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AIRSPACE COMPLEXITY FOR REGULATORY PURPOSES - PART I

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Abstract

The EEC initiated a study in 2007, on request of the Regulatory Unit, with the objective to investigate a possible link between airspace complexity and the applicability of implementing rules.

The objectives of this study were:

- to investigate if it is possible to determine airspace complexity criteria/indicators for selecting the parts of the airspace in which new functions (e.g. data-link) could be **mandated**;
- If so, to make proposals to RU in terms of complexity criteria/indicators which could be used in Implementing Rules.

In part I of the report and account is given of the review of relevant complexity indicators.

In part II, the results are given of a specific potential application to the Analysis of the relationship between the percentage of 8.33 kHz converted frequencies and airspace complexity.

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EXECUTIVE SUMMARY

The EEC initiated a study in 2007, on request of the Regulatory Unit, with the objective to investigate a possible link between airspace complexity and the applicability of implementing rules.

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- If so, to make proposals to RU in terms of complexity criteria/indicators which could be used in Implementing Rules.

The work initially consisted in:

- a review of relevant work undertaken by EEC 'Network' unit for PRU (complexity indicators at macroscopic level) and at MUAC (complexity indicators used to characterise a sector complexity from an operational perspective-Sector Id card);
- a potential extension of the analytical work conducted at MUAC on more operational complexity indicators;
- an assessment of the feasibility of extracting from the above complexity indicators, criteria/elements which could be useful from a regulatory perspective;
- a validation of the use of the proposed set of complexity indicators on one or two examples (e.g., data link Implementing Rule);
- the development of recommendations for the phased implementation of complexity indicators in Implementing Rules

This report presents the results of this study.

In part I of the report and account is given of the review of relevant complexity indicators.

In part II, the results are given of a specific potential application to the Analysis of the relationship between the percentage of 8.33 kHz converted frequencies and airspace complexity.

A high number of COCA indicators appeared to be sensitive to the implementation of the different C/N/S functions studied. The sensitivity of the complexity indicators is highly linked to a function and to the type of airspace in which this function is supposed to be implemented.

The determination of the "best" linear function (above-mentioned step 4) aiming at linking the percentage of 8.33 kHz frequencies converted of the ACC according to their complexity parameters required a lot of trials. The best "possible" relationship (in terms of mathematical significance) emerged from the consideration of the congestion factor within the model (see Part II Section 6.2). This relationship was not fully satisfactory because the correlation coefficient (R^2) remained quite low (0.67). Due to the poor information available in the context of this study, the output remained limited.

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1. INTRODUCTION

The objective of this report is to provide the results of a review of the **indicators** developed and used in previous Complexity and Capacity (COCA) studies in order to define possible **criteria** for selecting the parts of the airspace in which new functions (e.g. data-link) could be subject to implementing rule, and; how such criteria could be progressively implemented.

1.1. DOCUMENT STRUCTURE

The remainder of this document is organised as follows:

- Section 2 begins the literature review with an overview of COCA project findings. Two complexity studies are presented in details: the COCA-Performance Review Unit (PRU) complexity metrics study dedicated to the definition of a set of high level complexity indicators and the Maastricht Upper Airspace Control Centre (MUAC) complexity study, an operational analysis of the Maastricht Centre.
- Section 3 summarizes in a table the list of indicators found in the previous section. The aim of this section is to group the indicators under complexity "areas", and to map each area on specific domains linked with Communication, Navigation and Surveillance (C/N/S).
- Section 0 discusses the links between complexity indicators and C/N/S subjects.
- Section 5 gives recommendations about the elements to be careful with.

1.2. THE LITERATURE REVIEW

The RU proposed this review should focus on COCA work only and more especially should investigate two important complexity studies.

1.3. BACKGROUND

In support of the implementation of the SES, the RU has to draft the regulatory material and to run the formal consultation processes for most implementing rules. The draft implementing rule document is generally developed in parallel with a justification material document. The latter has the role to identify the impact on stakeholders in terms of safety, efficiency, civil-military coordination, etc…and to compare the situation before with the expected situation after the application of the rule. The major changes to the rule following the consultation may lead to changes to the justification material.

One of the important points of both documents is to define the airspace of applicability, in other words, the area of deployment of a function. Here is an example of the definition of airspace of applicability for Data Link Services (DLS) (see Draft[1] implementing rule prepared by EUROCONTROL in response to a European Commission's request, laying down requirements on Data Link Services for the Single European Sky):

Article 1:

[1] This draft that still has to be reviewed/approved by the EC through the commitology procedure.

[…]

(3) This Regulation shall apply to all flights operating as general air traffic in accordance with instrument flight rules within:

(a) the airspace above FL285 defined in Annex I Part A;

(b) From 5 February 2015, the airspace above FL285 defined in Annex I Part B.

[…]

ANNEX I

PART A

The airspace referred to in Articles 1 (3) a) shall include the airspace above FL 285 within the following Flight Information Regions (FIR) and Upper Flight Information Regions (UIR):

- *Amsterdam FIR, Wien FIR, Barcelona UIR, Brussels UIR, Canarias UIR, France UIR, Hannover UIR, Lisboa UIR, London UIR, Madrid UIR, Milano UIR, Rhein UIR, Roma UIR, Scottish UIR and Shannon UIR*

PART B

The airspace referred to in Articles 1 (3) b) shall include the airspace above FL 285 within the following Flight Information Regions (FIR) and Upper Flight Information Regions (UIR):

- *Bratislava FIR, Bucuresti FIR, Budapest FIR, Kobenhavn FIR, Ljubljana FIR, Nicosia FIR, Praha FIR, Sofia FIR, Warszawa FIR, Finland UIR south of 61°30', Hellas UIR, Malta UIR, Riga UIR, Sweden UIR south of 61°30', Tallinn UIR, Varna FIR, Vilnius UIR,*

It is generally very difficult to explicitly define the geographic coverage of an implementing rule and the RU considers useful to use implementing rules expressed via specific criteria like "traffic load", "traffic complexity" for characterising the zone of applicability. Morevover, with eliciting indicators to measure such criteria and defining quantitative thresholds for these indicators, it could become possible to select geographical airspace matching---objectively---the criteria.

Indicator and criterion:

To begin with, we would like to explain how "indicators" and "criteria" can be linked. A definition[2] for indicator is: "an indicator quantifies and simplifies phenomena and helps us understand complex realities. Indicators are aggregates of raw and processed data but they can be further aggregated to form complex indices".

A criterion is: "a standard, rule, or test on which a judgment or decision can be based".

A natural link between indicator and criterion can be expressed. In effect, indicators are quantifiable measurements that reflect the critical success factors of an organization. With defining a target value (α), an indicator may meet the criteria of reflecting the organizational target.

In this document, we will identify the possible indicators to be used for implementing rules. Let A be an indicator and B be a function. More explicitly, we make an attempt to define the (A,B) pairs in the following statement:

"In the areas where the complexity indicator A equals/is greater than/is less than α apply the function B". Our goal is not to provide the RU with the target value (α). The latter would have to be defined by the RU, during the development of the regulatory material.

[2] Definition given by the International Institute for Sustainable Development (IISD).

1.4. GLOSSARY OF TERMS

4D	Four dimensions
ACC	**A**rea **C**ontrol **C**entre
ACE	**A**TM **C**ost **E**ffectiveness
ADS-B	**A**utomatic **D**ependant **S**urveillance **B**roadcast
AMWM	**A**dapted **M**acroscopic **W**orkload **M**odel
ANSP	**A**ir **N**avigation **S**ervice **P**rovider
ATC	**A**ir **T**raffic **C**ontrol
ATFCM	**A**ir **T**raffic **F**low and **C**apacity **M**anagement
ATFM	**A**ir **T**raffic **F**low **M**anagement
ATM	**A**ir **T**raffic **M**anagement
BADA	**B**ase of **A**ircraft **D**ata
CAA	**C**ivil **A**viation **A**uthority
CENA	**C**entre d'**É**tudes de la **N**avigation **A**érienne
CFMU	**C**entral **F**low **M**anagement **U**nit
C/N/S	Communication, **N**avigation and **S**urveillance
COCA	**Co**mplexity and **Ca**pacity
COLA	**Co**mplexity **L**ight **A**nalyser
DD	**D**ynamic **D**ensity
DFS	**D**eutsche **F**lug**s**icherung
DLS	**D**ata **L**ink **S**ervices
ECAC	**E**uropean **C**ivil **A**viation **C**onference
EEC	**E**urocontrol **E**xperimental **C**entre
FIR	**F**light **I**nformation **R**egions
GAT	**G**eneral **A**ir **T**raffic
GPS	**G**lobal **P**ositioning **S**ystem
HDIF	Potential **H**orizontal **D**ifferent **I**nteracting **F**lows
ICAO	**I**nternational **C**ivil **A**viation **O**rganization
ID	**Id**entity
IFR	**I**nstrument **F**light **R**ules
FL	**F**light **L**evel
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
MUAC	**M**aastricht **U**pper **A**irspace **C**ontrol Centre
NATS	**N**ational **A**ir **t**raffic **S**ervices UK
NET	**Net**work
OAT	**O**perational **A**ir **T**raffic
PRC	**P**erformance **R**eview **C**ommission
PRU	**P**erformance **R**eview **U**nit

RAMS	**R**eorganised **A**TC **M**athematical **S**imulator
RNAV	Area **nav**igation
RNP	**R**equired **N**avigation **P**erformance
RVSM	**R**educed **V**ertical **S**eparation **M**inimum
SDER	**S**ous-**D**irection **E**tudes et **R**echerche appliquée (formerly CENA)
SDIF	Potential **S**peed **D**ifferent **I**nteracting **F**lows
SES	**S**ingle **E**uropean **S**ky
VDIF	Potential **V**ertical **D**ifferent **I**nteracting **F**lows
RU	**R**egulatory **U**nit
TMA	**T**er**m**inal **A**rea
UIR	**U**pper **F**light **I**nformation **R**egion
WG	**W**orking **G**roup
WX	**W**eather

2. COCA LITERATURE REVIEW

2.1. COMPLEXITY

At the end of the nineties, the ATFM studies, the Airspace Design studies, the ATM Performance & Efficiency studies, and the Economical studies for ATM, regularly expressed some needs in terms of evaluation of Air Traffic Complexity and Capacity of Volumes of airspace, at the level of route segments, crossing point, sectors, centres, or even states. These evaluations were requested to be achieved either on air traffic demand, or on actual air traffic, or on both. In some cases, the requests involved comparisons of the measurements in different pieces of airspace (e.g. USA/Europe) or under different conditions (e.g. RVSM). In other cases the requests involved defining statistical correlations between different complexity indicators.

To satisfy these requests, the EEC has set up a project in 2001 under the name of COCA, standing for “COmplexity and CApacity” Analysis.

The goal of COCA is to analyse the relationship between complexity, controller workload, sector type and capacity. This is achieved by designing relevant complexity indicators and capacity evaluators, and to use them for specific requests expressed by the customers.

The COCA complexity indicators include a number of generally accepted factors relating to static airspace factors, traffic flows and traffic mix. The COCA project has expanded upon these and developed new composite indicators and ones that capture temporal and spatial aspects of traffic density, concentration and interaction of flights.

The COCA macroscopic sector controller workload models are constructed by linking the controller’s tasks directly to the complexity indicators. Using statistical classification methods, sectors are first clustered into groups sharing common complexity characteristics. Traffic criteria are then linked to the workload of the task associated with the flight. This evaluation is further refined by applying weighting factors correlated with each sector type.

The COCA indicators are mainly tailored for en-route airspace. As a consequence, they could not be directly used for assessing complexity in other types of airspace (especially for TMA, airport…) without a validation phase.

2.2. USE OF COCA INDICATORS FOR PERFORMANCE REVIEW

The COCA approach was adopted by EUROCONTROL and the member states as the benchmark against which complexity is measured and expressed in the context of the work performed by the Performance Review Unit.

2.2.1. Context

The **ATM Cost-Effectiveness (ACE) Working Group** (see reference [1]) defined a set of high level complexity indicators to be used for ANSP benchmarking purposes. The working group, consisting of representatives of ANSPs, CAAs, airspace users, the PRU, the PRC and the EEC, set out to develop a set of primarily macroscopic (for ANSP and ACC) indicators to capture the external factors that impact controller workload and complexity, without considering the internal, ATC procedures-related factors.

The Working Group (WG) first worked on the definition of “complexity” and found three main factors to define complexity:

- Traffic Characteristic Complexity (traffic density, traffic in evolution, flow structure, traffic mix),

- Airspace Complexity (sectorisation, route structure),
- External Constraint Complexity (military areas, interface with adjacent units).

As explained previously, the WG tried to capture the complexity due to the traffic characteristics and the external constraints only, independently from the route network and sector design.

The Traffic Characteristic Complexity factor emerged as being the relevant dimension for the ACE benchmarking. The Airspace Complexity factor was judged to be mainly an internal factor which could be managed by the ANSP. Lastly, the External Constraint Complexity factor has not been kept because it could not be quantified in this study.

2.2.2. Indicators

The WG agreed upon a set of four indicators representing the Traffic Characteristic Complexity factor of *en-route* airspace. The first indicator, assessing Traffic Density, is related with the concentration of the flights. The three other indicators are based on the notion of "interactions", highlighting, that it is the presence of several aircraft---having different behaviors---in the same area, at the same time that generates complexity. It is important to underline that probability[3] of interactions *only* have been assessed. Indeed, as the indicators are to be used at a macroscopic level (the results are expressed at yearly level per ANSP or ACC), the potential interactions and not the actual ones have been inspected.

To compute these indicators, at ACC and ANSP levels, a 4D grid which divides the ECAC area into cells has been used. A sensitivity analysis with respect to the size of the cells has been performed and the "ideal" grid size for the benchmarking is made of 20 nm x 20 nm x 3000 feet x 1 hour cells.

The Table 1 below describes the indicators:

Table 1: Complexity Indicators defined by the ACE working Group, 2006

Dimension	Indicator
1. Traffic density	Adjusted density, which considers how much traffic is concentrated in space or time. It represents the average number of interacting aircraft (i.e. the number of aircraft present in the cell) that a flight crossing the ANSP/ACC airspace might expect to encounter.
2. Traffic in evolution	Potential vertical interactions (VDIF). This indicator reflects the probability of vertical interactions, defined as the simultaneous presence of two aircraft in different flight phases in the same cell.
3. Flow Structure	Potential horizontal interactions (HDIF). A potential horizontal interaction is the presence of two aircraft with different headings (with angle between them of 20 degrees or more) in the same cell.
4. Traffic mix	Potential Speed interactions (SDIF). Measures the complexity arising from the interactions between aircraft with different speeds (a speed interaction is counted when the difference between the speeds of a pair of aircraft is greater than 35 kts) in the same cell.

The detailed definitions of the indicators are given in Annex 1.2.

[3] The indicators do not measure the actual number of interactions but the *potential* number interactions arising from the traffic.

These indicators are meant to be used at a macroscopic level; as a consequence, the WG recognized that it missed the operational complexity at the 'real world' level because it does not focus on actual interactions but on potential ones.

The data used for the validation of the indicators consisted of IFR traffic samples (from CFMU), airspace definitions (from CFMU) and base of Aircraft Data (from BADA). The indicators have been systematically calculated the whole ECAC airspace under the control of the ANSP and ACC above FL85 (excluding oceanic services).

The ultimate goal of the working group was to define a complexity score in order to rank the ANSPs (or ACCs) with respect to their complexity features. As a consequence, an aggregated indicator has been defined in order to express the complexity score:

Complexity Score= HDIF + VDIF + SDIF

2.2.3. Study Results

Results were computed for the entire ECAC area for two 1-week periods, using both the COCA fast-time simulator and SDER (formerly CENA) model. Results agreed with the general expectations, for example that density is higher in the core ECAC area (DFS, SkyGuide, Belgocontrol, NATS). Results for these indicators also showed that complexity decreases with altitude and the group agreed that further work would be needed to develop indicators for approach and TMA.

COCA indicators developed in cooperation with the **ACE Working Group** have been adopted by EUROCONTROL member states, as part of the PRU annual benchmarking of performance efficiency and complexity.

2.3. MUAC OPERATIONAL STUDY

2.3.1. Context

A safety survey conducted at Maastricht, coupled with the annual safety report of 2002, highlighted the need to study airspace complexity at MUAC. The safety survey highlighted incident 'hot-spots' and post incident data inferred that complexity may have been a key factor.

2.3.2. Study

The COCA project conducted a study in 2004 to identify and measure airspace complexity factors existing in MUAC area of responsibility in general, and in the REMBA area in particular to assess the effect of airspace modifications. An evaluation of the operational complexity of all sectors in Maastricht airspace was performed with a particular focus on the Brussels sectors[4]. A complexity baseline has been established for Maastricht sectors against which future changes could be measured to assess how sector complexity has changed. A workload measure has been derived to be used throughout the analysis.

Practically, the study was conducted in 2 phases: the first phase ran in April, 2004, prior to the airspace change; and the second in August, 2004, after the airspace change. During both phases the COCA team collated and collected static and "dynamic" operational data (including military activity) between 0700 – 1900 (local) for 6 days. The corresponding CFMU traffic data was used to compute complexity indicators for the two phases of the project.

[4] MUAC is divided into three « groups » of sectors: Brussels sectors, Hannover sectors and DECO sectors.

2.3.3. Indicators

Considering the high number of sectors and the volume of data to study, the concept of “Complexity ID Cards” has been created. It consisted of summarising the results found under a common template (the “ID Cards”) containing a list of complexity indicators and associated values for each sector.

The complexity indicators thought to be most relevant to the MUAC sectors were:

- Interaction between flights:
  - DIF indicator: captures the interacting flows and respective number of flights. Two flows are considered to interact when they have different phases---climbing/cruising/descending---or different headings. This DIF indicator is equivalent to both HDIF and VDIF interactions in Table 1 of the COCA-PRU study.

- Traffic phase
  - Traffic mixture in relation to percentage of flights in climb, cruise and descent within the sector;
  - Mix of Traffic attitudes index: it represents the variety of aircraft attitudes within the sector. This index has a range between 0 and 100. The higher the index, the more mixed the traffic in terms of attitude.

- Presence of proximate aircraft pairs;
  - Number of Proximate Pairs: occasions when two aircraft have approached within 10 NM horizontally and 1000 ft vertically of each other;
  - Types of Proximate Pairs: the proximate pairs are distributed under three categories
    - Along Track: it counts the proximate pairs for which the angle between the two trajectories is less than 45°,
    - Opposite Track: it counts the proximate pairs for which the angle between the two trajectories is more than 150°,
    - Crossing Track: it counts the proximate pairs which are neither along track nor opposite track.

- Traffic evolution:
  - Number of Flight Level crossed on average by an aircraft.

- Spatial traffic distribution (density):
  - Number of cells[5] used to mesh the sector,
  - Number of cells containing more than 3 aircraft.

- Mixture of aircraft types and performance:
  - The average ground speed, as well as the standard deviation to the average ground speed, has been chosen to reflect the diversity of aircraft types. The Base of Aircraft Data (BADA) performance tables are used to approximate the aircraft speeds. It is more the standard deviation to the average ground speed indicator which gives an indication on the mixture of aircraft types.

[5] As for the set of COCA-PRU indicators described above (see section 2.4), the evaluation of some indicators has been performed using a grid to mesh the area of interest (MUAC sectors). The cell size (7.5 nm x 7.5 nm x 3 000 ft x 10 min) was chosen to reflect the level of the study (sector level).

- Sector dimensions:
    - Total Volume: it is the sector volume calculated from the environment definition,
    - Average Volume Not Available: it is the percentage of sector volume not available because of restricted areas or military activity,
    - Average Transit Time: it is the average time spent by a flight within the sector.

- Traffic rate:
    - Traffic throughput per 10 min: the average number of aircraft entering the sector during a 10 min period.

and;

- Workload calculation :

Workload is computed using the Adapted Macroscopic Workload Model (AMWM) developed by the COCA project. The model is based on the workload used in the RAMS Plus fast time simulator and is fully described in reference [3]. It calculates an approximation of the executive controller's workload and this is performed at a macroscopic level. Only a few controllers' tasks (routine tasks, level change tasks and conflict tasks) are considered, which aggregate the multiple tasks the controller has to achieve. For example, the conflict task includes identification, resolution and monitoring of conflicts.

The workload is calculated for each sector using a linear formula. The latter is based on a set of three weights which depend on the complexity of the sector. The sectors to be studied are preliminary clustered according to their complexity features and the sets of three weights are identified for each cluster. The resulting workload value per sector is a:

- Workload per flight: the average time in seconds for a controller to deal with a flight as well as the standard deviation to the average workload value have been estimated.
- Standard Deviation of Workload per flight: it is a measure of the variability of the workload per flight value.

Apart from the ID cards, the other results produced were:

- a classification of MUAC sectors according to shared complexity indicators, and;
- a comparison of complexity metrics following airspace changes close to the REMBA navaid.

2.3.4. Study Results

Sectors were classified into groups using the complexity indicators and a clustering method. Three groups of complexity (low, medium and high) have been identified. Most of the Brussels sectors were concentrated in the high complexity cluster. The workload model AMWM has been calibrated for each complexity cluster.

As a final activity for this study, a focus group brainstorming session was conducted at MUAC with 6 en-route controllers. The participants discussed a provisional list of 33 COCA complexity factors and 9 factors selected from the Dynamic Density (DD) research (see reference [4]). The controllers provided valuable insights into the combinations of critical factors that are sufficient to drive complexity to excessive levels. The revised list of factors is provided in Annex A.

This activity was the first step towards applying the COCA approach in an operational environment and compared and validated objective analyses with the controllers'perceived notion of complexity and workload. The results were extremely encouraging and support a natural next step to move from retrospective measurement and analysis of complexity, to complexity prediction.

2.4. COMPLEXITY INDICATORS AND COMPUTATIONAL ASPECTS

We propose in this paragraph to summarise the list of indicators of the both studies mentioned above. Table 2 enumerates the indicators under high level complexity areas (yellow highlighting) and gives indications on the computation aspects. In the first column of Table 2, the COCA-PRU indicators (listed in section 2.2) are highlighted in green and MUAC indicators (listed in section 2.3) are highlighted in blue. The "aggregated" indicators (*Workload* and *Score*) which are a combination of several complexity elements are reported at the bottom of the table.

The necessary input data are mentioned in column two. The necessary material to calculate the complexity indicators is quite undemanding. Basically, the computations require flight plan aircraft trajectories (traffic data) and, environment data (geographical definition of the airspace and opening schemes data).

Columns three and four in Table 2 detail the different units in terms of space and time. There are different degrees of analysis possible, depending on the airspace level (sector, centre, ANSP…) and on the area of interest (whole ECAC, core area…). The spatial scale generally constrains the temporal scale because of processing time aspects.

For microscopic studies, the more precise the input data, the more realistic the complexity evaluation. Logically, considering actual traffic instead of flight plans will bring more accuracy with respect to the indicators (interaction metrics, proximate pairs, density…). It is even more crucial with opening scheme data (actual opening/closing times will bring more reliability than standard CFMU definitions).

Finally, the fifth and sixth columns in Table 2 give some processing details. The indicators are computed using a complexity fast-time simulator named COLA V0.7 (COmplexity Light Analyser). The PRU developed at a later stage a simulator to calculate the chosen indicators in order to provide greater flexibility when calculating results for the benchmarking process.

Macroscopic studies, at yearly level, require a limited number of days of traffic (about 2 weeks[6]). For more microscopic studies, the size of the traffic sample can be smaller but the temporal parameters are generally of a finer granularity.

Some indicators, linked with interactions and density, are computed using a 4D (spatial and temporal) mesh. The size of this mesh has to be carefully chosen and should be a trade-off between accuracy on one side and processing time on the other. The values calculated within the mesh are then aggregated---spatial and temporal average values, in general---at a higher level (sector, centre or ANSP level) depending on the study needs.

[6] It is important to select representative days of traffic.

Table 2 : COCA Complexity Indicators Details

COMPLEXITY INDICATORS	*Input Data*	*Output Level*		*Computational Level*	
Ouput data	**Data required**	**Spatial Unit**	**Timescale**	**Spatial Unit**	**Timescale**
Flight Interactions					
DIF per minute (-)	Traffic+Environment	Sector	Daily value: avg of 10 min values for week days or week-end days	Mesh (cell size 7.5nm*7.5nm*3000ft)	10 min
HDIF (-)	Traffic+Environment	ANSP/ACC	Yearly value: avg of 1h values for 2 weeks	Mesh (cell size 20nm*20nm*3000ft)	1 h
VDIF (-)	Traffic+Environment	ANSP/ACC	Yearly value	Mesh (cell size 20nm*20nm*3000ft)	1 h
SDIF (-)	Traffic+Environment	ANSP/ACC	Yearly value	Mesh (cell size 20nm*20nm*3000ft)	1 h
Traffic Phase					
Cruising traffic (%)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Climbing traffic (%)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Descending traffic (%)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Mix of traffic attitudes (-)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Presence of Proximate Aircraft Pairs					
Normalised Proximate Aircraft Pairs (%)	Traffic+Environment	Sector	Daily value	Sector (presence)	10 min
Along track (%)	Traffic+Environment	Sector	Daily value	Sector (presence)	10 min
Crossing (%)	Traffic+Environment	Sector	Daily value	Sector (presence)	10 min
Opposite track (%)	Traffic+Environment	Sector	Daily value	Sector (presence)	10 min
Traffic Evolution					
Nb levels crossed (100 ft)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Density					
Total cell number (-)	Traffic+Environment	Sector	Daily value	Mesh (cell size 7.5nm*7.5nm*3000ft)	10 min
Cells with more than 3 aircraft (%)	Traffic+Environment	Sector	Daily value	Mesh (cell size 7.5nm*7.5nm*3000ft)	10 min
Traffic Density (-)	Traffic+Environment	ANSP/ACC	Yearly value	Mesh (cell size 20nm*20nm*3000ft)	1 h
Mixture of Aircraft Types					
Average Ground Speed (kts)	Traffic+Env.+BADA tables	Sector	Daily value	Sector (entry)	10 min
Std Deviation of Avg Ground Speed (kts)	Traffic+Env.+BADA tables	Sector	Daily value	Sector (entry)	10 min
Sector Dimensions					
Total Volume (nm*100ft)	Environment	Sector	Daily value	Sector, based on airac cycle	-
Average volume not available (%)	Military Env.	Sector	Daily value	Sector, based on opening schemes	-
Average Transit Time (min)	Traffic+Environment	Sector	Daily value	Sector (entry)	-
Traffic Rate					
Traffic throughput per 10 min (-)	Traffic+Environment	Sector	Daily value	Sector (entry)	10 min
Workload					
Workload per flight (s)	Traffic+Environment	Sector	Daily value	Clustered Sector (wrt complexity)	1 h
Std Deviation of Workload per flight (s)	Traffic+Environment	Sector	Daily value	Clustered Sector (wrt complexity)	1 h
Score					
Complexity Score (-)	Traffic+Environment	ANSP/ACC	Yearly value	Mesh (cell size 20nm*20nm*3000ft)	1 h

3. MAPPING THE INDICATORS

After having listed the potential indicators which could be useful from a regulatory perspective, the next step is to draw a link between these indicators and the domains covering the concepts---functions—which could be mandated.

Basically, the domains covered by the functions to be mandated are:

- Communication (C),
- Navigation (N),
- Surveillance (S).

These domains cover a large number of issues and mapping the complexity indicators directly to the domains appear to be very difficult (heterogeneity of levels). To overcome this difficulty, we divided the C/N/S domains into sub-categories which correspond to the main "Implementation Objectives" found in the Detailed Objective Descriptions of the European Convergence and Implementation Plan—ECIP--(see reference [5]). The Implementation Objectives listed in the ECIP cover seventeen different ATM areas including COM, NAV and SUR. We chose to focus on a list of nine objectives within the C/N/S areas, relevant in terms of complexity. They are listed hereafter.

Communication:

- **Implementation of 8.33 kHz above FL195,**
- **Implementation of DataLink,**

Navigation:

- **Implementation of Precision RNAV (P-RNAV) as an interim step towards RNP RNAV,**
- **Implementation of Required Navigation Performance (RNP),**
- **Enable implementation of RNAV approach Procedures based on DME/DME and/or Basic GNSS, and RNAV Approach Procedures with Barometric Vertical Guidance (ICAO APV/Baro VNAV)**

Surveillance:

- **Implementation of Mode S elementary (ELS) surveillance,**
- **Implementation of Mode S enhanced (EHS) surveillance,**
- **Improve ground-based surveillance using ADS-B,**
- **Enhance surveillance in Non-Radar Airspace using ADS-B.**

With studying the benefits[7] expected with respect to the implementation of these objectives, and with the help of operational experts, we built the matrix linking complexity indicators and the chosen objectives. The matrix is displayed on Table 3.

We have identified, in the Table 3, the complexity indicators impacted by the implementation of the some concepts. The reasons of the impacts on the complexity indicators are detailed in the next paragraph. We made an attempt on indicating the general tendency for complexity indicators to change (*increase* or *decrease* of the indicators' values) with justifying the reasons. But, due to the high level of the study, it is very difficult to give general conclusions on the implementation of

[7] The benefits considered are linked with Air Traffic System (ATFM, ATC) but neither related to costs nor revenues. The source documents used to draw the mapping are listed in Chapter 6. When some benefits are reported, it is supposed to be at a constant level of safety.

specific functions. The reader has to be especially careful with these tendencies because they are context-dependent. The impacts reflect the benefits of applying a function in a specific area (e.g. *en-route* sector) and would not be similar in another context (e.g terminal area).

While achieving the mapping phase, it appears necessary to enhance the list of indicators coming from the two COCA studies with complementary indicators:

- Density:
  - **Bunching**: situation in which aircraft enter the sectors in groups with little, especially too little, distance between them.
- Sector dimensions:
  - **Average Distance Travelled**: it is the average distance flown by a flight within the sector.
- Traffic rate:
  - **Hourly Capacity**: the number of aircraft entering the sector during a 1 hour period.

Some specific “complexity” indicators at airport level have been added to the list, too:

- Traffic Load:
  - **Take-Off/Landing rate**: it is the number of aircraft departing from/arriving to the runway per specific period of time,
- Distance & Time Saved:
  - **Push-back delay**: extra time spent while the aircraft is under movement in taxiing phase under pushback or towing,
  - **Track Distance**: distance flown by the flight between the stack and the runway,
  - **Holding Time**: a predetermined or ad-hoc maneuver which keeps an aircraft within a specified airspace while awaiting further clearance,
  - **Taxi time**: duration of the movement of an aircraft on the surface of an aerodrome under its own power, excluding take-off, including taxi-holding position.

3.1. COMMUNICATION

- **Implement 8.33 kHz above FL195,**

The COM objective linked to the implementation of 8.33 kHz frequency channel spacing in Europe has been partially finalised (at least, above FL195). The carriage and operation of 8.33 kHz capable equipment has been effective above FL245 since 1999 and is mandatory above FL195 in ICAO EUR Region from 15 March 2007. The development of a draft interoperability implementing rule (IR) for the deployment of air-ground voice communications based on reduced channel spacing (deployment of 8.33 kHz above FL 195) has been led by the EUROCONTROL Regulatory Unit with support from the 8.33 kHz Programme. We thought it could be interesting to address—in terms of complexity impact--a concept the RU has already carefully studied.

The complexity indicators presumably involved in the implementation of such a concept are:

- Volume (*possible re-sectorisation*) => there is a potential creation of additional of sectors within the centre as some more frequencies would be available,

- Density (*possible increase*) => the density could also increase as a consequence of a higher number of sectors – consequently of smaller size- within the centre,

- Hourly Capacity/Traffic Throughput (*possible increase*) => for the same reasons as for density, the opening of new sectors could increase the centre’s/sector’s capacity.

- **Implement DataLink,**

The data link will provide controllers with a second communication channel to pilots that can be managed by either the Tactical or Planning Controller. This facility will enable an evolution of the controller working method, transferring Tactical Controller workload to the Planning Controller. It is expected that reducing the reliance on the radio channel may reduce sector frequency congestion, increase safety, and ultimately enable higher sector capacity.

The complexity indicators that would be impacted because of the implementation of DataLink are the following:

- Interactions, Presence of Proximate Pairs (*possible reduction*) => the potential aircraft interactions could be reduced because the planner can modify the route using a 2D-Trajectory editor and the ability of uplinking trajectories,

- Bunching *(possible reduction)* => due to the possibility of issuing a scheduled time of arrival (an initial estimate of the aircraft's nominal meter fix crossing time), the bunching effect could be reduced in the sectors located close to the destination airport.

- Volume (*no need for re-sectorisation*) => by reducing controller workload, the Air/Ground data link enables the ANSPs to accommodate higher levels of en route traffic without adding sectors.

- Hourly Capacity/Traffic Throughput *(possible increase)* => the availability and use of an Air/Ground data link could enable sector capacities to be increased.

- Workload (*possible reduction*) => due to the reductions in frequency usage (identified in real-time simulations), EUROCONTROL researchers calculated total sector workload reduction associated with Air/Ground data link usage for each level of data link equipage using the conservative estimate of communications workload.

3.2. NAVIGATION

The goal of the three NAV objectives is to enhance terminal airspace organisation using improved aircraft capabilities.

- **Implement P-RNAV**

RNAV is a method of navigation that permits aircraft operation on any desired flight path. P-RNAV (Precision RNAV) is the RNAV equipment having a lateral track keeping accuracy of ±1 NM. P-RNAV is being introduced for RNAV applications in terminal airspace. It requires aircraft conformance to a track-keeping accuracy of ±1NM for at least 95% of flight time, together with advanced functionality, high integrity navigation databases. Many existing aircraft can achieve P-RNAV capability without additional onboard equipment.

Implementing the P-RNAV approach could involve changes for the following complexity indicators (the benefits identified are even more applicable in final Approach airspace):

- **Interactions/Proximate Pairs** (*possible reduction*) => with P-RNAV, tracks could be segregated by origin/destination (more specifically in approach sectors) and allow tactical positioning without radar headings. Moreover, P-RNAV system could help in reducing conflicts by means of systemization,

- Density (*potential reduction*) => because of the possible reduction of route spacing, the traffic would be more evenly spread and the traffic less concentrated,

- Bunching (*better airspace utilisation*) => using P-RNAV in demanding en-route sectors which are squeezed by airspace constraints (such as military danger areas) would allow a better utilisation of the airspace.

- Average Transit Time/Average Distance Flown (*potential reduction*) => flight efficiency could be enhanced thanks to the use of optimal 4D trajectories (more direct routes, continuous descent approaches…).

- Hourly Capacity/Traffic Throughput (*potential increase*) => same impact as for Interactions/Proximate Pairs (additional routes where needed), the enhanced accuracy capability of P-RNAV approved aircraft means that less airspace is required to accommodate P-RNAV terminal area procedures. As a consequence, increase of capacity could be obtained.

- **Implement RNP**

RNP is a method of aircraft navigation that utilizes modern flight computers, GPS (Global Positioning System) and innovative new procedures. Aircraft using RNP precisely fly predetermined paths loaded into their flight computers. Accurate navigation performance is ensured through continual monitoring with alerts if position becomes uncertain, one feature of RNP representing its advancement over RNAV. RNP does not rely on any ground based navigation aids, radio beacon based or air traffic controller based. A more specific goal of implementing RNP is to facilitate user-preferred 4-D trajectory. The possible impacts at terminal areas and at airports are listed hereafter:

- Proximate Pairs (*possible reduction*) => RNP could be used for aircraft separation (ability of RNP to maintain close parallel operations in poor weather) and would reduce the potential conflict.

- Bunching (*possible reduction*) => thanks to RNP, a reduction of TMA spacing and a better 4D arrival management could help in bunching mitigation.

- Mixture of Aircraft (*possible increase*) => as the aircraft must be certified to be capable of meeting the requirements of performance-based navigation, the controller could better apprehend the different types of aircraft within his area of responsibility.

- Average transit Time/Average Traveled Distance (*possible reduction*) => the implementation of RNP helps in reducing time and distance paths (continuous climbs and descent, optimal route in en-route and terminal).

- Hourly Capacity/Traffic Throughput (*possible increase*) => utilisation of RNP could increase on-time performance which could result in an increase in capacity (especially at airport). More specific impacts could be measured:

- Terminal: decoupling of flows and reduction of TMA spacing would help in improving capacity management.
- Approach: improvement of airway utilization due to 4D arrival management.
- En-route: (see Bunching) improvement of airspace utilisation.

- Workload per flight (*possible reduction*) => the reduction of voice communication (pilot-controller) and chance of operational errors could help in reducing controller's workload.

At airport level, the following (specific) complexity indicators could be impacted:

- Landing rates (*possible increase*) => RNP often provides improved minima compared to the existing non-precision approaches, this could allow aircraft to complete landings in a broader range of weather conditions.

- Taxi times / Track Distance (*possible reduction*) => as the RNP approach procedures are designed for specific runway ends and have to be tailored for specific aircraft, the taxi times and track distance could be optimised.

- Airport delay (*possible reduction*) => the potential increase of on-time performance due to the utilisation of RNP could reduce airport delays.

- **Implement RNAV Approach Procedures Based on DME/DME and/or Basic**

GNSS, and RNAV Approach Procedures with Barometric Vertical Guidance (ICAO APV/Baro VNAV)

A more specific goal of implementing RNAV approach procedures is to implement best practices and refined procedures. The following complexity indicators could be impacted, in TMA and at airport level too:

- Density/Bunching (*possible reduction*): with RNAV approach procedures, new routes could be designed and a reduction of separation minima could be possible which would reduce aircraft concentration.

- Mixture of Aircraft (*possible better organisation*) => there would be a possibility of distributing the aircraft along different routes with respect to their level of equipment (RNAV/non-RNAV) or performances (e.g. jets, propeller aircraft…).

- Average transit Time/Average Traveled Distance (*possible reduction*): due to the enhancement of the route flexibility[8] and due to optimal flight procedures, transit time as well as traveled distance could be reduced.

- Hourly Capacity / Traffic Throughput (*possible improvement*): terminal navigation (straight approaches for all runway ends) could be improved which would result in capacity enhancement and airport throughput improvement.

The following airport complexity indicators would be impacted too:

- Landing rates (*possible increase*) => RNAV Approach Procedures which allow guided and stabilized descent for approach and landing could help in improving runway utilization (capacity and landing rates increase),

- Track Distance (_possible reduction_**)** => for reasons mentioned above, the distance flown by the flight between the stack and the runway could be reduced as well.

[8] The highest flexibility is certainly achieved in a pure radar vectoring environment.

3.3. SURVEILLANCE

The goal of implementing MODE S (ELS and EHS) objectives is both an automatic provision of airborne data to enhance ground systems functions including surveillance and to maintain and improve the quality of surveillance.

- **Implement MODE S ELS**

Implementing MODE S ELS would have an impact on the following complexity indicators:

- **Hourly Capacity/ Traffic Throughput** (*possible increase*) => the possible reduction of Radio Frequency (RF) congestion (due to the selective addressing of aircraft) would enable more aircraft to be handled by the radar. Consequently, MODE S is an enabler for increased capacity.

- **Workload** (*possible reduction*) => firstly, the automatic acquisition of Aircraft Identification (Flight ID) enhances radar identification and has the capability to relieve the shortage of Mode A codes. On the top of that, the selective addressing of aircraft overcomes garbling, fruiting and over-interrogation (which together constitute RF congestion). As a consequence, the tactical controllers' workload could be reduced.

- **Implement MODE S EHS**

Implementing MODE S EHS would involve changes with respect to the following complexity indicators, especially in TMA and at Airport:

- **Interactions / proximate Pairs** (*possible reduction*) => not only monitoring tools (e.g. Short Term Conflict Alert) but also the provision of actual aircraft derived data help the controller to better assess the separation situations. This could result in reducing flight interactions.

- **Density / bunching** (*possible reduction*) => automatic laddering could help in reducing bunching effect,

- **Hourly Capacity** (*possible reduction*) => at airport, MODE S EHS would increase situational awareness, especially in low visibility contexts, allowing the improvement of capacity management,

- **Workload** (*possible reduction*) => the provision of actual aircraft derived data, such as Magnetic Heading, Air Speed, Selected Altitude and Vertical Rate, enables controllers to reduce the radio telephony (RT) workload

At airport:

- Push-Back delay (*possible reduction*) => the experiments realised at Schipol airport showed MODE S EHS could give a better situational awareness in cul-de-sacs,

- Taxi Time (*possible reduction*) => the better capacity management in low visibility thanks to MODE S EHS, could help reducing the taxi times.

- **Improve ground-based surveillance using ADS-B**

ADS-B (Automatic Dependent Surveillance Broadcast) is a surveillance technique that relies on aircraft broadcasting their identity, position and other aircraft information. This signal can be captured on the ground for surveillance purposes (ADS-B-out) or on board other aircraft for air traffic situational awareness (ADS-B-in) and airborne separation assistance.

The following complexity indicators could be sensitive to the implementation of ADS-B:

- **Interactions / Proximate Pairs** (*possible reduction*) => the implementation of ADS-B could provide the controller with short time conflict alert parameters which would enable the improvement of trajectory prediction and would help in preventing the potential proximate pairs,

- **Volume** (*better airspace management*) => ADS-B could provide surveillance to remote or inhospitable areas that do not currently have coverage with radar, which would help in a better utilisation (coverage) of airspace,

- **Hourly Capacity/Traffic Throughput** (*possible increase*) => in non-radar environment, ADS-B could allow for reduced separation and greater predictability in departure and arrival times, it would then a trigger for capacity enhancement,

- **Workload** (*possible reduction*) => in non-radar environment, ADS-B could improve ability of air traffic controllers to plan arrivals and departures far in advance which would be a way of better monitoring workload.

- **Enhance surveillance in Non-Radar Airspace using ADS-B**

The complexity indicators which could be sensitive to the implementation of ADS-B NRA do not appear in the list of indicators extracted from the COCA studies. The indicators impacted belong to the list of “airport complexity indicators”:

- Airport delay (*possible reduction*) => the utilisation of ADS-B NRA would allow a reduction of separation minima (compared to procedural) in the approach areas, which would save airport delay,

- Holding Time (*possible reduction*) => implementation of ADS-B in NRA could improve ability of air traffic controllers to plan arrivals and departures far in advance which would avoid holding times,

- **Take-off/Landing rates** (*possible increase*) => there would be several reasons for enhancing the “runway rates”: potential reduction of separation minima, better arrival and departure planning, better traffic management in low visibility conditions.

Table 3: Mapping of the COCA Indicators to C/N/S Functions

	Communication		Navigation			Surveillance			
Implementation Objectives	COM03		NAV03	NAV05.1	NAV07	SUR02	SUR04	SUR05	
In the areas where the complexity indicator … is equal to/greater than /less than α implement the concept …	Implementation of 8.33 kHz channel above FL195	Implementation of Data-Link	Implementation of Precision Area Navigation RNAV (P-RNAV) (En-route/Terminal/approach)	Implementation of Required Navigation Performance (RNP) (Terminal/Approach)	Implementation of RNAV Approach Procedures Based on DME/DME and/or Basic GNSS (Terminal/Approach)	Implementation of Mode S ELS	Implementation of Mode S EHS	Improve ground-based surveillance using ADS-B	Enhance surveillance in Non-Radar Airspace using ADS-B
Complexity Indicators									
Flight Interactions									
DIF/VDIF/SDIF/HDIF/Complexity Score		x	x				x	x	
Traffic Phase									
Nb. Of Climbing/Cruising/Descending flights									
Presence of Proximate Pairs									
Nb/types of PP		x	x	x			x	x	
Traffic Evolution									
Nb LC									
Density									
Density	x		x		x		x		
Bunching		x	x	x	x		x		
Mixture of aircraft types									
Avg Ground Speed/StDev Ground Speed				x	x				
Airspace Dimensions									
Volume	x	x						x	
Volume Available (military activity)									
Total/Avg flight time in sector			x	x	x				
Total/Avg distance traveled in sector			x	x	x				
Traffic Load									
Traffic Throughput	x	x	x	x	x	x	x	x	
Hourly Capacity	x	x	x	x	x	x	x	x	
Workload									
Controller Workload		x		x		x	x	x	x
Added Indicators									
Proposed AIRPORT complexity indicators									
Traffic Load									
Take-Off/Landing rates				x	x				x
Distance & Time Saved									
Push-back delay							x		
Airport Delay				x					x
Track Distance				x	x				
Holding Times									x
Taxi times				x			x		

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4. DISCUSSION

A high number of COCA indicators appear to be sensitive to the implementation of the different C/N/S functions studied. The sensitivity of the complexity indicators is highly linked to a function and to the type of airspace in which this function is supposed to be implemented. It is very hazardous to directly map complexity indicators to domains.

First of all, three out of the fourteen COCA indicators presented in Table 3 seem not to be affected by the functions studied. They are:

- The Traffic phase and Traffic evolution indicators: the functions observed seem to have positive influence neither on the attitudes of the flights nor on their vertical evolutions (number of level changes),
- The “available volume” indicator: the functions studied seem to have no influence on this particular indicator because they do not address the problems linked to the presence of military activities.

The remaining eleven indicators could be sensitive to the implementation of the C/N/S functions:

- The capacity and traffic throughput indicators have been extensively ticked off in Table 3. In effect, whatever the domains, the improvement of capacity is one of the triggers for implementing new functions.
- For the same reasons, the controller workload is another complexity indicator which could be systematically modified (possible decrease due to the reduction of the number of communications, and the utilisation of monitoring and decision tools…) if new functions were to be implemented.
- Traffic density, traffic bunching or traffic interactions would be impacted by the implementation of the C/N/S functions studied, essentially due to the possibility for the controller of having a better knowledge of the tracks and being able to avoid congested situations. Another important reason for some changes is linked with the possibility of reducing separation minima in specific areas, which would modify the density.
- The airspace volume, which is not really a complexity indicator itself but often used for complexity clustering processes, would be subject to be modified after the implementation of the functions studied. A better management of the available airspace in terms of volume could be possible using Communication and Surveillance functions.
- Finally, with implementing the Navigation functions studied, a possible reduction of average flight times and flight distances would become possible thanks to optimal flight procedures.

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5. RECOMMENDATIONS

When studying the benefits linked to the implementation of C/N/S functions, we focused on ATFM and ATC benefits but we noticed that the functions would impact safety and environmental aspects as well. It could be interesting to investigate the SESAR Key Performance Indicators linked to Safety and Environment Sustainability (see reference [6]).

Due to the fact the COCA indicators have been validated for en-route centres only, it would be important to re-consider the settings (thresholds given in the indicators definitions mentioned in Annex 0) to better estimate the complexity for other types of airspace (Approach, TMA …). On the top of that, some airport indicators have been created (see bottom of Table 3). They could not be measured using COCA toolboxes due to the lack of information in the CFMU traffic data.

It could be interesting to evaluate the complexity indicators sensitive to an “already implemented” function (e.g. “8.33 kHz channel above FL 195”). Indeed, evaluating the complexity indicators before and after the implementation of the function would help in

- validating our findings, and;
- giving an idea on the “magnitude” of the function’s impact on the sensitive indicators.

As the mapping phase allowed us to express the sensitivity of some *complexity indicators* to *functions* and *airspace*[9]; it could be interesting to investigate the reverse link and try to identify the sensitivity of *airspace* to *functions* and *complexity indicators*.

To do so, we propose to evaluate the eleven selected COCA indicators for all the centres of the ECAC in order to define a complexity baseline. From this baseline, we would recommend achieving a clustering analysis of the centres based on the values of the selected complexity indicators. It would enable us to better identify the centres sharing similar complexity features. The goal of a clustering analysis would be twofold:

1. to help determining the parts of the airspace (geographical locations of the centres belonging to the clusters),
2. to help determining the target values (α) mentioned in Section 1. In effect, studying the complexity characteristics of each cluster (given by the average complexity values of each indicator, per cluster) could trigger the quantitative thresholds.

These recommendations are addressed in Part II of the present report.

[9] We intend by “airspace” the location of the airspace within the horizontal plane, that is to say the geographical location of the centres.

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COMPLEXITY

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8.33

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1. ANNEX

1.1 COCA-PRU Indicators: how to compute interactions

We give in this paragraph the basic definitions of the COCA-PRU indicators. For more information, these elements are carefully defined in the COCA-PRU report (see document [1]).

1.1.1 The grid

As explained in section 2.2, the airspace to be studied (ANSP or ACC) is covered by a mesh. The mesh is made of regular 4-D (spatio-temporal) cells. For information, the cell size is 20 NM x 20 NM x 3000 ft x 1h). The mesh is vertically spread between from FL85 to FL415. A cell is assigned to one ANSP or ACC. The indicators being calculated in each cell, this provides flexibility when combining and aggregating the data at ACC and ANSP level.

1.1.2 Definition of the indicators

An "Interaction" is defined by the simultaneous presence of two aircraft in the same cell.

"Flight Hours" is defined by the sum of the flight hours controlled in a given volume (typically, a cell), over a period of time (one hour in this study).

"Hours of Interactions" is defined by the sum of the duration of the different interactions that occur in a given airspace (typically, a cell) over a period of time.

Let us recall the definitions of the four indicators:

1. **Adjusted density**: takes into account whether the traffic is evenly spread or concentrated in one part of the centre (busiest sectors) or one part of the day (peak periods).

   Adjusted Density is the ratio between the hours of interactions and flight hours.
2. **VDIF**: measures the complexity arising from the "vertical" evolution and focuses on the interactions between flights in different flight phases.

   VDIF is the ratio between hours of vertical interactions and flight hours.
3. **HDIF**: measures the complexity arising from the "horizontal" plane and focuses on the interactions between flights with different headings.

   VDIF is the ration between hours of horizontal interactions and flight hours.
4. **SDIF**: measures the complexity arising from the "speed" heterogeneity and focuses on the interactions between flights having different speeds.

   SDIF is the ratio between hours of speed interactions and flight hours.

For better understanding, let us detail the computation of "vertical interactions" within a cell, as an example.

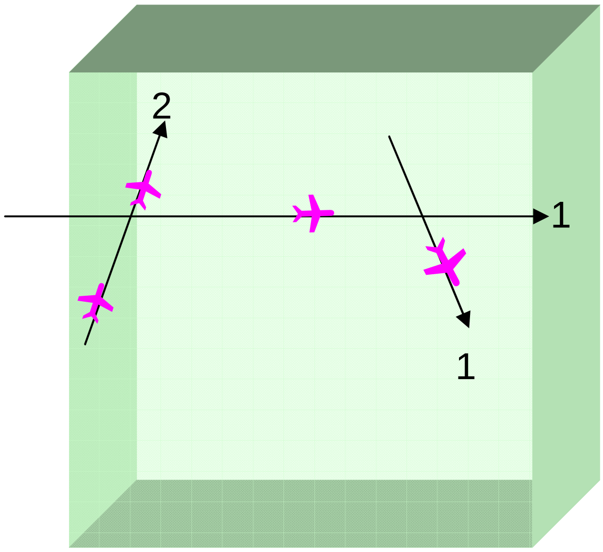

Figure: 1A: Diagram of a Cell with 4 Aircraft for VDIF Computation

Let us consider a cell with 4 aircraft present during the same hour. In Figure 1A, two aircraft are climbing, one is cruising and the other one is in descent.

The corresponding VDIF calculation is given by:

VDIF = [Flight Hours of Vertical Interactions] / [Total Flight Hours]

VDIF = [(hours of climbing) x (hours of cruising + hours of descending) + (hours of cruising) x (hours of climbing + hours of descending) + (hours of descending x (hours of cruising + hours of climbing)]/ [hours of cruising + hours of descending + hours of climbing]

For simpler calculations, let us consider that each aircraft stayed 12 minutes (1/5 hour) in the cell. When applying the numerical values, the indicator equals to:

- VDIF = [((2/5) x (2/5)) + ((1/5) x (3/5)) + ((1/5) x (3/5))] / [(4/5)]
- VDIF = 1/2
- VDIF = 0.5

The same type of computation is applied for horizontal interactions HDIF. A flow is made by aircraft having relative trajectory angles no greater than 20°.

The same principle is applied for speed interactions SDIF. A flow is constituted by aircraft having relatively comparable speeds (difference between them no more than 35 kts).

For the Adjusted Density indicator, the hours of interactions are calculated by adding the durations of all the interactions (vertical, horizontal and speed).

1.2 COCA-MUAC Indicators

1.2.1 Definition of the Indicators

The MUAC indicators are carefully detailed in the reference [2], Annex F.

1.2.2 List of Complexity Factors

The following complexity factors were compiled from a preliminary list of COCA project factors and a subset of the NASA Dynamic Density factors, with comments from the controller focus group described under Hilburn (2004b) in Section 2.3. These factors are not ranked; the numbers are used only to facilitate references and discussion.

COMMUNICATIONS WITH PILOTS

1 RT congestion

2 Blocked frequency

3 Pilots not listening / complying with R/T

4 Pilot requests

AIRCRAFT

5 Restricted flight profile

6 Mix of climbing and descending traffic

7 Traffic flows converging at same point

8 Mix of OAT/GAT

9 Multiple crossing points in sector

10 Crossing points close to sector boundaries

11 Mix of high and low performance aircraft (both airspeed and climb performance)

12 Traffic bunching

13 High number of aircraft

14 Merging / crossing aircraft at narrow angles

15 Emergencies

16 Special flights

17 Number of path changes

AIRSPACE

18 Military or other restricted area

19 FLs not available for use

20 Lack of holding areas

21 Change to non RVSM

22 Turbulence / WX

23 Sector volume

24 Number of aerodromes

OTHER SECTORS

25 Controlling traffic in another sector

26 Late transfer of communications to control sector

27 Interface with another sector / centre

28 Opening / closing of a sector

OTHER

29 Staffing

30 On-the-job training (OJT)

31 Number of required procedures

32 Equipment status (fully functional versus degraded)

33 Other