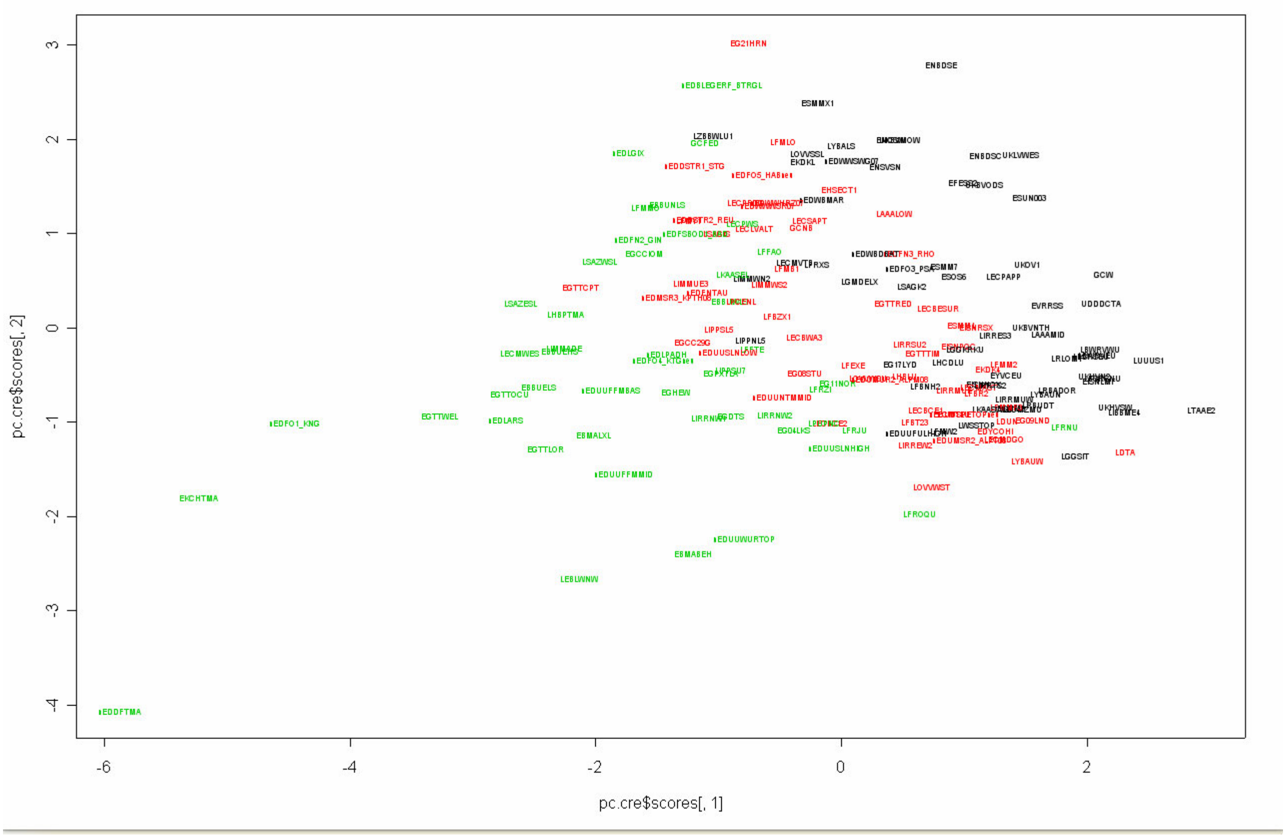


Figure 5: The 3 Clusters represented on the PCA axes.

On Figure 5, the sectors belonging to the first cluster are written in black, the ones belonging to the second cluster are written in red and the ones belonging to the third cluster are written in green.

Analysis of the clusters found:

The remaining sectors have been distributed into the clusters found:

The 1st cluster is made of 265 sectors and appears to be the less complex cluster. The 2nd cluster is made of 208 sectors and appears to be moderately complex sectors. The 3rd cluster is made of 168 sectors and appears to be the most complex cluster.

The "properties" of the clusters are shown in Table 3:

		Volume	AvgTT	PP	Along PP	Cross. PP	LC	AvgSpeed	StdSpeed	FI	Cruising	Climbing	Descend.
Cluster1	Avg	3.6E+06	11.0	0.020	0.008	0.007	0.603	402	53	1.62	51%	25%	24%
	StDev	*7.8E+06*	*5.2*	*0.012*	*0.008*	*0.007*	*0.528*	*44*	*29*	*0.98*	*28%*	*17%*	*19%*
Cluster2	Avg	2.1E+06	9.7	0.053	0.022	0.020	0.737	404	50	2.30	52%	24%	25%
	StDev	*4.5E+06*	*4.9*	*0.010*	*0.014*	*0.013*	*0.563*	*35*	*24*	*0.84*	*27%*	*18%*	*20%*
Cluster3	Avg	1.1E+06	8.2	0.134	0.061	0.045	1.144	390	59	3.06	23%	38%	39%
	StDev	*1.7E+06*	*3.5*	*0.077*	*0.046*	*0.043*	*0.688*	*32*	*23*	*1.41*	*22%*	*19%*	*21%*

Table 3: Complexity properties of the 3 Clusters.

We have tagged the sectors of the study according to their "type". The sector types have been defined "manually" according to their min/max levels. The following "limits" have been used:

TMA: below FL95
Low: between FL0 and FL285
Transition Low: between FL215 and FL285
Transition High: between FL215 and FL345
High: above FL285
Low+High: between FL0 and FL999.

When considering the distribution of the sector types within the clusters, we obtained the distribution shown in Table 4:

	TMA	Low	Transition Low	Transition High	High	Low+High
Cluster 1 (less complex)	3%	19%	5%	12%	25%	35%
Cluster 2 (moderately complex)	0%	31%	11%	17%	26%	14%
Cluster 3 (most complex)	3%	57%	4%	13%	14%	9%

Table 4: Distribution of the sectors types within the 3 Clusters.

Unsurprisingly,

- High and Low+High sectors are found in majority in the least complex cluster. The traffic in High sectors is generally cruising traffic with few numbers of proximate pairs.
- Low sectors are found in majority in the most complex cluster, where controllers have to deal with traffic with heterogeneous attitudes, aircraft types, and a higher number of proximate pairs than in Cluster 1.
- Low and High sectors are found in approximately same moderate proportions in Cluster 2, which is a "mixed" cluster.

4.5 Workload evaluation

The workload evaluation deals with the estimation of the weights in Equation 1 (Macroscopic Workload Model Formula). They are presented in Table 5.

Task durations in s	ω_{AC}	ω_{CNF}	ω_{LC}
Cluster 1	62	42	23
Cluster 2	58	69	13
Cluster 3	48	61	10

Table 5: Workload task weights according to the clusters found.

These weights have been applied to evaluate the workload per aircraft for each sector. Then, the sector capacities have been evaluated using regression method described in the chapter 3. This has been achieved for each cluster and for each type of traffic (S15%, S33% and S66%).

4.6 Sector Capacity Changes

We compared the sector capacities for each sector:

- Difference between the baseline (S15%) and S33%,
- Difference between the baseline (S15%) and S66%

4.6.1 Overall sector capacity changes

The variations between S15% and S33% as well as variations between S15% and S66% have been observed and reported in Figure 6.

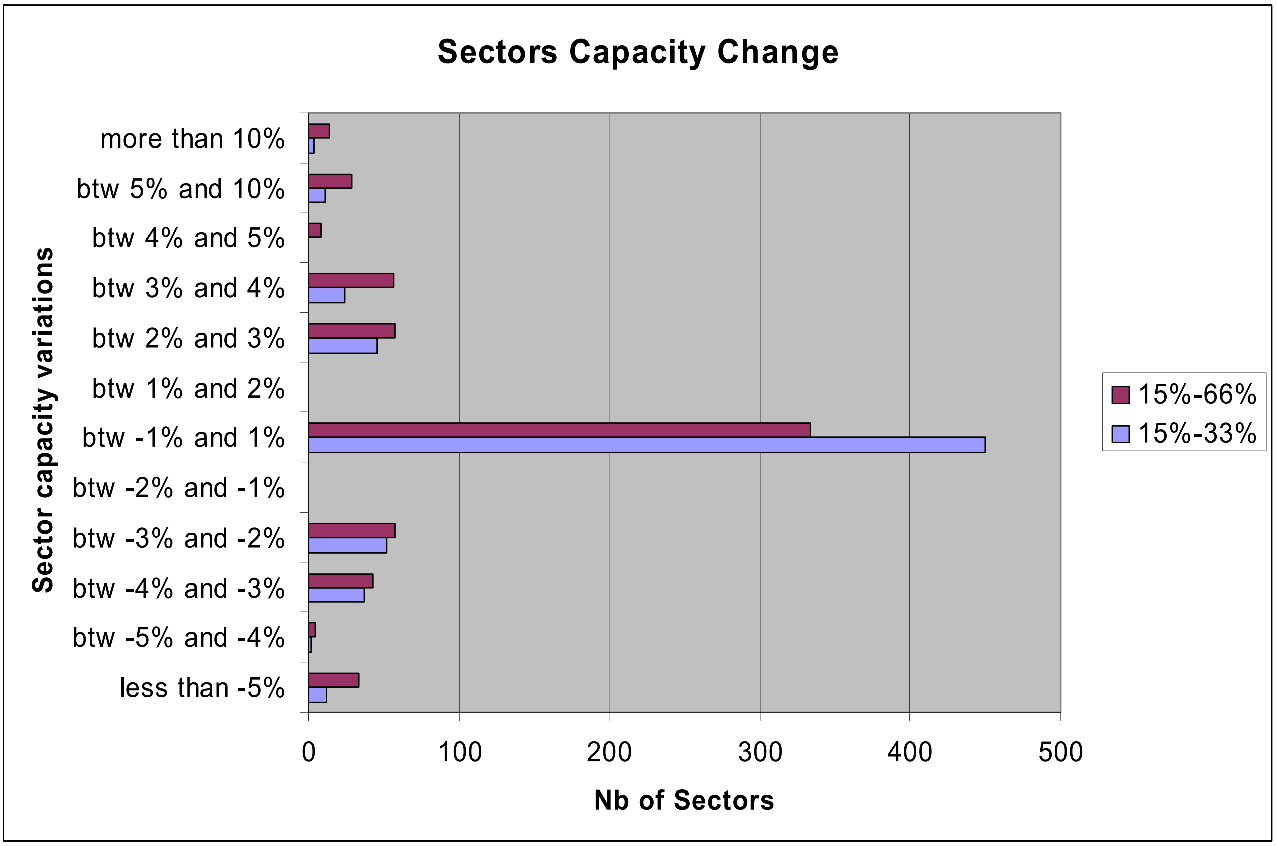


Figure 6: Sectors capacity changes

As observed on Figure 6, most of the sectors did not show any significant capacity change. For the sectors where capacity changes have been observed, the results were balanced between positive and negative variations:

When comparing S15% and S33% capacities:
- 16% of the sectors showed a capacity decrease less or equal to -2%;
- 70% of the sectors showed no capacity change;
- 14% of the sectors showed a capacity increase more or equal to 2%.

When comparing S15% and S66% capacities:
- 22% of the sectors showed a capacity decrease less or equal to -2%;
- 52% of the sectors showed no capacity change;
- 26% of the sectors showed a capacity increase more or equal to 2%.

4.6.2 Biggest sector capacity changes

The following tables (Table 6 and Table 7) show the sectors where the biggest sector capacity changes have been observed.

Sector capacity changes are smaller than -5%: for these sectors, the sector capacity has decreased for S33% compared to S15%.

Sector capacity changes are greater than 5%: for these sectors, the sector capacity has increased for S33% compared to S15%.

Centre	*Sector*	*Variation 15-33%*
nEDFLACC	nEDLHMML	*-15%*
LFMMACC	LFMST	*-13%*
EKDKACC	EKDKX	*-9%*
nEDMBACC08	nEDMMWRnew	*-8%*
EFESACC	EFESS2	*-8%*
LIBBACC	LIBBND4	*-8%*
EFESACC	EFESS4	*-7%*
EKDKACC	EKDKV	*-6%*
LUUUACC	LUUUS1	*-6%*
LFMMACC	LFMB2	*-5%*
LBSR08	LBSRSNL	*-5%*
LFFFACC	LFFTL	*-5%*
…		
EFPSACC	EFPSSN	*5%*
LFBBACC	LFBX2	*6%*
LJLAACC	LJLAUD	*6%*
ESMMACC	ESMM6	*6%*
EISNACC	EISNHGK	*6%*
nEDFLACC	nEDFW2_KIR	*6%*
LFFFACC	LFFTM	*6%*
LFMMACC	LFMF2	*8%*
LDZOACC	LDTA	*9%*
LIRRACC	LIRRTS1	*9%*
LGGGACC	LGGWML	*10%*
LBSR08	LBSRSNU	*11%*
LJLAACC	LJLALMD	*14%*
LIBBACC	LIBBSW1	*15%*
EKDKACC	EKDKS	*19%*

Table 6: Biggest capacity changes between S15% and S33%.

Sector capacity changes are smaller than -5%: for these sectors, the sector capacity has decreased for S66% compared to S15%.

Centre	*Sector*	*Variation 15-66%*
nEDFLACC	nEDLHMML	*-22%*
LFMMACC	LFMST	*-13%*
LFRRACC	LFRNI	*-12%*
EFESACC	EFESS4	*-11%*
nEDWWACC07	nEDWBDBAS	*-10%*
EKDKACC	EKDKV	*-9%*
EIDWACC	EIDWCTS	*-9%*
LGGGACC	LGGWMU	*-9%*
EKDKACC	EKDKX	*-9%*
LSATCG	LSAGMA	*-8%*
LAAAACC	LAAAMID	*-8%*
EFESACC	EFESS2	*-8%*
LBSR08	LBSRSNL	*-8%*
LFFFACC	LFFTL	*-8%*
EGTTACC	EG05BCN	*-8%*
LKAAACC	LKAANEU	*-8%*
nEDFLACC	nEDLLKAW	*-7%*

Sector capacity changes are greater than 5%: for these sectors, the sector capacity has increased for S66% compared to S15%.

ESMMACC	ESMMM	*-7%*
LECLAPP	LECLVALT	*-7%*
LFFFACC	LFFTE	*-7%*
nEDFLACC	nEDLLNOR	*-6%*
EKDKACC	EKDK4	*-6%*
nEDUBMUAC08	nEDUMSR4_CHIL08	*-6%*
ENNORTH	ENBDSE	*-6%*
LFFFACC	LFFOGY	*-6%*
LECBACC	LECBESUR	*-6%*
…		
LAAAACC	LJLAUD	*6%*
LFFFACC	LFBX2	*6%*
LIMMACC	EPWWJED	*6%*
LIBBACC	LIRRMIW	*6%*
EGPXACC	LECMSCA	*6%*
nEDFLACC	LFMM2	*6%*
LECBACC	LIRRMIE	*6%*
EGTTTC	LRMOPT	*6%*
LECSACC	nEDBTRG	*6%*
LFBBACC	LGMSKP	*6%*
LFFFACC	LDTA	*6%*
LIRRACC	LIBBND4	*6%*
nEDFLACC	nEDFO4_KTGneu	*6%*
LSATCG	EGTTTIM	*6%*
nEDWWACC07	LFRZS	*6%*
EFESACC	EGPXHUM	*6%*
EGTTACC	nEDMMWRnew	*6%*
ESMMACC	ESMM4	*7%*
nEDFLACC	nEDDSTR2_REU	*7%*
nEDUBMUAC08	nEDUUSLNHIGH	*7%*
EKDKACC	EKDKN	*8%*
LAAAACC	LAAAUPP	*8%*
LPPCACC	LPSOUTH	*8%*
GCCCACC	GCAPP	*9%*
LBSR08	LBSRSSL	*9%*
LFMMACC	LFMDD	*9%*
LFMMACC	LFMF2	*10%*
LIBBACC	LIBBSW1	*11%*
EFPSACC	EFPSSN	*11%*
LZBBACC	LZBBWU5	*11%*
LBSR08	LBSRSNU	*11%*
EKDKACC	EKDKS	*12%*
LFRRACC	LFRNU	*12%*
LIRRACC	LIRRTS1	*13%*
LJLAACC	LJLALMD	*14%*
nEDFLACC	nEDFO5_HABneu	*15%*
LGGGACC	LGGWML	*15%*
LBSR08	LBSRSEU	*21%*
UKHVACC	UKHVN1	*24%*
EFESACC	EFESS3	*24%*

Table 7: Biggest capacity changes between S15% and S66%.

4.7 Remarks

We have listed the most important hypotheses made for this study:

4.7.1 DMEAN hypotheses

1. *One day of the sample has been used for assessing the changes in sector capacities for the different types of traffic (difference between S15% and S33% and difference between S15% and S66%). The same capacities changes have been applied to the 13 other days of the sample in the FAP process;*

2. *The whole COCA methodology has been applied to the baseline traffic. Then, with taking into account the results found on the baseline (clusters and corresponding weights in the workload formula), the sector capacities ONLY have been assessed for the 2 remaining traffic samples S33% and S66%.*

4.7.2 COCA methodology hypotheses

1. *We assume the sector reference capacities to be valid (the ones recorded in situ do not necessarily correspond to the ones published in the CFMU files);*

2. *The workload evaluation is supposed to be correctly estimated when sectors studied are "loaded" enough. Indeed, we can give a good sector capacity estimation only when sector workload high enough;*

3. *The workload evaluated corresponds to executive controller's workload;*

4. *The workload assessed using this method is an objective value which needs to be checked and validated by operational experts.*

5. Delay forecast - Results

5.1 Delay forecast, Medium Scenario

5.1.1 DMEAN scenario: 15% use of CDRs

5.1.1.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the DMEAN baseline context for the Statfor medium traffic growth hypothesis.

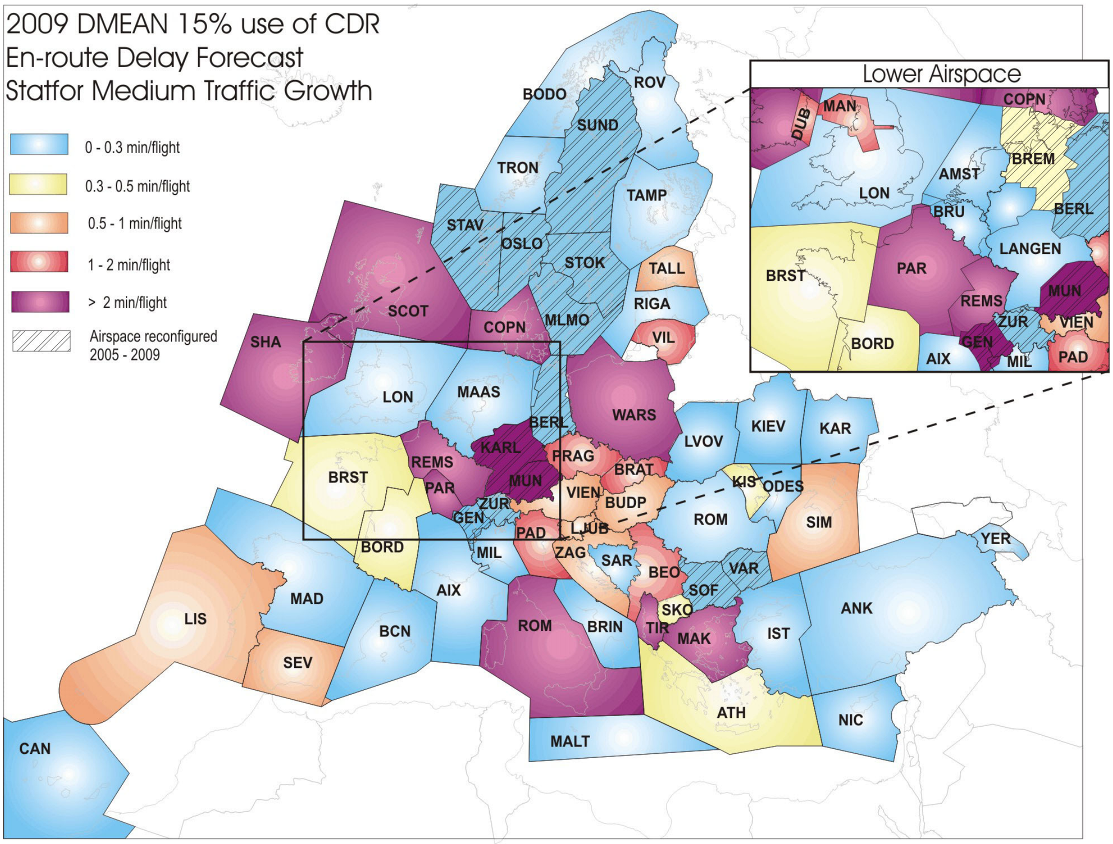


Figure 7: 2009 DMEAN 15% use of CDR delay forecast (Statfor Medium Scenario).

5.1.1.2 ECAC results

Traffic growth hypothesis Medium

Delay per flight	**DMEAN 2009 (15% use of CDR)**
En route delay	2.2
Total delay (en route + airports)	4

5.1.2 DMEAN scenario: 33% use of CDRs

5.1.2.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the context of this re-routings scenario (33% utilisation of CDRs instead of 15%) for the Statfor medium traffic growth hypothesis.

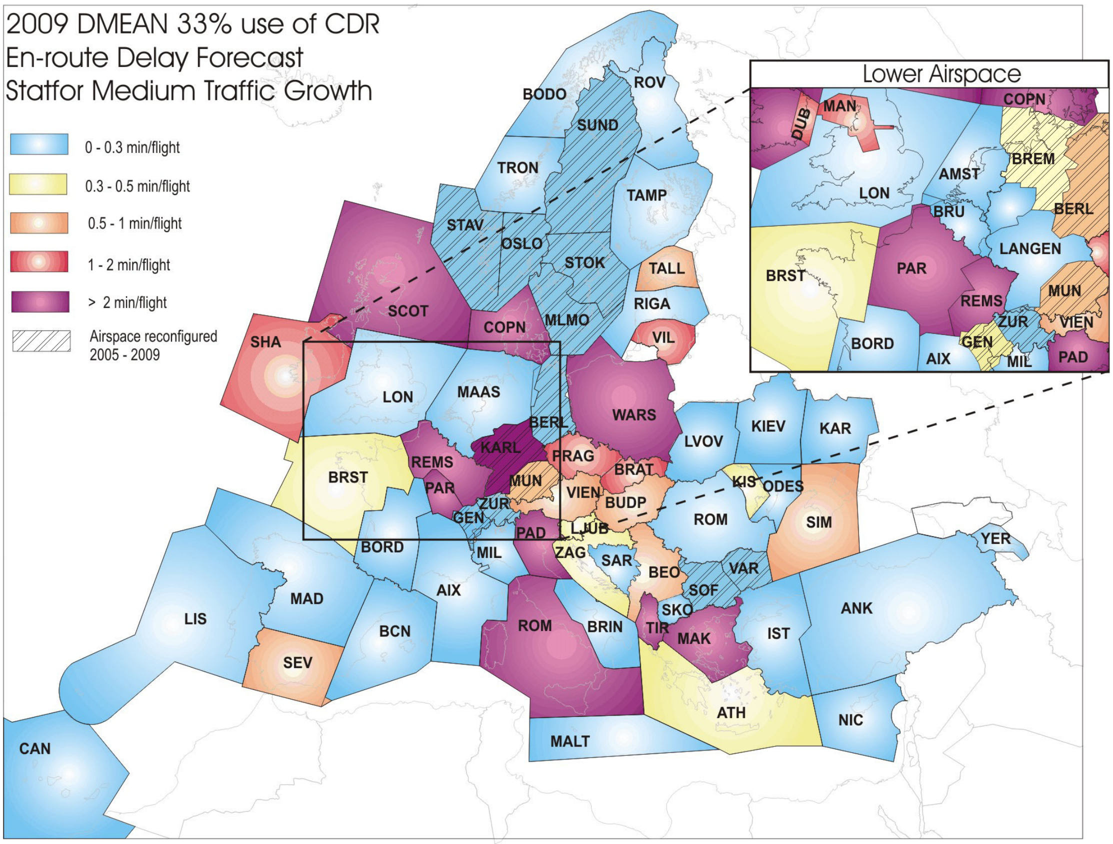


Figure 8: 2009 DMEAN 33% use of CDR delay forecast (Statfor Medium Scenario).

5.1.2.2 ECAC results

Traffic growth hypothesis Medium

Delay per flight	**DMEAN 2009 (15% use of CDR)**	**DMEAN 2009 (33% use of CDR)**
En route delay	2.2	1.8
Total delay (en route + airports)	4	3.6

5.1.3 DMEAN scenario: 66% use of CDRs

5.1.3.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the context of this re-routings scenario (66% utilisation of CDRs instead of 15%) for the Statfor medium traffic growth hypothesis.

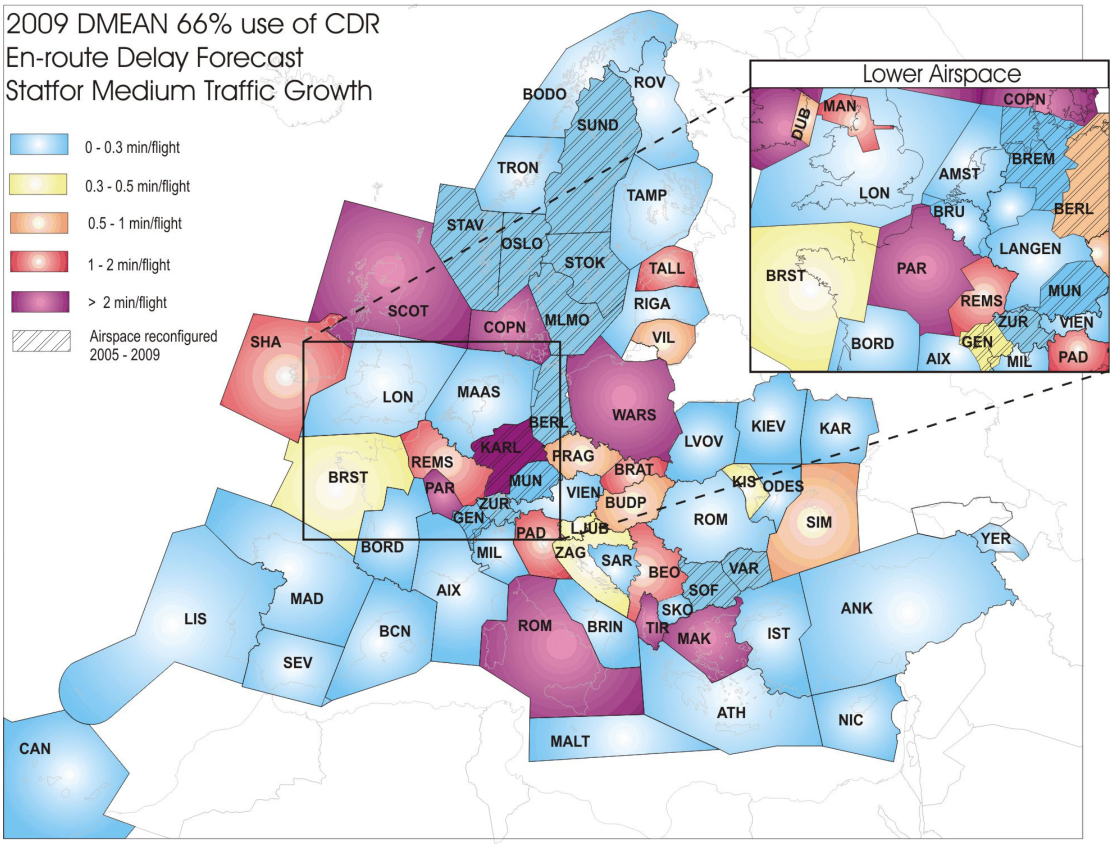


Figure 9: 2009 DMEAN 66% use of CDR delay forecast (Statfor Medium Scenario).

5.1.3.2 ECAC results

Traffic growth hypothesis Medium

Delay per flight	**DMEAN 2009 (15% use of CDR)**	**DMEAN 2009 (66% use of CDR)**
En route delay	2.2	1.2
Total delay (en route + airports)	4	3.1

5.2 Delay forecast, High Scenario

5.2.1 DMEAN scenario: 15% use of CDRs

5.2.1.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the DMEAN baseline context for the Statfor high traffic growth hypothesis.

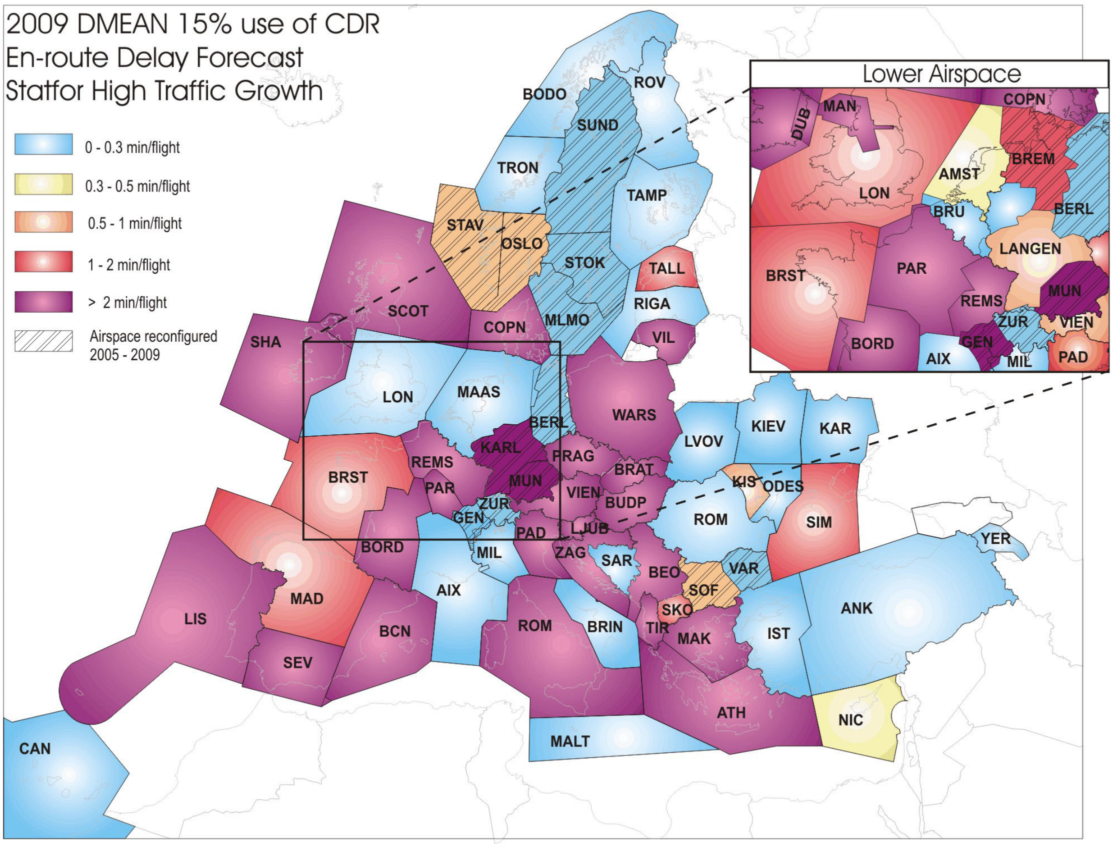


Figure 10: 2009 DMEAN 15% use of CDR delay forecast (Statfor High Scenario).

5.2.1.2 ECAC results

Traffic growth hypothesis High

Delay per flight	**DMEAN 2009 (15% use of CDR)**
En route delay	2.8
Total delay (en route + airports)	6.1

5.2.2 DMEAN scenario: 33% use of CDRs

5.2.2.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the context of this re-routings scenario (33% utilisation of CDRs instead of 15%) for the Statfor high traffic growth hypothesis.

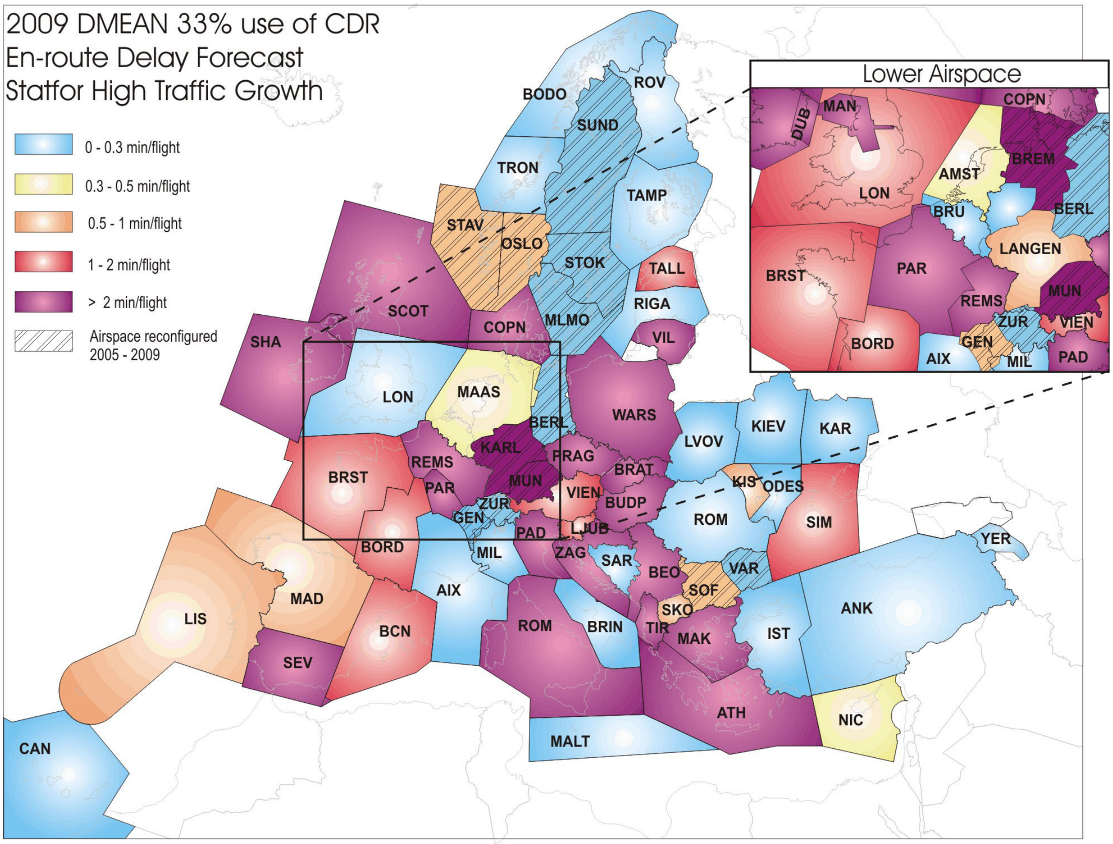


Figure 11: 2009 DMEAN 33% use of CDR delay forecast (Statfor High Scenario).

5.2.2.2 ECAC results

Traffic growth hypothesis High

Delay per flight	**DMEAN 2009 (15% use of CDR)**	**DMEAN 2009 (33% use of CDR)**
En route delay	2.8	2.3
Total delay (en route + airports)	6.1	5.4

5.2.3 DMEAN scenario: 66% use of CDRs

5.2.3.1 Delay distribution

The map below gives an indication of the delay forecast at ACC level for 2009, in the context of this re-routings scenario (66% utilisation of CDRs instead of 15%) for the Statfor high traffic growth hypothesis.

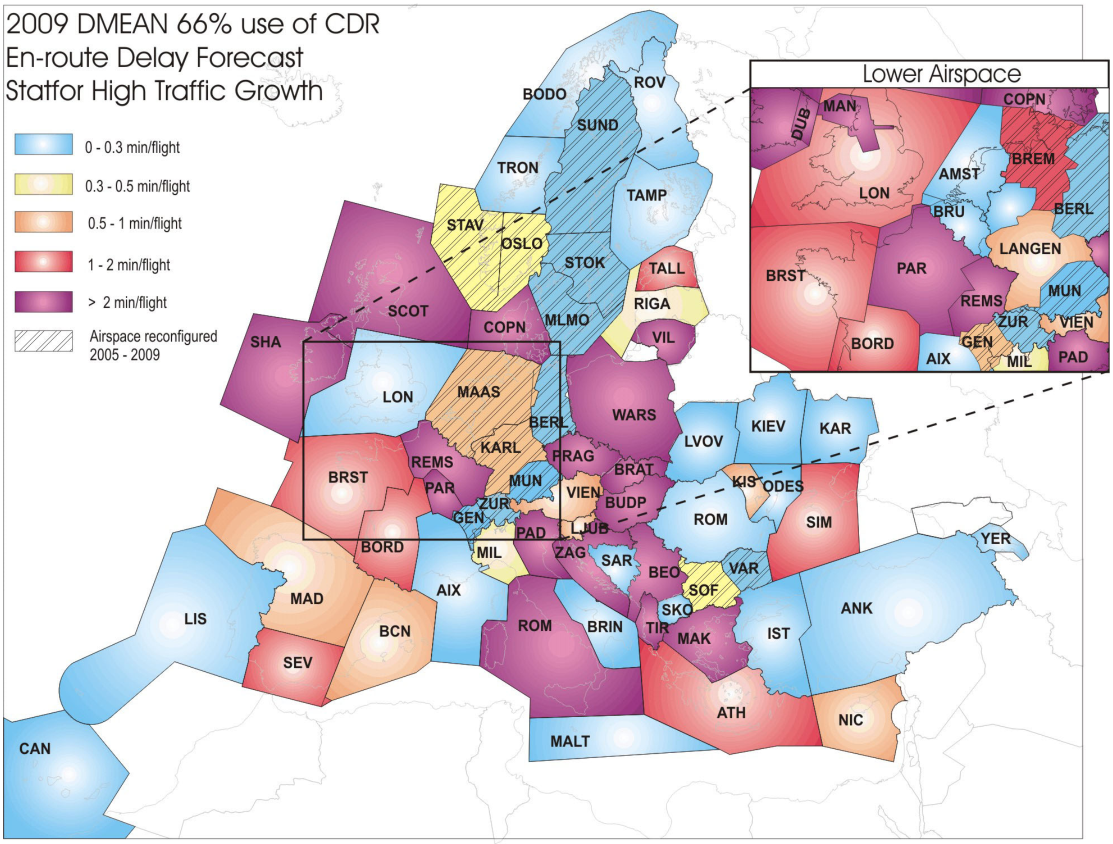


Figure 12: 2009 DMEAN 66% use of CDR delay forecast (Statfor High Scenario).

5.2.3.2 ECAC results

Traffic growth hypothesis High

Delay per flight	DMEAN 2009 (15% use of CDR)	DMEAN 2009 (66% use of CDR)
En route delay	2.8	2
Total delay (en route + airports)	6.1	5.3

5.3 Delay forecast conclusion - benefits

5.3.1 Route length

In the context of the 2009 DMEAN benefits study, 4 scenarios were simulated depending upon the percentage of CDRs usage:

- S15%, is the reference scenario and reflect the currently observed figure of CDR usage (15%)
- S33% and S66% are low and high scenarios after implementation of DMEAN,
- S100% is the shortest route scenario (the one used in the EUROPEAN MEDIUM TERM ATM NETWORK CAPACITY PLAN 2006-2009 issued by CEF in July 2005).

The tables below highlight the route length reduction from the scenario 0% (no use of CDRs) for the entire ECAC and the average en-route delay per flight for each ACC and for ECAC.

Table 8 - Route length reduction in DMEAN context.

Route length REDUCTION from S0%			
S15%	**S33%**	**S66%**	**S100%**
0.08%	0.18%	0.36%	0.57%

5.3.2 Delay

The assessment of DMEAN benefits, in terms of Centre delay, highlighted imbalance between expected traffic demand and the retained capacity plans (prior to summer 2005) for several Centres where a 15% use of CDRs in 2009 (i.e. DMEAN baseline) would lead to unrealistic delay. In order to reflect an operational reality, those Centres have been removed from the simulations. There are also uncertainties due to the traffic samples used. There are not optimized at the network level concerning the CDRs usage. In this context the delay forecast using the Statfor medium growth hypothesis seems to present the more reliable picture for the 2009 DMEAN benefits. Results of those simulations are presented below.

The following table highlights the average en-route delay per flight for ECAC. A table with the average delay per flight for each ACC is provided in annex 1.

Table 9 - Average en-route delay per flight.

ECAC delay per Flight (in minutes)		
S15%	**S33%**	**S66%**
2.2	1.8	1.2

The chart below gives an overview of the delay distribution in terms of number of Centres for each DMEAN scenarios (15%, 33% and 66%).

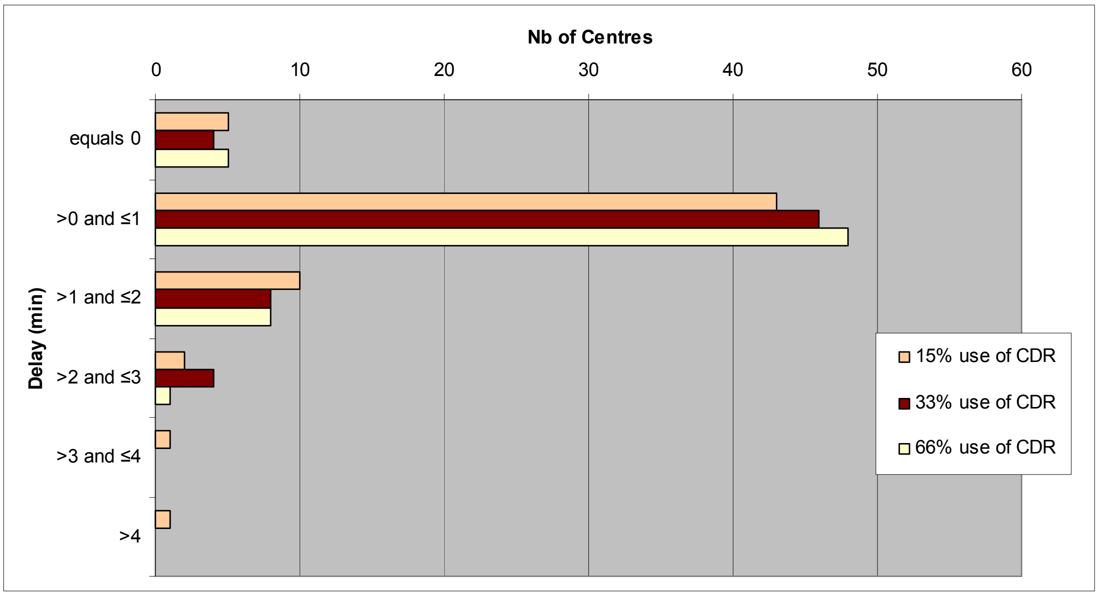


Figure 13: Delay distribution by DMEAN scenarios.

The chart below gives an overview of the Centre capacity increase distribution for each DMEAN re-routing scenarios (33% and 66%) compared to the 2009 DMEAN baseline (15%). The complete list of Centre capacity for all scenarios is provided in annex 2.

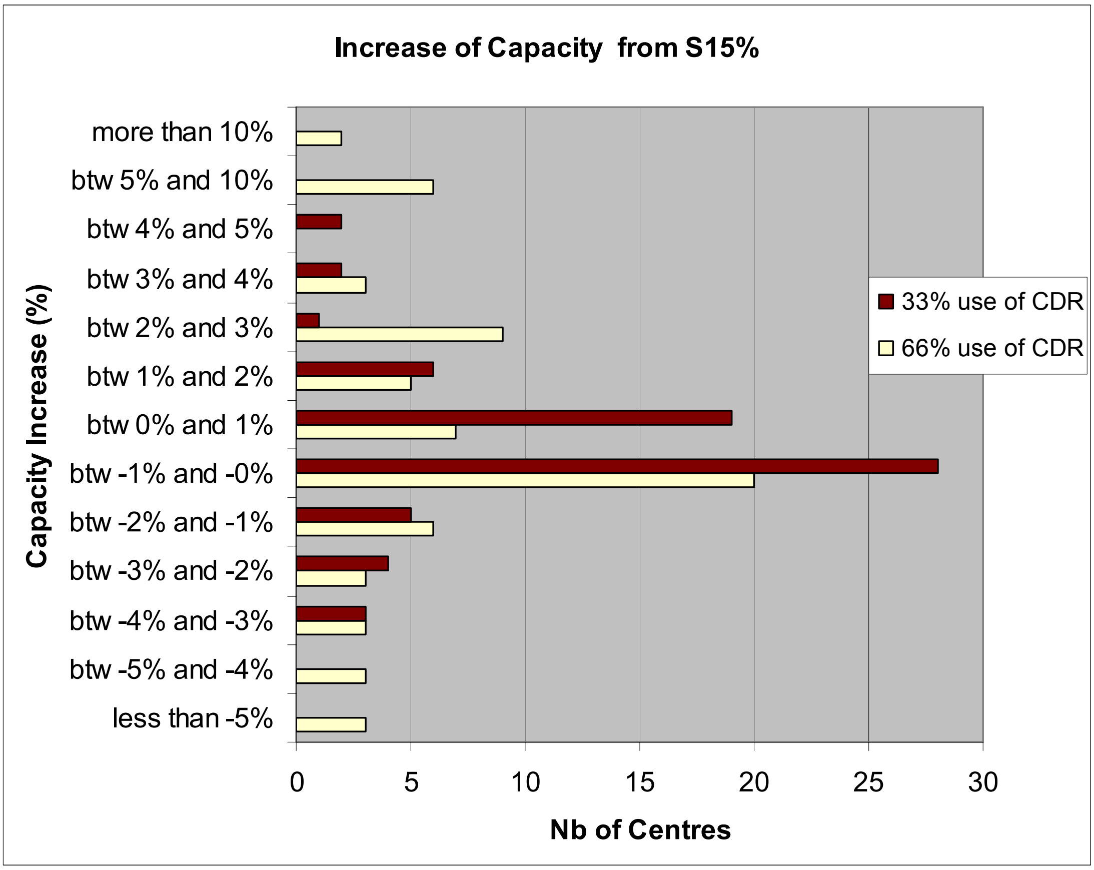


Figure 14: Increase of capacity from the 2009 DMEAN baseline.

6. Conclusion and Follow-up

A methodology to assess the expected benefits of a better use of CDRs has been developed. It particular, the use of COCA to evaluate sector capacity variations provided interesting results which could have been translated in forecast delay variations, using PACT and GASEL.

The results in terms of delay reduction are conservative for the following reasons:

- ACCs with un-realistic delay in S15% were removed from the simulated area.
- The traffic samples were not optimised: an even and random use of CDRs was simulated.

Therefore, the use of these results can be used initially as input in a CBA.

It is proposed to conduct an other study with the following improvements:

- Various enhancements of the methodology.
- Use of optimised traffic samples. This optimisation could be done automatically, using SAAM, or manually by operational experts. The results in terms of capacity variations, both at sector and centre levels, can provide a significant help to such a process.
- Update of the ACC capacity figures: 2005 baselines and LCIPs up to 2010 are now available.

• References

[1] Pessimistic Sector Capacity Estimation, EEC note N° 21/03, G. M. Flynn, A. Benkouar, R. Christien, Web link: `http://www.eurocontrol.int/eec/gallery/content/public/documents/EEC_notes/2003/EEC_note_2003_21.pdf`

[2] Adaption of Workload Model by Optimisation Algorithms and Sector Capacity Assessment, G. M. Flynn, A. Benkouar, R. Christien, Web link: `http://www.eurocontrol.int/eec/public/standard_page/2005_note_07.html).`

[3] Air Traffic Complexity: Potential Impacts on Workload and Cost, T. Chaboud (EEC), R. Hunter (NATS), J. C. Hustache (EEC), S. Mahlich (EEC), P. Tullett (NATS), EEC note issued in July 2000. Web link: `http://www.eurocontrol.int/eec/public/standard_page/2000_note_11.html`

[4] RAMS Plus Data Manual, Release 5.08, March 2004, Gate-To-Gate ATM Operations

[5] Air Traffic Complexity Indicators & ATC Sectors Classification, R. Christien, A. Benkouar, 5th USA/Europe Air Traffic Management R&D Seminar, June 2003, Budapest, Hungary

ANNEX 1: average delay per flight for each ACC

The table below presents the average delay per flight for each ACC, elaborated with the Statfor medium traffic growth forecast hypothesis.

ACC delay per Flight (in minutes)			
ACC	**S15%**	**S33%**	**S66%**
EBBUACC	0.0	0.0	0.02
EDYYACC	0.0	0.1	0.09
EETTACC	0.9	1.0	1.18
EFESACC	0.1	0.1	0.14
EFPSACC	0.0	0.0	0.00
EGCCACC	1.4	1.4	1.09
EGTTACC	0.0	0.0	0.02
EGTTTC	0.3	0.2	0.31
EHAAACC	0.1	0.1	0.04
EIDWACC	1.1	1.2	0.65
EISNACC	3.6	1.7	1.56
EKCHAPP	0.0	0.1	0.06
ENNORTH	0.1	0.1	0.14
ENSOUTH	0.3	0.2	0.16
ESMMACC	0.0	0.0	0.00
ESOSNEW	0.0	0.0	0.00
EVRRACC	0.1	0.3	0.34
EYVCACC	1.3	1.2	0.75
GCCCACC	0.1	0.1	0.06
LBSR08	0.3	0.3	0.11
LCCCACC	0.3	0.2	0.25
LDZOACC	0.7	0.5	0.47
LECBACC	0.2	0.1	0.09
LECMACC	0.1	0.1	0.04
LECPACC	0.5	0.3	0.16
LECSACC	0.8	0.6	0.32
LFBBACC	0.4	0.3	0.26
LFEEACC	2.7	2.7	1.69
LFMMACC	0.0	0.0	0.01
LFRRACC	0.4	0.5	0.41
LGGGACC	0.4	0.4	0.26
LHCCACC	1.0	1.0	0.78
LIBBACC	0.0	0.0	0.01
LIMMACC	0.0	0.0	0.09
LIPPACC	1.9	2.9	1.32
LIRRACC	4.4	2.3	2.24
LJLAACC	0.6	0.5	0.18
LKAAACC	1.9	2.0	0.77
LMMMACC	0.0	0.1	0.02
LOVVACC	0.6	0.6	0.21
LPPCACC	0.7	0.2	0.10
LRBBACC	0.0	0.0	0.01
LSATCG	3.0	0.5	0.43

LSATCZ	0.0	0.0	0.03
LSAUAC	0.0	0.0	0.01
LTAAACC	0.0	0.0	0.00
LTBBACC	0.0	0.0	0.05
LTBJAPP	1.2	1.4	1.51
LUUUACC	0.4	0.5	0.51
LWSSACC	0.5	0.3	0.19
LYBAACC	1.4	1.0	1.54
LZBBACC	1.4	1.2	1.23
nEDFLACC	0.2	0.3	0.23
nEDMBACC08	1.5	1.0	0.02
nEDWWACC07	0.5	0.9	0.13
UBBBACC	0.0	0.0	0.00
UDDDACC	0.0	0.0	0.00
UKBVACC	0.0	0.0	0.02
UKFVACC	0.8	0.8	0.85
UKHVACC	0.1	0.1	0.08
UKLVACC	0.0	0.0	0.01
UKOVACC	0.0	0.0	0.00

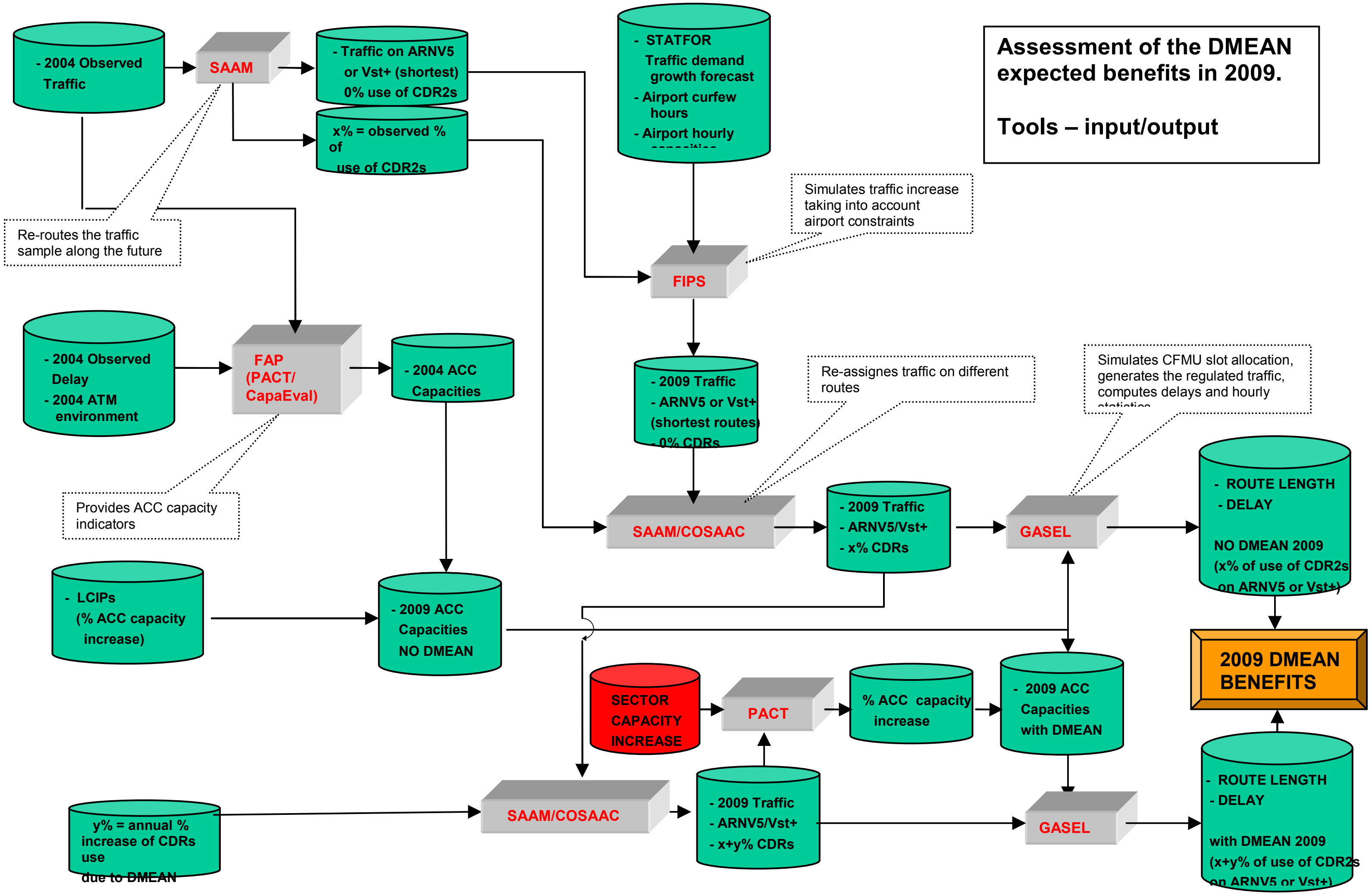
ANNEX 2: ACC capacity

The table below presents the 2009 ACC planned capacities. The capacities in S100% correspond to the LCIPs, the figures in the other scenarios have been derived using the complexity of the traffic at sector level.

ACC	Capacity S15%	Capacity S33%	Capacity S66%	Capacity S100%
EBBUACC	153	153	157	158
EDYYACC	348	335	329	317
EETTACC	37	37	37	37
EFESACC	61	60	59	58
EFPSACC	25	25	25	25
EGCCACC	147	147	146	146
EGPXACC	142	146	150	155
EGTTACC	419	420	413	413
EGTTTC	282	283	280	281
EHAAACC	143	144	147	148
EIDWACC	65	63	63	61
EISNACC	93	94	98	98
EKCHAPP	83	83	83	83
EKDKACC	110	115	123	128
ENNORTH	53	53	52	52
ENSOUTH	90	89	91	91
EPWWACC	90	91	91	93
ESMMACC	178	176	162	161
ESOSNEW	161	156	151	146
EVRRACC	52	52	52	52
EYVCACC	45	45	45	45
GCCCACC	82	81	80	79
LAAAACC	40	41	44	44
LBSR08	116	117	118	119
LCCCACC	61	61	61	61
LDZOACC	147	149	151	153
LECBACC	194	195	200	201
LECMACC	224	224	225	225
LECPACC	96	93	94	91
LECSACC	90	91	93	93
LFBBACC	195	197	197	198
LFEEACC	175	173	182	180
LFFFACC	252	265	278	292
LFMMACC	288	284	277	274
LFRRACC	203	200	199	196
LGGGACC	116	116	118	119
LGMDACC	66	69	72	74
LHBPAPP	40	40	40	40
LHCCACC	140	140	140	140
LIBBACC	122	122	116	116
LIMMACC	179	178	171	170
LIPPACC	150	151	159	160

LIRRACC	226	228	227	228
LJLAACC	94	95	96	97
LKAAACC	151	149	152	150
LMMMACC	36	36	37	37
LOVVACC	212	208	211	207
LPPCACC	96	94	95	94
LRBBACC	153	151	153	152
LSATCG	86	88	88	90
LSATCZ	151	145	143	138
LSAUAC	173	175	178	180
LTAAACC	142	140	140	139
LTBBACC	113	112	111	111
LTBJAPP	52	52	52	52
LUUUACC	25	25	25	25
LWSSACC	78	78	80	80
LYBAACC	137	137	133	133
LZBBACC	90	90	90	90
nEDFLACC	278	276	274	272
nEDMBACC08	227	229	234	237
nEDUBMUAC08	325	333	356	366
nEDWWACC07	141	141	144	144
UBBBACC	52	52	52	52
UDDDACC	25	25	25	25
UKBVACC	68	68	68	68
UKFVACC	52	52	52	52
UKHVACC	45	45	45	45
UKLVACC	57	57	57	57
UKOVACC	59	59	59	59

ANNEX 3: Tools diagram



Assessment of the DMEAN expected benefits in 2009.

Tools – input/output

- 2004 Observed Traffic

SAAM

- Traffic on ARNV5 or Vst+ (shortest) 0% use of CDR2s

x% = observed % of use of CDR2s

Re-routes the traffic sample along the future

- STATFOR Traffic demand growth forecast
- Airport curfew hours
- Airport hourly

Simulates traffic increase taking into account airport constraints

FIPS

- 2004 Observed Delay
- 2004 ATM environment

FAP (PACT/ CapaEval)

- 2004 ACC Capacities

Provides ACC capacity indicators

- 2009 Traffic
- ARNV5 or Vst+ (shortest routes)
- 0% CDRs

Re-assignes traffic on different routes

Simulates CFMU slot allocation, generates the regulated traffic, computes delays and hourly

SAAM/COSAAC

- 2009 Traffic
- ARNV5/Vst+
- x% CDRs

GASEL

- ROUTE LENGTH
- DELAY

NO DMEAN 2009 (x% of use of CDR2s on ARNV5 or Vst+)

- LCIPs (% ACC capacity increase)

- 2009 ACC Capacities NO DMEAN

2009 DMEAN BENEFITS

SECTOR CAPACITY INCREASE

PACT

% ACC capacity increase

- 2009 ACC Capacities with DMEAN

y% = annual % increase of CDRs use due to DMEAN

SAAM/COSAAC

- 2009 Traffic
- ARNV5/Vst+
- x+y% CDRs

GASEL

- ROUTE LENGTH
- DELAY

with DMEAN 2009 (x+y% of use of CDR2s on ARNV5 or Vst+)