INTERNATIONAL CIVIL AVIATION ORGANIZATION

ASIA/PACIFIC REGIONAL GUIDANCE

FOR ASSESSMENT OF

AIRPORT CAPACITY AND AIRSPACE CAPACITY

Version 1.0, APRIL 2026

This Guidance Document was developed by the Asia/Pacific Air Traffic Flow Management & Airport Collaborative Decision Making Steering Group (ATFM & A-CDM/SG)

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RECORD OF AMENDMENTS AND CORRIGENDA

Amendments / Corrigendum			
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Chapter 1 - Introduction

1.1 Purpose and overview of the guidance

1.1.1 This guidance aims to enhance States' understanding of recommended methodologies to assess airport and ATC sector capacity, within Asia/Pacific (APAC) region. The purpose of this document is to assist ATM planners to develop plans, where necessary, to improve such capacity in order to meet present or future demands of the system. Although the document is aimed at Asia/Pacific region, the concept, application and guidance presented herein is globally applicable.

Note: In this document the terms "airport and/or aerodrome" refer to "controlled aerodrome".

1.1.2 The guidance captures most of the necessary processes from preparatory to implementation phases. Information in this guidance can be used to facilitate further improvement in ATM Services by the States.

1.1.3 A stepwise (process-wise) structure of the guidance is expected to allow each State to refer to chapters, sections or subsections useful for the commencement, implementation or improvement of its capacity assessment process to support effective ATM.

1.1.4 This Guidance is intended to be referred to by the ATM community to ensure common understanding for the implementation and/or enhancement of capacity assessment process.

1.2 Development of Regional Guidance Document

1.2.1 ICAO APAC Air Traffic Flow Management Steering Group (ATFM/SG) 13th meeting, held in September 2022 in Bangkok, noted that assessment of Airport and Airspace capacity is an essential initial step towards ATFM implementation. However, the detailed explanation for carrying out Airport and Airspace Capacity assessment has not yet been specified in Annex 11. The meeting also noted that specific regional guidance material is necessary to assist States in developing and implementing airport and airspace capacity assessment to support effective ATM and agreed to conduct a workshop as a way towards developing the regional guidance material.

1.2.2 ICAO conducted a workshop on Airport and Airspace Capacity Assessment in June 2025 in Yogyakarta, Indonesia.

1.2.3 A draft regional guidance document for conducting airport and airspace capacity assessment to support ATM operations was presented during the workshop. The draft document was circulated to ATFM points of Contact (POC) of APAC States and administrations in October 2025 for further development and a final draft presented to APAC ATFM & A-CDM/SG in April 2026 for approval.

1.3 Process towards implementation

Preparatory Phase- Need for Capacity Assessment

1.3.1 Regular assessment of historical air traffic statistics at major airports provides an overview of air traffic demand. Flight delays are ~~is~~ usually the best source for identifying capacity shortfalls. The departure and arrival delay as well as punctuality statistics obtained from the different sources (airspace users, airports, ANSPs), and compiled together, are among the best sources for identification of capacity imbalances and shortcomings. When it is noted that air traffic demand consistently exceeds the available airport and airspace capacity, the ATM planners should initiate a comprehensive capacity assessment process to identify bottlenecks, either for an airport or for airspace or for both. ~~for identifying bottlenecks~~. Other triggers for capacity assessment could be expected growth of the traffic, or due to change in ATM resource airport infrastructure, procedures or change in the traffic mix, etc.

1.3.2 Doc 9971 in Appendix II-D recommends that an annual capacity planning and assessment process, as well as a cyclical process that identifies and quantifies the capacity requirements for the short- and medium-term, should be put in place.

1.3.3 Asia Pacific Seamless ANS Plan V4.0 also recommends that regular airport capacity analysis (Para 7.1 c) and ATC Sector capacity assessment (Para 7.40) should be conducted.

Stakeholders' consultation-

1.3.4 Airport and Airspace Capacity assessment is a collaborative process involving all the stakeholders of the aviation system such as airport operators, ANSPs, Airspace users, military authorities, ground handling agencies, security agencies etc. The capacity assessment process will involve the stakeholders concerned at many stages. For example, airport capacity assessment is not restricted only to the runway capacity, but also considers the combined system: runways, taxiways, aprons and terminals. Hence the involvement of all stakeholders in the process is essential.

1.3.5 The following is an extract from Doc 9971 on establishing an Airport ~~Aerodrome~~ Arrival Rate (AAR) process at an airport. It shows the collaborative process.

Note: For example, to establish an AAR Process;

- *Identify the organization responsible for the establishment and implementation of AARs at the selected airports*

  NOTE: It is recommended that you establish a small working group of stakeholders that will have input into the AAR value. For example, ATCOs, supervisors, airport authority, a major airline.

- *Establish optimum AARs for the airport identified; and*
- *Review and validate the airport primary runway configurations and associated AARs at least once each year*

--Doc 9971, Appendix II-B, 2

Past events and Case Studies-

1.3.6 ATM Planners can draw upon the lessons learned from organizing large scale events such as air shows, military exercises, long duration airport maintenance work, major upgradation of crucial CNS facilities etc., which resulted in large scale air traffic disruptions and rescheduling. Such events provide valuable ~~steps~~ information for demand and capacity balancing process. Post operation analysis after the event will also indicate the accuracy of capacity and demand estimation. Such analysis will help in refining the capacity assessment process.

Data Collection Phase-

1.3.7 ATM Planners will need to carefully consider the data required for capacity assessment process. The type, extent and accuracy of data will determine the quality of the capacity assessment process. The following is an indicative list of data which may be considered for the airport capacity assessment process.

Data	**Type of data/Time period**	**Units**
Traffic	Monthly, daily, hourly	Average/distribution
Traffic mix	Type of aircraft, Operator share, Patterns (AA/DD, ADA…)	Average/distribution

Data	Type of data/Time period	Units
Runway use	~~Hours~~ Hourly, Daily, Monthly	Average/distribution
Arrival Throughput	Hourly/30'/15'	Average/distribution
Departure throughput	Hourly/30'/15'	Average/distribution
Max observed throughput in peak	Hourly/ Daily	Average
Runway Occupancy Time(ROT)-Arrival	Per aircraft, runway and exit point	Average/distribution/median
ROT-Departure	Per aircraft, runway and entry point	Average/distribution/median
Separation on final approach	Distance or Time	Average
Separation Minima (Terminal airspace)	Distance	Average

Table 1- List of Data Considered for Airport Capacity Assessment Process

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Chapter 2 - Understanding Capacity

2.1 What is Capacity?

2.1.1 Annex 11 to the ICAO Convention 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 each period of time, taking due account of weather, ATC unit configuration, available staff and equipment, and any other factors that may affect the workload of the controller responsible for the airspace.

2.1.2 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 to improve operational efficiency and increase capacity.

2.1.3 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 maximize the use of existing system capacity; and develop plans to increase capacity in order to meet current or foreseen demand.

2.1.4 The following is an extract from draft proposal of ATMOPS Panel. It shows how the definition of CAPACITY is evolving to recognize the relationship with time.

- ***Strategic capacity***. *A measurement of the ability of the ATC unit to provide safe, orderly and efficient service to aircraft during normal circumstances expressed as the number of aircraft entering a specified controlled airspace or operating at a specific aerodrome in a given period of time. Strategic capacity is often referred to or considered as ~~Planned~~ Declared Capacity.*

  Note*: Declared capacity' and 'Strategic capacity' are equivalent terms and have been used interchangeably in this document.*

- ***Operational capacity***. *A dynamic, time-specific capacity value derived from strategic capacity, to be updated as required and used in ATFM pre-tactical planning and ATFM tactical operations.*

2.1.5 Strategic capacities are primarily used for multi-year and investment planning. Declared, expected (or Operational) capacities are used in strategic, pre-tactical and tactical traffic flow management as well as for measuring and monitoring service delivery and efficiency. In contrast to normal circumstances considered for Strategic capacity evaluation, Operational capacity accounts for evolving operating conditions on the day-of operation.

2.1.6 Some ANSPs may prefer not to declare capacities in advance based on normal operating circumstances, instead establishing these capacities daily based on known/current operational factors. Establishing capacities at different planning horizons provides an important reference for understanding the total system performance under normal operating conditions and provides a basis to work from when determining the impact of operational factors limiting capacity. These factors include – but are not limited to – Air Traffic Control Office (ATCO) availability and workload.

2.2 Importance of Capacity and Demand Assessment

2.2.1 Annex 11 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.

2.2.2 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 expected/forecasted 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.

2.2.3 In order to achieve demand-capacity balance in long-term , strategic horizon,, it is necessary to know the current and expected demand, to establish a capacity baseline using an analytical calculation, to analyze 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 management improvement plan.

2.2.4 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 shortfall of future capacity, as inferred from traffic forecasts. The second reason is that if there is already a shortfall 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 to implement best practices on operational performance.

2.2.5 There are many methods for calculating capacity and, as readily noted from the different models described in this document, 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.

2.2.6 DOC 9971 in Appendix II-D note that:

The overriding objective is to develop a capacity assessment process that contributes to the requirement to:

"provide sufficient capacity to accommodate the demand in typical busy hour periods without imposing significant operational, economic or environmental penalties under normal circumstances."

2.3 Key Performance Indicators for Measurement of Capacity

2.3.1 The Global Air Navigation Plan (Doc 9750) notes the following Key Performance Indicators (KPIs) for measuring airport and airspace capacity.

KPI09 Airport Peak Capacity

Definition: The highest number of operations an airport can accept in a one-hour time frame (also called declared capacity). Can be computed for arrivals, departures or arrivals + departures combined.
Measurement Units: • Number of departures per hour, • Number of landings per hour, • Number of (departures + landings) per hour
Operations Measured: The capacity declaration of an airport.

Variants: • Variant A: Airport peak arrival capacity • Variant D: Airport peak departure capacity • Variant AD: Airport peak movement capacity (departures + arrivals)
Objects Characterized: • The KPI is computed for individual airports.
Utility of the KPI: This KPI indicates the highest number of operations that an airport will can accept, using the most favorable runway configuration under optimum operational conditions. The runways may or may not be the most constraining factor for airport capacity: at some airports the most constraining factor may be the terminal airspace, the taxiways, the number of gates, passenger handling capacity etc. The KPI is typically used for scheduling and ATFM purposes, and to develop capacity investment plans.

<u>KPI06 En-Route Airspace Capacity</u>

Definition: The maximum volume of traffic an airspace volume will can safely accept under normal conditions in a given time period.
Measurement Units: • Variant 1: Movements/hr • Variant 2: Number of aircraft (occupancy count)
Operations Measured: • The nominal capability of an ANSP to deliver ATM services to IFR traffic in a given volume of en-route airspace, as seen at a given planning horizon.
Different Type of capacity for each horizon: • Planned capacity: expected values one or more years ahead for planning and investment purposes • Declared capacity: values used during the strategic and pre-tactical ATFM processes • Expected capacity: values as finalised at the end of the pre-tactical process • • Actual capacity: values as actually used on the day of operation during tactical ATFM and ATC.
Variants: • Variant 1: airspace throughput (entry flow rate) • Variant 2: airspace occupancy count
Objects Characterized: • The KPI is typically used at the level of individual sectors (sector capacity) or en-route facilities (ACC capacity).
Utility of the KPI: The KPI measures an upper bound on the allowable throughput or occupancy count of an en-route facility or sector.

Chapter 3 - Airport Capacity Assessment

3.1 Introduction

3.1.1 Airport Capacity Assessment is a crucial process for understanding an airport's ability to handle a specific volume of aircraft and passenger traffic within a given timeframe while maintaining desired levels of service. It involves evaluating the capabilities of various airport components, identifying bottlenecks, and providing insights for future planning and development.

> ***Definition**: Airport capacity refers to the maximum throughput that an airport system or its individual components (runways, taxiways, terminals, airspace, etc.) can accommodate over a specific period (e.g., hourly, annually) without causing unacceptable delays*.
>
> *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).*

3.1.2 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. The scope of airport capacity can cover airside or landside, however primary KPIs will be different (airside typically focuses on air traffic movements, while landside on passenger counts. Both will contribute to the overall airport capacity) however most of the information presented in this document focuses on the airside aspects.

3.1.3 Airport airside capacity is driven by capabilities and bottlenecks along the arrival and departure trajectories, from TMA, Runway, surface and apron. These should be separately analyzed, to determine the capacity for each segment/area and identify the most constraining one, and act on these.

3.1.4 In some cases, the physical capacity of the aircraft parking area—defined by the number of aircraft it can accommodate—may be lower than the estimated runway capacity for the same aerodrome. In such instances, the apron becomes the actual limiting factor for airport operations.

3.1.5 When all applicable requirements 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 an operational capacity lower than the strategic capacity may also be considered in order to manage contingencies or uncertainties.

3.2 Importance of Airport Capacity Assessment:

- Identifying current and future limitations: Pinpointing areas of congestion and potential bottlenecks.
- Supporting strategic planning: Informing decisions about infrastructure development, operational improvements, and resource allocation.
- Maintaining service quality: Ensuring acceptable levels of service for passengers and airlines by minimizing delays and congestion.
- Optimizing efficiency: Maximizing the utilization of existing infrastructure.
- Stakeholder communication: Providing data for discussions with airlines, air traffic control, and the community.

3.3 Factors to be considered for assessment of Airport Capacity

Numerous factors affect an airport's capacity, including:

- Airfield Characteristics: Number of runways, the runway and runway rapid exit taxiways (RETs) configuration, Runway length, and separation of runways; layout of taxiways; number of aprons and parking stands.
- Airspace Management: Design and complexity of airspace, air traffic control procedures and equipment and technology.
- Applicable separation and spacing minima (e.g., wake, surveillance, arrival spacing), separation delivery accuracy, runway occupancy time.
- Meteorological Conditions: Visibility, wind, and other weather phenomena.
- Aircraft Mix: Types and performance characteristics of aircraft using the airport.
- Operational Procedures: Efficiency of takeoff and landing procedures, ground handling, and ~~gate~~ parking stand utilization.
- Terminal Building Infrastructure: Size and layout of terminals, number of gates, check-in counters, security checkpoints, and baggage handling systems.
- Passengers' profiles (or mix): travel purpose (business vs. leisure), group type (families, PRMs, short connectors), and nationality or visa status.

3.4 Methodologies

<u>Calculating and Expressing Airport Capacity - Contributing Factors</u>

3.4.1 Normally defined as the total number of movements, i.e. arrivals and departures, that the aerodrome can handle during the given period.

- Capacity values are calculated for each aerodrome runway configuration and for the anticipated range of weather conditions, i.e., visual meteorological conditions, instrument meteorological conditions, and low visibility conditions
- Often infrastructure-related, as opposed to ATCO workload-related, airport capacity is easier to calculate using mathematical models.
- Nonetheless, the ATCO workload element, e.g., the need for the ATCO to coordinate departures with the adjoining unit, remains important and should be assessed during the calculation of-airport capacity

3.4.2 Methodologies for Assessment: Various qualitative and quantitative methods are employed to assess airport capacity. These can range from relatively simple analytical models to complex simulation tools. Some common approaches include:

- Analytical tools use mathematical formulas to estimate capacity based on factors like runway occupancy time, separation standards, and aircraft mix (e.g., FAA's Airfield Capacity Model (ACM))-ACM is a widely recognized analytical tool used to calculate the runway capacity of an airport. It considers factors such as runway configuration, aircraft mix, weather conditions (VMC/IMC), and operational procedures. The model estimates capacity by analyzing the time intervals between successive aircraft operations. The FAA has upgraded this model over time to incorporate more features and improve accuracy.
- Mathematical models use formulas based on queuing theory and statistical analysis to estimate capacity. They consider factors like runway occupancy times and separation

requirements. These models can provide quick assessments but might oversimplify complex airport operations.

- Employing computer simulations to model aircraft and passenger flows under different scenarios and analyze their impact on capacity and delays.
  - ✓ Runway Capacity Analyzer: This tool employs Monte Carlo simulation to account for uncertainties in input parameters and provides probabilistic estimates of runway throughput. It can optimize flight sequences and analyze the impact of factors like fleet mix and required aircraft separation. This is the methodology used by EUROCONTROL when performing Airport Capacity Assessment, described in **Appendix B**.
  - ✓ Discrete Event Simulation Models: These models simulate individual aircraft movements on the ground (taxiways, runways, gates) and in the airspace as discrete events occurring over time. They can provide a detailed analysis of airport operations, including delays and bottlenecks, under various scenarios. They may also incorporate a 3D modeling capability.
- Analyzing historical operational data (e.g., arrival and departure rates, delays) to understand current capacity and identify constraints.

  Note: It is fundamental that the use of models have their baseline operations calibrated against real-life operations and data. Often models are simplified value or approximations, also for critical parameters influencing capacity, for example on runway capacity, which could lead to over-estimated or under-estimated capacity, while there is observed variability in operations, such as aircraft landing speed, or achieved separation at runway threshold, runway occupancy time or runway exit usage. This has a direct effect on the arrival or departure throughput/capacity. The model parametrization should reflect the observed variability in operations, such as aircraft landing speed, or achieved separation at runway threshold, or runway occupancy time, usage of runway exits, accounting for the actual observed average but also the distribution spread around.

3.4.3 Key considerations when using models to assess Airport Capacity

- Data Accuracy: The accuracy of the model outputs heavily depends on the quality and granularity of the input data (e.g., traffic schedules, aircraft characteristics, operational procedures).
- Model Scope: Different models have varying scopes. Some focus primarily on runway capacity, while others can model the entire airport system, including terminals and landside operations.
- Level of Detail: The choice of model depends on the required level of detail and the complexity of the airport and the analysis being conducted.

  Assumptions and Limitations:

  It is crucial to understand the underlying assumptions and limitations of each model to interpret the results correctly. Analytical models often rely on simplifying assumptions, while simulation models can be computationally intensive and require careful calibration and validation.

3.4.4 In practice, a combination of different models and analysis techniques is often used to provide a comprehensive assessment of airport capacity. The FAA also provides guidelines and methodologies for conducting airport capacity analyses in its Advisory Circulars.

3.5 Measures for Enhancement of Airport capacity

3.5.1 Airport capacity enhancement is a multi-faceted challenge, requiring a comprehensive approach that addresses various components of the airport ecosystem. It is important to differentiate between measures for improving airport capacity (new runways, new gates, wake RECAT, new procedures that reduce spacing between aircraft, etc.) and improving throughput or the use of existing capacity (A-CDM, etc).

3.5.2 Measures can be broadly categorized into infrastructure expansion, technological integration, and operational efficiency improvements. The following figure is a (indicative) list of airport capacity enhancement measures.

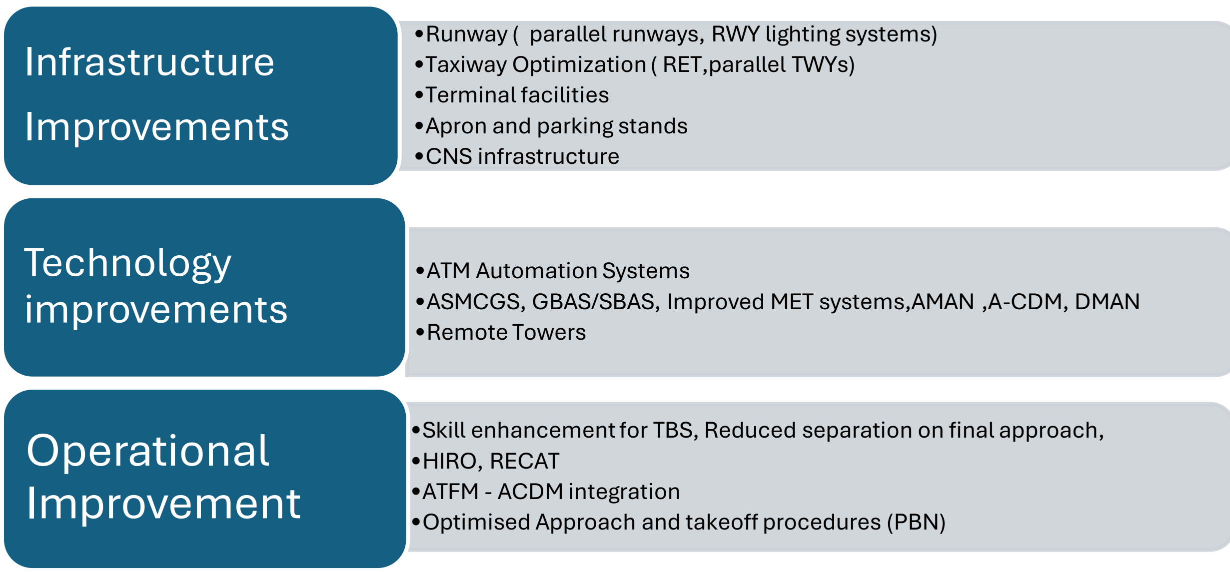

Figure 1- Airport Capacity Enhancement Measures

3.5.3 The primary factor driving the maximum arrival or departure throughput is linked to the arrival or departure separation attained, which itself is dependent on separation or spacing minima established and the delivery performance to these minima. The separation and spacing constraint are in turn linked to surveillance needs, and wake turbulence and runway occupancy of preceding traffic. Optimization can then come from enhancement to separation minima or to the ATC capabilities to deliver traffic closer to the minima, reducing unnecessary buffers.

3.5.4 By strategically combining these measures, airports can significantly enhance their capacity, reduce delays, improve efficiency, and accommodate growing air travel demand. It is crucial to consider the interdependencies between airport and airspace components, as increasing capacity in one area without addressing others can lead to new bottlenecks.

3.5.5 Optimum utilization of airport capacity (NATS example)- To utilize existing airport capacity effectively, NATS takes into consideration the following factors.

1. Sharing information across the airport ensures that all stakeholders—from ground operations to air traffic control—are aligned and responsive to real-time and strategic developments.
2. Making better use of existing resources allows for optimization without the need for major infrastructure investments.
3. Balancing demand through dynamic scheduling and coordination helps prevent bottlenecks and improves flow.

4. Getting your sequence right—whether in aircraft departures, arrivals, or parking stand assignments—can significantly reduce delays and improve throughput; and
5. Being consistently consistent in applying procedures and standards fosters predictability and reliability, which are crucial for maintaining high operational performance.

3.6 Role of Airport Collaborative Decision Making (A-CDM) in Airport Throughput Optimization

3.6.1 If the Airport capacity assessment identifies bottlenecks that will require fundamental infrastructure changes and the Airport has limited opportunities to tackle them, it is worth considering operational optimization to improve the airport throughput. One such optimization may come from improved monitoring of the turnaround process and timely information sharing.

3.6.2 To address the challenges and issues that arise from ineffective data and information exchange between airports and airspace operations, Airport Collaborative Decision Making (A-CDM) has been developed. A-CDM supports both normal and disrupted operations with the aim of increasing the efficiency of airport operations and improving the performance of the overall ATM network, by:

- Reducing delays
- Improving predictability
- Optimizing the use of resources

3.6.3 Another advantage of improving the efficiency of the operation is that aircraft spend less time taxiing and standing with engines running in queues for departure. This is good for the operators and environment as less fuel is burnt.

3.6.4 Airport Collaborative Decision Making (A-CDM) plays a crucial role in enhancing the use of airport capacity by fostering a shared understanding and optimizing operational processes among all stakeholders. It moves beyond traditional, siloed approaches to overall airport capacity management by promoting real-time information exchange and coordinated decision-making.

3.6.5 A-CDM primarily focusses on airport throughput optimization and may support identification of factors useful in airport capacity assessment by:

- Enhanced Situational Awareness: A-CDM provides a common operational picture (COP) for all stakeholders, including airlines, air traffic control (ATC), ground handlers, and airport authorities. This shared view of real-time data on aircraft movements, parking stand availability, baggage handling, and passenger flows allows for a more accurate and dynamic assessment of current and projected capacity.
- Improved Predictability and Planning: By integrating data from various sources, A-CDM enables better prediction of potential bottlenecks and capacity constraints. This allows stakeholders to proactively adjust their plans, such as optimizing departure sequences, managing gate assignments, and allocating ground resources more efficiently, thereby maximizing existing infrastructure capacity.
- Optimized Resource Utilization: A-CDM facilitates the efficient allocation of critical airport resources like runways, taxiways, gates, stands, and ground support equipment. Through collaborative planning and real-time adjustments, it helps ensure that these resources are utilized to their fullest potential, reducing idle times and improving throughput.
- Reduced Delays and Congestion: By enabling quicker and more informed decisions, A-CDM helps mitigate the impact of disruptive events (e.g., adverse weather, technical issues) on airport operations. This leads to fewer delays, reduced taxi times, and less congestion

on the airfield and in the terminals, effectively increasing the operational capacity of the airport.

- Decision Making supported by data: A-CDM relies heavily on common operational picture, however supported by associated data support analytics to identify trends, predict future states, and evaluate the impact of different operational choices. This data-driven support provides a more robust foundation for capacity assessment, allowing airports to make more tailored and flexible decisions about infrastructure investments, operational procedures, also in the long planning horizon.
- Stakeholder Collaboration: At its core, A-CDM is about collaboration. It establishes formal and informal mechanisms for stakeholders to communicate, share information, and jointly resolve issues related to capacity and efficiency. This collective intelligence leads to more effective solutions than any single entity could achieve alone.

3.6.6 In summary, A-CDM transforms static, reactive airport process into a dynamic, proactive, and collaborative endeavor. By leveraging turnaround monitoring, sharing real-time information, fostering common understanding, and optimizing resource allocation, it helps airports unlock and increase utilization of their capacity, improve operational efficiency, and enhance the overall passenger experience.

3.7 KPIs for Airport Performance Assessment

3.7.1 GANP describes the following KPIs for Airport Operational Performance Assessment. These KPIs indicate the operational capacity of the airport and infrastructure bottlenecks.

Total ATM (Departure, Arrival, Total)

i. Peak Capacity and throughput
ii. Taxi-In time
iii. Taxi-Out Time
iv. Arrival and Departure Punctuality

3.7.2 In addition, the data analysis should also provide metrics such as

- ROT-Arr
- ROT-Dep
- Stand Occupancy time

3.8 Conclusion

3.8.1 In conclusion, Airport Capacity Assessment is a multifaceted process that provides essential information for the efficient operation, planning, and development of airports. By understanding the factors that influence capacity and utilizing appropriate assessment methodologies, airports can proactively address congestion, optimize infrastructure use, and enhance the overall passenger experience.

Chapter 4 - Airspace (Sector) Capacity Assessment

4.1 Introduction

4.1.1 Airspace sector capacity assessment is the process of determining the maximum number of aircraft that an air traffic control (ATC) sector can safely and efficiently handle within a specific period while maintaining an acceptable level of controller workload. It's a critical element of air traffic flow and capacity management (ATFM), ensuring a balance between traffic demand and the ability for ATC to safely handle the traffic in a volume of the airspace to accommodate it.

> ***Definition:*** *Airspace sector capacity represents the maximum throughput of aircraft that can enter and transit a defined volume of airspace managed by a specific ATC unit or sector over a given time (usually hourly or within a 15-minute interval). This capacity is constrained by the controller's ability to safely and effectively manage the traffic.*

4.1.2 Airspace sector capacity is not unlimited, but it can be more or less optimized depending on many factors, such as airspace sector 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; complexity of traffic flows in volume of airspace and the equipage and type of aircraft in the fleet.

4.1.3 Airspace Capacity & Separation Standards

- Airspace capacity is directly related to the applicable separation standard.
- The smaller the separation standard, the more aircraft fit in an airspace volume (sector)CNS infrastructure improvements improve the accuracy of information about aircraft position and movements, resulting in lower separation standard; for instance, PBCS separations in oceanic airspace.

4.1.4 When analyzing airspace capacity, the document focuses on ATC sector capacity and, in this sense, highlights 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. The document describes some models used to measure and assess the parameters employed to determine capacity to meet air traffic demand.

4.1.5 While the document mostly focusses on Terminal Area (TMA) and En-route Area Control (ACC) operations, it is important to distinguish that workload dynamics in these environments differ significantly from other air traffic control (ATC) sectors encompassing uncontrolled airspace. Although TMAs and ACCs manage higher volumes of passengers and aircraft, sectors with uncontrolled airspace face unique complexities, specifically the provision of Flight Information Services (FIS), combined areas of controlled and uncontrolled airspace, larger geographic coverage, and a higher density of operational aerodromes where aircraft and passenger movement data is recorded.

4.1.6 Additionally, the provision of air traffic services within uncontrolled airspace often results in periods of acute workload intensity that are less predictable than those in terminal areas. In APAC region, there are many such areas, which present unique mixed airspace challenges. However, this document specifically does not address capacity measurement of uncontrolled aerodrome and airspace operations.

4.2 Calculating and Expressing Airspace Capacity (Annex 11)

4.2.1 The strategic capacity of controlled airspace and designated aerodromes is to be determined on a seasonal or annual basis and periodically reviewed and updated to account for changing circumstances, such as a new runway being commissioned, new automation systems being implemented, or a new separation standard being introduced or changes to ATC procedures.

4.2.2 The operational capacity is initially set by referencing the strategic capacity as a baseline value, and re-calculated iteratively to account for dynamic, short-term, time-specific changes in factors affecting operating conditions and ATCO workload.

4.2.3 There is no universal rule for calculating capacity because it can be affected by many variables and other considerations

- Depending on the local regulatory environment, the State, appropriate ATS authority, ATC unit, and/or ATFM unit decide how to calculate capacity.
- Methods range from observation-based basic models to highly sophisticated mathematical models.
- Typically, capacity assessment is normally done by using detailed analysis by specialist ATFM personnel, input from ATCOs and other operational ATS staff (e.g., planner and flow ATCOs, assistants and supervisors), review of safety information regarding high ATCO workload, and real-time observations.
- Due consideration should be given to the methods employed by neighboring States and within the region to ensure consistency in the methods that consider the same traffic flows.
- Multilateral agreements may be established for sharing are great tools for ensuring consistency in capacity calculation methodologies to ensure consistency.

4.3 Importance: Accurate capacity assessment is essential for:

- Ensuring safety: Preventing sector overload and maintaining adequate separation between aircraft.
- Optimizing airspace utilization: Maximizing the efficiency of the airspace by accommodating the highest possible traffic volume without compromising safety.
- Minimizing delays: Proactively identifying potential bottlenecks and implementing ATFCM measures to mitigate congestion.
- Supporting ATC planning: Informing decisions about sector design, staffing levels, and the implementation of new procedures and technologies.
- Facilitating coordination: Providing a common understanding of airspace limitations for all stakeholders, including ATC units, airlines, and airport operators.

4.4 Factors to be considered

4.4.1 Factors Influencing Sector Capacity: As illustrated in Figure 2,several factors impact the capacity of an airspace sector:

- Airspace Complexity: The size, shape, vertical limits, presence of Prohibited, Restricted and Danger Areas and route structure within the sector. Complex airspace with numerous crossing routes or altitude changes typically has lower capacity, as does the temporary designation of airspace for special activities or events.
- Traffic Characteristics: The volume, type (aircraft mix), speed, and direction of traffic flows. Predictable and uniform flows allow for higher capacity.
- ATC Procedures: The complexity and efficiency of separation standards, coordination requirements with adjacent sectors, coordination mechanism with Military Units and the use of standard routings.
- ATC Tools and Technology: The availability and sophistication of surveillance systems, automation tools, and communication systems. Advanced tools can enhance a controller's situational awareness and workload management, potentially increasing capacity.

- Controller Workload: The number and complexity of tasks required to manage traffic within the sector, including communication, coordination, conflict detection and resolution, and data management. An acceptable level of workload is a primary constraint on capacity.
- Meteorological Conditions: Adverse weather (e.g., thunderstorms, turbulence) can increase controller workload due to required deviations, special procedures and increased communication, thus reducing capacity.
- Sector Configuration: Changes in sector boundaries or the opening/closing of sub-sectors can dynamically affect capacity.

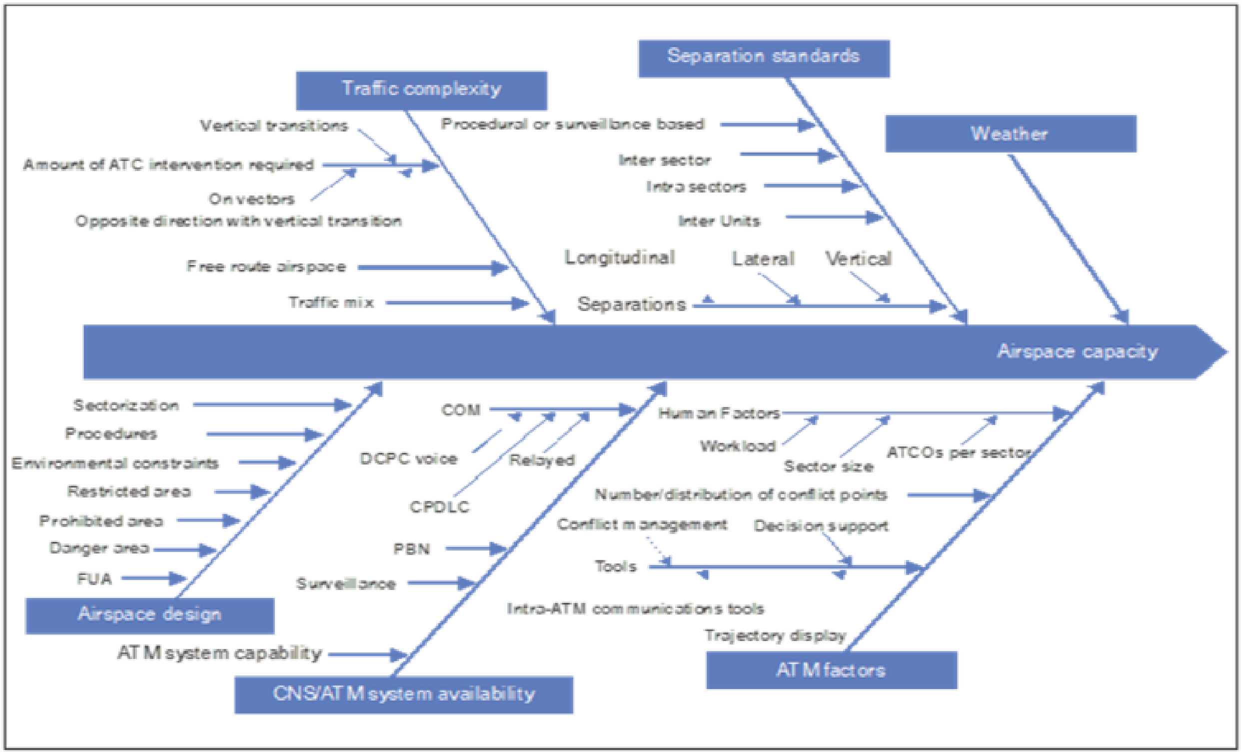

Figure 2- Factors Affecting Airspace (Sector) Capacity (Doc 9971)

4.5 Methodologies

4.5.1 The capacity for a portion of airspace is normally expressed as

- Aan entry count monitoring value—the maximum number of aircraft which may enter the airspace in a given period of time, normally one hour, or.
- Aan occupancy count monitoring value — the number of aircraft which may simultaneously operate within the portion of airspace over a specific time period, normally one minute, and the average number of aircraft expected to be maintained over a longer elapsed period e.g., 10 minutes.

In some cases, instantaneous or short duration occupancy counts can be used to complement entry counts.

- This allows for more granular analysis to mitigate and temporarily accept higher traffic demand values that exceed the entry counts monitoring value.
- Such occupancy count capacities require accurate and frequent ATC movement messages and ATS surveillance system data updates to the ATFM service system.

- Occupancy counts should be made available in advance of the flight entry into the given airspace and on a frequent basis.

Evaluation Models

4.5.2 Airspace sector capacity assessment models are tools and methodologies used to determine the maximum number of aircraft that an air traffic control (ATC) sector can safely and efficiently handle within a given period. These models help in understanding sector limitations, optimizing airspace utilization, and mitigating potential congestion and delays.

Methodologies for Assessment:

4.5.3 Various methods are employed to assess airspace sector capacity, ranging from simple estimations to complex simulations:

i. Mathematical occupancy and complexity models –

These models use mathematical formulas and queuing theory principles to estimate capacity based on parameters like aircraft arrival rates, sector transit times, and controller task load. They can provide quick estimations but may simplify the complexities of real-world ATC operations.

These are relatively simple methods that define capacity based on the maximum number of aircraft allowed to enter a sector within a specific timeframe (entry count) or the maximum number of aircraft permitted to be within the sector at any given time (occupancy count). These models often incorporate buffer mechanisms and adjustments based on factors like sector size and complexity.

ii. Simulations Models: These are more complex models that use computer simulations to represent air traffic flow and controller actions within a sector.

a. Fast-Time Simulation (FTS): Tools like runway Simulator and customized versions of RAMS Plus (used in CAPAN methodology) fall into this category.

b. Real-Time Simulation: These involve human-in-the-loop simulations with controllers interacting with simulated traffic to assess workload and capacity under realistic conditions.

c. Data-Driven Models using historical data: These approaches analyze historical operational data (e.g., traffic counts, delays, controller inputs) to identify patterns and statistically estimate sector capacity based on observed performance under varying traffic levels.

iii. ATCO workload assessment models- Considers average execution times of definable and measurable tasks that contribute to ATCO workload.

Air Traffic Controller (ATCO) Workload

4.5.4 ATCO workload is the key driver of airspace capacity in high -density/high-complexity traffic areas

i. Operational experience suggests that a safer measure of capacity is based on ATCO's physical and mental work to ensure safe separation and control of traffic

ii. Capacity is often defined as the traffic volume that results in a controller workload reaching a predetermined acceptable threshold (e.g., 70-80% of available time), leaving a buffer for unexpected events or continuous actions which cannot be related to a specific task

iii. ATS authorities commonly use simulation techniques to model ATCO workload for estimation of airspace capacity; this allows greater flexibility in capacity estimation and ensuring impact assessment of wider ranges of capacity improvement proposals

4.5.5 While ATCO workload definition and evaluation methods vary, they aim to establish the relationship between aircraft numbers (entering or occupying a sector) and the resulting controller workload over a given time period.'

a) According to scientific literature, methods for measuring ATCO workload are usually categorized as subjective and objective.

b) Several workload measurement methods of different states of maturity are currently known and used in the simulation, such as: Self-Assessment Techniques, Workload assessment questionnaires, Third Person-Assessment Techniques, Primary/Secondary Task Performance, Technical measurements of any kind.

4.5.6 Below are the evaluation methodologies based on ATCO workload:

Operational Experience o Investigate how much traffic a particular volume of airspace can handle, followed by interviews to ascertain the ATCOs' perception of traffic load. o Limited ability to determine capacity for a future ATC setting.
Fast Time Simulations (FTS) o These models are based on evaluating the time required by controllers to perform all necessary tasks associated with managing air traffic within a sector. o Tasks are often categorized (e.g., communication, coordination, conflict detection, flight data management), and time weights are assigned to each. o Often described as calculating task-load rather than workload, FTS do not aggregate the functional relationship between the traffic numbers, airspace sector factors and ATCO workload; as such, they lack ATCO judgement, experience and way of thinking. o This can be mitigated by involving active ATC staff in an iterative process of simulation refinement through rigorous data analysis
Real Time Simulations (RTS) o RTS involves ATCOs, pilots, and a model of an ATC system to create the full operational environment. o While realistically capturing the human element, they are often costlier and require additional infrastructure along with longer simulation time and training of personnel.

4.5.7 Benefits and Limitations:

- Entry/Occupancy Count: Simple to implement but may not accurately reflect controller workload or airspace complexity.
- Frequency Occupancy: Focuses on a key controller task but might not capture other workload drivers.

- Controller Workload: Provides a direct measure of the limiting factor but requires detailed task analysis and can be subjective.
- Simulation Models: Offer high fidelity and can model complex interactions but are data-intensive and require significant computational resources and expertise.
- Mathematical/Analytical Models: Useful for initial estimations and theoretical studies but often rely on simplifying assumptions.
- Empirical Models: Based on real-world operations but are limited by the availability and quality of historical data and may not predict well under new conditions.

4.5.8 The choice of model depends on the specific objectives of the capacity assessment, the availability of data and resources, and the complexity of the airspace and traffic environment being analyzed. Often, a combination of different models and techniques can provide a more comprehensive and robust understanding of airspace sector capacity.

4.5.9 The following systems are sources of data to support the capacity assessment:

- ATC Automation system (Flight Data Processing System (FDPS), AFTN/AMHS flight plan data)
- Billing System (used for Route and Terminal navigation charges)
- ATFM system
- A-CDM/ AOCC (Airport operations) system
- Surveillance system data (archive)

4.6 Measures for Enhancement of airspace capacity

4.6.1 Enhancing airspace sector capacity is critical for managing growing air traffic volumes, reducing delays, and improving overall air navigation efficiency. This involves a combination of strategic airspace design, advanced technology, and optimized operational procedures.

4.6.2 The following figure provides a broad view of various measures that can be implemented to enhance airspace sector capacity.

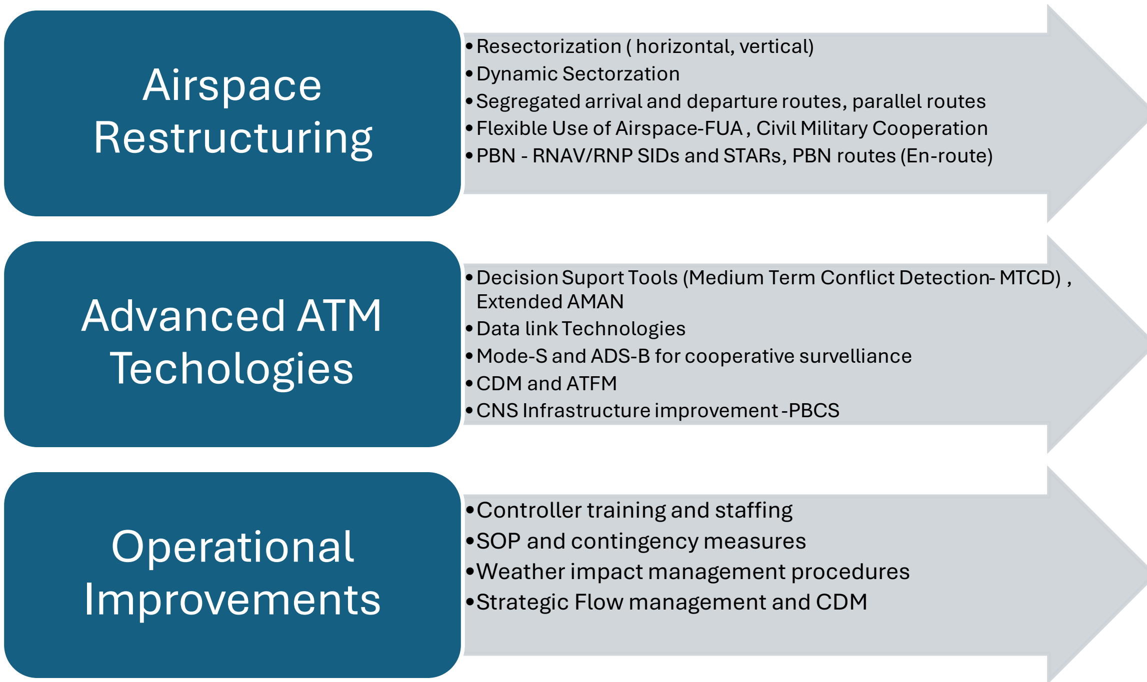

Figure 3- Airspace Sector Capacity Enhancement Measures

4.6.3 By integrating these measures, air navigation service providers can significantly enhance airspace sector capacity, leading to fewer delays, more direct routes, reduced fuel consumption, and improved environmental performance.

4.6.4 In summary, airspace sector capacity assessment is a vital process for ensuring the safe and efficient management of air traffic. By considering the various influencing factors and employing appropriate assessment methodologies, ATC authorities can effectively determine the operational limits of their airspace and implement strategies to optimize its use while maintaining acceptable levels of safety and service.

References

- ICAO Annex 11, Air Traffic Services.
- ICAO Doc. 4444- Air Traffic Management 15th. Edition.
- ICAO Doc. 9426, Air Traffic Service Planning Manual.
- ICAO Doc 9971, Manual on Collaborative Air Traffic Flow Management
- ICAO Global Air Navigation Plan (ICAO GANP Portal)
- ICAO APAC Seamless ANS Plan V4.0
- ICAO APAC Framework for collaborative ATFM

Appendix A – Airport Capacity Assessment

A-1 Determining Airport Arrival Rate (AAR)

Airport Arrival Rate (AAR) is a dynamic parameter specifying the number of arrival aircraft that an airport, in conjunction with

- terminal airspace,
- ramp space,
- parking space, and
- terminal facilities,

can accept under specific conditions during any consecutive 60-minute period.

--Doc 9971, Appendix II-B, 1.1

Determining the Airport Arrival Rate (Doc 9971, Appendix II-B)

Definitions

- Airport arrival rate (AAR) — a dynamic parameter specifying the number of arrival aircraft that an aerodrome, in conjunction with terminal airspace, ramp space, parking space, and terminal facilities, can accept under specific conditions during any consecutive 60-minute period.
- Aerodrome primary runway configuration– an aerodrome configuration that handles three percent or more of the annual operations.

Administrative Considerations

- Identify the organization responsible for the establishment and implementation of AARs at selected aerodromes;
- Establish optimal AARs for the aerodromes identified; and
- Review and validate the aerodrome primary runway configurations and associated AARs at least once each year.

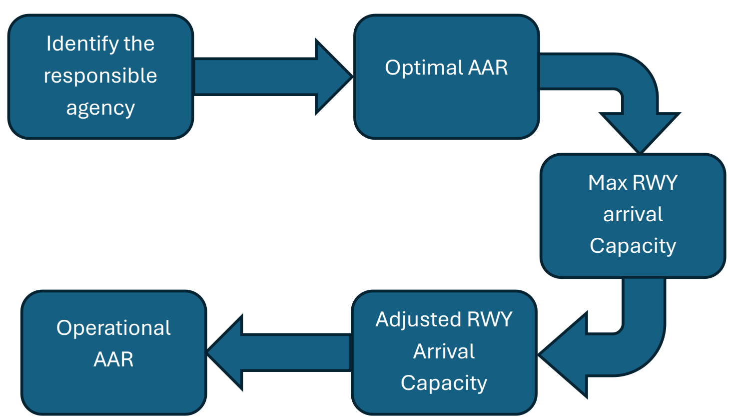

Figure APP.A- 1 Simplified Methodology for Establishing AARs[1]

[1] Scientific process developed by the FAA as in FAA Order JO 7210.3EE, Facility Operation and Administration, Chapter 10, Section 7

Optimal AAR

Calculate optimal AAR—the strategic capacity of a runway configuration– for the following meteorological conditions:

- visual meteorological conditions (VMC): meteorological conditions allow vectoring for visual approaches;
- marginal VMC: meteorological conditions do not allow vectoring for visual approaches, but visual separation on final is possible;
- instrument meteorological conditions (IMC): visual approaches and visual separation on final are not possible; and
- low IMC: meteorological conditions dictate Category II or III operations.

Maximum runway arrival capacity

Calculate the maximum runway arrival capacity as follows:

- Determine the average ground speed over the runway threshold and the spacing interval between successive arrivals accounting for required minima and separation delivery accuracy;
- Divide the ground speed by the spacing interval to determine the optimum AAR; and
- Round down to the next whole number, or refer to ICAO Doc 9971, Table II-App B-1.

Adjusted runway arrival capacity

Identify any conditions that may adjust the runway arrival capacity, including:

- intersecting arrival and departure runways;
- lateral distance between arrival runways;
- dual use runways — runways that share arrivals and departures;
- land and hold short operations;
- availability of high-speed taxiways;
- airspace limitations and constraints;
- procedural limitations (noise abatement, missed approach procedures);
- taxiway layouts; and
- meteorological conditions.

Determine the adjusted runway arrival capacity using the previous factors listed for each runway used in an aerodrome configuration:

- add the adjusted runway arrival capacity values for all runways used in an aerodrome configuration to determine the optimal AAR for that airport configuration.

Operational AAR

Calculate the operational AAR by accounting for real-time factors that require dynamic adjustments to the optimal AAR.

- aircraft type and fleet mix on final;
- runway conditions;
- runway/taxiway construction;

- equipment outages;
- approach control constraints; and
- wind (speed & direction).

Operational AAR = Optimal AAR - Adjustment Factors

A-2 Airport Capacity Assessment Process

Example of Airport Capacity Assessment Process by EUROCONTROL Network Manager

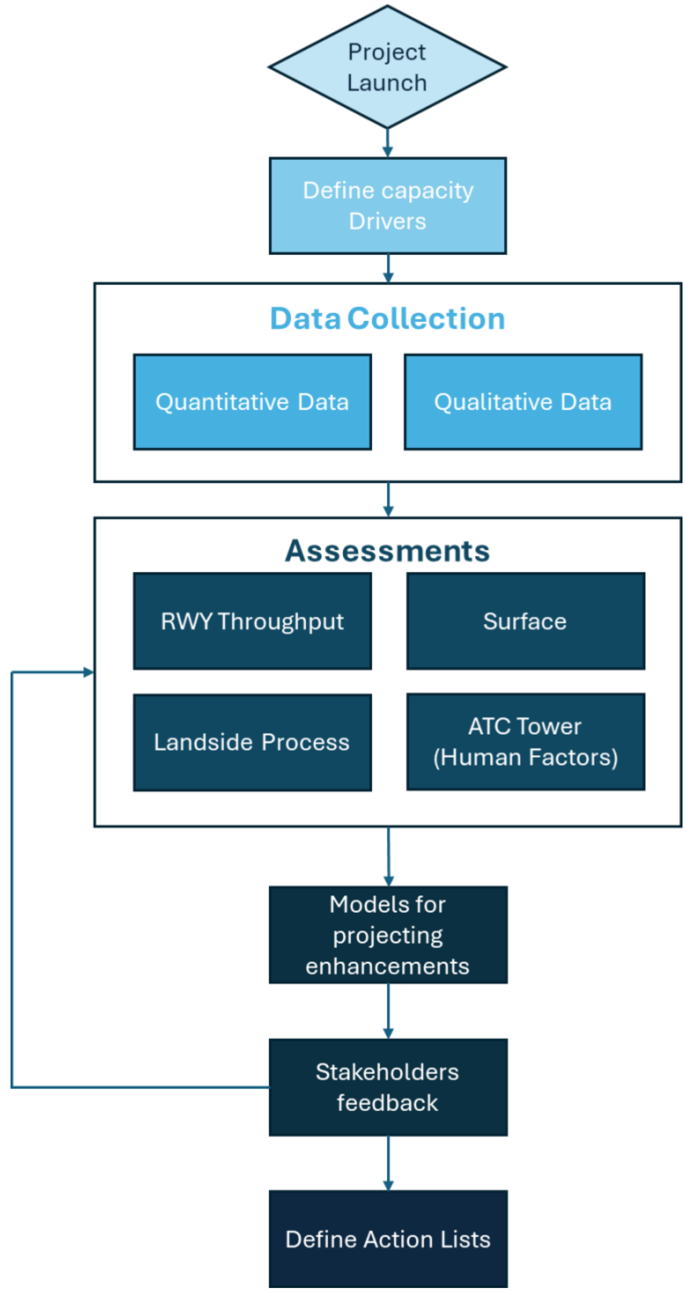

Figure APP.A- 2 Simplified Flow Chart on Methodology for Airport Capacity Assessment by EUROCONTROL

The explanation of the steps is as follows

1) Launch of Airport capacity assessment
2) Define the capacity drivers, by identifying the current operation status, collecting inputs from all Stakeholders on:
    a. Terminal
    b. Apron

   c. Surface
   d. Runway
   e. TMA

3) Collect Quantitative data based on Traffic and Passenger data
4) Collect Qualitative data based on OPS feedback and Stakeholders survey
5) Perform a RWY throughput assessment
6) Perform a Surface assessment
7) Perform a Landside process assessment if considered as relevant for the assessment
8) Perform an ATC Tower (Human Factors) assessment if considered as relevant for the assessment
9) Use models for projecting Airport capacity enhancements effect on runway throughput and develop scenarios
10) Present result to stakeholders (e.g. in forms of recommendations) and obtain feedback
11) Define action list and ensure regular follow-ups on implementation.

Appendix B – Airspace Sector Capacity Assessment

B-1 FAA sector capacity assessment model

Simple methodology for determining sector capacity developed by the FAA assumes that the sectors under consideration work best when they handle:

- no more than 25 aircraft during any 15-minute period; and
- no more than 18 aircraft during any one-minute period.

Therefore, each aircraft requires 36 seconds of a controller's work time

15 minutes x 60 seconds = 900 seconds
900 seconds / 25 aircraft = 36 seconds per aircraft

Sector capacity is calculated using the average sector flight time in minutes from 0700 hours to 1900 hours, Monday through Friday, for any 15-minute time period

$$\textbf{Optimum Sector Capacity} = \frac{\textbf{60 x Average Sector Flight Time (min)}}{\textbf{36 (seconds)}}$$

Avg Sector Flight Time (minutes)	3	4	5	6	7	8	9	10	11	12+
Optimum Sector Capacity (aircraft count)	5	7	8	10	12	13	15	17	18	18

Table APP.B- 1 Simplified Flying-time-based Method for calculating Sector Capacity[2]

This simple methodology limits capacity by considering controller workload by assuming that a controller spends 36 seconds providing an ATC service to each flight.

This optimum value needs to be adjusted for applicable factors, such as:

- ATS route structure;
- airspace volume (vertically and laterally);
- complexity;
- climbing and descending traffic;
- terrain and obstacles, if applicable;
- number of adjoining sectors that require interaction; and
- military operations.

The 36-second assumption does not account for dynamic changes in sector traffic complexity characteristics over time and may not be applicable to future capabilities.

Improvements to the simplified method: a workload model that considers the number of aircraft and their interactions with each other, ATC services needed by each aircraft, and the amount of time to provide services:

[2] ICAO Doc 9971 Manual on Collaborative ATFM, Third Edition, 2018, Appendix II-C, Table II-App C-1

- Estimate the workload associated with imposed task demands by considering the difficulty, number, rate, and complexity of demands;
- Calculate time-on-task workload for the en-route sector radar controller positions based on post-operation logs including sector configurations and
- Model sector tasks and task categories over a period of time to establish more accurate workload estimates for:
- entry (identify aircraft, establish clearance plan, handoff, flight crew call-in, ack);
- exit;
- non-standard (non-radar) arrivals and/or departures;
- vertical transitions (interim, altitude amendment),
- scanning;
- coordination (flash-through or point-out);
- separation assurance; and
- delay (vectoring, shortcut, reroute, holding, diversion).

Use industry-standard human performance modeling techniques to identify radar controllers' tasks per sector (or sector combination) and estimate task times:

- Field observations at ACCs
- Human-in-the-loop simulation

Steps for building a workload model:

1. Determine input and output parameters of the workload model:
   a. Identify tasks performed over a period of time (e.g., Mon-Fri, 0700-1900);
   b. Record task times and task distributions to execute each task; and
   c. Sum the task times to estimate of workload for each time period (e.g., rolling 15-minute intervals for 1440 intervals in 24 hours).
2. Set the workload threshold to 90% of the theoretical workload (e.g., 810 sec for a theoretical 15-minute/900 sec interval).
3. Describe the characteristics of traffic complexity for each period.
   a. Consider three complexity types: cruise, transition (climb/descent), and delay – which may be individual or combined; and.
   b. For each complexity type, consider if separation-related activity is low or high.
4. Determine the complexity profile that characterizes sector operations over a period of time; for each complexity type:
   a. Set an alert value according to the highest observed traffic count – hence, less complex sector operations receive higher alert values and more complex sector operations receive lower alert values;
   b. Express the occurrence of each complexity type as a percentage;
   c. Calculate the weighted average by multiplying the values from 4a and 4b; and
   d. The weighted averages are summed together and rounded to determine the monitoring value.

ATC experts can further tune the monitoring value produced by the workload model to:

a. propose experience-based adjustments; and
b. account for additional, frequently occurring sector combinations.

The monitoring value of the operational capacity can be dynamically adjusted during periods of reduced efficiency to reflect the ability to provide air traffic services (e.g., meteorological conditions, and temporary degradation of infrastructure). When efficiencies improve, the monitoring value is adjusted back to baseline.

Complexity-type	Avg. complexity type alert value for the sector	Frequency	Weighted average Complexity
Transition with low separation assurance workload	19	41%	***7.80***
Cruise with low separation assurance workload	22	32.4%	***8.13***
Delay and transition with low separation assurance workload	21	12.8%	***2.70***
Delay with low separation assurance workload	18	5.6%	***1.00***
Transition with high separation assurance workload	18	5.2%	***0.90***
Delay with high separation assurance workload	17	1.4%	***0.20***
Cruise with high separation assurance workload	19	0.8%	***0.15***
Delay with Transition with high separation assurance workload	17	0.5%	***0.09***
Calculated workload-based monitoring value (capacity)			***20***

Table APP.B- 2 Sample Case on Calculated Workload-based Monitoring Value

B-2 Brazil sector Capacity Assessment Model

In Brazil, the capacity of ACCs is calculated by observing the capacity of their sectors, which is analytically obtained according to the methodology established in the ICA 100-30, ATC personnel planning (DECEA, 2007).

Calculated capacity value represents the maximum number of aircraft that can be simultaneously controlled by each operational position (ATCO). According to the current model, the controller's workload is the summation of the time spent on each of the following tasks:

a. Communications (transmission/reception);
b. Manual activities (filling-out strips) and coordination; and
c. Traffic planning and distribution.

The Brazilian methodology applies the concept of the controller's "availability factor" (φ), which is defined as the percentage of time available for the ATCO to plan the aircraft separation procedures. This availability factor is found, usually, between a minimum value of 40% of the ATCO time in a non-surveillance environment, and 60% in a surveillance environment.

The number of aircraft that can be simultaneously controlled by a controller N, within the sector under consideration can be calculated as:

$$N = \frac{\varphi * \delta}{\eta * \tau_m * \nu_m}$$

Sector capacity is the function of the following factors:

- φ: factor of controller availability, defined as the percentage of time available to plan the aircraft separation procedures;
- δ: average distance flown by aircraft in the sector, which is a function of the ATS route structure within the sector;
- η : number of controller-pilot communications for each aircraft in the sector;
- τ_m: average duration of each controller-pilot communication; and
- v_m: average speed of the aircraft in the sector.

By replacing δ and v_m with the average time flown by aircraft in the sector T, where $T = \frac{\delta}{v_m}$, the number of aircraft that can be simultaneously controlled by a controller N can be calculated as:

$$N = \frac{\varphi * T}{\eta * \tau_m}$$

The values of the factors φ , T, η and τ_m are collected empirically, following the standardized procedures specified by the appropriate ATS authority.

Example for calculating the capacity:

- factor of controller availability: φ = 60%
- average flight time spent by the aircraft crossing the sector: T = 12 minutes
- number of controller-pilot communications for each aircraft in the sector: η = 6
- average duration of each controller-pilot communication: τ_m = 9 seconds

$$N = 60\% \cdot 12_{min} \cdot (6 \cdot 9_{sec})^{-1}$$
$$N = 60\% \cdot (12 * 60_{sec}) \cdot (6 \cdot 9_{sec})^{-1}$$

Number of aircraft controlled simultaneously by a single controller
$N = 8$

Dynamically changing conditions may necessitate updating sector capacity values to account for significant changes

Data gathering needs to be meaningful to accommodate a reasonable range of operational uncertainties and represent trustworthy values to the ATC unit.

In ideal conditions, data research shall be conducted when there is heavy air traffic activity, for this reason choosing the ideal season is a factor to be considered, once it has a direct influence in final results.

Brazil has calculated the capacities of all sectors, individual and combined. After calculating the initial sector capacity, further adjustment is made to account for the significant air traffic flows, the complexity of each sector, and the capacities of the adjacent sectors.

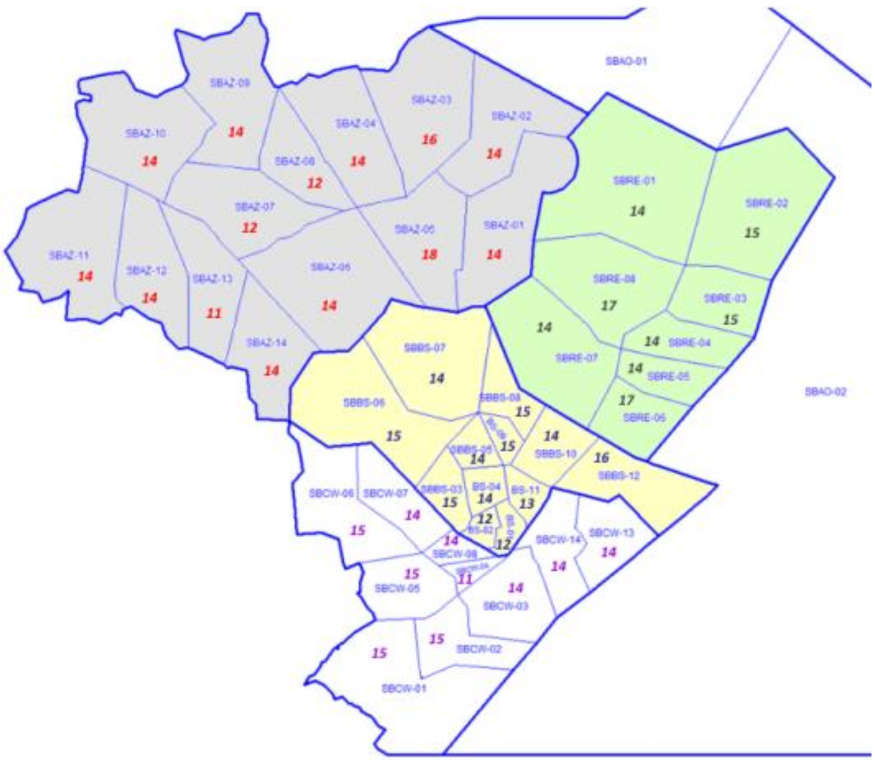

Figure APP.B- 1 Calculated Sector Capacity in Brazil

B-3 Saudi Arabia Capacity Assessment Model

ATC sector capacity calculation is based on the equations to determine the theoretical number of aircraft that can be managed and handled by ATCO. The ATS unit must perform further validation by a group of experts to confirm the calculated sector capacity and consider all possible factors that may impact that capacity.

The number of aircraft that can be controlled simultaneously by a single ATCO (Sector capacity) is calculated as the function of the following factors:

- ***φ*: ATCO Availability factor (expressed as %)**, defined as the percentage of time available for planning aircraft separation procedures;
- ***T*: Average flight time on the aircraft in the sector** (the unit of time needs to be the same as for τ_m);

- η : **Number of controller-pilot communications for each aircraft in the sector**; and
- τ_m: **Mean duration of each controller-pilot communication** (the unit of time needs to be the same as for T).

A significant data sampling is required to accommodate a reasonable range of operational uncertainties and determine reliable values for the ATC unit.

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

- Communication (transmission /reception)
- Manual activities (updating of flight progress strip) and coordination
- Traffic planning and distribution

Availability factor, φ, is defined as the percentage of time available for the ATCO to plan aircraft separation procedures. Its typical range is between 40% of ATCO time in a non-surveillance environment and 60% of ATCO time in a surveillance environment. It is thus clear that efforts need to focus on increasing the availability factor φ.

Studies conducted by experts, who analysed the sampling techniques, show that it is advisable to make at least 25 observations of each parameter for an average controller, during peak traffic, respecting the minimum number of controllers specified by the sampling technique used.

It is essential to collect as many observations from as many 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).

B-4: EUROCONTROL Methodology

EUROCONTROL developed the CAPAN (ATC Capacity Analysis) Methodology to calculate ATC sector capacity by assessing controller workload. The methodology ensures a consistent and robust technique to derive ATC controller workload and the associated sector/controlling position capacity through an ATC task-based fast-time simulation.

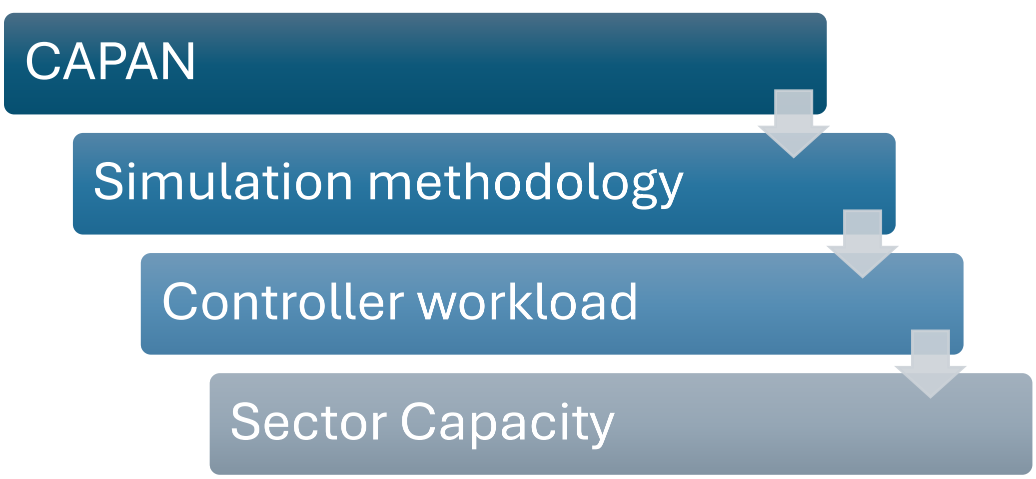

Figure APP.B- 2 Simplified Illustration on CAPAN Methodology

The methodology defines task categories and tasks representing controller actions, conflict detection and resolution mechanisms, a set of rules to mimic controller reasoning, a threshold for average theoretical working time corresponding to sector capacity and a technique, based on regression analysis, to establish the relation between workload and capacity.

The methodology uses a fast-time simulation engine which allows reproducing the ATC environment and follows an iterative process of validation for every assessment case.

Active ATC staff are involved throughout the full process of validation to guarantee simulation scenarios are as realistic as possible. This is fundamental to include the human component into the fast-time simulation, though it makes the process complex and long.

ATC controller workload is calculated by collecting the ATC related tasks generated through an ATC task-based fast-time simulation. The latter reproduces ATC related discrete events which in their turn are used to record tasks representing the actions performed by an ATC controller.

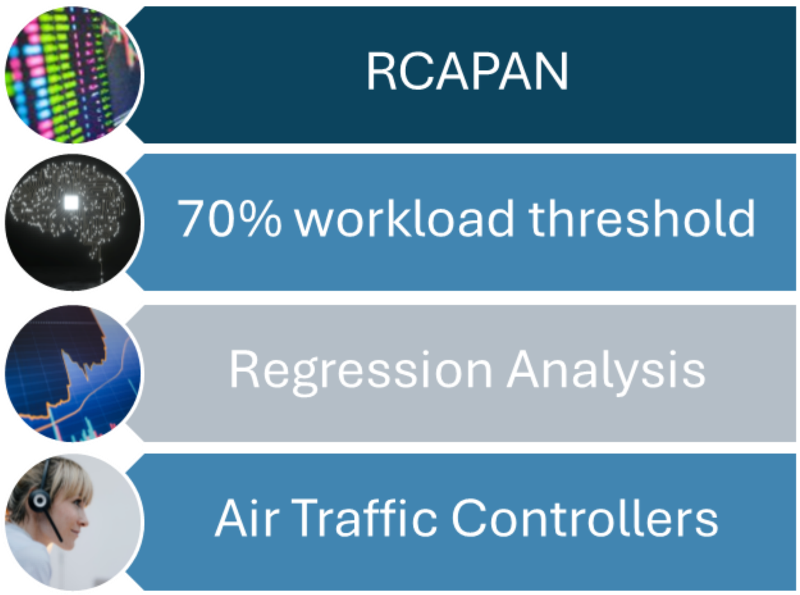

Figure APP.B- 3 CAPAN Main Principles

From a modelling point of view, the profile of a flight through airspace can be used to generate ATC related events, such as sector entry/exit, start of descent, etc.

These ATC events are used to trigger the controller tasks, which are given a specific time weight, representing the average ATC controller effort to perform each specific action.

The sum of all tasks for a certain sector and/or controlling position over a specific period of time, (normally one hour) determines the workload over that period of time.

The relationship between controller workload and the sector entries or occupancy over time is used for analysis of specific periods of the day in the sector, effectively showing the activity happening in the sector over the 24 hours.

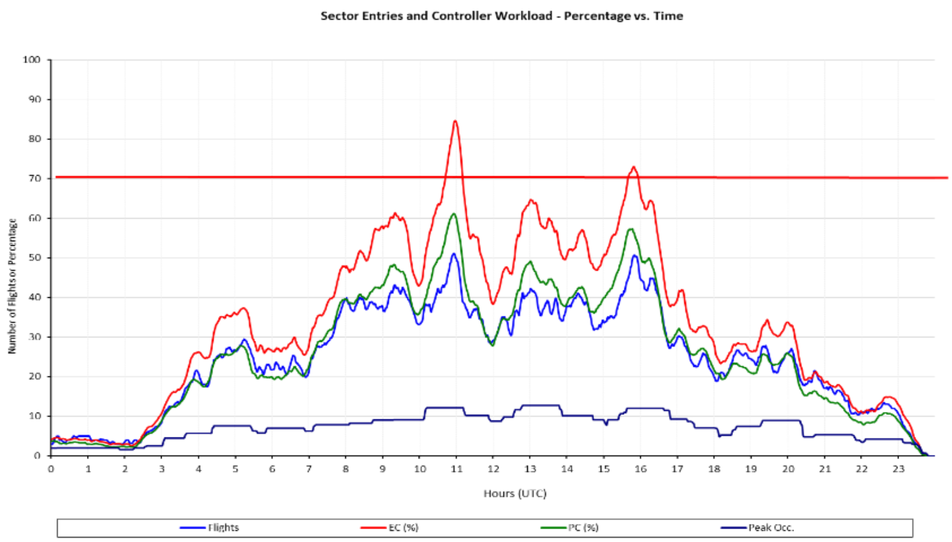

Figure APP.B- 4 Relationship between Sector Entries and Controller Workload

As illustrated in the figure above, the blue curve represents the number of sector entries in a one-hour period, using a sliding window every minute of the day; the green curve represents the corresponding planning controller (PC) workload percentage; the red curve represents the corresponding executive or radar controller (EC) workload percentage. The red line represents the overload threshold of 70% used by CAPAN to identify overloaded working positions.

Simulated workload percentage is often observed to vary with the period of the day, where sector entries can be of a similar number. This represents different complexity of the traffic flows present in this sector at different times of the day and enables a detailed analysis of the sector.

The CAPAN Methodology produces values representing the workload loading in the simulated control positions. Based on the measured workload level, quantitative threshold values and their corresponding qualitative interpretations are defined as follows;

- **Theoretical Sector Capacity** is attained when controller **workload reaches 70%** of the absolute working time, i.e. 42 minutes in an hour
- **30%** represents tasks which cannot be captured by discrete events, e.g. a general monitoring of the radar screen or recuperation time
- 70% threshold has been assessed through a **process of fine-tuning** of the discrete event logic when the first CAPAN studies were carried out together with several Real-Time simulations

Threshold	Interpretation	Recorded Working Time during 1 hour
70 % or above	Overload	42 minutes +
54 % - 69 %	Heavy Load	32 - 41 minutes
30 % - 53 %	Medium Load	18 - 31 minutes
18 % - 29%	Light Load	11 - 17 minutes
0 % - 17 %	Very Light Load	0 - 10 minutes

Table APP.B- 3 CAPAN Workload Thresholds

Capacity results are the average of a series of simulation runs – normally 25 - where the entry times of the flights and the aircraft performances are made to vary, to create different situations in the analysed ATC Sectors. This reduces the possibility that the traffic sample creates a too complex or a not enough complex situation. In the case sectors are not sufficiently loaded, flights can be cloned in a proportional way to create a traffic load sufficient enough to calculate theoretical sector capacities.

The mathematical technique, known as Regression Analysis, is used to evaluate an average theoretical sector capacity over a specific period of time. Sector/controlling position capacity is defined in terms of hourly entry rates as well as occupancy counts.

This Regression Analysis sector capacity value is based on the 24-hour average traffic complexity of the sector.

It should be noted that when the workloads recorded during the 24-hour simulation are light, the capacity by regression analysis may give too high values. In fact, as the traffic demand is low, the behaviour of the sector during difficult periods has not been measured and the function traffic/workload is almost linear. For this capacity calculation a minimum of ten iterations of the traffic sample would normally be used.

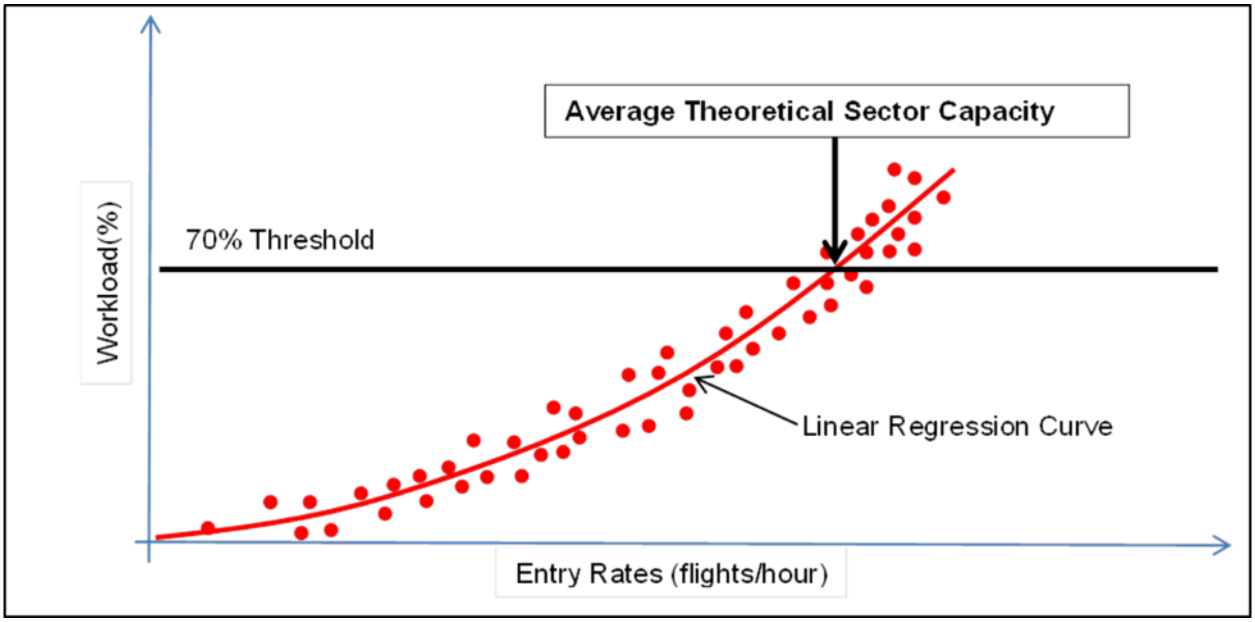

Figure APP.B- 5 Calculation of Regression Capacity

CAPAN Input Data

Traffic Data

Eurocontrol Network Manager's common archive DDR2 provides three types of traffic data:

- Initial demand: the latest flight plan updates.
- Regulated demand: flight plans impacted by flow restrictions.
- Actual demand: flight profiles derived from coordinated position reports.

Samples are selected to represent typical flows in the target area.

The prepared traffic is then iterated multiple times to simulate various scenarios (e.g., entry times, performances).

Airspace Data

Airspace data is directly available in EUROCONTROL Database, it is based on AIRAC Cycle Publication and can be complemented with AIP and tactical information.

Aircraft Performance

Eurocontrol Database BADA (Base of Aircraft Data) provides a range of aircraft type nominal performance tables. They are fundamental for trajectory calculation and totally customizable to local procedures and company policies.

ATC Model

Several parameters are required for fast-time simulation to properly model ATC procedures. CAPAN uses tailored parameters for ACC and TMA environments. Parameters include among others:

- Conflict detection and Resolution parameters
- Sector Manning
- ATC Tasks Several parameters required for fast-time simulation

Standard model for controller tasks for both ACC and TMA environment

Totally Customizable depending on system capabilities, specific procedures, separation minima, etc

Divided into 5 main task categories:

- ✓ Flight Data Management
- ✓ Conflict Search
- ✓ Coordination
- ✓ Standard Radio Telephony
- ✓ Radar
- ✓ Applicable to single/double man operations, multi-sector planner, etc.

Appendix -C – Capacity Assessment Examples from States

Capacity metrics will vary considerably, depending upon many factors such as the COM and SUR capabilities, the presence of terrain, physical attributes of aerodromes and weather. Thus, the expectations outlined for the following States need to be treated with caution, however they form a useful guide as to the sort of capability being achieved with modern systems and appropriately trained controllers.

The arrival rate is *obtained as the average ground speed (in kt) divided by the separation (in NM), rounded down to the closest integer.*

Table APP.D- 1 provides an indication of potential Aerodrome Airport Arrival Rate (AAR) for a single runway, given aircraft ground speeds and aircraft spacing near the runway threshold.

		Inter-arrival Spacing									
		3NM	3.5NM	4NM	4.5NM	5NM	6NM	7NM	8NM	9NM	10NM
Speed	140kt	46	40	35	31	28	23	20	17	15	14
	130kt	43	37	32	28	26	21	18	16	14	13
	120kt	40	34	30	26	24	20	17	15	13	12

The arrival rate is obtained as the average ground speed (in kt) divided by the separation (in NM), rounded down to the closest integer.

Table APP.D- 1 Potential Runway Arrival Rate[3]

ATC capacity calculations needed to take into account the volume of airspace of each sector, which varied considerably by State, and factors such as automation, density of traffic and complexity of routes/airspace. The *Manual on Collaborative Air Traffic Flow Management* (ICAO Doc 9971) contained guidelines for ATC sector capacity assessment. **Table APP.D- 2** provides simplified ATC sector calculation guidance from ICAO Doc 9971.

Avg Sector Flight Time (minutes)	3	4	5	6	7	8	9	10	11	12+
Optimum Sector Capacity (aircraft count)	5	7	8	10	12	13	15	17	18	18

Table APP.D- 2 Simplified ATC Sector Capacity Table (no complexity/automation allowance)

Australia, Japan, New Zealand, Singapore, Thailand and the United States of America provided runway and airspace (ATC Sector) capacity data, to indicate potential capacity figures in varying Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC) circumstances.

Australia

Brisbane and Melbourne airport capacity expectations:

- single runway: **48** (24 arrivals - 150 seconds between arrivals, 24 departures, VMC)
- single runway: **40** (20 arrivals - 180 seconds, 20 departures, IMC)

Japan

Airport capacity expectations:

[3] Guide for the Application of a Common Methodology to Estimate Airport and ATC Sector Capacity for the SAM Region, Attachment 7: Calculation of the Aerodrome Acceptance Rate used by the FAA

- Narita (dual runways): 56-64
- Haneda (4 runways): 74

New Zealand

Auckland airport capacity expectations:

- single runway: **45** (VMC)
- single runway: **39** (IMC circling)
- single runway: **37** (IMC below circling with missed approach protection for jets)
- single runway: **32** (IMC below circling with missed approach protection)

ATC Sector capacity expectations:

- terminal/low level Category T airspace: **12** aircraft
- en-route Category S airspace: **15** aircraft
- en-route Category R airspace: **15** aircraft

Singapore

Changi airport capacity expectations:

- two parallel/near parallel runways: **72** (IMC)

Thailand

Suvarnabhumi airport capacity expectations:

- single runway: **34** (VMC/IMC)

United States of America

Table APP.D- 3 provides an indication of optimal aerodrome parallel or near parallel arrival rate runway arrival capacity at selected USA aerodromes. It should be noted that multiple runway combinations or whether runways were used for arrivals, departures, or both yielded a number of permutations from the data.

Aerodrome	Runways	IMC	VMC
KATL	5	104	126
KORD	5	84	112
KDFW	5	90	96
KATL	4	92	112
KDEN	4	-	114
KLAX	4	64	80
KORD	4	-	92
KATL	3	76	96
KDEN	3	-	96
KIAD	3	72	100
KATL	2	68	82
KJFK	2	-	58
KSDF	2	40	52
KATL	1	34	42
KSDF	1	20	26
KSFO	1	25	27

Table APP.D- 3 Capacity at Selected United States of America Aerodromes

Average airport arrival capacity expectations (range):

- single runway: IMC average **26** (25-34), VMC average **32** (26-42)
- two parallel/near parallel runways: IMC **55** (40-68), VMC **64** (52-82)
- three parallel/near parallel runways: IMC **74** (72-76), VMC **97** (96-100)
- four parallel/near parallel runways: IMC **78** (64-92), VMC **100** (80-112)
- five parallel/near parallel runways: IMC **92** (84-104), VMC **111** (96-126)

ATC Sector capacity expectations:

- terminal/low level Category T airspace: **12-18** aircraft
- en-route Category S airspace: **16-20** aircraft
- en-route Category R airspace: **17-24** aircraft

Summary

Note: given the *unique operation environment and constraints of individual States, these figures are indicative only and do not represent the same expectation across different States in the region.*

Table APP.D- 4 summarizes runway and airspace capacity expectations from States, with the greatest capacity achieved in optimum conditions highlighted in bold.

	Parallel or Near Parallel Runway Capacity					ATC Sector Capacity		
	1	2	3	4	5	T	S	R
Australia	40-48							
Japan		56-64		74				
NZ	32-40					12	15	15
Singapore								
Thailand	34							
USA	**61**	**95**	**150**	**177**	**211**	12-**18**	16-**20**	17-**24**
ICAO Doc 9971 Simplified Table Comparison						15	18	18

Note: given the unique operation environment and constraints of individual States, these figures are indicative only and do not represent the same expectation across different States in the region.

Table APP.D- 4 Capacity Expectations Summary
