

ATM SYSTEM STATUS ANALYSIS METHODOLOGY

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Abstract

The objective of this paper is to present a methodology designed to evaluate the **status of a given ATC scenario** in terms of relationship between the offered capacity and the air traffic demand, that permits to identify weaknesses areas and to determine solutions.

Some general criteria are established to define the framework in which the analysis and diagnostic methodology presented is placed. They are: the use of ATC sectors as analysis unit, the presence of network effects, the tactical focus, the relative character of the analysis, objectivity and the exclusion of the human and CNS elements.

The steps followed by the methodology start with the definition of indicators and metrics, like the nominal criticality or the nominal efficiency of a sector; scenario characterization where the necessary data is collected; network effects analysis to study the relations among the constitutive elements of the ATC system; diagnostic by means of the System Status Diagram; analytical study of the ATC system development limit; and finally, formulation of conclusions.

This methodology was employed by Aena and INECO in the analysis of the Spanish ATC System in the frame of the INCA program.

Introduction

Objective and scope

As it is defined in ATM 2000+ Strategy, the mission of the ATM System is: “For all the phases of a flight, the ATM system should facilitate a **safe, efficient, and expedite** traffic flow, through the provision of adaptable ATM services that can be dimensioned in relation to the requirements of all the users and areas of the European air space. The ATM services should comply with the demand, be compatible, operate under uniform principles,

respect the environment and satisfy the national security requirements.”

The objective of this paper is to present a methodology designed to evaluate the **status of the ATC system** in terms of the relationship between the offered capacity and traffic demand, identifying weakness areas and proposing solutions. The first part of the methodology relates to the characterization and evaluation of the current system, while a second part proposes an approach to analyze the possible development limit. This methodology was used and effectively applied in a study of the ATC System in Spain, although it could be applied elsewhere.

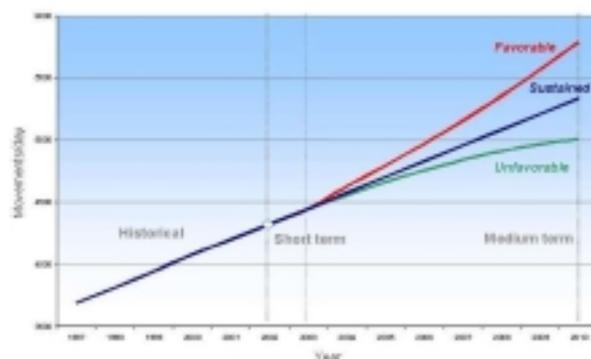


Figure 1. Evolution of the demand

To develop this methodology, an analytical or inductive method was followed, where the data used and the assumed hypothesis play an essential role to obtain the results, avoiding specific evaluations that could bias the results towards subjective estimations.

The analysis scenario presented in this paper is limited to the en-route ATC system, even though another methodology was considered to systematically analyze TMAs.

This work was carried out by Aena and INECO within the framework of the INCA project, whose objective was to increase the capacity of the Air Navigation System in Spain. The figures and

tables used as examples here are part of this work, although it is not the intention of this paper to present the results of the INCA project, but only to describe the methodology in which this project were supported. This methodology was developed taking into account several references on this subject across the aeronautical international community. Specially relevant for this purpose have been the set of studies developed by Eurocontrol using its FAP (Future ATM Profile) methodology to project ATM performance indicators into the future; despite this is based on simulations, in contrast with the analytical methodology presented here, both methods share the same final objective, this is, to identify and quantify capacity shortfalls of the ATM system in an anticipate way, so capacity management and associated decisions processes will progressively move from retro-active to proactive by forecasting system performances. Also important were references from the PRC's European ATM performance measurement system with respect to the definition of the performance metrics proposed to evaluate the "system status".

Use of the methodology

The methodology used for "the evaluation of the system current status", as described within the present paper, has been integrated as a key element into the capacity strategic planning continuous process, defined by Aena's Air Navigation Directorate. The process ultimate goal is to ensure that the capacity of the system is adapted to match the air traffic demand, well in advance. It is characterised by its annual periodicity and commences with the identification and analysis of both strengths and weaknesses of the system in relation to the forecasted air traffic demand for the evaluation period. The outcomes of this first stage facilitate and point the identification and selection of proposals, aiming to take advantage of existing capacity surpluses in order to compensate identified deficits. Then, and once the solutions that are intended to be implemented have been selected, the proposed method is applied to a new scenario. The obtained results bring us the conclusions that are intended to facilitate the decision-making process regarding to the nature of solutions that will be put into practice so as to meet the system users' operational needs. The study contemplates as its inputs, both the real operational scenario and factual

air traffic demand data. In addition, both outcomes and conclusions from the final assessment, enables a continuous information feedback that helps in optimising the method and consequently in enhancing the capacity planning process.

General criteria

The present methodology is based on a set of general criteria presented below. These criteria are supported in the following assumptions that are related to the diagnostics procedure proposed for the short and medium term.

- **ATC Sector:** The analysis uses the ATC sector as the basic capacity reference and as the most elemental operational component of ATC. This election is based on the fact that the sector is the only ATC domain for which a system performance value in terms of capacity/hour has been specified quantitatively.

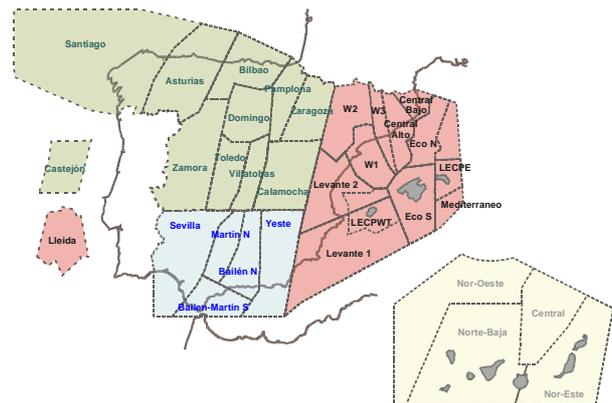


Figure 2. Route ATC Sectors in Spain

- **Network effect:** The risk of taking the sector capacity as focal point of the analysis is to obtain a vision with little network perspective. Due to this, the vision of the ATC as a system should be systemic and developed to take into account the network effect that results from the distribution of the demand organized by traffic flows.
- **Tactical focus:** methodology is focused onto the current ATC sector structure, thus limits the validity of the analysis results only to the short and medium term. This diagnostic methodology would not be applicable to longer term because

it is generally accepted through the aeronautical international community that the *modus operandi* based on the classic ATC sector concept will not be compatible with the expected air traffic demand for that time frame.

- **Relative character:** The lack of a capacity reference model has led to the need of performing the analysis in relative terms, that is, based on the comparison of the behavior of the different sectors analyzed. This deliberate relativity is a conceptual need if the results are to have effective value and not be so vulnerable to 'double nature' criticism.
- **Objectivity:** To avoid controversy, the previous relativity is complemented by a balanced view of the different topics used to qualify the sectors performance. That is, once the initial hypotheses are formulated, the application of the analysis methodology will obtain the results without incorporating any particular judgement. In this way, the results can only be argued as far as the initial hypotheses or the method can be adequate, moving the argument from the specific casuistic to the theoretical plane of the definitions.
- **Exclusion:** This criterion is used to fix the conditions of the analysis. The objective is to attain the asepsis of the method, in this sense two major assumptions are made: a "standard" CNS component for high density traffic ATC system is available, and the human component is qualified to perform the control of this CNS scenario. In other words, the methodology does not take into account the human or the CNS components.

Methodology

The methodology presented in this paper is based on the characterization of the ATC system following the criteria established above. The method proposed is based on a top-down inductive process, which ends with the diagnostic of the system and the proposal of possible solutions to the detected problems.

The steps to be followed are briefly described below, although they are explained in further detail in the upcoming sections.

- **Definition of system performance indicators:** Definition of the **metrics** that would allow to **model** the behavior of the system and, in this way, to measure and evaluate the features decided to be representative of its status.
- **Scenario characterization:** The process to obtain all the necessary **data** corresponding to the scenario, which can be measured as a function of the indicators defined earlier.
- **Network effects analysis:** Identification and quantification of the **relations** among the system elements.
- **Diagnostic:** Preparation of the **System status diagram** and evaluation of the ATM system development limit without modifying the current operational concept.
- **Conclusions:** Formulation of **conclusions**, simplified CBA and proposal of solutions.

Definition of performance indicators

Two different levels are taken into account to develop a definition of the system performance indicators. The lower level, System Status, deals with the system simplest components, the sectors, while the higher level, deals with relations among those elements.

System Status

The indicators based on the System Status are established as a function between the actual performance of the ATM system (Capacity) and the demanded services (Air traffic). They are expressed in quantitative terms related to the number of movements.

Two different aspects that characterize the System Status are considered: the criticality and the efficiency, which would define the demand versus capacity and the operating 'complexity' of the different sectors. To evaluate the nominal criticality and efficiency, which are the actual quantitative factors to be used in the diagnostics, they are subdivided into measurable magnitudes.

Criticality

The Criticality, in a qualitative formulation, provides the idea of the relationship between the air traffic demand and the capacity of a sector.

To express the Criticality in quantitative terms, the following “Capacities” are defined:

- Declared Sustained Capacity: Maximum number of movements per time unit (hour) that a sector is capable to manage in normal operational conditions.
- Declared Peak Capacity: Maximum number of movements per time unit (hour) that a sector is capable to manage (occasionally) without compromising the safety levels.
- Residual Capacity: Difference between the peak and the sustained capacity, multiplied by the number of hours of the time period.

Then, three factors are defined to characterize the relation between the traffic demand and the sector capacity.

- Occupation Factor: Percentage relation between the number of movements that do not exceed the declared sustained capacity of the sector and the total capacity of the sector (related to a period of time). See Figure SEQARABIC3.

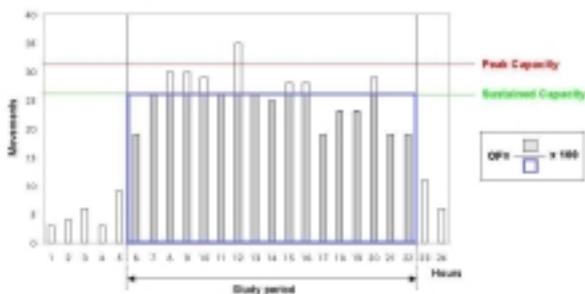


Figure 3. Occupation Factor

- Overflow Factor: Percentage relation between the number of movements that exceeding the declared sustained capacity of a sector and do not exceed its declared peak capacity, over the residual capacity of the sector (related to a period of time). See Figure4.

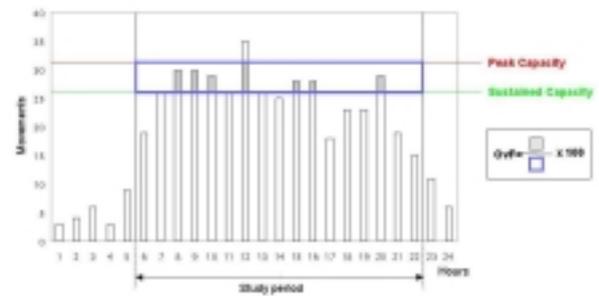


Figure 4. Overflow Factor

- Saturation Factor: Number of movements that exceed the sector’s peak capacity in a time period, multiplied by the relative saturation frequency (relation between the number of hours in which saturation exists and the total number of hours of the period). See Figure5.

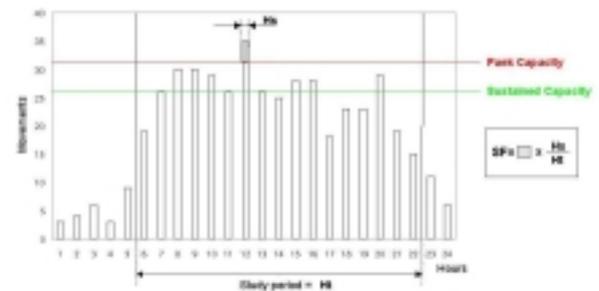


Figure 5. Saturation Factor

A sector is considered to be in **critical status** when, for a specific time interval (of several hours), it presents a traffic demand greater than its declared peak capacity; that is, a sector with **Saturation Factor** greater than zero. A priori, those sectors with **Occupation Factor** equal to 100% are also considered critical.

To establish a prioritization order, it is considered that for two sectors with equal Saturation Factor, the one with higher Occupation Factor shall be considered more critical. In the case that both factors are equal, the sector with greater Overflow Factor shall be considered more critical.

The actual quantitative indicator that shall be employed in the analysis is the so called **Nominal Criticality**, which is computed for every ATC sector. The Nominal Criticality is defined as the sum of the **Saturation Factor** and the **Occupation**

Factor, weighed by 1.2 and 0.8 respectively (results from empiric evidence).

$$C = 1.2SF + 0.8OF$$

Efficiency

The Efficiency, in qualitative formulation, allows to perform a **preliminary evaluation of the declared capacities** of the sectors, comparing the declared capacity with the capacity that could be expected taking into account several intrinsic (structural) features that can represent, in principle, the complexity of the sector.

These structural features are defined as follows:

- Collaterality: Number of sectors adjacent to a given sector that have interrelation by principal air traffic flow.
- Traffic Mix: Proportion between traffic in evolution and established traffic.
- Mean Flight Time: Statistic value that gives the mean time that a flight remains inside the sector.

Based on the previous definitions an efficiency indicator is defined, called **Declared Nominal Efficiency**, which is the sum of the **Declared Sustained Capacity** (scaled to a certain value of reference: i.e. 20 “points”) plus the sum of the **Collaterality**, **Traffic Mix** and **Mean Flight Time** (also scaled to “20”), weighed by factors 0.2, 0.5 and 0.3 respectively (historical experience).

$$DNE = DSCap + (0.2Col + 0.5TM + 0.3MFT)$$

Relationship between sectors

ATM is a complex system composed of (depending on the selected approach) a large number of elements (in this case, ATC sectors) strongly related to each other. With the goal of evaluating **network effects**, that is, the impact that the status and actions on a sector may have on the rest of the system, an indicator is defined to identify the relations among the different elements of the system and their “intensity”.

The related effects among the ATC sectors is based on the nature of air traffic demand, through the ‘main traffic flows’ of the system. They are defined as the aggregation of the main flows of each sector, which in turn are those flows that represent, at least, 80% of the number of movements/day in the sector.

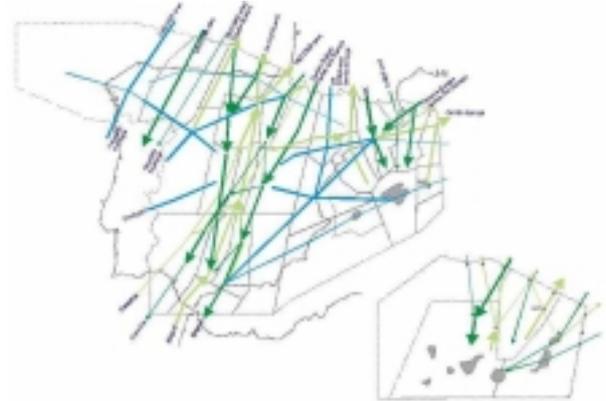


Figure 6. Identification of main traffic flows

The quantitative indicator, **Traffic Shared Between Sectors**, is defined as the number of aircraft per day that cross any pair of ATC sectors (all the combinations), independently of the fact that the sectors were or not collateral.

Analysis of network effects

With the purpose of obtaining an overall vision of the degree of interdependence among sectors, the proposed tool is to represent the sectors in a two-entry table ordering them by their nominal criticality (see Figure7). The result is a matrix symmetrical with respect to the main diagonal (top left corner, bottom right corner).

The criterion to group the sectors is that between them there is an exchange of movements greater than the value corresponding to the percentile 50 of the distribution.

In this way, several types of sector groupings can be found:

- Critical Sectors Grouping: Set of related sectors that are not able to cope adequately with the air traffic demand in their airspace. Due to this, they need “urgent” actions related with the improvement/optimization of their capacity, either individually or in-group.

- Non Critical Sectors Grouping: Set of related sectors that have enough capacity to efficiently cope with the air traffic demand in their airspace.
- Critical and ‘Support’ Sectors Grouping: Set of related sectors where sectors that are not able to cope adequately with the air traffic demand (critical sectors) coexist with other sectors that, in general terms, are still able to provide ATC service to a greater number of aircraft in their airspace (support sectors).

The following figure shows an example of Network Effect Analysis performed onto ATC sectors in Spain.

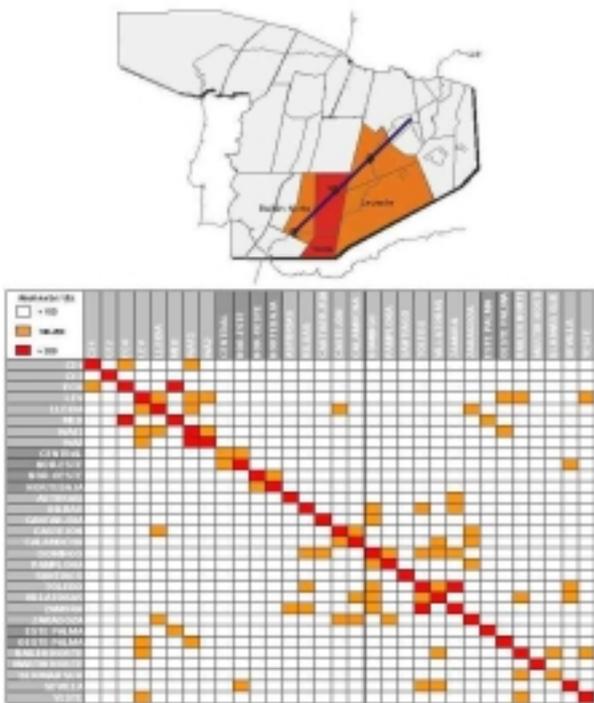


Figure 7. Analysis of Network Effects

Diagnostics: Status diagram

The Relative Status Diagram represents the situation of each sector respect from the collectivity as a function of a combined analysis of their physical characteristics, the traffic nature and demand and their declared capacities.

The Y-coordinate locates the sector according to its nominal criticality (as it is defined above and scaled to a certain value of reference) which

informs of the degree of agreement between the traffic and the declared capacity of the sector.

On the other hand, X-coordinate reflects its declared nominal efficiency (as defined above), providing information about the relation between the declared capacity and the ‘complexity’ of the sector.

Therefore, the position of a sector in the diagram and related to the position of the other sectors, indicates the degree of relative equilibrium (comparative analysis) between its “demand/capacity” and its “performance/stress”.

As this is a relative diagram, once the different sectors are represented, we would use the sector “best in its class” as a reference for comparison. This sector would be the one with highest efficiency and “good level of criticality”. Assuming the technical means and the qualification of the personnel in all the sectors are the same, it is possible to conclude that all of them could operate as well as the best one. In this way, we define another parameter, **elasticity**, which gives the idea of the possibility for improving the performance of the sector.

The following figure shows a status diagram and its graphical interpretation.

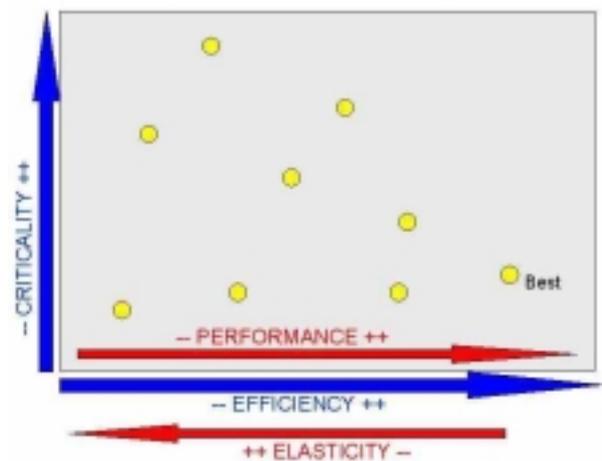


Figure 8. Status diagram. Interpretation

If we include in the diagram two lines that represent the medians (X and Y) for the values, the diagram is divided into four quadrants that can be interpreted as follows:

1. The top-left quadrant contains sectors with high criticality, low efficiency and high elasticity. These sectors have problems shown in the high criticality. To solve them, they require, comparatively, modifications with greater emphasis in the revision of their declared capacity than on redesign.
2. The top-right quadrant contains sectors with high criticality, high efficiency and low elasticity. These sectors also have problems, but have low margin to increase declared capacity as shown in their low elasticity. To solve them, they require, comparatively, modifications with greater emphasis on redesign than in the revision of their declared capacity.
3. The bottom-left quadrant contains sectors with low criticality, low efficiency and high elasticity. These sectors are underused, comparatively, and their resources are being wasted.
4. The bottom-right quadrant contains sectors with low criticality, high efficiency and low elasticity. These sectors, comparatively, are operating adequately.

This first level analysis allows to diagnose at a glance the ATC sectors and their improvement needs/possibilities. Figure9shows graphically these quadrants.

To move the analysis a step further and entering into the realm of future improvements and “what-if”, taking into account the statement mentioned above that all the sectors are “similar”, we would modify the declared capacity of all the sectors to obtain for each of them the declared nominal efficiency of the “best in the class”. In this way, the values for criticality are thus modified, so a new ordering in terms of criticality revised by efficiency considerations is obtained. This ordering is shown in a blue line in Figure9.

Figure9shows an example Status Diagram developed for the actual study of the Spanish ATC system mentioned above. A projection taking into account the expected traffic increase for the year 2003 is also included as a red bar in the right hand side.

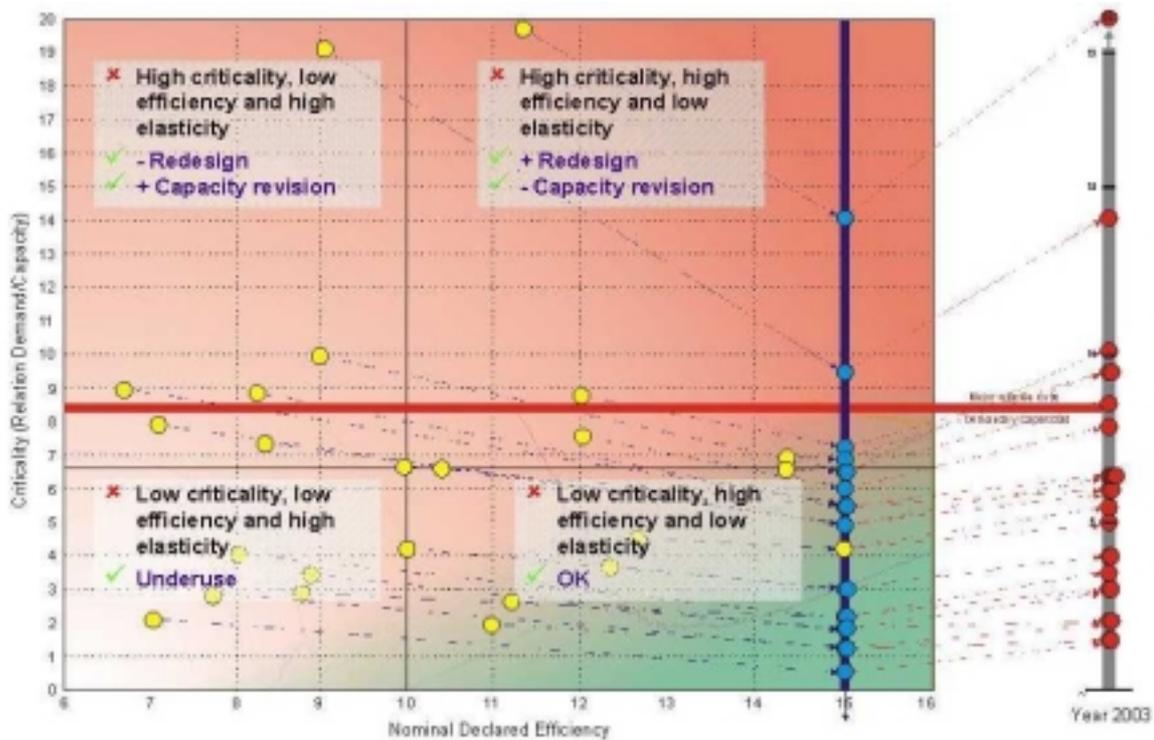


Figure 9. System Status Diagram

ATC system development limit

The diagnose methodology presented above is applicable for the current status evaluation and for short to medium term measures, but if we want to consider longer term analyses, it is important to take into account the widely accepted fact that the classical ATC sector concept could not cope with the expected air traffic demand for that time frame.

An analytical method to evaluate the ATC system development proposed methodology time limit is defined. The following magnitudes are defined for this purpose:

- Number of Aircraft Simultaneously in a sector (NAS): It is defined as the mean flight time (MFT) in the sector (expressed in hours) multiplied by the average Hourly Demand (HD) in the sector (in the considered time period) expressed in movements/hour.

$$NAS = MFT \times HD \quad (1)$$

- Number of Aircraft Simultaneously in ACC (NAS ACC): It is obtained as the sum of the NAS of the different sectors of the ACC (NAS_i).

$$NAS \text{ ACC} = \sum NAS_i$$

The initial hypothesis is based on statistical studies developed by EUROCONTROL (FAP) corresponding to the ECAC area that show that in ACC's with more than 600 movements per day, a correlation of 92% exists between the Volume of the sector (V_s) and the mean flight time (MFT) in it. (The 5 ACC's corresponding to the Spanish airspace fulfill, in average, this over 600 daily movement condition).

The relation between these two parameters is as follows:

$$MFT = K \times V_s^{0.31} \quad \text{where } K = 0.26 \quad (2)$$

From expression (1) and (2) we can conclude:

$$NAS = HD \times K \times V_s^{0.31}$$

If we assume that the average hourly demand in a sector (HD) is constant, then:

$$NAS = K' \times V_s^{0.31} \quad \text{where } K' = \text{constant}$$

Moreover, if we assume that the order of magnitude of the volume of the sectors of the same ACC is similar, that is, V_s=constant, and if we define N_s as the number of sectors of an ACC, then:

$$NAS \text{ ACC} = K' \times V_s^{0.31} \times N_s$$

This last expression provides a direct relation between the number of sectors of an ACC with the number of aircraft simultaneously in it, for a fixed time instant. The relation between NAS ACC and N_s in two different time instants 1 and 2 is:

$$\frac{NAS \text{ ACC} 2}{NAS \text{ ACC} 1} = \frac{K' \times V_{s2}^{0.31} \times N_{s2}}{K' \times V_{s1}^{0.31} \times N_{s1}} \quad (3)$$

As the volume of the ACC is constant, we find that the relation between the number of sectors of an ACC and their respective volume are in inverse ratio:

$$\frac{N_{s2}}{N_{s1}} = \frac{V_{s1}}{V_{s2}} \quad (4)$$

Finally, the combination of expressions (3) and (4) provide the analytic expression that allows calculating the increment in number of sectors of an ACC between two time instants if the air traffic demand (NAS) in those times is known:

$$N_{s2} = N_{s1} \times \left(\frac{NAS \text{ ACC} 2}{NAS \text{ ACC} 1} \right)^{\frac{1}{0.69}}$$

The following figure shows an example of this analytical calculation for the Spanish upper airspace:

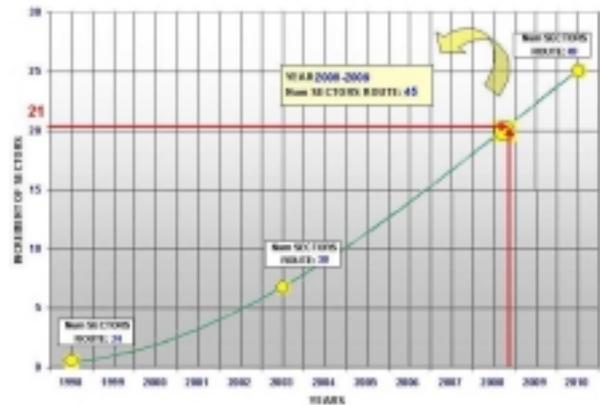


Figure 10. Increment of sectors. Example

Conclusions

The Diagnostic and Analysis methodology described above allow the following:

- Identification of weaknesses and strengths of the system elements in the short and medium term (using the so called Nominal Criticality).
- Evaluation and quantification the nature of the weaknesses, leading to the identification of possible solutions in terms of redesign or revision of capacity (using proposed Status Diagram).
- Identification of the relations among the system elements (sector grouping) and evaluation of common action possibilities (using proposed Network Effects Analysis).
- Identification of the current ATM system development limit without changing the operational concept (by mean of proposed formulation of the ATC system development limit).

References

- [1] Short-Term Capacity Targets 2002 for the European ANS, PFE-F-FA, December 2001.
- [2] Initial Strategic Performance Framework, SCS-SPAF, 09-05-00.
- [3] The PRC's European ATM performance measurement system. PRU, 01-06-99.
- [4] Airline Metric Concepts for evaluating air traffic service performance, ATSP FG, 01-02-99.

Key words

ATM, ATC, Methodology, Indicator, Performance, Sector, Capacity, Network

Biographies

Author 1. Luis Negrete (INECO) has developed his professional background in the research and development framework applied to the Air Traffic Management (ATM). He has worked in a variety of projects related to the establishment and application of methodologies for the analysis of ATC scenarios, ATM system performance and productivity of ATS/ATC facilities. He is currently

working on the introduction of quality management concepts applied to the ATM system in order to optimise the internal management processes of the Air Traffic Service Providers. He has been involved in international projects, supporting ATM service provision organisations, in the field of system performance analysis. He is currently Head of ATM Organisation Department, being responsible for management of different strategic activities within the ATM Division of INECO.

Author 2. Alvaro Urech has a MSc in Physics from the Universidad Complutense de Madrid, with specialization in Computer Science and Automatics. He worked for eight years at the Spanish National Institute for Aerospace Technologies in systems engineering and project management. In 2001 he joined the European Projects Division at the Aeronautical Systems business unit of INECO, where he is acting as project coordinator of the GADEROS Galileo Pilot project, as well as participating in other European projects like LEONARDO (Linking Existing ON Ground, ARrival and Departure Operations).

Author 3. Francisco Sáez has accumulated over 30 years experience in Air Navigation and Air Traffic Management. He joined Aena directly from Spanish Civil Aviation where he had the overall responsibility of Air Traffic Services as Deputy-Director General of CAA. His career in the Spanish CAA included the chairmanship of the Air Navigation Panel within the Steering Committee that was constituted by the Spanish Ministry of Transport to study and prepare the corporatisation of Spanish Air Navigation Services. Mr. Sáez was also charged with the responsibility of negotiating Spain's accession as a full member to EUROCONTROL. Since 1993 he rejoined his academic career as chair professor at the Polytechnic University of Madrid, from where he has maintained an intensive research activity in ATM. He has been involved as an external expert in the evaluation and review of proposals submitted in the different Calls for Tenders within the IV and V Framework Programs of the EC in the field of ATM. At INECO, as technical advisor, he is currently involved in different studies for the European Parliament, the European Commission, EUROCONTROL and Aena, all dealing with ATM/CNS issues.