

**GUIDE FOR THE APPLICATION OF A COMMON  
METHODOLOGY TO ESTIMATE AIRPORT AND ATC  
SECTOR CAPACITY FOR THE SAM REGION.**

**Regional Project: ICAO RLA/06/901**

**Lima, Peru, 6 to 17 July 2009**

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## I. Purpose

The purpose of this document is to provide SAM States with a guide on how to apply a common methodology to calculate airport and ATC sector capacity, thus allowing ATM planners to develop plans, if necessary, to improve such capacity in order to meet present or future demands of the system.

## II. Introduction

Annex 11 to the ICAO Convention, in paragraph 3.7.5.1, establishes that air traffic flow management (ATFM) will be implemented in airspaces where air traffic demand at times exceeds, or is expected to exceed, the declared capacity of the air traffic control services concerned, and paragraph 3.7.5.2 contains a Recommendation to implement ATFM through regional air navigation agreements or, if appropriate, through multilateral agreements, and that such agreements must make provision for common procedures and methods for determining capacity.

This same Annex 11 defines “*declared capacity*” as the measure of the ability of the ATC system or any of its subsystems or operating positions to provide service to aircraft during normal activities. It is expressed as the number of aircraft entering a specific portion of airspace in a given period of time, taking due account of weather, ATC unit configuration, available staff and equipment, and any other factor that may affect the workload of the controller responsible for the airspace.

Additionally, Document 4444, ATM, Procedures for Air Navigation Services, in paragraph 3.1.4.1 of Chapter 3, establishes that the appropriate ATS authority should periodically review ATS capacity in relation to traffic demand; and should provide for flexible use of airspace in order to improve efficiency operational efficiency and increase capacity.

Next, paragraph 3.1.4.2 states that, in the event that traffic demand regularly exceeds ATC capacity, resulting in continuous and frequent traffic delays, or it becomes apparent that traffic demand forecasts will exceed capacity values, the appropriate ATS authority should, to the extent possible, take steps to maximise the use of existing system capacity; and develop plans to increase capacity in order to meet current or foreseen demand.

GREPECAS determined that air traffic flow management (ATFM) implementation will help ensure optimum air traffic flow and will help reduce ground and airborne delays, thus avoiding an overload of the air traffic system. This is accomplished by balancing demand and system capacity, with a view to maintaining a safe, orderly and expeditious traffic flow. Accordingly, GREPECAS approved the CAR/SAM ATFM Operational Concept (CAR/SAM ATFM CONOPS), which reflects the expected order of events and should assist and guide planners in the design and gradual implementation of an ATFM system.

Through Conclusion 14/149, GREPECAS adopted the ATFM CONOPS and requested States to establish a work programme for the implementation of the ATFM CONOPS.

In this sense, a SAM ATFM implementation group was established within the scope of Project RLA/06/901, charged with taking action for the implementation of ATFM in the region.

With the sponsorship of Regional Technical Cooperation Project RLA 06/901 *Assistance for the implementation of a regional ATM system based on the ATM operational concept and the corresponding technological support for communications, navigation, and surveillance (CNS)*, a course on Airport and ATC Sector Capacity Calculation was held in March 2009, at the CGNA facilities in Rio, Brazil, in order to start standardising the training of ATM planners of the SAM States on this matter.

### **III. General**

In order to understand this document, we believe it is necessary to highlight some general considerations related to the purpose of this document, which, as a guide to the States, contributes to the achievement of ATFM goals.

The purpose of ATFM is to achieve a balance between air traffic demand and system capacity to ensure an optimum and efficient use of system airspace. This is achieved by balancing demand and the capacity declared by the appropriate air traffic service providers in order to accommodate a maximum number of flights under a gate-to-gate concept.

In order to manage this demand-capacity balance, it is necessary to know the current and expected demand, to establish a capacity baseline using an analytical calculation, to analyse the impact that expected demand will have on existing capacity, to identify the limitations of, and possible improvements to, the current system based on a cost/benefit analysis thereof, to set priorities, and to develop a capacity improvement plan.

#### Airspace Capacity

Airspace capacity is not unlimited but it can be more or less optimised depending on many factors, such as airspace design and flexibility; ATC system capacity; number of sectors and their complexity; segregated airspace; availability, training, and response capability of personnel; available CNS infrastructure; degree of automation; and even the equipage and type of aircraft in the fleet.

When analysing airspace capacity, we are interested in focusing on ATC system capacity and, in this sense, we have highlighted some concepts that must be taken into account as indicators to calculate the ATC sector capacity, such as: workload, the importance of observable and non-observable tasks performed by air traffic controllers. We also present some models used to measure and assess the parameters employed to determine capacity in order to meet air traffic demand.

#### Airport Capacity

Many different parameters are used for measuring airport and airspace capacity. Consequently, care must be taken when defining the scope of each capacity in order to better understand the indicators to be used for assessing each capacity.

This document defines airport capacity as the maximum number of airport operations in a given aerodrome under specified conditions (*e.g.*, aerodrome layout, aircraft mix, weather conditions, facilities, aircraft parking, etc.), taking into account all take-off and landing operations during a specified period of time (hour, day, month, year, season).

It may occur that the physical capacity of the aircraft parking platform, the number of aircraft defining airport capacity in a given aerodrome, is less than the number of aircraft resulting from estimating the runway capacity for that given aerodrome; in such case, this would be the real constraint for that airport.

When all of the requirements agreed upon are duly met, service capacity is 100%. This capacity is reduced when such requirements have operational limitations; the greater the constraint in resources, the lower the service capacity. But the declaration of a percentage lower than the actual capacity may also be taken into account in order to manage contingencies or any other type of unforeseen operation.

### The Workload Concept

It is necessary to analyse the impact that controller “workload” has on the measurement of ATC capacity in a given airspace sector, and to identify the techniques necessary to calculate traffic management in an automated system by using models.

Attempts have been made at measuring workload by assigning a value to the various tasks (task load) performed by the controller.

Consideration should also be given to the extensive studies on, and approaches to, workload that take into account human factors, where situational awareness, error detection and system monitoring, teamwork, trust and proper training, human error, etc., are fundamental aspects to be taken into account.

When analysing capacity it is important to consider the nature of the tasks that make up the workload, since there are tasks that can be observed and quantified, while others cannot be observed and, hence, are not so easy to quantify.

Nevertheless, it is possible to establish some constant values for these non-quantifiable tasks based on statistical analyses and, thus, factor them in the methodology used in some models.

### DORATASK Model

A model widely used for task assessment and workload analysis is the DORATASK model. This is an analytical model based on fast-time simulation that provides clear examples and logical calculations. This model was first used by the United Kingdom Operational Research and Analysis Bureau to estimate ATC sector capacity (DORA Interim Report 8818), for terminal sectors (DORA Interim Report 8916) and to calibrate a simulated model for two route sectors of the London ACC (DORA Report 8927).

In this model, workload is calculated by adding up the time it takes the controller to perform all the necessary tasks, both observable and non-observable, associated with air traffic flow in his/her sector and working position. Sector capacity is determined by adding the total task load to a parameter that indicates the amount of time needed for controller recovery.

Observable tasks are routine tasks performed by the controller, such as those applicable to all aircraft, irrespective of how many aircraft are under his/her control (*e.g.*, standard communications), and those tasks aimed at solving conflicts when an aircraft is facing an actual or potential conflict.

Non-observable tasks are the planning tasks carried out by the controller and the mental tasks required to detect or forecast conflicts. But it is important to note that some tasks cannot be observed in procedural systems, but can be observed and quantified in automated systems (*e.g.*, planning, conflict forecasting). Although planning is a non-observable task--with the aforementioned caveats--, the DORATASK Model contains algorithms that estimate workload, which is the time the controller spends on planning tasks. These estimates and examples are based on statistical data that provide constant values used to adjust analytical formulae.

In the case of terminal area capacity calculations, the DORATASK Model identifies two non-observable tasks, initial processing and radar monitoring. These tasks are modelled using the number of radar displays and the combination of pairs of aircraft that must be checked. Since these tasks are, by definition, linear and quadratic with respect to the number of aircraft, each of these measures is multiplied by an unknown number (constant value) that is estimated by each analyst after comparing with sectors of known capacity.

The DORATASK Model has served as the basis for many other capacity calculation applications and models, taking into account controller workload. However, it is not the only model to be taken into account since, as noted, it has some limitations. Nevertheless, this model is quite suitable for ATC sector capacity studies and, with the appropriate modifications, can be adjusted to automated systems.

#### **IV. Methodological Models for Estimating Capacity in the Region**

##### **ATC Sector Capacity Calculation Model used in Brazil**

In Brazil, ACC capacity is estimated by analysing the capacity of its sectors, which is analytically obtained using the methodology established in ICA 100-30, ATC Staff Planning (DECEA, 2007).

Currently, the estimated sector capacity value can be considered to be the maximum number of aircraft that each air traffic controller (ATCO) can control simultaneously in a given sector, thus providing the capacity applied by the ATC unit.

The Airspace Control Department (DECEA) uses a methodology to determine the APP and ACC sector capacity, which provides a sector capacity reference value.

This methodology consists in obtaining a value based on a mathematical formula. The basic data for such formula are derived from an investigation carried out by a special working group at the ATC unit, taking into account a busy period in which controller actions and availability to manage control sector traffic are observed and timed; this provides a data sample to be used in the ATC sector capacity calculation methodology.

The ATC Sector Capacity Calculation Model used in Brazil appears in **Attachment 1** to this Document.

#### Data sampling for estimating ATC sector capacity

It is important for data collection to be significant so as to dilute temporary stochastic deviations and to represent reliable values for the ATC unit.

In Brazil, the method used to determine sector capacity takes into account the load borne by an ATCO in performing his/her tasks, and is based on the assessment of the tasks performed by the controller at times of high traffic volume, as seen in the DORATASK model.

According to the current model, controller workload is the summation of times spent on:

1. communication (transmission/reception);
2. manual activities (filling out flight progress strips) and coordination; and
3. traffic planning and distribution.

The Brazilian methodology applies the controller “availability factor” ( $\phi$ ) concept, which is defined as the percentage of time available for the ATCO to plan aircraft separation procedures.

This availability factor normally falls between a minimum value of 40% of ATCO time for non-radar control, and 60% for radar control (ICA 100-30). It is thus clear that efforts need to focus on increasing the “availability factor”  $\phi$ .

The latter can only be achieved by applying measures to reduce the level of controller intervention in the activities mentioned in 1 and 2.

The percentage accounted for by this  $\phi$  factor could increase if the “Man/Machine Interface –MMI” is enhanced; that is, when increasing the level of automation in some tasks.

Studies conducted by Brazilian experts, who analysed the sampling techniques, show that it is advisable to make at least 30 observations of each parameter for each controller, during peak traffic, respecting the minimum number of controllers specified by the sampling technique used.

It is essential to collect as many observations and controllers as possible in the unit being assessed in order to eliminate extreme values and to minimise any type of trend (*e.g.*, cases of controllers or pilots who are either too slow or too quick in their communications, affecting the arithmetical mean).

A detailed and analytical explanation of the sampling technique used in Brazil to determine the number of observations required by sector and by controller is given in **Attachment 2** to this document. The form used in Brazil to assess ATC communications load is shown in **Attachment 3** to this document.

The form used by Brazil to assess the “availability factor” appears in **Attachment 4** to this document.

#### FAA ATC sector capacity calculation model for global event in Trinidad y Tobago

On occasion of the 20<sup>th</sup> Meeting of Eastern Caribbean Directors of Civil Aviation (20th E/CAR/DCA) held in Miami, Florida, United States, on 4-7 December 2006, the FAA presented a model to determine ATC sector capacity based on the experience gained in this field by the United States, in order to support ATFM-related activities during the Cricket World Cup held in Trinidad and Tobago.

This is a case of macroscopic calculation that includes an additional factor, which is a constant value to account for human factors, calculated by the FAA to measure the average time spent by a controller interacting with an aircraft.

Since we believe this could be very useful for a State that needs to apply a simple, safe, macroscopic methodology to face a specific event in which a greater-than-normal demand is expected, we have included this study as **Attachment 5** to this document.

## **V. Airport Capacity Calculation Models**

### Airport capacity calculation model applied in Brazil

In Brazil, the runway capacity calculation method assumes a take-off operation between two consecutive landings, maintaining the regulatory separation minima defined in ICA 100-12 (Rules of the Air and Air Traffic Services). Runway capacity is estimated for a 60-minute interval in function of average runway occupancy times.

In order to determine the capacity of the set of runways, the following factors are taken into account:

- a) Planning factors; and
- b) Factors related to landing and take-off operations.

Planning factors are elements used to simplify the mathematical models or the operational aspects that bear on the determination of runway capacity. The most commonly used are:

- a) Ideal air traffic sequencing and coordination conditions;
- b) All personnel is considered to have the same training and same operational performance;



- c) All navaids and visual aids are considered to be technically and operationally unrestricted; and
- d) All (VHF/telephony) communication equipment considered operational is operating normally.

Regarding factors related to landing and take-off operations, the following can be identified:

- a) Average runway occupancy times;
- b) Aircraft mix;
- c) Percentage of threshold utilisation;
- d) Length of the final approach segment;
- e) Regulatory aircraft separation minima applied;
- f) Runway and taxiway layout; and
- g) Final approach speed.

The main parameters used to estimate runway capacity in Brazil are listed below:

- Aircraft mix (aircraft category and approach speed)
- Average runway occupancy time (sec.)
- Separation criteria adopted by the ATC

Aircraft mix is defined as the percentage distribution of the aircraft fleet operating at the aerodrome according to aircraft categories. The aircraft mix for aerodromes must be estimated based on the total daily movement, a constant value in IEPV 100-34 (Movement of Aircraft at Aerodromes) or in the SGTC, which is determined using the arithmetical average of a sample containing data for a period of at least one week.

According to Doc 8168, aircraft are subdivided into five categories, depending on threshold speed, which must be 130% of the value of the stall speed in the landing configuration (full flaps, gear down). Accordingly, aircraft are classified as follows:

CAT "A" speed less than 90 kt

CAT "B" Speed between 91/120kt

CAT "C" Speed between 121/140kt

CAT "D" speed between 141/165kt

CAT "E" Speed between 166/210kt

The average runway occupancy time is the weighted arithmetical mean of runway occupation times, by aircraft category, where the aircraft mix operating in the aerodrome is the weighting factor.

This method is based on data collection, which, for the sake of greater precision, should be done at peak hour, since air traffic flow is more fluid during such period, thus reducing runway occupancy time. If data collected does not cover all categories, additional data may be gathered at other times and even on different days. Runway occupancy time during take-off shall be counted from the time the aircraft leaves the holding position up until it crosses the opposite threshold.

The separation criteria adopted by the ATC vary in light of the regulations in force on this matter in each State. For purposes of this study, Brazil has considered a separation of 5 NM, which coincides with the outer marker (OM) and the runway threshold.

If there is no OM, a point is determined in the final approach that has a known distance and that determines the impossibility for another aircraft from entering the runway while the aircraft that is about to land is flying over this point or is between this point and the runway threshold concerned.

The methodological steps and data collection forms to estimate the physical, theoretical, and declared runway capacity are described in **Attachment 6** to this document.

#### FAA Runway Capacity Calculation Model

The model used by the FAA to estimate capacity and analyse delays at airports is described in Advisory Circular (AC) 150/5060-5, Change 1 and 2, entitled "Airport Capacity and Delay".

This Circular contains calculations to determine airport capacity, annual volume of operations, and aircraft delays. It also contains a special calculation to determine capacity when it is affected by poor weather, airports with no radar coverage or without ILS, as well as detailed analyses to assess airports with parallel runways, and more refined calculations in order to analyse special situations that may affect runway capacity.

In this Model, the hourly capacity is influenced by runway configuration, aircraft mix, percentage of arrivals, percentage of go-around operations under visual flight rules (VFR), and location of taxiway exits. Hourly capacity is estimated for both VFR and instrument flight rules (IFR) conditions. Weather is a determining factor for this calculation method.

Furthermore, this Model is based on a large number of statistical data collected for many years, providing for very good performance in American scenarios in terms of theoretical and actual capacity.

**Attachment 7** to this document provides detailed information on the procedure used by the FAA to calculate the potential and actual airport acceptance rate (AAR). Advisory Circular (AC) 150/5060-5, Change 1 and 2, “Airport Capacity and Delay”, can be found at the following web site:

[http://www.airweb.faa.gov/Regulatory\\_and\\_Guidance\\_Library/rgAdvisoryCircular.nsf/ACNumber/641E65B7EA1DC3B685256D0C006289F6?OpenDocument](http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/ACNumber/641E65B7EA1DC3B685256D0C006289F6?OpenDocument)

#### Runway Capacity Calculation Model used in Colombia

In order to determine the El Dorado airport capacity, the ATM Procedures Group of the UAEAC of Colombia applied Advisory Circular (AC) 150/5060-5, Change 2, entitled “Airport Capacity and Delay”, to assess runway capacity of the El Dorado airport.

This method was derived from the calculation models used by the FAA to determine airport capacity. It was necessary to compare the theoretical calculations with the operational reality of the airport; theoretical values were similar to those obtained in practice.

Information regarding the methodology applied in Columbia to calculate airport acceptance and concerning an analysis carried out at El Dorado airport appears in **Attachment 8** to this document.

#### **VI. Capacity Improvement**

The demand/capacity analysis identifies a number of factors that are extremely important for the efficient planning of the ATM system so as to ensure an optimum balance that will benefit the ATFM. **Attachment 9** provides some guidelines for ATM planners to improve system capacity.

Regarding the planning process for demand, capacity, and delay analysis, we recommend that the CAR/SAM ATFM Manual be used. This manual is available in the ICAO South American Office web site.

#### **VII. Conclusion**

Knowledge of the capacity of air traffic sectors or ATC operating positions is necessary for two main reasons. The first is that, for long-term planning, it is necessary to anticipate efficiently any reduction of future capacity, as inferred from traffic forecasts. The second reason is that if there is already a reduction in capacity that calls for flow control, it must be known in order to restrict traffic without overloading the system or excessively affecting operators, or in order to implement best practices on operational performance.

There are many methods for calculating capacity and, as readily noted from the different models described in this Guide, air traffic controller workload is a significant parameter in these models. Therefore, a better knowledge of workload factors and their implications will provide for a more suitable operational adjustment of the services provided to meet the demand.

It is also essential to have a perfect understanding of the variables attributed to the mathematical model, using for the calculation the number of aircraft that can be served in ATC sectors and airport capacity in a given period of time.

To this end, a critical study and an impartial and detailed analysis of the reality of each State in relation to the results obtained in the data survey are necessary in order to quantify such variables, allowing planners to identify operational limitations of the services provided duly in advance.

On the other hand, the observation of occasional factors, such as communication deficiencies, adverse weather, preferential aircraft operations, military operations, aircraft in emergency, among many others that may cause operational delays, can have a negative impact on results and lead to conclusions that do not reflect reality if not properly weighted.

Likewise, information about the number of aircraft simultaneously controlled by a single controller in a given sector must be collected by rated teams knowledgeable of the characteristics of the place to be assessed, preferably air traffic controllers. Data collection frequency and the amount of data to be collected by sector and by controller should be such as to include cases of air traffic flow modification, sectoring, installation/failure of navigation infrastructure, new design for airspace optimisation, etc.

Concerning the data obtained from capacity calculations, they are not only useful for identifying system limitations or behaviour, but also are extremely important for defining the number of ATCOs required in a given ATC service.

Staff sizing should consider the number of persons required to cover all operating positions in the event of maximum configuration. The analysis conducted to create a control sector is based on a significant and constant increase of traffic in that sector. Traffic flow history and evolution are also used to forecast the need for, and size of, HARDWARE and human resources required for a given period of time.

The right number of operational air traffic control positions to face peak periods can be defined by correctly analysing and interpreting demand/capacity data, or reducing the numbers on certain schedules.

The capacity calculation models studied for purposes of this guide do not fully cover the many variables that should be taken into account, especially for quantifying non-observable tasks, where only long-term analysis of statistical data can support the use of a constant value in the mathematical formulation or the comparison with a reference system that has been tested in practice.

Hence, we note, for example, that some of the constant values used in the FAA system result from substantial statistical information gathered throughout many years, thus providing a high level of certainty. However, it may be concluded that this constant value has an additional factor inherent to the system from where data were collected, which is supplemented with very serious studies on human factors.

Regarding the above, it should be noted that, for different reasons, personnel performance measurements can vary significantly depending on the organisational culture involved, personnel recruitment levels, the number of staff available, training levels, and many other factors that cause this performance to have an impact on the human factor constant value.

The model applied in Brazil is quite complete since it applies a modern airport capacity approach, and is also very accurate in quantifying ATC sector capacity. However, as with other models, it assumes ideal conditions and it would be convenient to quantify a standard adjustment for each State when such conditions are not met in a given system, so as to reduce the acceptance number or the capacity in the formula.

Nevertheless, by applying best practices in airspace design, sequencing, coordination, and CNS maintenance; and by applying regulatory separation minima, and rigorously recruiting and training human resources, a State can raise the standard and optimise the mathematical formulation of the model applied, thus increasing capacity significantly.

Furthermore, the optimisation of the existing runway and taxiway configuration, the aircraft mix, the average runway occupancy times, the length of the final approach segment specified as safety distance, fleet capacity and equipment, and crew training are other factors that contribute to capacity optimisation and that must be considered when declaring the capacity of an ATC sector or of an airport.

As for the models applied in the region, no major differences in the results obtained for airport acceptance rates are found between the FAA model and the model used in Brazil for purposes of determining runway capacity. If we analyse the various ATC sector capacity calculation models, we will note that, to a greater or lesser extent, the main parameters are derived from the DORATASK Model.

With few exceptions, as we have seen, most of the States in the Region have little practical experience in the use of a model for calculating capacity. This has an impact on the size of the available database that could be used to adjust constant values in each of the different operational scenarios in the systems of the Region, unlike the FAA, whose databases have been fed with data collected for many years and are constantly updated.

Notwithstanding the above, experts from most of the States in the Region attended the Course on Airport and ATC Sector Capacity Calculation, held in March 2009, at the CGNA facilities in Rio, Brazil, under ICAO Project RLA/06/901, to receive training on the application of the model used in Brazil; this represents a very valuable capital that can be tapped.

### Recommendation

In order to take maximum advantage of the training provided under ICAO Project RLA/06/901, and taking into account that such training provides a standard calculation criterion for the region that can be used in a first phase as an initial common methodology to calculate the airport and ATC sector capacity, we recommend that SAM States use the Methodology to Calculate Airport and ATC Sector Capacity applied in Brazil.

We recommend this methodology for the following reasons:

- a) standard training for experts from the States participating in the Project;
- b) use of a model that is applicable to both airport and ATC sector capacity;
- c) low cost methodology that does not require any software;
- d) it does not require constant values derived from databases that some States do not have available yet;
- e) practical experience on the use of the model can be acquired immediately, resulting in:
  - ✓ the creation of a standard database for statistical purposes,
  - ✓ the evaluation of model weaknesses,
  - ✓ feedback to improve the model,
  - ✓ more experience gained in order to decide on the future application of a definitive common model for the SAM Region in a second phase;
- f) according to the planned regional ATFM implementation level, it is possible to leave for a near future the selection of a single definitive capacity calculation model to be used in the Region, as recommended by ICAO Annex 11, and
- g) it supplements the use of some methodologies applied in the Region (*e.g.*, Colombia) and, basically, is not in conflict with the airport acceptance rate calculation system used in Colombia in this first phase.

In summary, this guide serves as a basis to define the parameters and indicators to be taken into account for analysing delays, to identify best practices leading to increased capacity, and to detect the differences and similarities of the models used in the Region, thus creating a sound baseline so that in a near future, in a second phase, it may be possible to apply a common, optimised airport and ATC airspace sector capacity calculation model for the Region, enriched with the experience gained in this initial regional implementation.

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## I. Purpose

The purpose of this document is to provide SAM States with a guide on how to apply a common methodology to calculate airport and ATC sector capacity, thus allowing ATM planners to develop plans, if necessary, to improve such capacity in order to meet present or future demands of the system.

## II. Introduction

Annex 11 to the ICAO Convention, in paragraph 3.7.5.1, establishes that air traffic flow management (ATFM) will be implemented in airspaces where air traffic demand at times exceeds, or is expected to exceed, the declared capacity of the air traffic control services concerned, and paragraph 3.7.5.2 contains a Recommendation to implement ATFM through regional air navigation agreements or, if appropriate, through multilateral agreements, and that such agreements must make provision for common procedures and methods for determining capacity.

This same Annex 11 defines “*declared capacity*” as the measure of the ability of the ATC system or any of its subsystems or operating positions to provide service to aircraft during normal activities. It is expressed as the number of aircraft entering a specific portion of airspace in a given period of time, taking due account of weather, ATC unit configuration, available staff and equipment, and any other factor that may affect the workload of the controller responsible for the airspace.

Additionally, Document 4444, ATM, Procedures for Air Navigation Services, in paragraph 3.1.4.1 of Chapter 3, establishes that the appropriate ATS authority should periodically review ATS capacity in relation to traffic demand; and should provide for flexible use of airspace in order to improve efficiency operational efficiency and increase capacity.

Next, paragraph 3.1.4.2 states that, in the event that traffic demand regularly exceeds ATC capacity, resulting in continuous and frequent traffic delays, or it becomes apparent that traffic demand forecasts will exceed capacity values, the appropriate ATS authority should, to the extent possible, take steps to maximise the use of existing system capacity; and develop plans to increase capacity in order to meet current or foreseen demand.

GREPECAS determined that air traffic flow management (ATFM) implementation will help ensure optimum air traffic flow and will help reduce ground and airborne delays, thus avoiding an overload of the air traffic system. This is accomplished by balancing demand and system capacity, with a view to maintaining a safe, orderly and expeditious traffic flow. Accordingly, GREPECAS approved the CAR/SAM ATFM Operational Concept (CAR/SAM ATFM CONOPS), which reflects the expected order of events and should assist and guide planners in the design and gradual implementation of an ATFM system.

Through Conclusion 14/149, GREPECAS adopted the ATFM CONOPS and requested States to establish a work programme for the implementation of the ATFM CONOPS.

In this sense, a SAM ATFM implementation group was established within the scope of Project RLA/06/901, charged with taking action for the implementation of ATFM in the region.

With the sponsorship of Regional Technical Cooperation Project RLA 06/901 *Assistance for the implementation of a regional ATM system based on the ATM operational concept and the corresponding technological support for communications, navigation, and surveillance (CNS)*, a course on Airport and ATC Sector Capacity Calculation was held in March 2009, at the CGNA facilities in Rio, Brazil, in order to start standardising the training of ATM planners of the SAM States on this matter.

### **III. General**

In order to understand this document, we believe it is necessary to highlight some general considerations related to the purpose of this document, which, as a guide to the States, contributes to the achievement of ATFM goals.

The purpose of ATFM is to achieve a balance between air traffic demand and system capacity to ensure an optimum and efficient use of system airspace. This is achieved by balancing demand and the capacity declared by the appropriate air traffic service providers in order to accommodate a maximum number of flights under a gate-to-gate concept.

In order to manage this demand-capacity balance, it is necessary to know the current and expected demand, to establish a capacity baseline using an analytical calculation, to analyse the impact that expected demand will have on existing capacity, to identify the limitations of, and possible improvements to, the current system based on a cost/benefit analysis thereof, to set priorities, and to develop a capacity improvement plan.

#### Airspace Capacity

Airspace capacity is not unlimited but it can be more or less optimised depending on many factors, such as airspace design and flexibility; ATC system capacity; number of sectors and their complexity; segregated airspace; availability, training, and response capability of personnel; available CNS infrastructure; degree of automation; and even the equipage and type of aircraft in the fleet.

When analysing airspace capacity, we are interested in focusing on ATC system capacity and, in this sense, we have highlighted some concepts that must be taken into account as indicators to calculate the ATC sector capacity, such as: workload, the importance of observable and non-observable tasks performed by air traffic controllers. We also present some models used to measure and assess the parameters employed to determine capacity in order to meet air traffic demand.

#### Airport Capacity

Many different parameters are used for measuring airport and airspace capacity. Consequently, care must be taken when defining the scope of each capacity in order to better understand the indicators to be used for assessing each capacity.

This document defines airport capacity as the maximum number of airport operations in a given aerodrome under specified conditions (*e.g.*, aerodrome layout, aircraft mix, weather conditions, facilities, aircraft parking, etc.), taking into account all take-off and landing operations during a specified period of time (hour, day, month, year, season).

It may occur that the physical capacity of the aircraft parking platform, the number of aircraft defining airport capacity in a given aerodrome, is less than the number of aircraft resulting from estimating the runway capacity for that given aerodrome; in such case, this would be the real constraint for that airport.

When all of the requirements agreed upon are duly met, service capacity is 100%. This capacity is reduced when such requirements have operational limitations; the greater the constraint in resources, the lower the service capacity. But the declaration of a percentage lower than the actual capacity may also be taken into account in order to manage contingencies or any other type of unforeseen operation.

### The Workload Concept

It is necessary to analyse the impact that controller “workload” has on the measurement of ATC capacity in a given airspace sector, and to identify the techniques necessary to calculate traffic management in an automated system by using models.

Attempts have been made at measuring workload by assigning a value to the various tasks (task load) performed by the controller.

Consideration should also be given to the extensive studies on, and approaches to, workload that take into account human factors, where situational awareness, error detection and system monitoring, teamwork, trust and proper training, human error, etc., are fundamental aspects to be taken into account.

When analysing capacity it is important to consider the nature of the tasks that make up the workload, since there are tasks that can be observed and quantified, while others cannot be observed and, hence, are not so easy to quantify.

Nevertheless, it is possible to establish some constant values for these non-quantifiable tasks based on statistical analyses and, thus, factor them in the methodology used in some models.

### DORATASK Model

A model widely used for task assessment and workload analysis is the DORATASK model. This is an analytical model based on fast-time simulation that provides clear examples and logical calculations. This model was first used by the United Kingdom Operational Research and Analysis Bureau to estimate ATC sector capacity (DORA Interim Report 8818), for terminal sectors (DORA Interim Report 8916) and to calibrate a simulated model for two route sectors of the London ACC (DORA Report 8927).

In this model, workload is calculated by adding up the time it takes the controller to perform all the necessary tasks, both observable and non-observable, associated with air traffic flow in his/her sector and working position. Sector capacity is determined by adding the total task load to a parameter that indicates the amount of time needed for controller recovery.

Observable tasks are routine tasks performed by the controller, such as those applicable to all aircraft, irrespective of how many aircraft are under his/her control (*e.g.*, standard communications), and those tasks aimed at solving conflicts when an aircraft is facing an actual or potential conflict.

Non-observable tasks are the planning tasks carried out by the controller and the mental tasks required to detect or forecast conflicts. But it is important to note that some tasks cannot be observed in procedural systems, but can be observed and quantified in automated systems (*e.g.*, planning, conflict forecasting). Although planning is a non-observable task--with the aforementioned caveats--, the DORATASK Model contains algorithms that estimate workload, which is the time the controller spends on planning tasks. These estimates and examples are based on statistical data that provide constant values used to adjust analytical formulae.

In the case of terminal area capacity calculations, the DORATASK Model identifies two non-observable tasks, initial processing and radar monitoring. These tasks are modelled using the number of radar displays and the combination of pairs of aircraft that must be checked. Since these tasks are, by definition, linear and quadratic with respect to the number of aircraft, each of these measures is multiplied by an unknown number (constant value) that is estimated by each analyst after comparing with sectors of known capacity.

The DORATASK Model has served as the basis for many other capacity calculation applications and models, taking into account controller workload. However, it is not the only model to be taken into account since, as noted, it has some limitations. Nevertheless, this model is quite suitable for ATC sector capacity studies and, with the appropriate modifications, can be adjusted to automated systems.

#### **IV. Methodological Models for Estimating Capacity in the Region**

##### **ATC Sector Capacity Calculation Model used in Brazil**

In Brazil, ACC capacity is estimated by analysing the capacity of its sectors, which is analytically obtained using the methodology established in ICA 100-30, ATC Staff Planning (DECEA, 2007).

Currently, the estimated sector capacity value can be considered to be the maximum number of aircraft that each air traffic controller (ATCO) can control simultaneously in a given sector, thus providing the capacity applied by the ATC unit.

The Airspace Control Department (DECEA) uses a methodology to determine the APP and ACC sector capacity, which provides a sector capacity reference value.

This methodology consists in obtaining a value based on a mathematical formula. The basic data for such formula are derived from an investigation carried out by a special working group at the ATC unit, taking into account a busy period in which controller actions and availability to manage control sector traffic are observed and timed; this provides a data sample to be used in the ATC sector capacity calculation methodology.

The ATC Sector Capacity Calculation Model used in Brazil appears in **Attachment 1** to this Document.

#### Data sampling for estimating ATC sector capacity

It is important for data collection to be significant so as to dilute temporary stochastic deviations and to represent reliable values for the ATC unit.

In Brazil, the method used to determine sector capacity takes into account the load borne by an ATCO in performing his/her tasks, and is based on the assessment of the tasks performed by the controller at times of high traffic volume, as seen in the DORATASK model.

According to the current model, controller workload is the summation of times spent on:

1. communication (transmission/reception);
2. manual activities (filling out flight progress strips) and coordination; and
3. traffic planning and distribution.

The Brazilian methodology applies the controller “availability factor” ( $\phi$ ) concept, which is defined as the percentage of time available for the ATCO to plan aircraft separation procedures.

This availability factor normally falls between a minimum value of 40% of ATCO time for non-radar control, and 60% for radar control (ICA 100-30). It is thus clear that efforts need to focus on increasing the “availability factor”  $\phi$ .

The latter can only be achieved by applying measures to reduce the level of controller intervention in the activities mentioned in 1 and 2.

The percentage accounted for by this  $\phi$  factor could increase if the “Man/Machine Interface –MMI” is enhanced; that is, when increasing the level of automation in some tasks.

Studies conducted by Brazilian experts, who analysed the sampling techniques, show that it is advisable to make at least 30 observations of each parameter for each controller, during peak traffic, respecting the minimum number of controllers specified by the sampling technique used.

It is essential to collect as many observations and controllers as possible in the unit being assessed in order to eliminate extreme values and to minimise any type of trend (*e.g.*, cases of controllers or pilots who are either too slow or too quick in their communications, affecting the arithmetical mean).

A detailed and analytical explanation of the sampling technique used in Brazil to determine the number of observations required by sector and by controller is given in **Attachment 2** to this document. The form used in Brazil to assess ATC communications load is shown in **Attachment 3** to this document.

The form used by Brazil to assess the “availability factor” appears in **Attachment 4** to this document.

#### FAA ATC sector capacity calculation model for global event in Trinidad y Tobago

On occasion of the 20<sup>th</sup> Meeting of Eastern Caribbean Directors of Civil Aviation (20th E/CAR/DCA) held in Miami, Florida, United States, on 4-7 December 2006, the FAA presented a model to determine ATC sector capacity based on the experience gained in this field by the United States, in order to support ATFM-related activities during the Cricket World Cup held in Trinidad and Tobago.

This is a case of macroscopic calculation that includes an additional factor, which is a constant value to account for human factors, calculated by the FAA to measure the average time spent by a controller interacting with an aircraft.

Since we believe this could be very useful for a State that needs to apply a simple, safe, macroscopic methodology to face a specific event in which a greater-than-normal demand is expected, we have included this study as **Attachment 5** to this document.

## **V. Airport Capacity Calculation Models**

### Airport capacity calculation model applied in Brazil

In Brazil, the runway capacity calculation method assumes a take-off operation between two consecutive landings, maintaining the regulatory separation minima defined in ICA 100-12 (Rules of the Air and Air Traffic Services). Runway capacity is estimated for a 60-minute interval in function of average runway occupancy times.

In order to determine the capacity of the set of runways, the following factors are taken into account:

- a) Planning factors; and
- b) Factors related to landing and take-off operations.

Planning factors are elements used to simplify the mathematical models or the operational aspects that bear on the determination of runway capacity. The most commonly used are:

- a) Ideal air traffic sequencing and coordination conditions;
- b) All personnel is considered to have the same training and same operational performance;



- c) All navaids and visual aids are considered to be technically and operationally unrestricted; and
- d) All (VHF/telephony) communication equipment considered operational is operating normally.

Regarding factors related to landing and take-off operations, the following can be identified:

- a) Average runway occupancy times;
- b) Aircraft mix;
- c) Percentage of threshold utilisation;
- d) Length of the final approach segment;
- e) Regulatory aircraft separation minima applied;
- f) Runway and taxiway layout; and
- g) Final approach speed.

The main parameters used to estimate runway capacity in Brazil are listed below:

- Aircraft mix (aircraft category and approach speed)
- Average runway occupancy time (sec.)
- Separation criteria adopted by the ATC

Aircraft mix is defined as the percentage distribution of the aircraft fleet operating at the aerodrome according to aircraft categories. The aircraft mix for aerodromes must be estimated based on the total daily movement, a constant value in IEPV 100-34 (Movement of Aircraft at Aerodromes) or in the SGTC, which is determined using the arithmetical average of a sample containing data for a period of at least one week.

According to Doc 8168, aircraft are subdivided into five categories, depending on threshold speed, which must be 130% of the value of the stall speed in the landing configuration (full flaps, gear down). Accordingly, aircraft are classified as follows:

CAT "A" speed less than 90 kt

CAT "B" Speed between 91/120kt

CAT "C" Speed between 121/140kt

CAT "D" speed between 141/165kt

CAT "E" Speed between 166/210kt

The average runway occupancy time is the weighted arithmetical mean of runway occupation times, by aircraft category, where the aircraft mix operating in the aerodrome is the weighting factor.

This method is based on data collection, which, for the sake of greater precision, should be done at peak hour, since air traffic flow is more fluid during such period, thus reducing runway occupancy time. If data collected does not cover all categories, additional data may be gathered at other times and even on different days. Runway occupancy time during take-off shall be counted from the time the aircraft leaves the holding position up until it crosses the opposite threshold.

The separation criteria adopted by the ATC vary in light of the regulations in force on this matter in each State. For purposes of this study, Brazil has considered a separation of 5 NM, which coincides with the outer marker (OM) and the runway threshold.

If there is no OM, a point is determined in the final approach that has a known distance and that determines the impossibility for another aircraft from entering the runway while the aircraft that is about to land is flying over this point or is between this point and the runway threshold concerned.

The methodological steps and data collection forms to estimate the physical, theoretical, and declared runway capacity are described in **Attachment 6** to this document.

#### FAA Runway Capacity Calculation Model

The model used by the FAA to estimate capacity and analyse delays at airports is described in Advisory Circular (AC) 150/5060-5, Change 1 and 2, entitled "Airport Capacity and Delay".

This Circular contains calculations to determine airport capacity, annual volume of operations, and aircraft delays. It also contains a special calculation to determine capacity when it is affected by poor weather, airports with no radar coverage or without ILS, as well as detailed analyses to assess airports with parallel runways, and more refined calculations in order to analyse special situations that may affect runway capacity.

In this Model, the hourly capacity is influenced by runway configuration, aircraft mix, percentage of arrivals, percentage of go-around operations under visual flight rules (VFR), and location of taxiway exits. Hourly capacity is estimated for both VFR and instrument flight rules (IFR) conditions. Weather is a determining factor for this calculation method.

Furthermore, this Model is based on a large number of statistical data collected for many years, providing for very good performance in American scenarios in terms of theoretical and actual capacity.

**Attachment 7** to this document provides detailed information on the procedure used by the FAA to calculate the potential and actual airport acceptance rate (AAR). Advisory Circular (AC) 150/5060-5, Change 1 and 2, “Airport Capacity and Delay”, can be found at the following web site:

[http://www.airweb.faa.gov/Regulatory\\_and\\_Guidance\\_Library/rgAdvisoryCircular.nsf/ACNumber/641E65B7EA1DC3B685256D0C006289F6?OpenDocument](http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/ACNumber/641E65B7EA1DC3B685256D0C006289F6?OpenDocument)

#### Runway Capacity Calculation Model used in Colombia

In order to determine the El Dorado airport capacity, the ATM Procedures Group of the UAEAC of Colombia applied Advisory Circular (AC) 150/5060-5, Change 2, entitled “Airport Capacity and Delay”, to assess runway capacity of the El Dorado airport.

This method was derived from the calculation models used by the FAA to determine airport capacity. It was necessary to compare the theoretical calculations with the operational reality of the airport; theoretical values were similar to those obtained in practice.

Information regarding the methodology applied in Columbia to calculate airport acceptance and concerning an analysis carried out at El Dorado airport appears in **Attachment 8** to this document.

#### **VI. Capacity Improvement**

The demand/capacity analysis identifies a number of factors that are extremely important for the efficient planning of the ATM system so as to ensure an optimum balance that will benefit the ATFM. **Attachment 9** provides some guidelines for ATM planners to improve system capacity.

Regarding the planning process for demand, capacity, and delay analysis, we recommend that the CAR/SAM ATFM Manual be used. This manual is available in the ICAO South American Office web site.

#### **VII. Conclusion**

Knowledge of the capacity of air traffic sectors or ATC operating positions is necessary for two main reasons. The first is that, for long-term planning, it is necessary to anticipate efficiently any reduction of future capacity, as inferred from traffic forecasts. The second reason is that if there is already a reduction in capacity that calls for flow control, it must be known in order to restrict traffic without overloading the system or excessively affecting operators, or in order to implement best practices on operational performance.

There are many methods for calculating capacity and, as readily noted from the different models described in this Guide, air traffic controller workload is a significant parameter in these models. Therefore, a better knowledge of workload factors and their implications will provide for a more suitable operational adjustment of the services provided to meet the demand.

It is also essential to have a perfect understanding of the variables attributed to the mathematical model, using for the calculation the number of aircraft that can be served in ATC sectors and airport capacity in a given period of time.

To this end, a critical study and an impartial and detailed analysis of the reality of each State in relation to the results obtained in the data survey are necessary in order to quantify such variables, allowing planners to identify operational limitations of the services provided duly in advance.

On the other hand, the observation of occasional factors, such as communication deficiencies, adverse weather, preferential aircraft operations, military operations, aircraft in emergency, among many others that may cause operational delays, can have a negative impact on results and lead to conclusions that do not reflect reality if not properly weighted.

Likewise, information about the number of aircraft simultaneously controlled by a single controller in a given sector must be collected by rated teams knowledgeable of the characteristics of the place to be assessed, preferably air traffic controllers. Data collection frequency and the amount of data to be collected by sector and by controller should be such as to include cases of air traffic flow modification, sectoring, installation/failure of navigation infrastructure, new design for airspace optimisation, etc.

Concerning the data obtained from capacity calculations, they are not only useful for identifying system limitations or behaviour, but also are extremely important for defining the number of ATCOs required in a given ATC service.

Staff sizing should consider the number of persons required to cover all operating positions in the event of maximum configuration. The analysis conducted to create a control sector is based on a significant and constant increase of traffic in that sector. Traffic flow history and evolution are also used to forecast the need for, and size of, HARDWARE and human resources required for a given period of time.

The right number of operational air traffic control positions to face peak periods can be defined by correctly analysing and interpreting demand/capacity data, or reducing the numbers on certain schedules.

The capacity calculation models studied for purposes of this guide do not fully cover the many variables that should be taken into account, especially for quantifying non-observable tasks, where only long-term analysis of statistical data can support the use of a constant value in the mathematical formulation or the comparison with a reference system that has been tested in practice.

Hence, we note, for example, that some of the constant values used in the FAA system result from substantial statistical information gathered throughout many years, thus providing a high level of certainty. However, it may be concluded that this constant value has an additional factor inherent to the system from where data were collected, which is supplemented with very serious studies on human factors.

Regarding the above, it should be noted that, for different reasons, personnel performance measurements can vary significantly depending on the organisational culture involved, personnel recruitment levels, the number of staff available, training levels, and many other factors that cause this performance to have an impact on the human factor constant value.

The model applied in Brazil is quite complete since it applies a modern airport capacity approach, and is also very accurate in quantifying ATC sector capacity. However, as with other models, it assumes ideal conditions and it would be convenient to quantify a standard adjustment for each State when such conditions are not met in a given system, so as to reduce the acceptance number or the capacity in the formula.

Nevertheless, by applying best practices in airspace design, sequencing, coordination, and CNS maintenance; and by applying regulatory separation minima, and rigorously recruiting and training human resources, a State can raise the standard and optimise the mathematical formulation of the model applied, thus increasing capacity significantly.

Furthermore, the optimisation of the existing runway and taxiway configuration, the aircraft mix, the average runway occupancy times, the length of the final approach segment specified as safety distance, fleet capacity and equipment, and crew training are other factors that contribute to capacity optimisation and that must be considered when declaring the capacity of an ATC sector or of an airport.

As for the models applied in the region, no major differences in the results obtained for airport acceptance rates are found between the FAA model and the model used in Brazil for purposes of determining runway capacity. If we analyse the various ATC sector capacity calculation models, we will note that, to a greater or lesser extent, the main parameters are derived from the DORATASK Model.

With few exceptions, as we have seen, most of the States in the Region have little practical experience in the use of a model for calculating capacity. This has an impact on the size of the available database that could be used to adjust constant values in each of the different operational scenarios in the systems of the Region, unlike the FAA, whose databases have been fed with data collected for many years and are constantly updated.

Notwithstanding the above, experts from most of the States in the Region attended the Course on Airport and ATC Sector Capacity Calculation, held in March 2009, at the CGNA facilities in Rio, Brazil, under ICAO Project RLA/06/901, to receive training on the application of the model used in Brazil; this represents a very valuable capital that can be tapped.

### Recommendation

In order to take maximum advantage of the training provided under ICAO Project RLA/06/901, and taking into account that such training provides a standard calculation criterion for the region that can be used in a first phase as an initial common methodology to calculate the airport and ATC sector capacity, we recommend that SAM States use the Methodology to Calculate Airport and ATC Sector Capacity applied in Brazil.

We recommend this methodology for the following reasons:

- a) standard training for experts from the States participating in the Project;
- b) use of a model that is applicable to both airport and ATC sector capacity;
- c) low cost methodology that does not require any software;
- d) it does not require constant values derived from databases that some States do not have available yet;
- e) practical experience on the use of the model can be acquired immediately, resulting in:
  - ✓ the creation of a standard database for statistical purposes,
  - ✓ the evaluation of model weaknesses,
  - ✓ feedback to improve the model,
  - ✓ more experience gained in order to decide on the future application of a definitive common model for the SAM Region in a second phase;
- f) according to the planned regional ATFM implementation level, it is possible to leave for a near future the selection of a single definitive capacity calculation model to be used in the Region, as recommended by ICAO Annex 11, and
- g) it supplements the use of some methodologies applied in the Region (*e.g.*, Colombia) and, basically, is not in conflict with the airport acceptance rate calculation system used in Colombia in this first phase.

In summary, this guide serves as a basis to define the parameters and indicators to be taken into account for analysing delays, to identify best practices leading to increased capacity, and to detect the differences and similarities of the models used in the Region, thus creating a sound baseline so that in a near future, in a second phase, it may be possible to apply a common, optimised airport and ATC airspace sector capacity calculation model for the Region, enriched with the experience gained in this initial regional implementation.

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## ATTACHMENT 1

### ATC Sector Capacity Calculation Model Used in Brazil

In Brazil, the number of aircraft that can be controlled simultaneously by a single controller (N) in a given sector is estimated using the following formula (ICA 100-30):

$$\boxed{N = \phi \cdot \delta \cdot (\eta \cdot \tau_m \cdot v_m)^{-1}} \quad (1)$$

where ATC capacity is a direct or inverse function of some factors (ICA 100-30) to be considered:

Factors directly proportional to ATC capacity:

$\phi$  : the controller availability factor, defined as the percentage of time available for planning aircraft separation procedures;

$\delta$  : average distance flown by aircraft in the sector, which is a function of the paths and en route or terminal procedures established for each sector;

Factors inversely proportional to ATC capacity:

$\eta$  : number of communications for each aircraft in the sector, which must be limited to the least possible number required for an understanding between the pilot and the controller. This number can be minimised by issuing a complete clearance sufficiently in advance for flight planning;

$\tau_m$  : mean duration of each message. This factor can be minimised by issuing messages objectively, without long explanations that are detrimental for an understanding between the pilot and the controller; and

$v_m$  : mean speed of aircraft in the sector.

If  $\delta$  and  $v_m$  are replaced with the average flight time of the aircraft in the sector (T), this formula can be replaced with a simpler version:

$$\boxed{N = \phi \cdot T \cdot (\eta \cdot \tau_m)^{-1}} \quad (2)$$

The values of factors  $\phi$ , T,  $\eta$  and  $\tau_m$  are empirically obtained following the standard procedures (DECEA, 2007).

For example, we can consider T= 12 minutes,  $\tau_m = 9$  seconds,  $\phi = 60\%$ ,  $\eta = 6$ , which gives a number of aircraft  $N = 8$  simultaneously controlled by the controller in the given sector. In other words, in this sector and under these conditions, a controller would simultaneously control 8 aircraft.

There are several factors that are constantly influencing the number  $N$  and that are directly related, such as the size of the sector or route modification. Consequently, whenever a significant change is observed, the value obtained must be updated.

Under ideal conditions, data collection must be done with busy traffic. Therefore, the selection of the ideal period is a factor to be taken into account, since it has a direct impact on the final result.

## ATTACHMENT 2

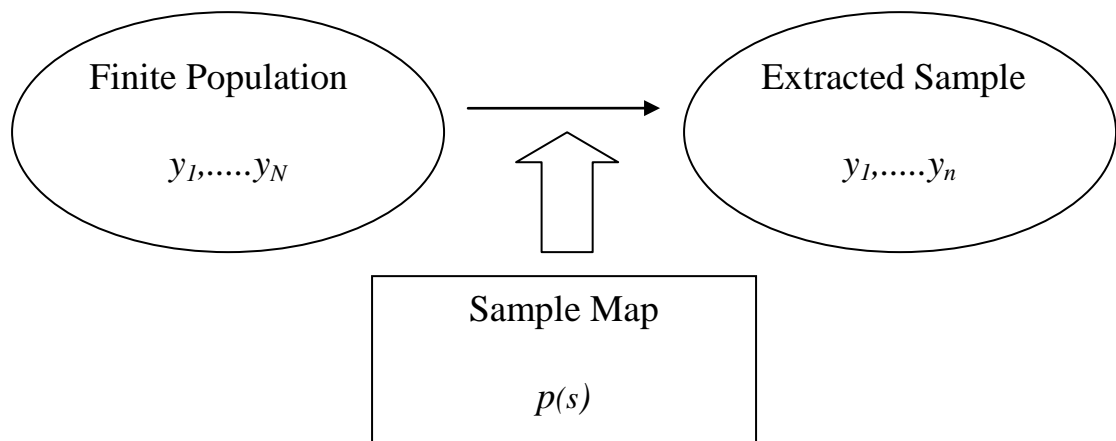
### 1. Sampling Technique to Estimate ATC Sector Capacity

1.1. In order to obtain information about aircraft population, and knowing that the investigation of all fleet elements is very costly--even though the population is finite--, a sample needs to be taken. The process of choosing the elements that belong to a sample is called sampling. The main idea is to draw a portion of the population (sample) that is representative and that allows investigators to make assertions and draw conclusions. For these considerations to be valid, sample selection must be random and probabilistic.

1.2. For a sample to be considered probabilistic, it must be drawn from a finite population, that is,  $U=\{1,\dots,N\}$ . Based on a finite population, a sample  $s = \{i_1,\dots,i_N\}$  is selected and attributed a selection probability designated by  $p(s)$ . The way in which the selection process is carried out is known as the sampling plan or sample design. This process determines a well-defined set of all possible samples, designated by  $S$ , and also assumes that the selection probability of each sample  $p(s)$  is known or can be calculated.

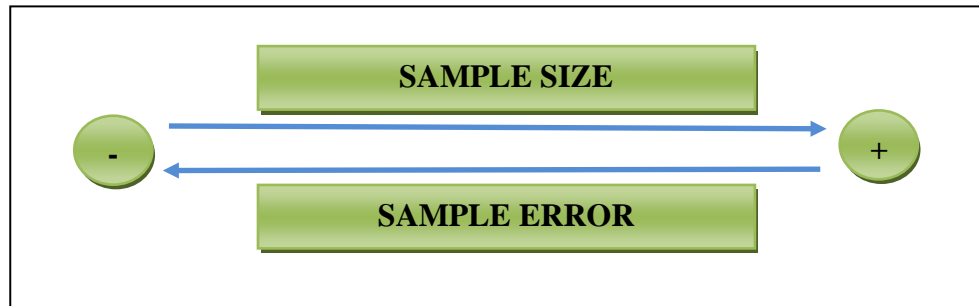
1.3. With regard to the population, some assumptions must be established: each of its elements ( $i \in U$ ) has a non-nil selection probability and the variable values of interest in the population under investigation  $y_1,\dots,y_N$  shall be considered fixed and unknown (VIEIRA, 2001). Maintaining generality, it is also possible to re-index the population so that the selected sample may be represented by the indices  $s=\{1,\dots,n\}$ . VIEIRA (2001) points out that a sample  $s \in S$  is selected using a random mechanism so that it is selected with a probability  $p(s)$ . Figure 1 describes this procedure:

Figure 1 – Random or Probabilistic Sample



1.4. The results obtained from an investigation based on samples are not rigorously exact with respect to the universe. These results present a measurement error called sample error ( $\varepsilon$ ). We cannot prevent this sample error from happening; however, its value can be limited by selecting a sample of the right size. Obviously, the sample error and the sample size go in different directions (figure 2). The larger the sample, the smaller the error and *vice versa*.

Figure 2 – Intuitive relationship between sample size and sample error



1.5. Normally, an error estimate of 3% to 5% is used. In this context, population parameters are estimated providing for their error margin estimation (PESSOA; NASCIMENTO SILVA, 1998). The sampling techniques used by the CGNA to measure SISCEAB ATC sector capacity are simple random sampling for an infinite population and simple random sampling of a finite population. These techniques were selected so as to respect the criteria set forth in ICA 100-30, which contains the mathematical model used to determine the number of aircraft that an air traffic controller can simultaneously at any given time.

## 2. Simple Random Sampling for an Infinite Population

2.1 In order to arrive at sample sizes that are compatible with the reliability level and the desirable sample error, the CGNA uses a formula (1) to determine the sample size of the parameters of the mathematical model used to estimate ATC sector capacity. Since it is not possible to determine with precision the population size of these parameters, the infinite population technique is used.

$$n = \left( \frac{Z_{\alpha/2} \cdot \sigma}{\varepsilon} \right)^2 \quad (1)$$

Where:

$n$  = Sample size;

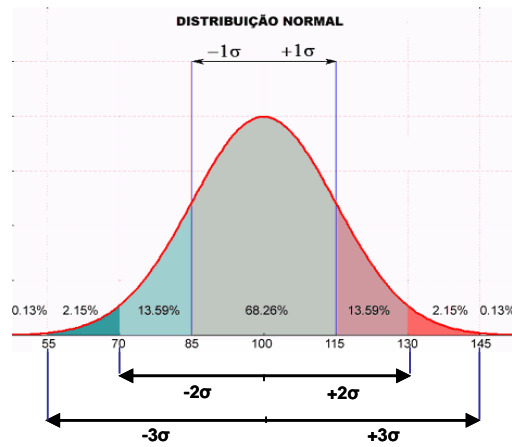
$Z_{\alpha/2}$  = Reliability level selected (95%), expressed by  $Z_{\alpha/2} = 1,96$ ;

$\sigma$  = Population standard deviation; and

$\varepsilon$  = Maximum error allowed.

2.2 The reliability level of the sample refers to the area of the normal curve that is defined based on the standard deviations from the average, as illustrated in figure 3:

Figure 3: Normal Distribution



1 standard deviation = 68,3% representative;  
 2 standard deviations = 95,5% representative;  
 and  
 3 standard deviations = 99,7% representative.

2.3 The most commonly used reliability values and the corresponding Z values are shown in table 1.

Table 1: Critical Values related to the reliability of the sample

Reliability Level	At	Critical Value $Z_{\alpha/2}$
90%	0,10	1,645
95%	0,05	1,96
99%	0,01	2,575

The reliability level adopted for the study is 95% reliability and the maximum error allowed is 5%.

2.4 Since  $\sigma$  is an unknown population parameter, we can use a preliminary value obtained from a pilot study, thus starting the sampling process. Based on a first data collection of at least 30 observations, the standard deviation of sample  $S$  is estimated and used instead of  $\sigma$ .

2.5 Excessively small samples may lead to unreliable results. Any result obtained from the formula involving a sample size of less than 30 must be increased to 30, since it is based on the use of the normal distribution.

### 3. Simple Random Sample for Finite Population

3.1 In order to determine the minimum number of controllers to be observed in each unit, the most suitable sampling technique is simple random sampling for finite populations. The formula below is used to determine sample size:

$$n = \frac{Z_{\alpha/2}^2 \cdot p \cdot q \cdot N}{\varepsilon^2 \cdot (N - 1) + Z_{\alpha/2}^2 \cdot p \cdot q} \quad (2)$$

Where:

$n$  = Sample size;

$Z_{\alpha/2}$  = Reliability level selected (95%), expressed by  $Z_{\alpha/2} = 1,96$ ;

$p$  = Proportion of individuals in the population that belong to the interest group;

$q$  = Proportion of individuals in the population that **do not** belong to the interest group  
( $q=1-p$ );

$N$  = Population size; and

$\varepsilon$  = Maximum error allowed.

Also, in this case, if the value of  $n$  is less than 30, it shall be increased to 30.

3.2 In the study,  $p$  is equal to the probability of a controller being observed on a given day; in other words, a day has  $x$  work shifts, hence the probability of a controller being observed in any of the shifts is  $x$  divided by the total number of controllers multiplied by the number of sectors, as shown in the formula below:

$$p = \frac{x}{N} \bullet \text{number of sectors} \quad (3)$$

### 4. Sampling Technique used in Sectors 02 and 09 of the Curitiba FIR

4.1 According to ICA 100-30, the mathematical model for estimating the number of aircraft simultaneously controlled by a single controller in a given ATC sector is expressed by the following formula (4):

$$N = \frac{f \cdot T}{n \cdot t \cdot m} \quad (4)$$

Where:

$N$  = number of aircraft controlled simultaneously by one controller;

$f$  = controller availability factor, as a percentage;

$T$  = average time flown by the aircraft in the sector;

$n$  = average number of communications of each aircraft in the sector; and

$tm$  = average duration of each message, in seconds.

4.2 In order to obtain sample sizes that are compatible with the reliability level and sample error desired, formula (1) will be used to determine the sample size of the parameters of the mathematical model used to calculate ATC sector capacity, and formula (2) will be used to determine the minimum number of controllers to be considered for timing operations.

4.3 The necessary data were collected from audiotape recordings of VHF communications in ACC-CW sectors 02 and 09, on 16 March 2009. This day was chosen because the team had prior knowledge that it was a peak day compared to the rest of the year. The total audiotape time was 125 minutes and accounts in the following schedules: from 10:29 to 11:14 UTC and 11:14 to 12:14 UTC (sector 02), and from 22:58 to 23:25 UTC and 23:25 to 23:58 UTC (sector 09). These schedules were chosen because they had the highest air traffic flow (peak traffic).

4.4 Formula (1) was used to calculate the sampling, considering 95% reliability and a sample error of 5%. The data collected from the recordings provided the sample standard deviation ( $S$ ) of parameter  $tm$  (average duration of each message, in seconds) equal to 12,31 (sector 02) and 11,72 (sector 09), from 137 and 122 measurements, respectively. Plotting these data in formula (1), we arrive at the following result:

$$\text{Sector 02} \rightarrow n = \left( \frac{Z_{\alpha/2} \cdot S}{\varepsilon} \right)^2 = \left( \frac{1,96 \cdot 12,31}{5} \right)^2 = 22,3 \quad (5)$$

$$\text{Sector 09} \rightarrow n = \left( \frac{Z_{\alpha/2} \cdot S}{\varepsilon} \right)^2 = \left( \frac{1,96 \cdot 11,72}{5} \right)^2 = 21,1 \quad (6)$$

4.5 As already mentioned, any value obtained from the formula that is below 30 must be increased to 30. Hence, the minimum number of repetitions to measure  $tm$  shall be at least 30.

4.6 The calculation of the minimum number of controllers to be considered for the timing shall account for the operational peculiarities of each ACC. In the case of ACC CW, the centre was deemed to have around 130 controllers working 4 shifts per day and capable of taking over positions in any of the 10 sectors. Based on this information and formula (3), the following is obtained:

$$p = \frac{4}{N} \bullet \text{number of sectors} = \frac{4}{130} \bullet 10 = 0,31 = 31\% \quad (7)$$

4.7 Considering 95% reliability, 5% tolerance, N equal to 130 and p equal to 0,31, using formula (2), we obtain the following result:

$$n = \frac{Z_{\alpha/2}^2 \cdot p \cdot q \cdot N}{\varepsilon^2 \cdot (N - 1) + Z_{\alpha/2}^2 \cdot p \cdot q} = \frac{1,96^2 \cdot 0,31 \cdot 0,69 \cdot 130}{0,05^2 \cdot (130 - 1) + 1,96^2 \cdot 0,31 \cdot 0,69} = 94 \text{ ATCOs} \quad (8)$$

4.8 The big size of the sample compared to the population (72%) is justified because the total size of the population is considered small. The smaller the size of the population, the closer the value of the sample size to that value. Nevertheless, this sample could be diluted given the number of ATC sectors. In the case of the ACC CW, the 94 controllers selected may be distributed among the 10 existing sectors; in other words, at least 9 controllers shall be observed in each sector.

4.9 It should be noted that sampling techniques reveal **minimum** values of relevant samples. Therefore, as long as it is possible to collect more samples, based on available time and money, we recommend gathering a larger number of samples. As already stated, the bigger the sample, the more accurate the study.

4.10 In this study, parameter T (average flying time of an aircraft in the sector) was generated by the SINCROMAX system in Brazil and parameter f was calculated based on previous studies. In the studies to be carried out in the ACCs, these parameters shall be measured on site in order to have an exact measure of what is really happening.

4.11 With the simple random sampling technique for infinite populations, we reach the conclusion that the minimum number of observations to obtain parameters n and tm in ACC CW sectors 2 and 9/10 is 30 observations per controller during peak traffic.

4.12 With the simple random sampling technique for finite populations, we reach the conclusion that the minimum number of controllers to be considered for time tracking is 94 ATCOs. This number can be distributed among the 10 existing sectors of ACC CW; hence the minimum number of controllers per sector is 9.

4.13 It is recommended that, in future studies, at least 30 observations of each parameter be recorded for each controller at peak hours, respecting the minimum number of controllers specified by the sampling technique used. Based on resource availability, it is suggested that as many observations be made of as many controllers in the unit as possible. This recommendation helps avoid ruling out possible *outliers* (extreme values) and to minimise any type of existing trend, such as controllers and/or pilots extending or restricting communications so much that it could lead to an increase/reduction of the *tm* trend.







## ATTACHMENT 5

### Modelo de la FAA de Cálculo para sector ATC

#### Definition

Sector capacity: The optimum number of flights in a given sector, for a specified period of time that can be managed safely and efficiently.

#### Factors that affect sector capacity

The following factors can all have an impact on sector capacity:

- a) Airway structure in the sector.
- b) Airspace volume of the sector.
  - 1) Vertically
  - 2) Horizontally
- c) Complexity of operations in the sector.
  - 1) Number of adjoining sectors
  - 2) Amount of climbing/descending traffic
  - 3) Terrain
  - 4) Military operations
  - 5) Special use airspace

#### Steps for determining sector capacity

For each 15-minute time period:

- a) Determine the average time a flight spends in a sector.
- b) In most cases, this will be measured from 7am to 7pm, Monday through Friday.
- c) Example:

20 flights are observed in the sector in 15 minutes  
 Add the flights individual sector times together  
 120 minutes

Divide 120 minutes by the 20 flights to obtain the average  
 $120 \text{ minutes} = 6 \text{ minutes} / \text{flight}$   
 20 flights  
 The quotient is the average sector flight time, in minutes  
 6 minutes

Next, multiply the average sector flight time by 60 seconds.

- a) Example:  
 $(6 \text{ minutes} / \text{flight}) \times (60 \text{ seconds}) = 360 \text{ seconds} / \text{flight}$   
 The product is the average sector flight time, in seconds

Next, divide the average sector flight time, in seconds, by 36 seconds.

Note: 36 seconds is a value established for use in the United States by human factor experts. It represents the average time a controller interacts with a flight while it is in the sector.

b) Example:

The average sector flight time from above is 360 seconds per flight

Divide 360 seconds per flight by 36 seconds (the time a controller interacts with a flight)

360 seconds per flight = 10 flights  
36 seconds

The quotient, 10, is the optimum sector capacity value for the 15 minute period.

Next, adjust the optimum sector capacity value for operational factors.

a) The value may be adjusted up or down, as appropriate, after taking into account the factors that affect the sector.

b) The factors include, but are not limited to:

- 1) Airway structure in the sector
- 2) Airspace volume of the sector -- vertically and horizontally
- 3) Complexity of operations in the sector
- 4) Number of adjoining sectors
- 5) Amount of climbing and descending traffic
- 6) Terrain
- 7) Military operations and special use airspace

c) Apply local, professional judgment and adjust the optimum sector capacity value up, or down, as necessary.

The optimum sector capacity adjusted for operational considerations is the sector capacity value.

OPTIMUM SECTOR CAPACITY VALUE  
plus/minus +/- ADJUSTMENT FACTORS  
equals SECTOR CAPACITY VALUE

A table method has also been developed for computing the Optimum Sector Capacity Value.





TABLE 3													
ARITHMETICAL MEAN OF RUNWAY OCCUPANCY TIMES DURING LANDING (MROTL), BY AIRCRAFT CATEGORY													
AERODROME: _____ RUNWAY: _____													
$\Sigma \text{ROTL}_{\text{CAT X}} / \text{N}^{\circ} \text{ACFT}_{\text{CAT X}}$	<table border="1"> <thead> <tr> <th>CAT</th> <th>TIME (sec)</th> </tr> </thead> <tbody> <tr> <td>A</td> <td></td> </tr> <tr> <td>B</td> <td></td> </tr> <tr> <td>C</td> <td></td> </tr> <tr> <td>D</td> <td></td> </tr> <tr> <td>E</td> <td></td> </tr> </tbody> </table>	CAT	TIME (sec)	A		B		C		D		E	
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	A												
	B												
	C												
	D												
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ARITHMETICAL MEAN OF RUNWAY OCCUPANCY TIMES DURING TAKE-OFF (MROTT), BY AIRCRAFT CATEGORY													
AERODROME: _____ RUNWAY: _____													
$\Sigma \text{ROTT}_{\text{CAT X}} / \text{\#ACFT}_{\text{CAT X}}$	<table border="1"> <thead> <tr> <th>CAT</th> <th>TIME (sec)</th> </tr> </thead> <tbody> <tr> <td>A</td> <td></td> </tr> <tr> <td>B</td> <td></td> </tr> <tr> <td>C</td> <td></td> </tr> <tr> <td>D</td> <td></td> </tr> <tr> <td>E</td> <td></td> </tr> </tbody> </table>	CAT	TIME (sec)	A		B		C		D		E	
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	B												
	C												
	D												
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ARITHMETICAL MEAN OF RUNWAY OCCUPANCY TIMES (AMROT), BY AIRCRAFT CATEGORY													
AERODROME: _____ RUNWAY: _____													
$(\Sigma \text{MROTL} + \Sigma \text{MROTT}) / 2$	<table border="1"> <thead> <tr> <th>CAT</th> <th>TIME (sec)</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>AMROTA</td> </tr> <tr> <td>B</td> <td>AMROTB</td> </tr> <tr> <td>C</td> <td>AMROTC</td> </tr> <tr> <td>D</td> <td>AMROTD</td> </tr> <tr> <td>E</td> <td>AMROTE</td> </tr> </tbody> </table>	CAT	TIME (sec)	A	AMROTA	B	AMROTB	C	AMROTC	D	AMROTD	E	AMROTE
	CAT	TIME (sec)											
	A	AMROTA											
	B	AMROTB											
	C	AMROTC											
	D	AMROTD											
E	AMROTE												

$\text{AMROTA} = \frac{\text{MROTTA} + \text{MROTLA}}{2}$	$\text{AMROTB} = \frac{\text{MROTTB} + \text{MROTLB}}{2}$
$\text{AMROTC} = \frac{\text{MROTT C} + \text{MROTL C}}{2}$	$\text{AMROTD} = \frac{\text{MROTT D} + \text{MROTL D}}{2}$
$\text{AMROTE} = \frac{\text{MROTT E} + \text{MROTL E}}{2}$	

**Step 3**

## c) Estimating aircraft mix

Based on total daily movement records obtained from any recognised statistical source that truly reflects the total movement of aircraft at the aerodrome, a weekly sample is obtained for estimating aircraft mix, and the resulting values are inserted in Table 4 (Form for Collecting Airport Percentage Utilisation Data by Aircraft Category - Mix).

<b>TABLE 4</b>																													
<b>AERODROME PERCENTAGE UTILISATION BY AIRCRAFT CATEGORY (MIX)</b>																													
<b>AERODROME:</b> _____																													
<table border="1"> <thead> <tr> <th colspan="2"><b>MONDAY</b></th> </tr> <tr> <th><b>CAT</b></th> <th><b># Aircraft (%)</b></th> </tr> </thead> <tbody> <tr> <td><b>A</b></td> <td></td> </tr> <tr> <td><b>B</b></td> <td></td> </tr> <tr> <td><b>C</b></td> <td></td> </tr> <tr> <td><b>D</b></td> <td></td> </tr> <tr> <td><b>E</b></td> <td></td> </tr> </tbody> </table>	<b>MONDAY</b>		<b>CAT</b>	<b># Aircraft (%)</b>	<b>A</b>		<b>B</b>		<b>C</b>		<b>D</b>		<b>E</b>		<table border="1"> <thead> <tr> <th colspan="2"><b>TUESDAY</b></th> </tr> <tr> <th><b>CAT</b></th> <th><b># Aircraft (%)</b></th> </tr> </thead> <tbody> <tr> <td><b>A</b></td> <td></td> </tr> <tr> <td><b>B</b></td> <td></td> </tr> <tr> <td><b>C</b></td> <td></td> </tr> <tr> <td><b>D</b></td> <td></td> </tr> <tr> <td><b>E</b></td> <td></td> </tr> </tbody> </table>	<b>TUESDAY</b>		<b>CAT</b>	<b># Aircraft (%)</b>	<b>A</b>		<b>B</b>		<b>C</b>		<b>D</b>		<b>E</b>	
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**TABLE 4 (CONT.)**

$\Sigma \# \text{Aircraft}_{\text{CAT X}} / \# \text{DAYS}$	<b>MIX</b>	
	<b>CAT</b>	<b># Aircraft (%)</b>
	<b>A</b>	
	<b>B</b>	
	<b>C</b>	
	<b>D</b>	
	<b>E</b>	

The value of the mix shall be determined by comparing the percentages, by day of the week, of the total number of aircraft in the respective day and the total number of aircraft in each category.

The following table illustrates aircraft mix calculation:

CAT	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
	Air-craft	%	Air-craft	%	Air-craft	%	Air-craft	%	Air-craft	%
<b>A</b>	32	8.42%	29	7.63%	25	6.51%	39	9.68%	25	6.31%
<b>B</b>	55	14.47%	57	15.00%	61	15.89%	73	18.11%	66	16.67%
<b>C</b>	283	74.47%	283	74.47%	286	74.48%	282	69.98%	297	75.00%
<b>D</b>	6	1.58%	11	2.89%	11	2.86%	8	1.99%	8	2.02%
<b>E</b>	4	1.05%	0	0.00%	1	0.26%	1	0.25%	0	0.00%
<b>Total</b>	<b>380</b>	<b>100%</b>	<b>380</b>	<b>100%</b>	<b>384</b>	<b>100%</b>	<b>403</b>	<b>100%</b>	<b>396</b>	<b>100%</b>

<b>ARITHMETICAL MEAN</b>	
<b>CAT</b>	<b>MIX</b>
<b>A</b>	7.71 %
<b>B</b>	16.03 %
<b>C</b>	73.68 %
<b>D</b>	2.27 %
<b>E</b>	0.31 %
<b>TOTAL</b>	<b>100 %</b>

**Step 4**d) Calculating Mean Runway Occupancy Time (**MROT**)

The values corresponding to runway occupancy times, by aircraft category, the constant values in Table 3, and the respective constant mix in Table 4 shall be taken to Table 5 (Calculating Mean Runway Occupancy Time), where the mean runway occupancy time (MROT) will be estimated using the weighted arithmetical mean.

<b>TABLE 5</b>																														
<b>CALCULATING MEAN RUNWAY OCCUPANCY TIME (MROT)</b>																														
<b>AERODROME:</b> _____		<b>RUNWAY:</b> _____																												
<table border="1"> <thead> <tr> <th colspan="2"><b>AMROT</b></th> </tr> <tr> <th><b>CAT</b></th> <th><b>TIME (sec)</b></th> </tr> </thead> <tbody> <tr> <td><b>A</b></td> <td></td> </tr> <tr> <td><b>B</b></td> <td></td> </tr> <tr> <td><b>C</b></td> <td></td> </tr> <tr> <td><b>D</b></td> <td></td> </tr> <tr> <td><b>E</b></td> <td></td> </tr> </tbody> </table>	<b>AMROT</b>		<b>CAT</b>	<b>TIME (sec)</b>	<b>A</b>		<b>B</b>		<b>C</b>		<b>D</b>		<b>E</b>		<b>X</b>	<table border="1"> <thead> <tr> <th colspan="2"><b>MIX</b></th> </tr> <tr> <th><b>CAT</b></th> <th><b>#AIRCRAFT (%)</b></th> </tr> </thead> <tbody> <tr> <td><b>A</b></td> <td></td> </tr> <tr> <td><b>B</b></td> <td></td> </tr> <tr> <td><b>C</b></td> <td></td> </tr> <tr> <td><b>D</b></td> <td></td> </tr> <tr> <td><b>E</b></td> <td></td> </tr> </tbody> </table>	<b>MIX</b>		<b>CAT</b>	<b>#AIRCRAFT (%)</b>	<b>A</b>		<b>B</b>		<b>C</b>		<b>D</b>		<b>E</b>	
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$\text{MROT} = \sum (\text{AMROT}_{\text{CATX}} \cdot \text{MIX}_{\text{CATX}}) / 100$																														

**Step 5**

e) The physical capacity PER runway (PCR) shall be calculated for a one-hour period, taking into account each threshold, by dividing the cited interval, translated to seconds (3600 sec), by the mean runway occupancy time, expressed in seconds.

<b>PCR = 3600 / MROT</b>
--------------------------

**Step 6**

## f) Aerodrome physical capacity calculation

It shall be based on the mean annual utilisation of each runway, in terms of percentage, together with data on total monthly movements obtained from any recognised statistical source, which truly reflect the total movement of aircraft at the aerodrome from which the desired sampling will be obtained.

## g) Runway utilisation percentage (UP):

An index calculated from the total monthly movement, obtained from a sampling containing data for a one-year period. Percentages are weighted against the capacity of each runway, the end result being a single value. The following tables illustrate how to calculate runway utilisation percentages:

**MONTHLY MOVEMENT OF AIRCRAFT**

<b>MONTH</b>	<b>RWY A</b>	<b>RWY B</b>	<b>Monthly movement</b>
<b>JAN</b>	7622	2631	10253
<b>FEB</b>	6364	3229	9593
<b>MAR</b>	9239	2409	11648
<b>APR</b>	9965	1184	11149
<b>MAY</b>	10811	896	11707
<b>JUN</b>	11280	291	11571
<b>JUL</b>	11637	620	12257
<b>AUG</b>	12145	263	12408
<b>SEP</b>	11687	273	11960
<b>OCT</b>	9177	2184	11361
<b>NOV</b>	7765	2936	10701
<b>DEC</b>	7487	3665	11152
<b>TOTAL</b>	<b>115179</b>	<b>20581</b>	<b>135760</b>

<b>RWY</b>	<b>% UTILISATION (UP)</b>
<b>A</b>	<b>86</b>
<b>B</b>	<b>14</b>
<b>TOTAL</b>	<b>100</b>

The mean annual percentage values per runway and the respective physical capacity values are weighted in order to obtain the physical capacity of the aerodrome, as defined in Table 6.

<b>TABLE 6</b>				
<b>AERODROME PHYSICAL CAPACITY (APC) CALCULATION</b>				
<b>PCR</b>	<b>X</b>	<b>% OF RWY UTILISATION</b>	<b>=</b>	
<b>RWY A</b>		<b>% RWY A</b>		<b>AERODROME PHYSICAL CAPACITY</b>
<b>RWY B</b>		<b>% RWY B</b>		
<b><math>APC = \sum (PCR_{RWYX} \cdot \%UTIL_{RWYX}) / 100</math></b>				

## THEORETICAL RUNWAY CAPACITY CALCULATION

Theoretical runway capacity is calculated for a sixty-minute interval, based on the mean runway occupancy time, taking into account *regulatory aircraft separation, as well as the planning factors and landing and take-off operational factors* of the aerodrome under study:

Runway occupancy times, aircraft mix, mean runway occupancy time, and annual runway utilisation percentage, will be used to calculate aerodrome and runway physical capacity, constant values in Tables 1 to 6.

### Step 7

- a) Flight time between the OM and the THR (T)

Flight times between the OM and the THR of the runway under study shall be collected and inserted in Table 7A (flight time between the OM and the THR), taking into account the various aircraft categories operating in the aerodrome. After calculating the respective mean values, they must be inserted in Table 7B (mean flight time between the OM and the THR), so as to calculate the mean speeds in the final approach for all thresholds.

<b>TABLE 7A</b>				
<b>FLIGHT TIME BETWEEN THE OM AND THE THR _____ (T)</b>				
<b>OM/THR DISTANCE _____</b>				
REGISTRY	TYPE	CAT	TIME (SEC)	TIME (MIN)

TABLE 7B		
MEAN FLIGHT TIME BETWEEN THE OM AND THE THR _____ (MT)		
OM/THR DISTANCE _____		
CAT	TIME (SEC)	TIME (MIN)
A		
B		
C		
D		
E		

$MT = \sum T_{CAT X} / \# AIRCRAFT_{CAT X}$

**Note 1:** Time is measured from the moment the aircraft crosses the outer marker until it crosses the runway threshold, or, in the absence of an outer marker, from the start of the final approach segment until crossing the runway threshold.

**Note 2:** Consider the distance between the OM and the THR, in NM.

**Note 3:** If there is no OM, we must select a point of a known distance in the final approach that determines the impossibility for any other aircraft to enter the runway while the landing aircraft is crossing it or is in any other segment between the referred point and the threshold under study.

### Step 8

b) Estimating the landing approach speed between the OM and the THR (V)

With the data obtained from Tables 7A and 7B, we can estimate, for each runway, the landing approach speeds between the OM and the threshold and the final approach segment (FAS)--taking into account each aircraft category--and record the values found in Table 8 (mean speed between the OM and the THR).

**Note 1:** This speed is obtained by dividing the length of the final approach segment by the mean flight time, by aircraft category, between the outer marker and the runway threshold (MT).

$AVA = \frac{FAS}{MTA}$	$AVB = \frac{FAS}{MTB}$	$AVC = \frac{FAS}{MTC}$	$AVD = \frac{FAS}{MTD}$	$AVE = \frac{FAS}{MTE}$
-------------------------	-------------------------	-------------------------	-------------------------	-------------------------

<b>TABLE 8</b>			
<b>MEAN SPEED BETWEEN THE OM AND THE THR _____</b>			
<b>CAT</b>	<b>SPEED (KT)</b>	<b>SPEED (NM/MIN)</b>	<b>SPEED (NM/SEC)</b>
<b>A</b>			
<b>B</b>			
<b>C</b>			
<b>D</b>			
<b>E</b>			
<b>SPEED (KT) = DIST (NM) / T FLIGHT<sub>OM/THR</sub> (H)</b> <b>SPEED (NM/MIN) = DIST (NM) / T FLIGHT<sub>OM/THR</sub> (MIN)</b> <b>SPEED (NM/SEC) = DIST (NM) / T FLIGHT<sub>OM/THR</sub> (SEC)</b>			

**Step 9**

- c) Mean speed in the final approach (MV):

The weighted mean of final approach speeds, taking into account the aircraft mix.

$$MV = \frac{MIX_A \times AVA + MIX_B \times AVB + MIX_C \times AVC + MIX_D \times AVD + MIX_E \times AVE}{100}$$

**Step 10**

- d) Determination of safety separation (SS):

The study foresees the possibility of having a take-off between two consecutive landings, but without affecting the regulatory separation minima (**RSM**) between incoming and outgoing aircraft that, in Brazil, are established in ICA 100-12. This requires the calculation of a safety distance to be added to the regulatory separation minima between aircraft in the approach phase in order to allow an aircraft to take off after the first has landed, without compromising its regulatory separation with the second aircraft in the approach phase.

By estimating the distance flown by the second aircraft in the final approach while the first aircraft is on the runway, and by adding the calculated distance to the adopted regulatory separation minima, we obtain the separation required between two consecutive landings.

This flown distance is obtained by multiplying the mean speed in the final approach by the mean weighted runway occupancy time.

$$SS = MV \times MROT$$

### Step 11

- e) Determination of total separation between two consecutive landings (**TS**):

The total separation is obtained by adding the safety separation and the regulatory separation minimum. Thus:

$$TS = SS + RSM$$

There are cases in which SS can be left out. Normally, this can happen at airports that have two or more runways, where operation dynamics can be enhanced by leaving an aircraft aligned on the runway while waiting for another aircraft to land on the other runway.

### Step 12

- f) Calculation of the mean weighted time between two consecutive landings, taking into account total separation (**MTTS**).

The mean weighted time it takes to cover the total separation between two consecutive landings is obtained by dividing this distance by the mean weighted speed of the aircraft mix.

$$MTTS = TS / MV$$

**Note 1:** The mean time must be calculated for each threshold in the aerodrome, based on the different taxiway configurations for each threshold in use.



**Step 13**

- g) Determination of the number of landings in a one-hour interval (P):

The resulting mean weighted time it takes to cover the total separation between two consecutive landings, in seconds, shall be the denominator for the number of seconds contained in an hour (3600 sec). The result will be the number of possible landings with the separation proposed for the threshold under study, according to Table 9.

<b>TABLE 9</b>
<b>NUMBER OF POSSIBLE LANDINGS</b>
$3600 / \text{MTTS} = \text{NUMBER OF LANDINGS}$

$$P = 1 \text{ hour} / \text{MTTS}$$

**Step 14**

- h) Determination of the number of take-offs in a one-hour interval (D):

Based on the total separation obtained, it is possible to insert a take-off between two consecutive landings. By subtracting one aircraft from the total number of landings, we obtain the possible number of take-offs within the time interval under study, according to Table 10.

<b>TABLE 10</b>	
<b>NUMBER OF POSSIBLE TAKE-OFFS</b>	
<table border="1"> <tr> <td><b>NUMBER OF LANDINGS - 1 = NUMBER OF TAKE-OFFS</b></td> </tr> </table>	<b>NUMBER OF LANDINGS - 1 = NUMBER OF TAKE-OFFS</b>
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$$D = P - 1$$

### Step 15

- i) Determination of theoretical runway capacity:

Add the resulting number of landings and take-offs in the sixty-minute interval for each threshold to obtain the theoretical operational capacity for the respective threshold, according to Table 11.

<b>TABLE 11</b>	
<b>THEORETICAL RUNWAY CAPACITY (TRC)</b>	
<table border="1"> <tr> <td><b>THEORETICAL RUNWAY CAPACITY = NUMBER OF LANDINGS + NUMBER OF TAKE-OFFS</b></td> </tr> </table>	<b>THEORETICAL RUNWAY CAPACITY = NUMBER OF LANDINGS + NUMBER OF TAKE-OFFS</b>
<b>THEORETICAL RUNWAY CAPACITY = NUMBER OF LANDINGS + NUMBER OF TAKE-OFFS</b>	

$$TRC = Landings + Take-offs$$

## CALCULATION OF THE DECLARED RUNWAY CAPACITY

The declared capacity is estimated taking into account the percentage annual utilisation of each runway, the same as the constant value in Table 6.

### Step 16

- a) Determining the declared capacity of the runway set (**DCR**)

The declared capacity of the runway set is the capacity that is fully sustainable from the operational point of view, taking into account the percentage annual utilisation of each runway. Accordingly, the weighted arithmetical mean between the utilisation percentage and the respective theoretical runway capacities is estimated.

Thus:

$$\text{DCR} = \frac{\text{UPA} \times \text{TRCA} + \text{UPB} \times \text{TRCB} + \dots + \text{UPN} \times \text{TRCN}}{\text{UPA} + \text{UPB} + \dots + \text{UPN}}$$

**Note:** It should be noted that, as stipulated in DOC 9426, an ATC unit can not operate at full capacity throughout the whole operating shift, since there are several variables that significantly reduce capacity at certain times. Therefore, it is advisable to adopt percentages between 80% and 90%, thus giving more flexibility to capacity values, that is, an ideal interval that preserves the safety of air operations.

## CONCLUSION

In order to maintain air traffic flow close to optimum conditions, avoiding possible system overloads, the CGNA has conducted studies to standardise the methods for estimating runway capacity, in the hope of analysing demand/capacity evolution at each airport, and to make recommendations to the airports involved for the sake of operational harmony.

The method presented herein is intended to show the use of the runway capacity calculation model in a general and simplified manner, and does not contemplate the many peculiarities of the aerodromes where it will be applied. Therefore, when conducting studies to determine aerodrome runway capacity, all factors that might affect the indices should be taken into account.

ACRONYMS

Meaning of the acronyms used in this Appendix.

ROT –	Runway occupancy time/Tiempo de ocupación de pista
ROTT -	Runway occupancy time during take-off/Tiempo de ocupación de pista durante el despegue
ROTL -	Runway occupancy time during landing/Tiempo de ocupación de pista durante el aterrizaje
MROTL-	Arithmetical mean runway occupancy time during landing per aircraft/Media aritmética de los tiempos de ocupación de pista durante el aterrizaje por categoría de aeronaves
MROTT-	Mean runway occupancy time during take-off per aircraft category/Media aritmética de los tiempos de ocupación de pista durante el despegue por categoría de aeronaves
AMROT -	Arithmetical mean runway occupancy time per aircraft category/Media aritmética de los tiempos de ocupación de pista por categoría de aeronaves
FAS –	Final approach segment/Segmento de aproximación final
MTTS –	Mean weighted time between two consecutive landings, taking into account total separation/Tiempo medio ponderado entre dos aterrizajes consecutivos, considerando la separación total
DCR –	Declared capacity of the runway set/Capacidad declarada del conjunto de pistas
MROT –	Mean runway occupancy time/Tiempo medio ponderado de ocupación de pista

## ATTACHMENT 7

### CALCULATION OF THE AERODROME ACCEPTANCE RATE (AAR) USED BY THE FAA

- a. **Aerodrome Acceptance Rate (AAR):** The number of incoming aircraft that an aerodrome can accept per hour--also taking into account weather, terminal airspace, apron space, parking space and facilities.
- b. **Main configuration of aerodrome runways:** The configuration of each aerodrome that handles 3 percent or more of annual operations.
- c. **Potential AAR:** The theoretical acceptance rate in the runway threshold--before considering other factors.
- d. **Actual AAR:** The potential AAR in the runway threshold, adjusted to other factors.  
For any runway configuration, the Potential AAR minus the Adjustment Factors is equal to the actual AAR:

POTENTIAL AAR

-- ADJUSTMENT FACTORS

ACTUAL AAR

- e. **Adjustment factors:** Factors that must be taken into account when establishing the actual AAR. These factors include, but are not limited to:
  1. weather
  2. runway conditions
  3. general availability of taxiways
  4. apron space
  5. facilities

Establishing the actual AAR

- a. Establish the actual AAR values for the general runway configuration at each aerodrome, for the following weather conditions:
  1. Visual meteorological conditions (VMC) – meteorological conditions permit vectoring for visual approach.
  2. Marginal VMC – meteorological conditions do not permit vectoring for visual approach, but visual separation is possible in the final approach.
  3. Instrument meteorological conditions (IMC) – Visual approach and visual separation in the final approach are not possible.

Calculate the actual AAR as follows:

- a. First, calculate the potential AAR.
  1. Determine the average ground speed when crossing the runway threshold and the spacing required between successive arrivals.
  2. Divide the ground speed by the spacing to determine the potential AAR.
  3. **METHOD USING A FORMULA:** The ground speed at the runway threshold, expressed in knots, divided by the spacing at the runway threshold, expressed in miles.

**NOTE:** When the quotient is a fraction, round up to the next lower whole number.

4. Example 1:  $130 \text{ KTS} / 5 \text{ nm} = 26$   
Potential AAR = 26 arrivals per hour
5. Example 2:  $120 \text{ KTS} / 7 \text{ nm} = 17.14$   
round up to 17

Potential AAR = 17 arrivals per hour

6. Or use the TABLE METHOD for determining the potential AAR.

**Table: Potential AAR**

<b>Nautical miles between aircraft at the runway threshold</b>										
	<b>3</b>	<b>3.5</b>	<b>4</b>	<b>4.5</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
	<b>Potential AAR</b>									
Ground speed at the runway threshold										
140 knots	46	40	35	31	28	23	20	17	15	14
130 knots	43	37	32	28	26	21	18	16	14	13
120 knots	40	34	30	26	24	20	17	15	13	12
110 knots	36	31	27	24	22	18	15	13	12	11

- b. Then, identify any condition that might reduce the potential AAR. These conditions include:
  1. Arrival and departure runways that cross

2. Lateral distance between arrival runways
  3. Dual-use runways – runways that share arrivals and departures
  4. Land and hold short operations
  5. Availability of high-speed taxiways
  6. Airspace limitations and restrictions
  7. Procedural constraints (noise abatement, missed approach procedures)
  8. Taxiway layout
  9. Meteorological conditions
- c. Finally, subtract the adjustments from the potential AAR to determine the actual AAR for each runway used in an aerodrome configuration.

POTENTIAL AAR

-- ADJUSTMENT FACTORS

ACTUAL AAR

- d. Example

**Table: EXAMPLE OF AN ACTUAL AAR TABLE**

<b>RUNWAY CONFIGURATION</b>	<b>AAR for VMC</b>	<b>AAR for MARGINAL VMC</b>	<b>AAR for IMC</b>
RWY 13	24	21	19
RWY 31	23	20	17

Administrative considerations:

- a. Identify the organisation responsible for the establishment and implementation of AARs in selected aerodromes.
- b. Establish a table of actual AARs for the aerodromes identified in each State/Territory.
- c. Review and validate the main runway configurations of the aerodrome and associated AARs at least once a year.

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## ATTACHMENT 8

### **DEMAND/CAPACITY ANALYSIS applied in Colombia - “ELDORADO” AIRPORT**

#### **1. INTRODUCTION**

Every airport has a limited number of aircraft operations that the runway and taxiway system can accommodate. This limitation is known as aerodrome capacity. Aerodrome capacity is assessed in one-hour periods for the runway/taxiway system. The purpose of the Demand/Capacity analysis is to determine aerodrome capacity and to identify the improvements, if any, that may be necessary to face future demand.

There are several methods or models (empirical, analytical, queues, and manuals) for calculating airport capacity.

Colombia has developed the demand/capacity analysis on the basis of the FAA standard method.

#### **2. DEMAND/CAPACITY ANALYSIS– “ELDORADO” AIRPORT**

The FAA standard method used to determine airport capacity and delay for purposes of long-term planning is described in “Advisory Circular (AC) 150/5060-5, Change 2, “Airport Capacity and Delay”. This model has been derived from computer models used by the FAA to analyse airport capacity.

Since the airport and the hourly capacity of its components vary according to the constant changes in the operational configuration of runways, the fleet mix operating in it, ATC regulations, etc., it was necessary to develop some of the calculations described in the cited methodology so as to calculate hourly runway capacity.

When performing the analysis to determine airport runway capacity, several factors are taken into account, as described below:

##### **2.1. AERODROME CHARACTERISTICS**

In order to properly conduct the FAA capacity analysis, it was necessary to identify some operational conditions and aerodrome characteristics. The elements affecting aerodrome capacity are:

- Runway configuration;
- Aircraft mix index;
- Taxiway configuration;
- Operational characteristics; and,
- Weather conditions

The joint analysis of all the aforementioned elements served as a basis for establishing airport operational capacity. Next, each capacity characteristic of the “Eldorado” airport was assessed.



### 2.1.1. RUNWAY CONFIGURATION

Runway configuration includes two 3800m-long parallel runways, with 1400m spacing, a 1300m staggering, and a NW/SW orientation.

This analysis assumes that the “runway” includes the landing surface as well as the different segments of the approach path shared by all aircraft.

### 2.1.2. AIRCRAFT MIX INDEX

Knowing the fleet mix operating at the airport according to the statistics of the UAEAC P.I.S.T.A. system, it was possible to establish the mix index required to apply the FAA method for calculating aerodrome capacity. The estimation of the mix index is based on the relative percentage of the operations carried out by each of the four classes of aircraft (A, B, C, D), according to its MTOW.

The table below shows the physical aspects of the four classes of aircraft and their relationship with wake turbulence classification standards.

AIRCRAFT CLASS	MAXIMUM CERTIFIED TAKE-OFF WEIGHT	NUMBER OF ENGINES	CLASSIFICATION BY WAKE TURBULENCE
A	12.500 lbs or less 7000 kg or less	One engine	S (Small) L (Light)
B		Multi- engine	
C	12.500 – 300.000 lbs 7000 kg – 136000 kg	Multi- engine	L (Large) M (Medium)
D	Over 300.000lbs Over 136000 kg	Multi- engine	H (Heavy) H (Heavy)

The formula of the FAA method to calculate the mix index is:

$$\%(C + 3D)$$

Where:

**C** - percentage of category C aircraft,

**D** - percentage of category D aircraft.

**Note:** Aircraft categories A and B are not considered when calculating the mix index.

Aircraft mix was determined based on the data requested in the following tables:

AIRCRAFT		MIX IN VFR		MIX IN IFR	
DESCRIPTION	CLASS	No. ops	% ops	No. Ops	% ops
ONE ENGINE	A	3	9	3	9
LIGHT TWIN-ENGINE	B	3	9	3	9
TRANSPORT-TYPE	C	24	76	24	76
WIDE BODY	D	2	6	2	6
TOTAL (No. Ops and % ops)		32	100	32	100

Rwy 13L

AIRCRAFT		MIX IN VFR		MIX IN IFR	
DESCRIPTION	CLASS	No. ops	% ops	No. Ops	% ops
ONE ENGINE	A	1	3	1	3
LIGHT TWIN-ENGINE	B	2	7	2	7
TRANSPORT-TYPE	C	24	80	24	80
WIDE BODY	D	3	10	3	10
TOTAL (No. Ops and % ops)		30	100	30	100

Rwy 13R

The mix index identified for “Eldorado” airport is:

**Runway 13L**

$$\% (76+3(6)) = 94$$

**Runway 13R**

$$\% (80+3(10)) = 110$$

**Note:** It may be noted that with an increasing mix index, aerodrome capacity will gradually drop. This is mainly because the ATC must provide greater separation between C and D aircraft and those of other categories, due to the wake turbulence generated by bigger aircraft.

### 2.1.3. TAXIWAY CONFIGURATION

Based on the FAA criterion for properly located exit taxiways, the exit factor is maximised when a runway has four exit taxiways within a range determined by the aircraft using the runway. For a mix index between 81 and 120, and depending on aerodrome elevation, this range is between 2377 m and 3328 m from the landing threshold.

Based on the FAA criterion, runway 13L has one exit taxiway, and runway 13R has two exist taxiways within the range for arrivals.

### 2.1.4. OPERATIONAL CHARACTERISTICS

The operational characteristics that may significantly affect aerodrome capacity include the arrival percentage and the percentage of touch and go's (T&G) or runway training.

#### 2.1.4.1. Percentage of arrivals

The percentage of arrivals is the relationship between landing operations and total airport operations.

This percentage is taken into account because an aircraft approaching an airport to land needs more runway occupancy time than an aircraft taking off. The FAA methodology applied here provides an arrival figure with percentages of 40, 50, or 60 in order to calculate aerodrome capacity.

$$\% \text{ of arrivals} = \frac{(A + \frac{1}{2} (T\&G))}{A + DA + (T\&G)} \times 100$$

Where:

**A** = No. of aircraft arriving within the hour.

**DA** = No. of aircraft taking off within the hour.

**T&G** = No. of T&G within the hour.

Based on statistical data, it was determined that the percentage of arrivals for "Eldorado" airport is the following:

#### Runway 13L

$$\% \text{ of arrivals} = \frac{(15 + \frac{1}{2} (0))}{15 + 17 + (0)} \times 100$$

$$\% \text{ of arrivals} = 47$$

**Runway 13R**

$$\% \text{ of arrivals} = \frac{(14 + \frac{1}{2} (0))}{14 + 16 + (0)} \times 100$$

$$\% \text{ of arrivals} = 47$$

**2.1.4.2. Percentage of Touch and Go's (T&G)**

The percentage of touch and go's plays a key role in determining airport capacity.

Touch and go's are counted as one landing and one take-off (two operations) and are normally associated with runway training.

\*No runway training is carried out at the "Eldorado" airport.

**2.1.5. DEMAND – "ELDORADO" AIRPORT**

In order to apply the FAA method, operational demand at the "Eldorado" airport and its behaviour over the last 2 years were analysed, in order to obtain the information required by the method.

The growth of demand and its characteristics were also analysed in order to identify future capacity issues and the processes to be implemented in order to keep capacity and demand in balance.

Operational demand has increased 10% in the last two years; the demand value used for this analysis was 62 operations.

**2.1.6. WEATHER CONDITIONS**

Weather conditions affect the operational configuration of the aerodrome, taking into account wind and other related weather conditions. Hence, these conditions can affect aerodrome capacity. Runway utilisation is normally driven by wind conditions, while visibility determines the spacing required between aircraft in the approach sequence.

Based on statistical data, runways 13R and 13L account for approximately 89% of total annual operations (take-offs and landings). This is because SE/NW winds prevail most of the year. It should be noted that runway 13R has ILS CAT II approach minima.

There are three cloud ceiling and visibility levels recognised by the FAA for calculating airport capacity. Such ceilings are:

- (VFR) – cloud ceiling over 1,000 ft AGL and visibility is 3 sm (4837m) or greater.
- (IFR) – cloud ceiling is 500 ft AGL or more but less than 1,000 ft AGL and/or visibility is 1 sm (1609m) or more but less than 3 sm (4837m).
- (PVC) – Reduced visibility and cloud ceiling – cloud ceiling is less than 500 ft AGL and/or visibility is less than 1 sm (1609m).

### 3. AERODROME CAPACITY ANALYSIS

The aforementioned aerodrome characteristics were used along with the methodology developed by the FAA in order to determine aerodrome capacity. As already mentioned, this FAA methodology yields the runway hourly capacity.

### 4. RUNWAY HOURLY CAPACITY

The runway hourly capacity is the maximum number of aircraft that can be accommodated by a given runway configuration at an airport within a one-hour period. Using the FAA methodology, the runway hourly capacity is calculated using the appropriate VFR and IFR figures for a given airport runway configuration. In these figures, the aircraft mix index and the percentage of arrivals are used to calculate the base hourly capacity. Additionally, a T&G factor is determined based on the percentage of T&G operations combined with the aircraft mix index.

\*The T&G factor for “Eldorado” airport is 1, since no runway training is performed at this airport.

These figures also take into account the exit factor.

Both for VFR and IFR conditions, the runway hourly capacity is calculated by multiplying the base hourly capacity, the T&G factor, and the exit factor. The equation is the following:

$$\text{Hourly Capacity} = C^* \times T \times E$$

Where:

**C\*** = base hourly capacity,

**T** = T&G factor,

**E** = exit factor.

An airport mix index can substantially change the value of the base hourly capacity in the FAA capacity tables.

The capacity figures taken from the FAA manual for the “Eldorado” airport are the following:

VFR Fig. 3-3

IFR Fig. 3-43

## 5. RESULTS OF THE DEMAND/CAPACITY ANALYSIS

MET	RWY. CONF.		CAP. FIG.	ACFT. MIX				% (C+3D)	% A R R	% T & G	RWY EXT (00 m)		BASE HOUR CAP. (C*)	T&G FACTOR (T)	EXIT FACTOR (E)	HOURLY CAP. (C*T*E)	
	DIA G.	No		% A	% B	% C	% D				LOC.	No					
13L VFR	—	1	3-3	9	9	7	6	94	47	0	26	1	56	1	0,89	50	
13L IFR	—	1	3-43	9	9	7	6	94	47	0	26	1	51	1	0,89	45	
13R VFR	—	1	3-3	3	7	8	1	110	47	0	25	31	2	57	1	0,93	53
13R IFR	—	1	3-43	3	7	8	1	110	47	0	25	31	2	51	1	0,94	48

## 6. CONCLUSION

HOURLY CAPACITY “ELDORADO” AIRPORT OPS/HR		
RUNWAY	VFR	IFR
13L	50	45
13R	53	48

Once the runway hourly capacity has been determined, a performance factor between 0.6 and 0.9 must be applied so as to take into account factors affecting capacity and that are difficult to measure and control.

## 7. OBSERVATIONS

After analysing the demand, and having determined the hourly capacity, and followed up on the operation after ATFM implementation at “Eldorado” airport, it has been noted that:

- During certain periods at the “Eldorado” airport, there are subsequent demands that exceed capacity and cause unacceptable delays.
- During certain periods at the “Eldorado” Airport, when the hourly demand is lower than hourly capacity, delays occur at intervals within the hour in which demand exceeds capacity.
- Demand size and scheduling by the operators is relatively unrestricted in relation to capacity per hour and per hourly intervals.

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## ATTACHMENT 9

### Guidelines for Improving Capacity

In order to improve the capacity of the system as a whole, it is advisable to analyse and identify the factors that may result in a reduction of airport and ATC sector capacity. Each factor has a weight in the capacity value, which varies according to the specific characteristics of the airport under study.

Some of the factors--not all factors are present in all systems--that may contribute to a reduction in capacity are as follows:

#### Longitudinal and Lateral Aircraft Separation Minima

Separation is established for safety reasons, both to avoid collisions and to prevent an aircraft from entering the wake turbulence of another aircraft, which is usually more critical when close to landing or during take-off, due to the low speeds applied. Runway configuration--the relative position and distance between runways--determines the interference that movements in one runway have on the other airport runways.

#### Procedures and Practices in Use

- a) Most airports are designed to serve the most common operation based on prevailing winds.
- b) Taxiways and parking aprons are built to serve the primary operation of the airport.
- c) Approach and departure procedures are designed to serve the primary operation of the airport
- d) Changes in the runway-in-use during traffic peaks may cause congestion.
- e) Changes in runways may create disadvantages for certain instrument departure or arrival procedures.

#### Weather conditions

Under adverse weather conditions (low ceiling and visibility), pilots and controllers work "more cautiously" and separations are extended, resulting in reduced capacity.

#### Aircraft Mix

Aircraft category and performance determine the time between two consecutive operations. It has been shown that the interval between the landing of a heavy aircraft and the landing of a light aircraft is much greater if the heavy aircraft lands first. This fact suggests the possibility of having an optimum sequencing of the aircraft waiting to land at a given airport. The aircraft sequencing problem is typically formulated as an issue of restricted optimisation, with a view to finding sequences that maximise the runway service ratio without excessively penalising some types of aircraft.

### Typical demand (take-off and landing mix)

Large concentrations of take-offs or landings can upset airport traffic flow. Delays in take-off can cause taxiway occupancy and approach problems. Landing sequencing may be affected by runway and taxiway configuration.

### Type of operation (landing/take-off ratio)

The spacing between movements depends on the types of operations covered; that is, a landing performed following a take-off requires a different spacing compared to a take-off performed following another take-off. Capacity varies according to landing-to-take-off ratio. Consequently, a single capacity indication makes no sense, in contrast with a capacity indication based on the operation mix.

### Quality and performance of navigation, surveillance, and control systems

Reliable and precise systems allow for a reduction in aircraft spacing, thus increasing capacity. The use of decision-support software to assist the controller, for instance, to foresee the optimum sequencing for aircraft approaching a given airport, provides for safe and rational operations.

### Controller and pilot performance

More experienced controllers and pilots make for more agile operations. A good example is the Congonhas airport, where controllers use the two runways for landings and take-offs; pilots conduct take-offs without stopping at the runway threshold (immediate take-off); pilots in slower aircraft try to maintain speeds that are consistent with those of commercial aircraft; etc.

### Location and types of runway exits

Landing runway exits, when properly located, allow pilots to leave the landing runway towards the taxiway system as soon as they have slowed down enough. If the exit is a fast exit, that is, at an angle of less than 90° with the landing runway, there is no need to reduce speed too much, thus reducing runway occupancy time.

### Environment

Noise can restrict operations on certain inhabited areas or fauna protection areas, generating additional restrictions to be considered when determining exit routes.



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### Restricted, prohibited, and dangerous areas

The existence of many restricted, prohibited and dangerous areas close to airports that do not apply procedures for coordination and flexible use of airspace constitutes an additional restriction to aircraft departure capacity.

Some of these factors may be of a temporary or permanent nature, depending on conditions. If they are considered permanent, they must be included in capacity calculations. Temporary factors, such as atmospheric conditions that can have a temporary impact on ATC sector capacity or airport operation, are managed by the ATC entity.

All these factors have an impact on the methodology used to determine capacity, and thus the importance of conducting a delay analysis.

This activity considers the available data coming from the recurrent delay monitoring process, but a more in-depth analysis of local circumstances is performed. The following is considered:

- Historical evaluation of delays
- Actual reason(s) for delays
- What is meant by ATC/Aerodrome delays?
- Who is involved in the capacity declaration process and is there a buy-in from all the stakeholders (the capacity declaration should reflect ATC/Aerodrome limits)?
- What are the reasons for additional traffic over and above the capacity declaration?
- How is extra traffic such as General Aviation accommodated?
- How many off-slot operations are experienced and how these are dealt with?
- Is there an (efficient) slot monitoring committee?

Airport delays should not be considered in isolation. Capacity at a number of airports is limited and action is required to ensure that capacity is not exceeded by demand at a particular moment on the day of operations.

Maximum airside capacity is not solely reliant on runway capacity. Aprons and taxiways must be capable of maintaining sufficient traffic throughput to match runway capacity. Terminal area capacity, arrivals and departures, the terminal building, ATC staff levels, and equipment should not be neglected during the capacity declaration process.

The demand-to-capacity ratio provides insight into the potential for delays at an airport. Together with the demand-to-capacity ratio used for defining traffic levels, medium-term annual demand data, based on airport-specific high, baseline and low forecasts for each of the selected airports are considered in this activity.

Some airports publish detailed demand and capacity analyses, taking into account hourly and seasonal variations, while others only publish an overall declared hourly capacity.

As general guidance, a plan to optimise capacity could include the following steps:

- Step 1 – Establish a capacity baseline
- Step 2 – Determine future demand

- Step 3 – Determine if there will be a capacity reduction
- Step 4 – Identify all limitations that affect capacity
- Step 5 – Quantify the impact of limitations
- Step 6 – Identify possible corrective actions and best practices
- Step 7 – Identify the impact and cost of corrective actions
- Step 8 – Establish priorities
- Step 9 – Develop the capacity improvement plan