# E.02.02-D11-NEWO-Final Report on Conclusions and Strategic Recommendations

| Document information | |
|---|---|
| Project Title | NEWO |
| Project Number | E.02.02 |
| Project Manager | Isdefe |
| Deliverable Name | Final Report on Conclusions and Strategic Recommendations |
| Deliverable ID | D10 (D5.1 in contract) |
| Edition | 01.00.00 |
| Template Version | 03.00.00 |
| **Task contributors** | |
| *Isdefe* | |

*Please complete the advanced properties of the document*


***Abstract***

This document collects the conclusions and recommendations coming from an exhaustive analysis of the overall project approach and results. Project methodology, modelling approach and simulation results are reviewed at high level, highlighting the feedback obtained from the Experts in the same topics during the project Final Dissemination Workshop (July 2013 at Isdefe premises in Madrid).
The analysis of the Most Capable best Served criterion's simulation results is also included.

# Authoring & Approval

| Prepared By - *Authors of the document.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| XXXXXXXXXXXXXX (Isdefe)/ XXXXXXXXXXXXXX (Isdefe) | Project Manager/Technical Contributor | 26/08/2013 |

| Reviewed By - *Reviewers internal to the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| XXXXXXXXXXXXXX | Previous Project Manager | 09/09/2013 |
| XXXXXXXXXXXXXX | Technical Contributor | 09/09/2013 |
| XXXXXXXXXXXXXX | Technical Contributor | 09/09/2013 |

| Reviewed By - *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| <Name / Company> | <Position / Title> | <DD/MM/YYYY> |
| | | |

| Approved for submission to the SJU By - *Representatives of the company involved in the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| XXXXXXXXXXXXXX/ Isdefe | Project Manager | <26/09/2013> |

| Rejected By - *Representatives of the company involved in the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| <Name / Company> | <Position / Title> | <DD/MM/YYYY> |
| | | |

| Rational for rejection |
|---|
| None. |

# Document History

| Edition | Date | Status | Author | Justification |
|---|---|---|---|---|
| 00.00.01 | 09/09/2013 | Draft | XXXXXX / XXXXXX / XXXXXX / XXXXXX | New Document |
| 00.00.02 | 27/09/2013 | Draft | XXXXXX / XXXXXX | Changes/corrections according to Eurocontrol comments. |

# Intellectual Property Rights (foreground)

This deliverable consists of *f*oreground generated as a result of the activities conducted by Isdefe within the framework of the project and co-funded with Isdefe resources. The foreground is therefore, according to the project contract[1], owned by Isdefe.

[1] EUROCONTROL Contract reference 10-220719-C7, Part II General Conditions, Article II.8.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# Table of Contents





©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# List of tables



# List of figures





©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# Executive summary

It is the objective of the present document to collect the conclusions and strategic recommendations coming from the analysis of the Simulation results, literature review and the discussions that took place during the project's Final Dissemination Workshop (FDW).

Overall project methodology, the basis for selecting the prioritization criteria, the modelling approach and simulation results are reviewed at high level in this document and feedback from the experts in these topics is also reported.

The profiles of the Experts who attended the Workshop (Airspace modelling and simulation, Airport Operations and Performance, CNS; ATM (military side) and Network Optimisation and modelling) and their participation in SESAR JU projects, made that the comments were mostly oriented to SESAR aspects. In other words, most of the recommendations are oriented to operational aspects rather than Complexity approaches.

In fact, links between the NEWO operational concept and concepts currently under development in SESAR projects are mentioned in the document i.e. Airport-CDM and even some potential links with specific SESAR JU projects such as WP-B to find synergies and complement approaches and C2, in terms of levels of equipage to be further addresses in Most Capable (Best Equipped) Best served (MCBS) criterion.

As part of further research activity performed during the last stage of the project, the analysis of the MCBS criterion is also included in the present document. The conclusions are supported by the statistical analysis, which is also attached to this Deliverable.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# 1 Introduction

## 1.1 Purpose of the document

The purpose of the document is to provide a detailed analysis of the results obtained from the Project's Final Dissemination Workshop. The document is structured as follows:

- Scope of NEWO assessment: This section summarizes the scope of the project in terms of project objectives, scientific method and modelling approach;
- Conclusions and Recommendations: This section includes the ideas under discussion during project's FDW, classified in different topics;
- Strategic Recommendations: This section collects the simulation results and the statistical analysis of MCBS criterion, including main findings and preliminary conclusions. In addition to this and linked to the preliminary results, new ways of further research are proposed. The proposal is supported by the suggestions and recommendation of the Experts who attended project FDW.
- References: This section includes references to the papers/ bibliography consulted.

## 1.2 Intended readership

The target readers of the document are:

- Members of SESAR WP-E network "Mastering Complex Systems Safely", interested in feedback about usability of a modelling approach integrating ideas from complexity science.
- ATM operational researchers and SESAR participants: they will found simulation feedback about innovative strategies potentially contributing to reach performance goals;
- ATM simulation and modelling experts, interested in the state of the art of modelling approaches applied to ATM;
- Complexity Science researchers, since NEWO applies an innovative perspective of approaches from complexity to manage the future Air Transport Scenario.
- SESAR Airspace User Group, they will find specific topics/phases where their support is required in R&D projects.

## 1.3 Inputs from other projects

This document leans upon previous work within NEWO captured in [1].

## 1.4 Glossary of terms

NA.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

## 1.5 Acronyms and Terminology

| Term | Definition |
| --- | --- |
| **ACC** | Air Control Centre |
| **ADD** | Average Delay per Delayed flight |
| **ADEP** | Airport Departure |
| **ADES** | Airport Destination |
| **AROT** | Average Runway Occupancy Time |
| **AOBT** | Actual Off Block Time |
| **AOG** | Aircraft On Ground |
| **ATC** | Air Traffic Control |
| **ATCO** | Air Traffic Controller |
| **ATCFM** | Air Traffic Control Flow Management |
| **ATM** | Air Traffic Management |
| **ATM NEMMO** | ATM Network Macro MOdel |
| **ATS** | Air Traffic System |
| **BEBS** | Best Equipped Best Served |
| **CDM** | Collaborative Decision Making |
| **CFMU** | Central Flow Management Unit |
| **CODA** | Central Office for Delay Analysis |
| **CTOT** | Controlled Take Off Time |
| **DCB** | Demand and Capacity Balancing |
| **E-ATMS** | European Air Traffic Management System |
| **ECAC** | European Civil Aviation Conference |
| **EG** | Expert Group |
| **ENR ATCO** | En Route Air Traffic Controller |
| **EOBT** | Estimated Off Block Time |
| **ETA** | Estimated Time of Arrival |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

| Term | Definition |
|---|---|
| **ETO** | Estimated Time Over |
| **ETOT** | Estimated Take Off Time |
| **FMP** | Flow Management Position |
| **FCFS** | First Come First Served |
| **FTS** | Fast Time Simulation |
| **HDA** | High Density Area |
| **ICAO** | International Civil Aviation Organization |
| **IFR** | Instrumental Flight Rules |
| **KPA** | Key Performance Area |
| **KPI** | Key Performance Indicator |
| **MCBS** | Most Capable Best Served |
| **NM** | Nautical Miles |
| **NOP** | Network Operations Plan |
| **PCE** | Probability of Change in ETOT |
| **PFC** | Probability of Flight Cancellation |
| **PNF** | Probability of New Flight |
| **PI** | Performance Indicator |
| **RBT** | Reference Business Trajectory |
| **ROT** | Runway Occupancy Time |
| **RT** | Rotation Time |
| **RWY** | Runway |
| **SBT** | Shared Business Trajectory |
| **SESAR** | Single European Sky ATM Research Programme |
| **SESAR Programme** | The programme which defines the Research and Development activities and Projects for the SJU |
| **SJU Work Programme** | The programme which addresses all activities of the SESAR Joint Undertaking Agency |
| **TAT** | Turn Around Time |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

| Term | Definition |
|---|---|
| **TIT** | Taxi In Time |
| **TMA** | Terminal Manoeuvring Area |
| **TOT** | Taxi Out Time |
| **UDPP** | User Driven Prioritisation Process |
| **WP E** | SESAR Programme WP-E “Long Term and Innovative Research” |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# 2 Scope of NEWO assessment

NEWO mainly addresses WP-E theme Mastering Complex Systems Safely. Complexity science can help understanding the behaviour of the ATM complex system. The air traffic system contains a huge number of elements and agents that interact, in many situations nonlinearly, giving rise to degrade behaviours of parts of the network or of the whole network. NEWO applies the complexity prism to air transport network modelling, further developing and exploring the potential of the ATM-NEMMO modelling tool which incorporates schemes from the complexity science. The approach puts effort on global modelling to capture the nonlinear coupling effects and emergent behaviour. In particular, NEWO project covers the following topics:

- Intelligent modelling: Investigate the modelling of the ATM system of systems using methods and tools from the science of complexity, with models able to capture its changing, dynamic and evolutionary behaviour.
- Emergent behaviour: Use any results to better understand emergent properties such as delay, predictability and safety.
- Non-determinism: Investigate the impact of uncertainty on overall system behaviour.

## 2.1 Objectives

The project explores the potential network-wide benefits and/or adverse effects of the application of different local operational approaches in ATM. In particular:

- Prioritisation rules on departure flights, based on pre-defined common criteria for weighting flights, in support of the definition of the UDPP;
- Airline operational strategies (such as point-to-point, hub-and-spoke).

Additionally, NEWO further develops and explores the potential of innovative modelling and simulation techniques for studying nonlinearities and emergent behaviours of the air transport network.

## 2.2 Strategies for managing Departure queue

The way NEWO explores the definition of common and transparent rules for the prioritisation of flights and their translation into new operational approaches is by means of literature reviews, questionnaires and direct interviews with experts from diverse domains. The performance of a Workshop is fit-for-purpose to both gathering and stimulating the production of ideas and out-of-the-box thinking. The workshop allows deepening in the problem contextualisation and a positive feedback communication with experts. Besides, for the case where the target is a group of experts from diverse domains, a workshop provides the perfect context to apply group techniques to elicit views and knowledge.

Amongst the domains dealing with complex networks management from which new operational approaches can be mirrored to ATM are data communication networks, electricity distribution and logistics, apart from directly borrowing from the theoretical approaches studied as part of Complexity Science research.

Logistic and electricity networks share with the air transport system non-trivial topological features and patterns of connection between their elements that are neither purely regular nor purely random, and are all characterised by an irregular structure, complex and dynamically evolving in time.

The workshop opportunity of extracting information from experts builds on the application of brainstorming techniques; the 1st NEWO workshop was designed more as a working session than as a dissemination conference. In particular, Expert Group (EG) technique was applied. The technique is based on gathering a group of people with specific professional profiles, i.e. backgrounds, knowledge and expertise, and using both the individual skills and the synergy of the group in a structured manner



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

for developing a set of predetermined concepts and bringing them to a workable level, making decisions, and identifying risks.

The project first workshop was planned for the identification of the new local operational approaches and capture potential solutions to support User Driven Prioritisation Process (UDPP) in ATM.

The aim of this workshop was to capture 'out-of-the-box' ideas for dynamical management of the air transport complex network

For the study of specific ATM related phenomena and in order to collect as much promising solutions as possible, experts from different fields of knowledge were contacted:

The workshop was organised in three phases:

- Opening session, including presentations about "Overview of NEWO and workshop objectives" and "Problem Description and the Air Transport Framework; Introduction to the UDPP concept"; with the participation of Marc Dalichampt, SJU P7.6.4 User Driven Prioritisation Process;
- Parallel sessions for "identification of innovative operational approaches and solutions for UDPP";
- Consolidation sessions, one after each parallel session and one final plenary session for the workshop wrap-up.

As a result of this one-day event a preliminary set of prioritization strategies was defined. Then all the criteria were reviewed and further analysed one by one. The list of the criteria was reduced drastically due to several duplicities among the criteria and the limitations for implementation in ATM-NEMMO tool.

The list of criteria is as follows:

**Criterion 1:**

- **Ci-1** Priority for those flights that fly to airports with **higher number of outgoing flights;**
- **Ci-2** Priority for those flights that fly to airports with **lower number of outgoing flights;**

**Criterion 2:**

- **Cii-1** Priority for those flights **flying to more congested airports**
- **Cii-2** Priority for those flights **flying to less congested airports**

**Criterion 3:**

- **Ciii**- Priority for the **airlines with hub & spoke structure** over airlines with point to point structure

**Criterion 4**:

- **Civ**- Priority **for the last flight of the day**

**Criterion 5:**

**Cv**- Priority **for the flight with higher number of subsequent flight legs**

**Criterion 6:**

- **Cvi-1** Priority for those **flights with longer turnaround time at next airport**
- **Cvi-2** Priority for those **flights with shorter turnaround time at next airport**

**Criterion 8:**

- **Cviii**- Priority on **random basis**

**Criterion 9:**

- **Cix**- Priority for those **flights flying to less central destination**



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

**Criterion 10:**

- **Cx**- Priority for those **flights connecting different communities.**

**Criterion 7:**

This criterion is related to the Best Equipped Best Served Strategy. Initially, different possibilities for modelling this criterion were studied and because of lack of specific data in the traffic sample (equipment level of the aircrafts) the implementation and in consequence the analysis of this criterion was rejected.

It was the Project officer who proposed re-considering the idea of analysing this criterion since this is the most promising criterion under analysis according to the latest research works in the ATM field. This is the reason why the codification of the list of criteria jumps from Cvi to Cviii.

## 2.3 Modelling approach

ATM-NEMMO mathematical model is a simplified representation of the whole ECAC air transport network intended to explore through simulation the network behaviour and performance under different initial and operational conditions.

The model is a dynamic and stochastic simulation model. The approach is mesoscopic, an intermediate line between microscopic models, which consider the dynamics and detailed routing of every individual vehicle, and macroscopic ones, which focus on system properties as a result of integrating the state of the ATM elements. Mesoscopic models exploit probabilistic methods to account for the microscopic details without losing the macroscopic and strategic view of the system.

A statistical evaluation at the micro level is used for the statistical modelling of different elements and the randomisation of the simulation model, and then Monte Carlo simulations are used to estimate the probability distribution of a number of local and global indicators.

In the following sections, ATM-NEMMO structure, its operation and implementation rules and the outcomes of modelling are reviewed.

### 2.3.1 Model Structure

The model network is composed of heterogeneous nodes (saturated areas and airports) linked by air routes aggregations:

- Nodes are ATM elements with capacity restrictions: airports and high density airspace areas.
- Network topology includes geodesic coordinates of airports, distance layer and design capacities of each node, regardless of the specific capacity limiting factor.
- Local rules determine how traffic flows diffuse across the network by modelling the internal dynamics of the nodes behaviour, and they are the mean of simulating airport operations from a macroscopic point of view.
- Global and local variables are defined to obtain performance indicators and to depict the network behaviour.

The input traffic sample is the flown traffic of 24$^{th}$ April 2012 composed of 27658 flights. The number of airports considered is 133, in particular the **first 133 European airports** in terms of traffic: those handling 90% of traffic in the selected traffic sample. Additionally, the list is extended with **five nodes** called AREA nodes that integrate *departures from/ arrivals to* airports outside ECAC grouped by geographical areas. Finally, one node OTHER integrates *departures from/ arrivals to* airports not included in main ECAC set of airports (secondary airports).

The type of input traffic managed by the tool consists of a list of scheduled flights with at least the following basic information for each flight: Estimated Take-Off Time, Callsign, departure airport, destination airport, and flight duration. For each particular flight a set of customisable milestones are



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

considered to mark the transition between phases of flight (e.g. Off-Block Time, Take-Off Time, Arrival Time and In-Block Time).

Free routing is assumed to be in place for most connections between airports, and thus airports are linked by the shortest routes. Highly congested areas are considered as additional nodes of the network with capacity restrictions. These areas are defined based on the assumption that the airspace structure will, in most cases, be able to deliver the required capacity for the area, i.e. that most capacity limitations lie within the nodes, typically airports. Congested airspace areas are simulated by introducing additional nodes. Ad-hoc or user defined airspace areas with capacity restrictions can be set, for instance to analyse the impact of a meteorological event affecting part of the network (airports and airspace). These ad-hoc airspace areas are set to infinite capacity in nominal conditions and their capacity is reduced according to the temporal occurrence of the disturbance in abnormal conditions.

An airspace density map can be built from the traffic demand, in order to identify the trajectories (links between airport nodes) crossing each area.

### 2.3.2 Operation of the Model and Implementation of Routing rules

The model confronts, for the day of operations, the planned demand (input traffic sample) and available capacity at nodes. Demand and capacity balance is observed by dynamically adapting traffic to capacity constraints, according to the defined rules for traffic diffusion. Departures and arrivals are aligned with actual network conditions: when capacity at departure airport and/or destination airport is insufficient to accommodate demand, departures and arrivals are managed according to prioritisation rules on flights.

A dynamic graph is generated from the traffic demand. Distances between nodes are modelled in terms of time units (each time unit representing a time interval). Planned traffic is thus grouped into flows, according to the defined time interval, generating a dynamic graph.

In air transport, two flights can be linked because both are using the same aircraft. The model applies on the traffic sample an algorithm for linking flights. For two consecutive, linked flights, a minimum rotation time is defined (considered as the minimum turnaround time required), so that there is a start-to-end link between the *n+1* rotation and the precedent flight.

The routing rules define how flights are handled at airports and airspace high density areas. They define which criteria must be fulfilled for a flight to go from a milestone of the set of customisable milestones to the next one

The model checks in real-time or within a pre-defined time interval if the estimated capacity at nodes is exceeded for any $T_i$. In case a capacity problem is detected, regulation is applied in the form of ground delays, holdings and flight speed adjustments.

Prioritisation criteria are applied to flights for imposing delays.

The level of granularity of such rules can be customised, from traffic flows to individual flights. Traffic flows can be defined in terms of departure airport, arrival airport, airline, type of aircraft, etc.

Internal disturbances account for all the potential sources of uncertainty related to the air transport system: turnaround process of aircraft at airports, taxi and flight duration variability, etc. They are modelled as aggregated parameters which values are obtained from a statistical analysis of delay data. In the case of the turnaround, for instance, a fixed rotation time is defined (considered as the minimum turnaround time required for each type of aircraft being modelled) and variability is included as a stochastic variable added to the fixed rotation time. This variable follows a probability distribution defined in line with available statistics of actual variability (or primary delays) of turn-around time at airports.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

### 2.3.3 Type of Modelling Outcomes

ATM-NEMMO[2], produces different results at each simulation run, for the same given set of network static conditions (topology, capacities and planned traffic). This is related to the existence of the stochastic parameters permeating the performance of all elements and processes and producing different variability values in each simulation run.

Monte Carlo simulation is performed, repeating each simulation run a significant number of times. Features studied are local (at airport level) and global (at network-wide level) indicators, which serve to characterise the network state and behaviour.

The table below collects the Indicators both Local and Global that are monitored by the tool:

| KPA | Performance Indicator (PI) ID | LOCAL | GLOBAL | PI Name (unit) | PI Definition |
|---|---|---|---|---|---|
| **Efficiency** | EFF.ECAC. PI1 | X | X | Percentage of flights departing on time | A comparison is made between ETOT and ATOT of each flight. If the difference is higher than 15mins (this is customisable), the flight is considered as delayed. |
| | EFF.ECAC. PI2 | X | X | Average departure delay per flight (min) | This is the average departure delay taking into consideration all the flights (on time and delayed). |
| **Capacity** | CAP.ECAC.PI 2 | X | | Hourly throughput overloads | The total number of flights over airport capacity. |
| **Predictability** | PRED.ECAC.PI 2 | X | X | Average delay of delayed departure flights | Average delay of flights suffering delay of more than 15 minutes. |

Figure 1 List of Performance Indicators

The graphical representation provided by the tool is composed of average values bars diagram at global (all the airports) and local (selected airport) levels, standard deviation and the density map composed of all the nodes with colour code basis capacity indications.

In the example below, the average values of EFF.ECAC.PI1 'Percentage of flights departing on time' are represented at local LPPR (bars in green) and global (bar diagrams in yellow) levels.

[2] ATM-NEMMO (NEtwork Macro Model) modelling tool framework has been developed from 2008 onwards by Isdefe R&D Department, Modelling and Simulation Group (M. Sánchez Cidoncha, E. Ochovo and R. García Lasheras).



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

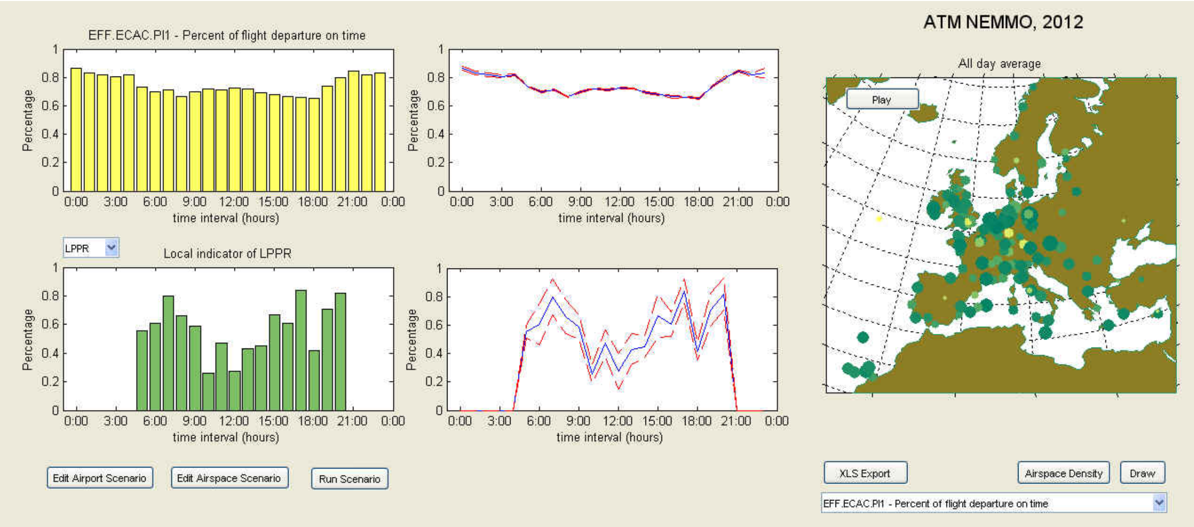



Figure 2 Simulation result's representation by ATM-NEMMO

As for the standard deviation, a slight deviation is appreciated at network level whereas more pronounced deviation is appreciated at local level.

Finally, on the right side, the Density map represents the average values of the congestion level at each node modelled inside ECAC area.

The basis for the Results Analysis is the comparison between the values of the Indicators of different exercises (one criterion is analysed per exercise). Since the model is able to represent just one exercise's results at the same time, Excel tool is used to create new histograms which represent the values of different exercises (criteria) in just one picture.

The analysis and reporting activities include the study of both Global and Local aspects.

A statistical study is used to obtain information from the outputs of the model. Quantitative analysis is carried out to reach a specific numerical result, with an associated statistical level of confidence ($\beta$=95%). Some post-processing activities have been carried on to compute the indicators selected based on the raw data provided by ATM-NEMMO.

## 2.4 Scientific method

The network-wide effects of the different prioritization criteria are analysed through four different scenarios. The scenarios have been customized according to the Experts proposals (from the first project workshop) and the best way to analyse the criteria.

The Modelling Scenarios are as follows:

- Scenario 1: Impact of the prioritization criteria on the network stability

The target of this scenario is to analyse the effectiveness of each prioritization criterion in terms of network efficiency in comparison to the corresponding Generic Scenario (FCFS basis) used as baseline.

- Scenario 2: Relation between network stability and equity ($\alpha$ calibration and priority points)

This scenario is based on an algorithm presented during the first project WS. This airline-network algorithm calculates priority for each flight as a value which is the sum of priority points of two categories: airline driven and network driven. To this end, an initial classification of the criteria is required.

- Scenario 3: Airlines interest as a black box



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

The algorithm used in Scenario 2 is also the basis for this Scenario but assuming that airline business is a black box for the network manager. Each flight is analysed in terms of the network criterion whereas the airline part of the equation remains random.

- Scenario 4: Network critical load analysis

Looking at the Challenge of Growth 2008 [2]the number of flights forecast by 2030 will be between 1.7 and 2.2 times the number of flights in Europe seen in 2007. Subsequent forecasts made in following years (like “Long Term forecast 2010”) shift this scenario 2 years back.

Since NEWO project is focused on long term, three traffic growth scenarios have been selected, with the target in a traffic growth scenario similar to the one envisaged by CoG 2008.

Scenario 4.1 = Current traffic + 1/3 Current traffic,

Scenario 4.2= Current traffic + 2/3 current traffic,

Scenario 4.3= 2 Current traffic,

Once the scenarios were defined an Experimental Plan was detailed.

### 2.4.1 Experimental Plan

Initially, the **Generic Scenario** is defined and modelled. This allows checking if the problems that are present in the network when simple **FCFS criteria** are applied are solved or even worsened when specific prioritisation criteria are in place.

**Internal disturbances** are related to the variability associated to air traffic processes or elements and are inherent to the air traffic network, appearing under nominal conditions. These are considered as Input Data and a set of parameters is defined per each Exercise just before conducting each Exercise. The values for each parameter were defined in D3.1 (see [3]).

**External disturbances** are produced by an element which is not part of the Air Transport network. They are unexpected events that lead to abnormal conditions (in opposition to nominal conditions) when external events (e.g. weather) condition the system performance.

The set of External disturbances to be modeled is as follows:

- External Disturbance type A.-Storm affects Holland, Belgium and Luxembourg (BENELUX)
- External Disturbance type B. Effects of an Ash cloud in Iceland
- External Disturbance type C. London Heathrow security check
- External Disturbance type D. French airspace controllers on strike

For each disturbance (A, B, C, D) scenario, the analysis is done, paying special attention to how the external disturbance, which is originally well delimited in time and location, is propagated to other regions of the network (FABs) along the day.

Once the Generic Scenario (FCFS) is defined, and both internal and external disturbances are modelled, specific Exercises are defined for the analysis of each criterion.

In the figure below, the matrix of exercises to be modelled and compared in Scenario 1 is showed. For detailed information about the matrix of exercises of the rest of scenarios see [1].



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

| SCENARIO 1 | | | | | | |
|---|---|---|---|---|---|---|
| Exercise list | Baseline FCFS | CURRENT TRAFFIC<br>External Disturbances | | | | |
| | | G1A | G1B | G1C | G1D | |
| EX1-G1-FCFS | | | | | | BASELINE FCFS |
| EX2-G1A-FCFS | | X | | | | |
| EX3-G1B-FCFS | | | X | | | |
| EX4-G1C-FCFS | | | | X | | |
| EX5-G1D-FCFS | | | | | X | |
| TO BE COMPARED | | | | | | |
| EX6-G1-Ci-1 | EX1-G1-FCFS | | | | | PRIORITIZATION CRITERIA |
| EX7-G1-Ci-2 | EX1-G1-FCFS | | | | | |
| EX8-G1A-Ci-1 | EX2-G1A-FCFS | X | | | | |
| EX9-G1A-Ci-2 | EX2-G1A-FCFS | X | | | | |
| EX10-G1-Cii-1 | EX1-G1-FCFS | | | | | |
| EX11-G1-Cii-2 | EX1-G1-FCFS | | | | | |
| Ex12-G1B-Cii-1 | EX3-G1B-FCFS | | X | | | |
| EX13-G1B-Cii-2 | EX3-G1B-FCFS | | X | | | |
| EX14-G1-Ciii | EX1-G1-FCFS | | | | | |
| Ex15-G1C-Ciii | EX4-G1C-FCFS | | | X | | |
| EX16-G1-Civ | EX1-G1-FCFS | | | | | |
| EX17-G1D-Civ | EX5-G1D-FCFS | | | | X | |
| EX18-G1-Cv | EX1-G1-FCFS | | | | | |
| EX19-G1C-Cv | EX4-G1C-FCFS | | | X | | |
| EX20-G1-Cvi-1 | EX1-G1-FCFS | | | | | |
| EX21-G1-Cvi-2 | EX1-G1-FCFS | | | | | |
| EX22-G1D-Cvi-1 | EX5-G1D-FCFS | | | | X | |
| EX23-G1D-Cvi-2 | EX5-G1D-FCFS | | | | X | |
| EX24-G1-Cviii | EX1-G1-FCFS | | | | | |
| EX25-G1A-Cviii | EX2-G1A-FCFS | X | | | | |
| EX26-G1-Cix | EX1-G1-FCFS | | | | | |
| EX27-G1D-Cix | EX5-G1D-FCFS | | | | X | |
| EX28-G1-Cx | EX1-G1-FCFS | | | | | |
| EX29-G1B-Cx | EX3-G1B-FCFS | | X | | | |

Figure 3 Exercise Plan for Scenario 1

### 2.4.1.1 Simulation Results Analysis

All the results provided by the tool are stored per criteria and per Performance Indicator. The focus of the analysis is on whether the values of global Performance Indicators obtained through the application of prioritization criteria present improvements with respect to FCFS basis.

One hour time intervals are analyzed, representing average values of each Performance Indicator. The most representative time intervals are highlighted and commented. These results can be found in [1].

- Analysis of the effects at Local Level

The effects of the different prioritization criteria at Airports are analysed following these two aspects:

The top 20 affected departure airports in 2011 according to the CODA 2011

The type of External Disturbance applied at each airport.

The results are represented in a Table, making a comparison between the Baseline (FCFS basis) and each criterion, grouped per External Disturbance type (A, B, C or D).

- Analysis of the effects at Global Level

The Network effects are analysed through Histograms. Thus, each Histogram represents the average values and standard deviation per each Performance Indicator, grouping several exercises each time.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

### 2.4.2 Statistical Analysis

In a research context, statistical significance simply conveys that the 'probability of the observed difference arising by chance was sufficiently small' (Norman & Streiner, 2003, p.32).This does not refer to the size of the difference or whether the difference is meaningful. To address meaningfulness, researchers can report and interpret an effect size estimate.

Before discussing effect size, it is important to recall a point about statistical significance.
Statistical analysis indicates whether a non-zero difference between groups is likely to be a random occurrence or if it is likely to be found again and again if the study is repeated; thus, statistical significance is based on estimates of probabilities. The first point concerns interpretation of ρ values, the most common metric by which statistical significance is determined. Most often, a finding of statistical significance is one in which a particular test value corresponds to a probability estimate of less than 0.05; the chance that this finding is spurious is less than 5%. The ρ value concerns only probability, not important findings.

For the simulation results' statistical analysis, the following tests have been performed:

- Test for Normal Distribution: Kolmogorov-Smirnov with Lilliefors correction and Saphiro-Wilk.;
- Significance level, and;
- Effect size.

## 2.5 Limitations of the modelling approach

This section collects the modelling solutions found to solve specific issues arisen during the implementation. These issues are mainly related to the limitations of the ATM-NEMMO and in some cases, the key is the lack of specific data.

- **Modelling flights crossing ECAC and departing from/arriving at outside ECAC airport**: these AREA nodes are points in the limits of the grid that represent the ECAC area. For defining the exact location of these nodes, the intersections between the grid limits and five representative flows, going from the main European airports to representative airports in each of the areas, have been calculated. The five flows considered are:
  - LFPG (Paris- Charles de Gaulle) to FAJS (Johannesburg –OR Tambo) for AREA 1 node.
  - EDDF (Frankfurt) to YSSY (Sydney –Kingsford Smith) for AREA 2 node.
  - EHAM (Amsterdam- Schiphol) to RJAA (Tokyo-Narita) for AREA 3 node.
  - EGLL (London-Heathrow) to KJFK (New York- JFK) for AREA 4 node.
  - LEMD (Madrid – Barajas) to SABA (Buenos Aires-Ezeiza) for AREA 5 node.

  For the nodes AREA type, capacity is set at a high value (400.000 movements/ hour).

- **Internal disturbances**. The approach to categorise internal disturbances followed in ATM-NEMMO with the purpose of introducing this "noise" is to cluster them according to flight phases delimited by flight milestones. The milestones used are partially extracted from those defined in A-CDM3: milestones selected are related to physical positions of the aircraft throughout the flight taking the airport as a reference. Additionally, two other milestones, not included in A-CDM, are added: Runway Start Time (aircraft at start of runway) and Out of Runway Time (aircraft exits runway).

[3] Airport CDM Implementation Manual, version 4, EUROCONTROL, March 2012.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

Within each flight phase, disturbances can come from diverse sources. The classification of sources of disturbances is based on the aggrupation of causes of **primary delay** proposed in CODA[4]:

Based on the CODA delay causes, sources of internal disturbances are grouped by flight phase.

In order to model these sources of internal disturbances in ATM-NEMMO, probabilistic parameters are added to the estimated times used as reference of the flight status. Given that available data in CODA that can be used to characterise the probabilistic distributions are aggregated by CODA cause, the approach in NEWO is to aggregate as well parameters a1, a2 and c1 in a single **a1** parameter that is added to DTOT to account for all sources of internal disturbances during flight rotation. Up to date CODA statistics are used to estimate the probabilistic distribution to be input as **a1**.

- **Linked Flights**: In case traffic sample does not include aircraft registration, an algorithm is used to create the links for flights within the same airline taking into account a minimum stopover time. The algorithm used for linking flights is on [3]

- **Lack of future Capacity data for airports**: For modelling traffic growth scenarios, only a limited number of airports have their forecast capacity data uploaded in the Airport Corner, so for the rest of them, an assumption relaying the traffic growth and the capacity growth has to be made (see section 6.5 of [1]).

[4] CODA Digest 2011, Central Office for Delay Analysis, EUROCONTROL, March 2012.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# 3 Conclusions from Final Dissemination Workshop

The aim of this section is to record all the discussions, questions and suggestions arisen during the project Final Dissemination Workshop (FDW) held on the 23rd of July at Isdefe premises (Madrid).

## 3.1 Main topics under discussion and Attendees profiles

The meeting started with a round table presentation and review of the agenda. The topics presented were as follows:

- Overview of NEWO Project;
- NEWO and SESAR WPE Context;
- NEWO Technical Approach;
- Prioritisation Strategies studied in the project;
- ATM-NEMMO Tool demo: Setting the tool and results;
- NEWO results and conclusions, and;
- Further research.

The attendee's profiles are listed below:

- Airspace modelling and simulation;
- Airports, aviation, transport networks;
- Airport operations, airport performance;
- CNS; ATM (military side);
- Network optimisation and modelling.

Different discussions took place during the presentations. The main questions, clarifications and ideas arisen are detailed in the following sections grouped in discussion topics.

## 3.2 Methodology for identifying innovative prioritisation approaches

The basis for the identification of the Prioritization criteria was the first project workshop. The project team explained that even with a specific plan for catching as much expertise profiles as possible, the different fields of knowledge of the Experts involved in the first project workshop was reduced to:

- Experts on Complexity Theory and complex networks;
- Experts on logistics and distribution;
- Experts on UDPP;
- Experts on ATM.

Some questionnaires were also shared via email with other contributors not able to attend the first workshop.

The participants in the final workshop suggested that it could have been interesting also to have a sort of segmentation among ATM Experts involved in the first workshop. The rationale for this is that a ground handling agent/ a crew member/ or cargo would have proposed different interests for prioritization.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

## 3.3 Innovative prioritisation approaches

All the prioritization strategies were presented. For some of them, some discussions about the modelling approach chosen took place. The participants therefore proposed some new ideas either for re-considering some criteria or addressing new ones:

- Prioritisation of Flights Carrier vs Low Cost;
- When prioritising best equipped (criterion Best Equipped Best Served (BEBS/MCBS)), since the priority is assigned depending on the equipage levels of the aircrafts, one of the participants suggested a new research topic, based on studying how the delays are spread between equipped airlines/aircrafts;
- BEBS/MCBS and UDPP: It was recommended to consider the participation of UDPP experts from EUROCONTROL when further developing the BEBS/MCBS criterion as well as making intensive use of existing literature on the topic.

## 3.4 ATM-NEMMO modelling approach

The ATM-NEMMO modelling approach was presented and several questions were asked regarding the traffic samples used for modelling: type of flight data, specific Times (milestones), routing rules used, etc.

All the questions were answered and during the discussions, some additional suggestions were proposed by the participants:

- Consider new milestones at airports, including engines switch on/off;
- Distinguish delays at airports and in the air;
- Consider the possibility to model flight routes;
- Consider the possibility to model operational improvements more in detail;
- Consider Airport CDM; is there any possibility to integrate somehow the A-CDM concept in the model

Note that some of the topics arisen are also part of the limitations of the modelling approach (see section 2.5 Limitations of the modelling approach).

## 3.5 Simulation Results

Supported by histograms, the more significant aspects of the simulation results were presented. Contrary to what it was expected at the project initiation phase, all the data gathered brought us to the conclusion of the preference for FCFS criterion in terms of network stability. In other words, none of the criteria analysed showed better results than the ones for FCFS for all the Performance Indicators evaluated.

As for the type of Indicators chosen for the analysis, some of the participants suggested the option of defining new Indicators oriented to the Airlines interests. The project team's answer was that somehow the airlines interests were considered in scenario 2 and 3 (see 2.4). In these scenarios, among the criteria under study in the project, the criteria that benefit airlines interests and the ones that benefit Network Manager were identified and grouped, so that performance benefits in one case and the other could be compared.

For defining specific indicators oriented to measure benefits for airlines, an implication of airlines' representatives in the project would have been required.

A participant pointed out that to this aim and for this type of research projects, any compensation for airlines is required. Otherwise, their collaboration will never be a fact.

Another participant proposed consolidating additional metrics to provide inputs to the UDPP process.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

It was finally recommended to make a clearer link between NEWO's findings and results from previous research.

## 3.6 Miscellaneous

This section collects the potential areas for further research proposed by Experts through filling in the WS questionnaires:

- To consider/create new parameters for modelling Airspace Users negotiation process;
- The possibility to model and distribute the delays in the airside (in case of RBT negotiation modelling is possible) with the aim of modelling a Trajectory Management 4D.The aim behind this is the possibility of considering absorbing delays in the air;
- To consider criteria for automatic acceptance of any modification of RBT/SBT;
- Further analysis on the propagation of the delays through the network;
- To try to find different ways of benchmarking techniques for the model;
- To define more milestones at airports;
- It was also discussed the possibility of studying not only the level of equipage from the Airspace Users point of view, but from an ANSP view as well.

## 3.7 Overall Conclusions

The discussions that took place during the FDW lead us to the conclusions summarised below.

Regarding **SESAR programme** and possibilities of cross fertilization between WPs/Projects, it deserves to mention that the FDW participants found links between the **NEWO operational concept** and concepts currently under development in SESAR projects such us Airport CDM and UDPP. The key is that NEWO project is on its last stage so there is no possibility of updating the concept.

Potential links with specific SESAR JU projects were also mentioned:

- SJU project C2: to check what is being considered in terms of levels of equipage to be further addressed in BEBS criterion.
- SJU WP-B projects: to consider potential benefits of showing NEWO's approach and results to SJU WP-B projects to identify synergies and complementary approaches.

In terms of the **potential of innovative modelling techniques**, there is a need of developing Knowledge Management activities to avoid overlapping and to ease identifying synergies amongst different projects under WP-E. Some sort of benchmarking amongst the different toolkits being used in SJU WP-E Projects linked with modelling and Complexity could be performed with the aim of developing a comprehensive repository of such tools. A dedicated workshop during SESAR Innovation Days 2013 could be a potential way forward.

As for the **traffic data availability**, it is recognised that there is a problem with this in Europe. During the project's FDW it was discussed the possibility for all WP-E Projects to acquire basic traffic data in a centralised manner so that acquisition costs are reduced and information is better managed.

It is known and accepted by most of the modelling experts that **Airlines** play a key role when defining strategies to manage departure queues. However, the Airlines are not willing to share their own strategies and in consequence, the approaches used when implementing the rules for prioritization are based on assumptions. This disturbs the approach and the results. A centralised approach with the support of SJU (maybe using the Airspace Users mechanism) could be useful and give a lot of WP-E projects an added value



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# 4 Strategic Recommendations

## 4.1 Further research on innovative prioritisation criteria

After finalizing the study of the most promising prioritization criteria without finding one which improves the behavior of the network as compared to the First Come First Serve (FCFS) option), the project team looked back and reanalyze some of the ideas arising during the first project workshop and that were disregarded for the modeling phase due to different reasons.

One of this ideas, or potential prioritization criterion, initially ruled out, was the Best Equipped Best Served (BEBS) strategy. This strategy was mentioned during the workshop, but due to the lack of equipage information in the original set of input data for the simulations, it was not possible to further investigate it by modeling it with the ATM NEMMO tool. Since the criterion was discarded due to project specific constraints and not to scientific reasons, it was rescued for further research, using an implementation approach based on the assumptions described in **Error! Reference source not found.** The following sections describe the scope and conclusions of this work.

### 4.1.1 Most Capable (Best Equipped) Best Served: MCBS

#### 4.1.1.1 State-of-the-Art

One of the key enablers in SESAR and NextGen capabilities is the advanced onboard equipage of the aircraft, and it seems implicit that the usage of this equipment will provide the equipped aircrafts an advantage over the non-equipped ones in an environment that allows enhanced operations.
Traditionally, any change related to the aircraft is slow and gradual and requires a huge investment with a long return rate, financial and operational. Those aircraft operators who have been innovators and first adopters of the most modern avionics systems have been disappointed in their attempts to improve their operational efficiency. [5]

Notwithstanding the high degree of automation in many highly technical fields, air traffic control remains a human centric endeavor where humans must balance a formidable number of variables and priorities to quickly make and execute decisions that affect aviation safety, capacity and efficiency. While growing automation capabilities provide an organization with enhanced presentation of data and information as decision support tools, the controller must still assess the information available and render conclusions and decisions. There is no “autopilot” for air traffic controllers. [6]
Experience soon teaches air traffic controllers that homogenous operations make their job easier and its execution safest. In other words, the application and use of consistent standards and repeatable procedures, along with routine and similar aircraft operational performance, allows greater number of aircraft movements in a safe, orderly and expeditious flow of air traffic.

Mixing different types of aircraft with divergent operating characteristics or mission requirements significantly increases controller workload and the demand for mental processing increases, sometimes dramatically. While this can be accomplished by an air traffic controller or team of controllers, the increase in workload decreases the number of aircrafts that can be managed safely. Air traffic controllers estimate that an 80% aircraft equipage compliant rate is necessary before they can start using and advantaging a new technology.[7]

So, how to encourage the airlines to do such investments in a short timeframe and not to wait until the ATM systems are prepared to provide benefits to the equipped aircrafts?. One way to move forward is to develop or adopt policies and procedures that rewards operationally these aircrafts (or the airlines that are behind the investments), offering incentives to the early adopters, until the network is prepared to give real benefits to the equipped aircrafts, i.e., “Best Equipped Best Served” policies.
IATA has a preference for the term **Most Capable Best Served** (MCBS) [9] which better represents the intent of optimizing the efficiency of airspace operations. “Most Capable” is a term that regroups aircraft equipage, crew training, operational certification, flight planning capability and the ability to efficiently and seamlessly convey the pertinent capability to ATM. The expression Most Capable Best Served will be used in this analysis.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

While the procedure to identify equipped aircrafts seems simple, the real challenge lies in how these services would be accomplished. It would be impractical for the controllers to re-sequence airborne aircraft based on aircraft equipage. In fact, this effort would be chaotic and significantly reduce capacity and safety. However, a simple solution exists: Establish these queues in the ground prior to aircraft departure. [8]

At some airports, simply allowing equipped aircraft to pass non-equipped aircraft to or in the departure queue could be an acceptable method to re-sequencing departure allowing equipped aircrafts to depart first, assuming that, if an aircraft departs first, it most likely will arrive first. This implementation possibility is the one analysed in NEWO, in line with the prioritization criteria proposed during the project first workshop.

#### 4.1.1.2 Implementation Approach

Assuming a long transition phase until the aircraft, ground systems and staff evolve from today's operations to a future "better equipped" world, the implementation of advanced capabilities in the airlines will be gradual. Several scenarios representing this "step- by- step" introduction of equipment have been selected.

Based on the "Current Traffic" data sample, all the flights have been grouped per airline. Using the classification made for Criterion III (Hub and Spoke versus point to point flights), and taking the assumption that hub & spoke airlines are the ones that have the financial capability to invest in advanced equipment and crew training (and will be therefore the first ones implementing it), different percentages of their flights have been labeled as "Capable". This has resulted in four different exercises that will represent different stages in the introduction of the measures in the fleet:

a. Exercise 1:All the "Hub and Spoke" airlines have 20% of their flights labeled as "capable"

b. Exercise 2 : Half "Hub and Spoke" airlines have 50% of their flights labeled as "capable", the other half have 20% of their flights labeled as "capable"

c. Exercise 3: Half "Hub and Spoke" airlines have 80% of their flights labeled as "capable", the other half have 20% of their flights labeled as "capable"

d. Exercise 4: Half "Hub and Spoke" airlines have 80% of their flights labeled as "capable", the other half have 50% of their flights labeled as "capable"

The flights labelled as "capable" will be prioritized in the allocation of departure slots over non-capable flights using the algorithm described in the next section.

#### 4.1.1.3 Algorithm

Before starting to run the process, the flights of the "Current Traffic" sample are classified as "Hub and Spoke" and "Non Hub and Spoke", according to the airline they belong to. This classification is static and will remain unchanged in the four exercises.

Then "Hub and Spoke" flights are divided in two groups, more or less of the same number, with the condition that all the flights that belong to an airline will be in the same group, with the aim of being able to compare different percentage of capable flights in the same exercise

According to the exercise selected, a percentage of the flights of each group is labeled as "Capable". If a flight is labeled as "capable", all the flights linked to it are "capable" as well.
For the model execution, in each time step and at each airport, all departure flights are ordered for departure priority, being the first positions for "Capable" flights sorted by time of departure, and the list



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

completed with the rest of flights ordered also according to their departure time. Available departure slots are assigned according the following scheme:

- If the number of Capable flights is lower than the number of available slots, all the Capable flights have a slot and the rest are assigned to non- capable ;
- If the number of capable flights is higher than the number of available slots, the slots are assigned chronologically, so that the rest of Capable flights and all non-capable flights are delayed until the next time step.

#### 4.1.1.4 Metrics and Indicators

The same three indicators used for the rest of criteria are used here:

- EFF.ECAC.PI1: Percentage of flights departing on time
- EFF.ECAC.PI2: Average departure delay per flight
- PRED.ECAC.PI2  Average delay of delayed departure flights

The objective of this simulation is twofold:

- To assess if this prioritization criteria improves the overall situation at a global level.
- To assess if, for the airlines which have part of their fleet capable, which is the threshold (in terms of percentage of fleet "Capable") to start to experience benefits.

For the first objective the indicators will be calculated for the whole traffic sample for the four scenarios and compared with the results obtained for the FCFS

To evaluate the second objective, the indicators will be calculated for subsets of the whole traffic sample.
The following figures represent the four exercises implemented, depicting the percentage of capable and non-capable flight in each of them. It is also indicated the subsets selected in each exercise over which the previous indicators will be evaluated.

For exercise a), selected subsets are:

- aHS (Hub and Spoke Flights): flights belonging to hub and spoke airlines;
- aNHS (non Hub and Spoke Flights): rest of flights.


©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

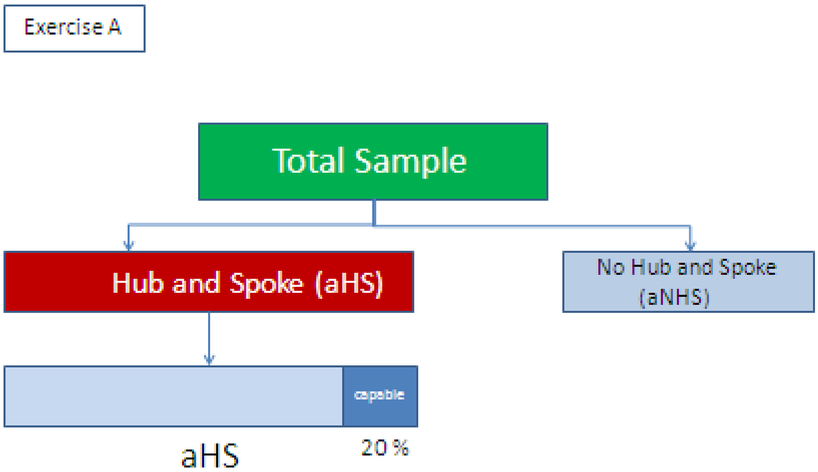



Figure 4 Exercise A schema

For exercise b):

- bHS20 (flights belonging to Hub and Spoke airlines with 20 % of flights capable)
- bHS50 (flights belonging to Hub and Spoke airlines with 50 % of flights capable)
- bHS (Flights belonging to Hub and Spoke airlines)
- bNHS (Flights not belonging to Hub and Spoke airlines)



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

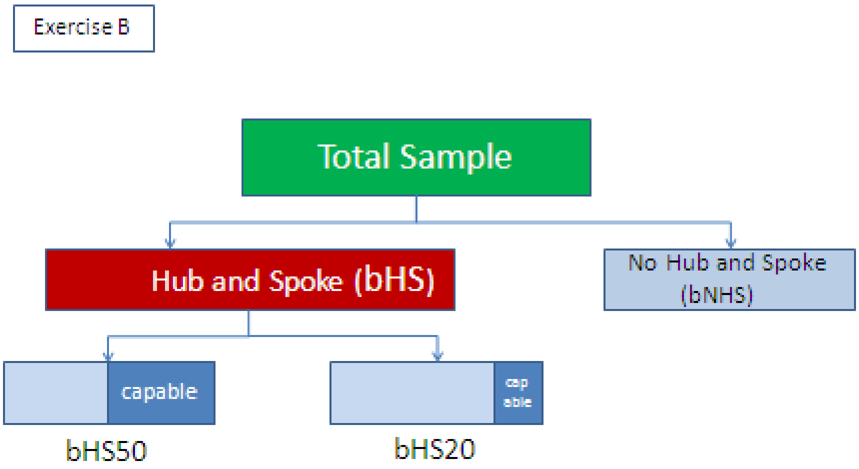



Figure 5 Exercise B schema

For exercise c):

- cHS80 (flights belonging to Hub and Spoke airlines with 80 % of flights capable)
- cHS20 (flights belonging to Hub and Spoke airlines with 20 % of flights capable)
- cHS (Flights belonging to Hub and Spoke airlines)
- cNHS (Flights not belonging to Hub and Spoke airlines)



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

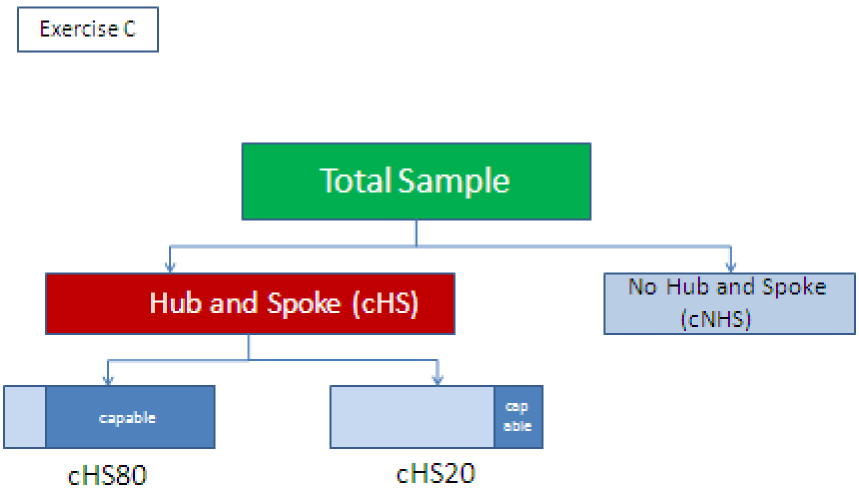



Figure 6 Exercise C schema

For exercise d):

- dHS80 (flights belonging to Hub and Spoke airlines with 80 % of flights capable)
- dHS50 (flights belonging to Hub and Spoke airlines with 50 % of flights capable
- dHS (Flights belonging to Hub and Spoke airlines)
- dNHS (Flights not belonging to Hub and Spoke airlines)



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

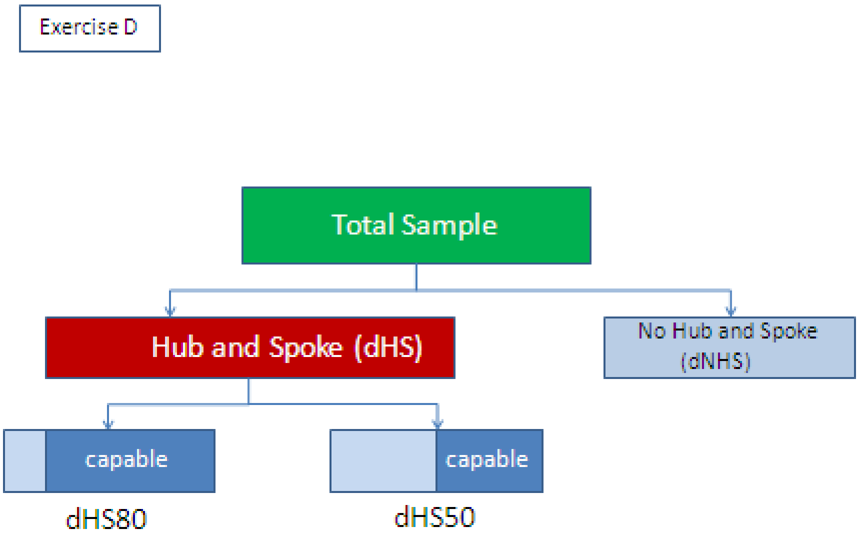



Figure 7 Exercise D schema

The indicators for each subset will be compared internally for each exercise and among them in order to give response to the objectives cited above.

### 4.1.1.5 Analysis of results

Due to hardware constraints, it has not been possible to apply the algorithm for calculate the optimal number of runs described in section 2.2 of D3.2 (see [1]), and the number of runs was limited to 10 [5], so the values showed are the average of each indicator for these 10 runs. The small variations in the values of the total number of flights, and Hub and Spoke and Non Hub and Spoke flights come from the application of the PFC (Probability of Flight Cancellation),and PNF (Probability of New Flights) parameters described in section 6.3 of D3.1 (see [3]).

As well as in the other simulations, a statistical analysis has been performed. The results and conclusions of this analysis are in **Error! Reference source not found.**

- **Exercise A**
    - Total number of flights (TS)**: 22989**
    - Flights Belonging to Hub and Spoke Airlines (aHS)**: 13177 (57,32 %)**
    - Flights Not Belonging to Hub and Spoke Airlines (aNHS): **9812 (42,68%)**
    - Capable Flights**: 2750 (11,96%)**

[5] These simulations have to be run in a less powerful laptop (with MATLAB license) because the original one with MATLAB license used for the first set of simulations was not available at the time of running the exercises.


©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

### Indicators

| | Total Sample | aHS | aNHS |
|---|---|---|---|
| **% of flight departing at time** | 77,15% | 77,43% | 76,78% |
| **Av. Departure Delay for all the flights (min)** | 8,04 | 7,93 | 8,19 |
| **Av. Departure Delay for delayed flights (min)** | 35,21 | 35,15 | 35,29 |

**Table 1** Indicators value for Exercise A

The number of capable flights is about 12 % of the total sample. The values of the indicators for the airlines with 20 % of their fleet "Capable" are slightly better than for the global sample or the not capable, but not enough to convince the airline that this kind of investment will report improvements at short term.

- **Exercise B**
  - Total number of flights (TS)**: 22946**
  - Flights Belonging to Hub and Spoke Airlines (bHS)**: 13200 (57,53 %)**
  - Flights Not Belonging to Hub and Spoke Airlines (bNHS): **9746 (42,47%)**
  - Flights belonging to Hub and Spoke airlines with 50 % of flights capable(bHS50):8438 (36,77%)
  - Flights belonging to Hub and Spoke airlines with 20 % of flights capable(bHS20):4732 (20,75%)
  - Capable Flights: **5299 (23,09%)**

### Indicators

| | Total Sample | bHS | bNHS | bHS50 | bHS20 |
|---|---|---|---|---|---|
| **% of flight departing at time** | 76,54% | 76,88% | 76,09% | 76,49% | 76,69% |
| **Av. Departure Delay for all the flights (min)** | 8,04 | 7,91 | 8,24 | 7,98 | 7,94 |
| **Av. Departure Delay for delayed flights (min)** | 34,27 | 34,19 | 34,46 | 33,94 | 34,08 |

**Table 2** Indicators value for Exercise B

Now the number of capable flights is slightly over the 20% of the whole sample, once again it seems that this percentage of capable flights is not enough to perceive a significant improvement in the behavior of any of the indicators.

- **Exercise C**
  - Total number of flights (TS)**: 22925**
  - Flights Belonging to Hub and Spoke Airlines (cHS)**: 13211 (57,63 %)**


©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

- Flights Not Belonging to Hub and Spoke Airlines (cNHS): **9714 (42,37%)**
- Flights belonging to Hub and Spoke airlines with 80 % of flights capable (cHS80):6907 (30,13%)
- Flights belonging to Hub and Spoke airlines with 20 % of flights capable (cHS20):6304 (27,50%)
- Capable Flights**: 6901 (30,10%)**

## Indicators

| | Total Sample | cHS | cNHS | cHS80 | cHS20 |
|---|---|---|---|---|---|
| **% of flight departing at time** | 76,49% | 76,84% | 76,09% | 75,95% | 76,87% |
| **Av. Departure Delay for all the flights (min)** | 8,11 | 7,93 | 8,36 | 8,25 | 7,86 |
| **Av. Departure Delay for delayed flights (min)** | 34,52 | 34,22 | 34,98 | 34,31 | 34,01 |

**Table 3** Indicators value for Exercise C

The percentage of Capable flights of the sample is now 30 %, again the values of the indicators are almost similar for all the samples.

- **Exercise D**
  - Total number of flights (TS)**: 22876**
  - Flights Belonging to Hub and Spoke Airlines (dHS)**: 13161 (57,53 %)**
  - Flights Not Belonging to Hub and Spoke Airlines (dNHS): **9715 (42,47%)**
  - Flights belonging to Hub and Spoke airlines with 80 % of flights capable (dHS80):4820 (21,07%)
  - Flights belonging to Hub and Spoke airlines with 50 % of flights capable (dHS50):8314 (36,46%)
  - Capable Flights: **8162 (35,68%)**

## Indicators

| | Total Sample | dHS | dNHS | dHS80 | dHS50 |
|---|---|---|---|---|---|
| **% of flight departing at time** | 75,18% | 75,49% | 74,67% | 75,05% | 75,64% |
| **Av. Departure Delay for all the flights (min)** | 8,30 | 8,17 | 8,52 | 8,34 | 8,05 |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

| | | | | | |
|---|---|---|---|---|---|
| **Av. Departure Delay for delayed flights (min)** | 33,42 | 33,32 | 33,63 | 33,40 | 33,04 |

**Table 4** Indicators value for Exercise D

Now the percentage of Capable flights rises above 35 % of the sample, but again the values of the indicators are very similar among the different samples. Surprisingly, the value of the first indicator (Percentage of flights departing on time) is slightly lower for all the subsets than in previous exercises.

Finally, First Come First Served option is analyzed.

- **FCFS**

**Indicators**

| | **Total Sample** |
|---|---|
| **% of flight departing at time** | 77,17% |
| **Av. Departure Delay for all the flights (min)** | 8,18 |
| **Av. Departure Delay for delayed flights (min)** | 35,84 |

**Table 5** Indicators value for FCFS

When comparing the results obtained for the four exercises with the First Come First Serve criterion, only a slight improvement in the third indicator (average departure delay of delayed flights) is perceived.

The best values for the indicators are highlighted in green, surprisingly the best values for the percentage of flights departing at time (EFF.ECAC.PI1) and for the Average departure delay per flight (EFF.ECAC.PI2) do not come from the exercises with higher numbers of "Capable" flights (although the differences are very small) and do not represent an improvement from the original situation (FCFS).

From the statistical analysis, it can be concluded that, for the two first indicators the differences between all the distributions are statically significant and meaningful. For the third indicator PRED.ECAC.PI2, the differences between FCFS and Exercise A are not significant.

### 4.1.1.6 Conclusions and Recommendations

According to the results, the application of departure precedence to Capable flights does not represent an improvement to the situation at a global level. From a second read of the data, the four chosen exercises only represent a gap from 10% to 35% of Capable flights, so the main conclusion extracted from the simulation is that giving priority to a percentage of flights labeled as Capable up to 35% of the total sample, does not represent an improvement to the global situation. The conclusion for higher percentages of capable flights should be confirmed in further simulations.

From a "capable" airline point of view, the conclusion extracted from the simulation could be interpreted the other way around: To give precedence to capable flights, which means an advantage at local level for the airline, has not harmful effect for the global network behavior, this could be an argument for justify an investment in more advanced equipage

Taking advantage of these simulations, other aspects like identifying certain airports as most suitable for capable flights or calculating the indicators per airline, could be explored.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

## 4.2 Key Stakeholders (Airlines) involvement

It have been no possible to obtain during the project the involvement of an airline, although they were identified as key stakeholders at the beginning of the project, and several approaches were made during the project as inviting them to the workshops, always with a negative outcome. This has not allowed us to explore other lines of research based on modelling the strategies of the airlines.

Regarding the involvement of key SESAR projects like UDPP, the principles of it were mentioned in the Conceptual Framework, but finally and due to the lack of advance in this initiative, this kind of slots-dealing mechanism were not modelled in NEMMO tool.

These two aspects have been therefore identified as potential future lines of research.

## 4.3 Further research on complexity

Some characteristics of the complex network mentioned in the Conceptual Framework were not further explored in the project, which opens the door to continue with the research on complexity applied to ATM network. The main characteristics identified were:

- **Betweenness centrality** is a topological property of a node i defined as the average number of times that a random walk between any pair of nodes of the network passes through i.;
- **Dynamic Robustness** study the impact of the dynamics in the ability of a network to avoid cascading of overloads failures when a fraction of its constituents is damaged;
- Existence of **Percolating vulnerable clusters** to predict the potential occurrence of global cascades which will demonstrate the existence of weak points in the network.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# 5 References

**[1]** NEWO, 'DEL0E02.02 Simulation Results and Analysis', D07, Edition 00.00.04, 03/09/2013

**[2]** Challenges of Growth 2008, Summary Report, Eurocontrol.

**[3]** NEWO, 'DEL0E.02.02-D06-NEWO-Modelling Scenarios and Experiments Plan', D06, Edition 00.00.06, 25/06/2012.

**[4]** CODA Digest 2011", Central Office for Delay Analysis, EUROCONTROL, March 2012.Name of project, Title of document1, Identification number, Edition, date

**[5]** 'Integrating best-equipped best-served principles in ground delay programs' Andrew. M. Churchill, Michael O. Ball and A.D Donaldson. Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011)

**[6]** 'Flight Prioritisation Deep Dive: Final Report', Next Generation Air Transportation System Joint Planning and Development Office, January 2011

**[7]** 'Understanding the impact of Potential Best-Equipped Best-Served Policies on the En-Route Air Traffic Controller Performance and Workload' HongSeok Cho and R. John Hansman, MIT International Center for Air Transportation, Report Nº ICAT-2012-2, February 2012

**[8]** 'An Achievable Approach to implementing "Best Equipped Best Served", Gary R. Church, Aviation Management Associates inc. The Journal of Air Traffic Control, Summer 2012

**[9]** 'Migration towards "Best Equipped Best Served" (BEBS) ATM operation' , Twelfth Air Navigation Conference IATA, Montreal 19 to 30 November 2012, AN-Conf/12-IP/61



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

# Appendix A MCBS versus FCFS: simulation results statistical analysis

**TEST FOR SIGNIFICANCE**

Five exercises have been considered for the significance test analysis. The five Performance Indicators will be evaluated for each exercise.

- **FCFS**
- **Exercise A MCBS_20**
- **Exercise B MCBS_50_20**
- **Exercise C MCBS_80_20**
- **Exercise D MCBS_80_50**

As in the past, two tests are applied: Kolmogorov-Smirnov with Lilliefors correction and Saphiro-Wilk. We want to contrast for a given level of confidence, the null hypothesis that the data used come from a population that follows a Normal Distribution.

**If the significance is higher than 0.05, we will accept that the data belong to a population that follows a Normal Distribution.**

- **EFF.ECAC.PI1.**

So the results obtained for the EFF.ECAC.PI1 using SPSS tool are as follows:

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| Ex1_G1_FCFS | ,034 | 235 | ,200* | ,998 | 235 | ,982 |

a. Corrección de la significación de Lilliefors

*. Este es un límite inferior de la significación verdadera.

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| MCBS_20 | ,165 | 10 | ,200* | ,925 | 10 | ,405 |
| MCBS_50_20 | ,182 | 10 | ,200* | ,971 | 10 | ,898 |
| MCBS_80_20 | ,148 | 10 | ,200* | ,962 | 10 | ,812 |
| MCBS_80_50 | ,205 | 10 | ,200* | ,904 | 10 | ,244 |

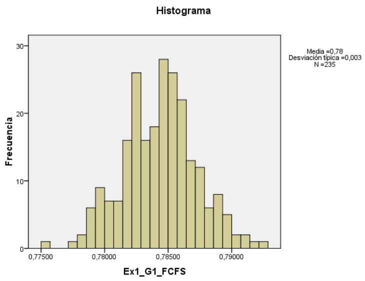
a. Corrección de la significación de Lilliefors

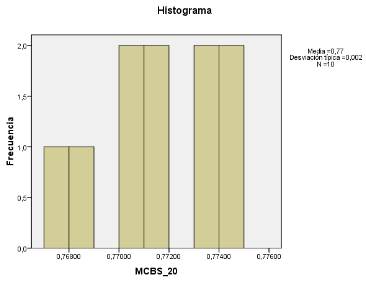
*. Este es un límite inferior de la significación verdadera.

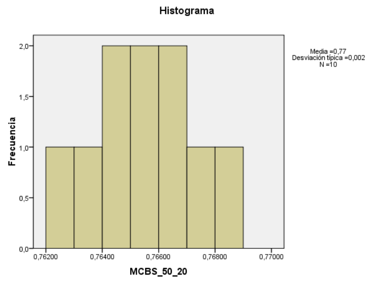


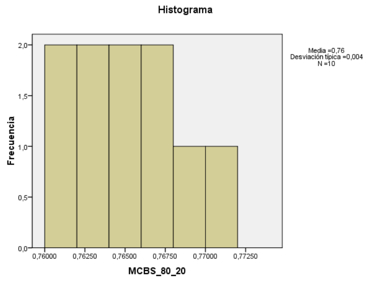
©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

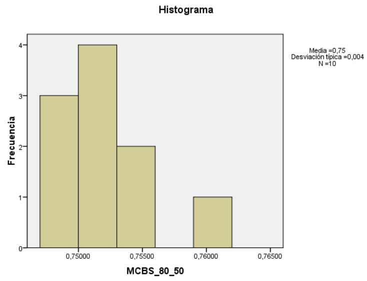
The exercises follow a normal distribution.
The SPSS tool provides the histograms[6] below to 'see' the bell-shaped distributions for each exercise.




- **EFF.ECAC.PI2.**

The results obtained for EFF.ECAC.PI2 are shown in the table below:

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| Ex1_G1_FCFS | ,032 | 235 | ,200* | ,995 | 235 | ,708 |

a. Corrección de la significación de Lilliefors

*. Este es un límite inferior de la significación verdadera.

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| MCBS_20 | ,263 | 10 | ,048 | ,869 | 10 | ,098 |
| MCBS_50_20 | ,110 | 10 | ,200* | ,962 | 10 | ,805 |
| MCBS_80_20 | ,148 | 10 | ,200* | ,968 | 10 | ,873 |
| MCBS_80_50 | ,207 | 10 | ,200* | ,944 | 10 | ,604 |

a. Corrección de la significación de Lilliefors

[6]The first Histogram corresponds to EX1, second one to MCBS_20, the third one to MCBS_50_20, the forth one to MCBS_80 _20 and the last one to NCBS_80_50.



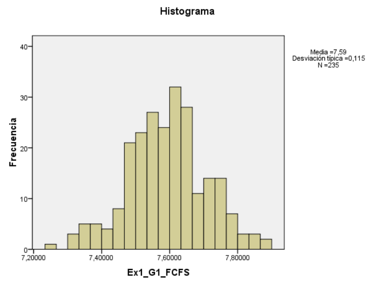
©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

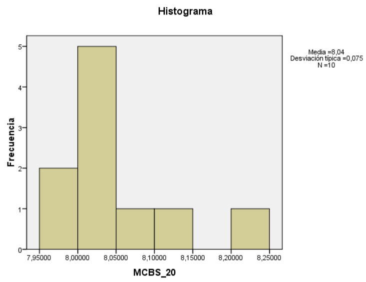
**Pruebas de normalidad**

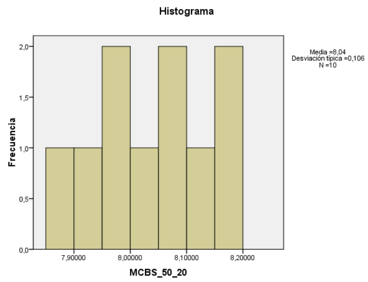
| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| MCBS_20 | ,263 | 10 | ,048 | ,869 | 10 | ,098 |
| MCBS_50_20 | ,110 | 10 | ,200* | ,962 | 10 | ,805 |
| MCBS_80_20 | ,148 | 10 | ,200* | ,968 | 10 | ,873 |
| MCBS_80_50 | ,207 | 10 | ,200* | ,944 | 10 | ,604 |

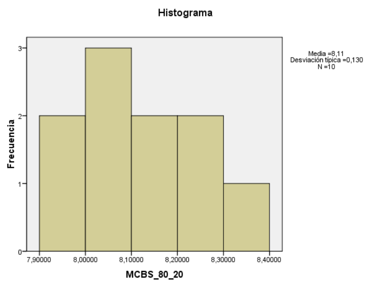
*. Este es un límite inferior de la significación verdadera.

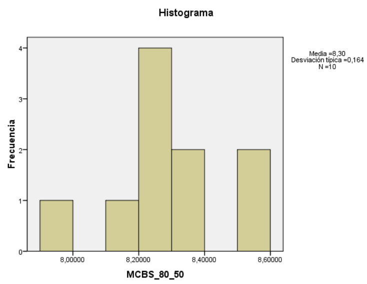
The exercises follow a normal distribution.




- **PRED.ECAC.PI2.**

The results obtained for PRED.ECAC.PI2 are shown in the table below:

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
| Ex1_G1_FCFS | ,025 | 235 | ,200* | ,996 | 235 | ,777 |

a. Corrección de la significación de Lilliefors

*. Este es un límite inferior de la significación verdadera.

**Pruebas de normalidad**

| | Kolmogorov-Smirnov[a] | Shapiro-Wilk |
|---|---|---|



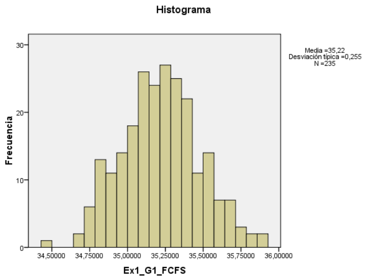
©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

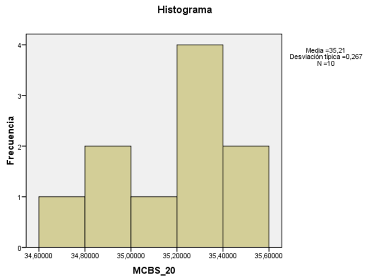
| | Estadístico | gl | Sig. | Estadístico | gl | Sig. |
|---|---|---|---|---|---|---|
| MCBS_20 | ,098 | 10 | ,200* | ,966 | 10 | ,852 |
| MCBS_50_20 | ,154 | 10 | ,200* | ,922 | 10 | ,374 |
| MCBS_80_20 | ,157 | 10 | ,200* | ,924 | 10 | ,393 |
| MCBS_80_50 | ,190 | 10 | ,200* | ,972 | 10 | ,906 |

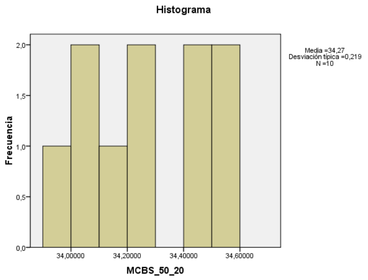
a. Corrección de la significación de Lilliefors

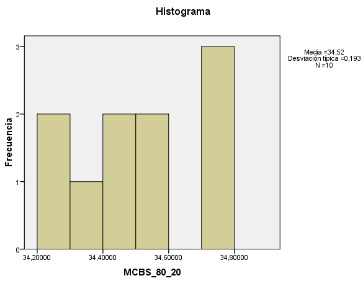
*. Este es un límite inferior de la significación verdadera.

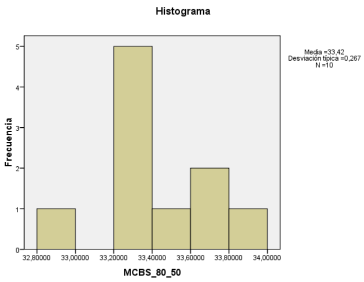
The exercises follow a normal distribution.




As all the exercises are Gaussians we can use parametric test to test for significance between two sample distributions. This test is based on T-Student mean difference analysis.
We want to contrast for a given level of confidence, the null hypothesis that the data from two different exercises follow the same distribution. **If the significance is higher than 0.05, we will accept that the data belong follows the same Distribution.**

So the results obtained for the **EFF.ECAC.PI1** using SPSS tool are as follows:

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | ,7844117 | ,00288233 | ,00018802 |
| | EX20_G1_Cvi_1 | 10 | ,7715370 | ,00234669 | ,00074209 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,410 | ,522 | 13,921 | 243 | ,000 | ,01287466 | ,00092483 | ,01105294 | ,01469637 |
| | No se han asumido varianzas iguales | | | 16,818 | 10,191 | ,000 | ,01287466 | ,00076554 | ,01117326 | ,01457606 |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | ,7844117 | ,00288233 | ,00018802 |
| | MCBS_50_20 | 10 | ,7654220 | ,00188293 | ,00059543 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | 2,009 | ,158 | 20,625 | 243 | ,000 | ,01898966 | ,00092073 | ,01717603 | ,02080329 |
| | No se han asumido varianzas iguales | | | 30,412 | 10,880 | ,000 | ,01898966 | ,00062442 | ,01761348 | ,02036584 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | ,7844117 | ,00288233 | ,00018802 |
| | MCBS_80_20 | 10 | ,7649330 | ,00359633 | ,00113726 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | 1,076 | ,301 | 20,717 | 243 | ,000 | ,01947866 | ,00094021 | ,01762666 | ,02133066 |
| | No se han asumido varianzas iguales | | | 16,898 | 9,498 | ,000 | ,01947866 | ,00115270 | ,01689179 | ,02206553 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | ,7844117 | ,00288233 | ,00018802 |
| | MCBS_80_50 | 10 | ,7517580 | ,00376519 | ,00119066 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,770 | ,381 | 34,636 | 243 | ,000 | ,03265366 | ,00094276 | ,03079664 | ,03451068 |
| | No se han asumido varianzas iguales | | | 27,089 | 9,454 | ,000 | ,03265366 | ,00120541 | ,02994667 | ,03536065 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

The results obtained for **EFF.ECAC.PI2** are shown in the table below:

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 7,5930690 | ,11494489 | ,00749818 |
| | EX20_G1_Cvi_1 | 10 | 8,0431610 | ,07460961 | ,02359363 |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | 2,367 | ,125 | -12,259 | 243 | ,000 | -,45009202 | ,03671421 | -,52241072 | -,37777332 |
| | No se han asumido varianzas iguales | | | -18,181 | 10,906 | ,000 | -,45009202 | ,02475645 | -,50463825 | -,39554579 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 7,5930690 | ,11494489 | ,00749818 |
| | MCBS_50_20 | 10 | 8,0397840 | ,10612363 | ,03355924 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,153 | ,696 | -12,069 | 243 | ,000 | -,44671502 | ,03701250 | -,51962130 | -,37380874 |
| | No se han asumido varianzas iguales | | | -12,991 | 9,920 | ,000 | -,44671502 | ,03438670 | -,52341713 | -,37001291 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 7,5930690 | ,11494489 | ,00749818 |
| | MCBS_80_20 | 10 | 8,1140840 | ,13045774 | ,04125436 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,642 | ,424 | -13,964 | 243 | ,000 | -,52101502 | ,03731159 | -,59451044 | -,44751960 |
| | No se han asumido varianzas iguales | | | -12,426 | 9,604 | ,000 | -,52101502 | ,04193024 | -,61496616 | -,42706388 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises on´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 7,5930690 | ,11494489 | ,00749818 |
| | MCBS_80_50 | 10 | 8,2975140 | ,16393644 | ,05184125 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | 1,081 | ,300 | -18,627 | 243 | ,000 | -,70444502 | ,03781814 | -,77893823 | -,62995181 |
| | No se han asumido varianzas iguales | | | -13,449 | 9,380 | ,000 | -,70444502 | ,05238071 | -,82221006 | -,58667998 |

In this case we can accept the variance equivalence but not the mean equivalence so the two exercises don´t follow the same distribution.

The results obtained for **PRED.ECAC.PI2** are shown in the table below:



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 35,2202596 | ,25534640 | ,01665696 |
| | EX20_G1_Cvi_1 | 10 | 35,2066000 | ,26730972 | ,08453076 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,019 | ,892 | ,165 | 243 | ,869 | ,01365957 | ,08259405 | -,14903206 | ,17635121 |
| | No se han asumido varianzas iguales | | | ,159 | 9,712 | ,877 | ,01365957 | ,08615627 | -,17908317 | ,20640232 |

In this case we can´t accept the variance equivalence and neither the mean equivalence so the two exercises don´t follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 35,2202596 | ,25534640 | ,01665696 |
| | MCBS_50_20 | 10 | 34,2726000 | ,21915302 | ,06930227 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,200 | ,655 | 11,551 | 243 | ,000 | ,94765957 | ,08204462 | ,78605018 | 1,10926897 |
| | No se han asumido varianzas iguales | | | 13,296 | 10,069 | ,000 | ,94765957 | ,07127593 | ,78899342 | 1,10632573 |

Again we can accept the variance equivalence but not the mean equivalence so the two exercises do not follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 35,2202596 | ,25534640 | ,01665696 |
| | MCBS_80_20 | 10 | 34,5185000 | ,19299122 | ,06102918 |

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Intervalo de confianza para la diferencia | |
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,769 | ,381 | 8,580 | 243 | ,000 | ,70175957 | ,08179050 | ,54065075 | ,86286840 |
| | No se han asumido varianzas iguales | | | 11,093 | 10,389 | ,000 | ,70175957 | ,06326149 | ,56151565 | ,84200350 |

Again we can accept the variance equivalence but not the mean equivalence so the two exercises do not follow the same distribution.

**Estadísticos de grupo**

| | Tipo | N | Media | Desviación típ. | Error típ. de la media |
|---|---|---|---|---|---|
| Results | Ex1_G1_FCFS | 235 | 35,2202596 | ,25534640 | ,01665696 |
| | MCBS_80_50 | 10 | 33,4235000 | ,26685129 | ,08438579 |



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

**Prueba de muestras independientes**

| | | Prueba de Levene para la igualdad de varianzas | | Prueba T para la igualdad de medias | | | | | 95% Intervalo de confianza para la diferencia | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | gl | Sig. (bilateral) | Diferencia de medias | Error típ. de la diferencia | Inferior | Superior |
| Results | Se han asumido varianzas iguales | ,020 | ,888 | 21,756 | 243 | ,000 | 1,79675957 | ,08258832 | 1,63407921 | 1,95943993 |
| | No se han asumido varianzas iguales | | | 20,889 | 9,714 | ,000 | 1,79675957 | ,08601404 | 1,60434193 | 1,98917722 |

Again we cannot accept the variance equivalence and neither the mean equivalence so the two exercises do not follow the same distribution.

**TEST FOR THE EFFECT SIZE**

As all the distributions show statistically significant differences we calculate the effect size. In relation with the new assumption relative to consider only one interval per day, we can only offer a date of effect size for each couple of exercises.

If we look at Cohen's d definition, the effect size is considered meaningful when the value of d is at least higher than 0.5.

As it is previously mentioned, there are no External Disturbances included in the runs. **The bigger the effect size is the more significant the difference is between the exercises.** The study of effect size is based on *The interpretation of Cohen's d* and the values obtained through SPSS tool are the ones shown below:

- **EFF.ECAC.PI1:**

**Ex1_G1_FCFS VS MCBS_20 => 0.9257227053617404**
**Ex1_G1_FCFS VS MCBS_50_20 => 0.968667227228102**
**Ex1_G1_FCFS VS MCBS_80_20 => 0.9483311904695713**
**Ex1_G1_FCFS VS MCBS_80_50 => 0.9795564739045791**

We can conclude that the differences between all the distributions are statistically significant and meaningful with this indicator.

- **EFF.ECAC.PI2:**

**Ex1_G1_FCFS VS MCBS_20 => 0.9184483117451045**
**Ex1_G1_FCFS VS MCBS_50_20 => 0.8962289394314853**
**Ex1_G1_FCFS VS MCBS_80_20 => 0.9043403260177077**
**Ex1_G1_FCFS VS MCBS_80_50 => 0.9279535352085646**

We can conclude that the differences between all the distributions are statistically significant and meaningful with this indicator.

- **PRED.ECAC.PI2:**

**Ex1_G1_FCFS VS MCBS_20 => 0.024862471783246343**
**Ex1_G1_FCFS VS MCBS_50_20 => 0.8935207622531558**
**Ex1_G1_FCFS VS MCBS_80_20 => 0.8403978872404135**
**Ex1_G1_FCFS VS MCBS_80_50 => 0.960228377899462**

We can conclude that the differences between Ex1_G1_FCFS VS MCBS_50_20, Ex1_G1_FCFS VS MCBS_80_20 and Ex1_G1_FCFS VS MCBS_80_50 are statistically significant and meaningful with this indicator. The differences between Ex1_G1_FCFS VS MCBS_20 are not significant with this indicator.



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.

**-END OF DOCUMENT-**



©SESAR JOINT UNDERTAKING, 2011. Created by Isdefe for the SESAR Joint Undertaking within the frame of the SESAR Programme co-financed by the EU and EUROCONTROL. Reprint with approval of publisher and the source properly acknowledged.