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AIRPORT CAPACITY ASSESSMENT METHODOLOGY

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This document provides for a harmonised methodology on how to assess airport capacity. It is intended to provide Stakeholders with a methodology and definitions that are commonly shared and understood. It further provides for enhancement recommendations to build on a solid assessment.			
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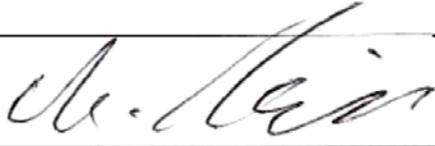
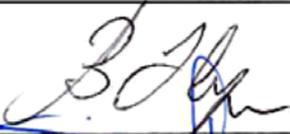
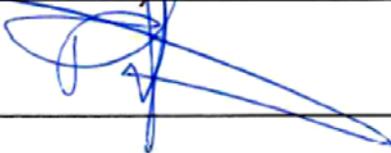
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1 INTRODUCTION

Airports need to be recognized as being part of the whole ATM system in a “gate-to-gate” environment. As the supervisor or “person with an overarching view” of the total ATM network, the Network Manager collaborates with all operational stakeholders; air traffic control, airspace users and airport operators. In operational terms, this means improving Air Traffic Flow and Capacity management to help resolve imbalances with capacity. This in turn improves predictability of traffic thus improving network operations and planning.

In order to deliver the required predictability and performance levels, all network aspects have to be considered when managing the available airport capacity effectively which includes having access to timely information on what is happening in from macro-strategic to day of operations time frames.

This guidance material provides support to both the local airport and the Network Management role by advocating an assessment methodology for airport capacity to enable analysis to be based on quantitative data that has been agreed by all stakeholders. This data can then become the baseline to compare post-operations analysis to identify shortfalls, adapt strategic plans and apply agreed mitigation tactics for capacity enhancements.

1.1 Purpose of the document

Although airport capacity is key for providing the baseline against which to compare throughput there is no single methodology for its calculation. Good airport capacity assessment ensures all relevant factors are taken into consideration – including environmental impacts, resilience, commercial factors and economic factors – rather than just delay. For airports where current demand meets or exceeds capacity, assessments should provide a framework for the most appropriate management of capacity and, for those not presently facing excess demand, capacity assessment can highlight the options for growth and the risks of over scheduling.

To enable capacity enhancement decisions that are targeted appropriately, analysis must include more than the runway, considering also taxiways, aprons, gates, terminals and local airspace to provide sufficient data to target the most appropriate enhancements for achieving performance for all stakeholders at the airport. As discussed in section 2.2 regulation is also increasingly influencing the need to perform capacity assessment at airports, regardless of whether a current demand/throughput imbalance exists or not.

This document aims to highlight the importance of an airport understanding its capacity – whether on years in advance or on the day before operation – and to demonstrate sound principles for airport capacity assessments.

As key terms throughout this document it is also important to clarify upfront the difference between:

- Demand: the airline/s schedule from creation right up to the flight plans submitted on the day of operation.
- Throughput: the airport’s actual air traffic movement on the day of operations.

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- Capacity: the theoretical air traffic movement capability of an airport. This document contains a chapter on defining this term in more detail (Chapter 3).

1.2 Scope

Despite all relevant factors from Airspace to Airside and Landside being crucial to capacity assessment, the scope of this guidance material is focused on an airport’s airside capacity as illustrated by the orange coloured section in Figure 1. The interfaces between the Runway and Terminal Manoeuvring Area (TMA) and the Approach function and the Gates and Stands are highlighted. As explained further in Chapter 2, to understand an airports current airfield performance it is critical to understand the baseline capacity. From there a growth plan can be derived that targets all the prioritized, strategic drivers including safety, resilience, environment etc. and not only delay.

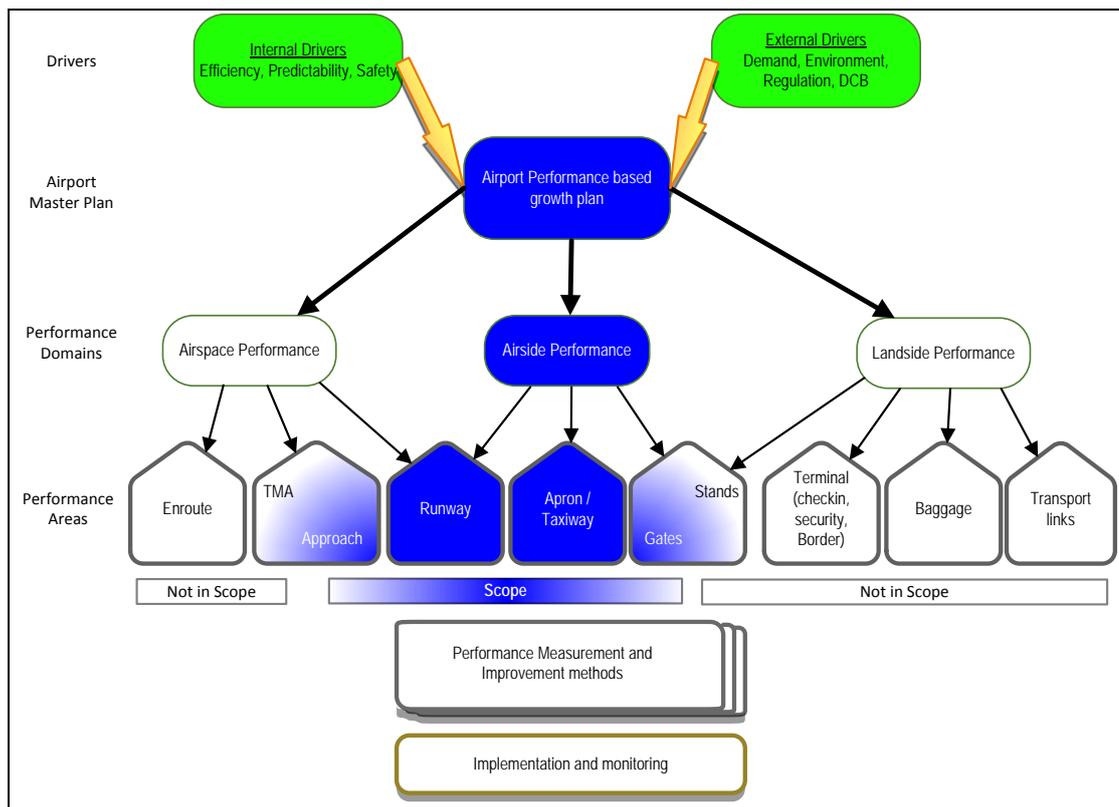


Figure 1: Airside Performance in Context

Although not included in this document scope, the interdependencies with airspace capacity and landside capacity are mentioned in Chapter 4 particularly for those areas that overlap between the domains. The Terminal Airspace and ATC Approach function is one area where the systemic airspace structure, systems and procedures directly affect the capacity of the runway. Likewise, the capacity of the gates is impacted on by the structure, systems, technology and procedures applied on the landside operations.

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1.3 Methodology Approach and Document Structure

The guidance material begins in **Chapter 2** by establishing the motivations for proactive capacity assessment and presents the key differences between capacity and delay assessments.

Chapter 3 develops these motivations into three distinct capacity definitions where the justification for excluding delay from capacity analysis is provided. These definitions are linked to the NM and IATA scheduling views.

Chapter 4 then considers the topic of measuring capacity itself and provides guidance on the various methods and their pros and cons. The various different capacity definitions in Chapter 3 are expanded and the scope of each one linked to a methodology for its calculation.

The choice over which specific capacity enhancement measures are taken are not in the scope of this document, however **Chapter 5** provides guidance on some important components in setting up a capacity enhancement team and various examples of capacity enhancement options.

Finally, **Chapter 6** presents examples from different sized airports on their capacity assessment process within the scope of the proposals in this guidance material.

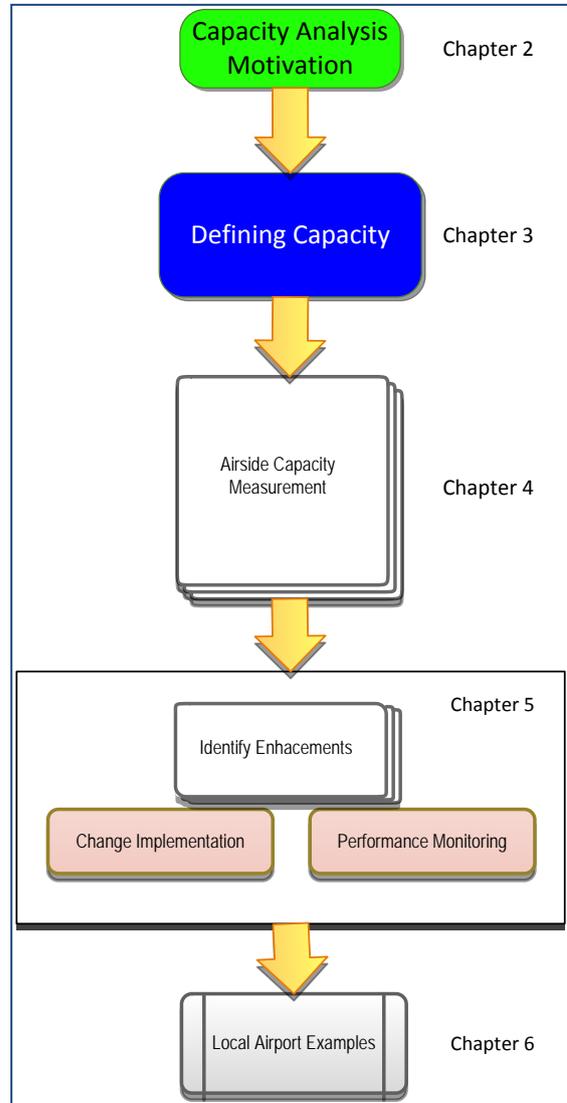


Figure 2: Approach and Structure

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1.4 Target reader

This guidance material is targeted at the following end users:

End User	Benefits
Airport Executives such as General Managers, CEO's and Directors of Finance and Operations.	Executives require concise data to support decision making. The business case will normally describe a number of scenarios such as 'Do Nothing', 'Invest option 1', 'Invest option 2' and so on. To substantiate the return on investment a baseline that is derived specifically for the local environment is critical.
Airport Capacity and Operational Managers	Provides an overall methodology that can be tailored to the local procedures for capacity assessment as well as a structure for justifying why proper capacity assessment is vital for strategic planning.
Airport Master Planning teams	Provides a clear link between the need for infrastructure planning and the baseline capacity of the airport. Also provides a method for prioritising strategic planning recommendations based on their impact on performance
ATC and Airport Analysts and Simulation Experts	Clearly separates the actual performance of an airport in throughput from the potential of the airport in capacity to support a true comparison of performance. Procedure revision planning can be justified operationally.
Airline Operators and other airport stakeholders	Allows for coordination on capacity enhancement activities to be transparently linked to the potential of the airport without involving delay. Schedule planning decisions can be supported.
Government Bodies overseeing capacity assessment	Typically, for coordinated airports, a capacity assessment is required as part of their regulatory requirements.

2 Why Measure Airside Capacity?

To achieve a sustained increase in throughput performance, an airport needs to increase capacity in all weather conditions. To increase capacity, the airport must first understand what the current capacity is across various scenarios and where any inefficiencies are.

The two main drivers why an airport needs to measure its capacity are:

1. Current demand is causing delays (reactive indicator) in good or poor weather conditions, or traffic growth is forecast and both economic and network related drivers will require the demand to be accommodated (proactive indicators). This is covered in section 2.1.
2. Regulation on airport performance monitoring and target achievements related to capacity will continue to expand. This is covered in section 2.2.

Before a decision can be made regarding enhancements required to improve the sustained throughput performance, an airport needs to understand how efficient it is (i.e. baseline performance) and where enhancements could be made.

To determine an airport's current airside efficiency, there must be a comparison to its potential performance. This potential performance is referred to as Capacity. This comparison will help determine where inefficiencies lie and hence where to prioritise enhancements. As throughput efficiency can be measured at the runway, the capacity assessment must also be measured in taxiways, apron and gates to enable the comparison. Section 3 provides more detail Capacity versus Efficiency.

This material focusses on providing guidance on how an airport could calculate its capacity across the three different airfield domains of Runway including the TMA and final approach, Taxiway/Apron and Stands. This enables an airport to set a bespoke baseline for performance measurement and enhancement decisions. When using the word 'Airport' this guidance material focuses on the airfield domain.

2.1 Demand Growth

One of the most striking quantitative results from EUROCONTROL's Challenges of Growth 2013 analysis was a sharp reduction in airports' expansion plans: an increase of just 17% in capacity by 2035 compared to 38% by 2030 reported five years earlier. The report found that the reduced demand experienced in recent years and weaker growth in the future should have given an eight-year head start on meeting the airport capacity. In the most-likely scenario, 12% of total demand (or 1.9 million flights) will not be accommodated by 2035 according to the plans that airports reported in the 2013 study. That is equivalent to an estimated 120 million passengers unable to make their outbound and return trip. At best the report suggests in an optimistic analysis that non-infrastructure related plans may accommodate 50million of those passengers with the balance coming from infrastructure related gains.

This demand growth will continue to drive both a local airport and network view on capacity monitoring and growth, operational efficiency and network

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robustness to assist the European region in meeting performance targets. Delay performance and the relationship between capacity and the network management view are further discussed in Chapter 3.

By 2035 more than 20 airports in Europe are estimated to be operating at 80% or more of capacity for 6 or more hours per day, compared to just 3 in summer 2012. This will drive ATFM airport delay (all causes) up from around 1 minute/flight in 2012 to 5-6 minutes in 2035, taking it from a minor or intermittent cause to a permanent, major contributor of delay.

2.2 Regulation

Under the Performance Scheme Commission Implementation Regulation 390/2013 the only capacity KPI target that applies (to Airports with 70,000 IFR movements per year or more) is the target en-route ATFM delay (all causes) per flight of no more than 0.5 minutes for each calendar year. This is expressed as the difference between the Estimated Take Off Time (ETOT) and the Calculated Take Off Time (CTOT) allocated by the central unit of Air Traffic Flow Management.

Arrival ATFM delay caused by landing restrictions (all causes) has been established for European monitoring and benchmarking as well as local target setting and could potentially be allocated EU wide targets in future changes to the performance regulation.

Airports should also monitor the adherence to ATFM slots and the average minutes of ATC related pre-departure delay caused by take-off restrictions measured by delays in aircraft ready to receive start-up clearances. The regulation also includes local monitoring of additional taxi-in and ASMA (Arrival Sequencing and Metering Area) times under the environment KPI.

European Regulation does not yet wholly cover Airport Airside performance indicators, however monitoring and benchmarking is ongoing and further EU wide target setting for surface operations is possible. Further targets may be implemented in future Reference Periods (RPs). Proactive capacity assessment is vital to ensure local performance benchmarking can occur to ensure a strategic plan can be established based on performance indicators relevant for each airports surface management.

2.3 Changing Assumptions

Increasing demand or regulation are not the only reasons for measuring capacity. Pressure from external parties to change the environment such as reduced staffing availability, increasing environmental pressures (noise and emissions for example), and/or changed operational procedures such as modes of operation, or scheduled major maintenance projects (i.e. runway closure) can cause airports to reduce capacity.

These effects must be put into the assessments to either identify trigger points for enhancement activities (which may include the building of new airports or runways at existing airports for example) or as counter arguments to external parties that are proposing the changes. If a government body wants to impose

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a change in runway modes, and the airport has already a sound capacity assessment methodology, then it will be better prepared to discuss the impacts of those changes.

Pressures from external stakeholders that change the way the airport can be operated due to such drivers as emissions, noise abatement, cost reductions, procedure changes etc. also may impact negatively on the available capacity of an airport and being aware of the critical areas allows for a proactive approach to risk management.

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3 Definitions

ICAO doc 9883 is the Manual on Global Performance of the Air Navigation System and one of its objectives is to promote the use of harmonised terminology among ATM community members applying the performance-based approach in their area of interest. This ICAO document has defined 11 Key Performance Areas. The ones most relevant for Airports are KPA_02: Capacity, KPA_04: Efficiency and KPA_09: Predictability. Efficiency and predictability are normally considered as performance areas where delay characteristics from actual or predicted demand are indicators.

The Airports Council International¹ (ACI) allocates the ICAO Capacity KPA to the Service Quality KPA. This performance area involves both capacity and delay aspects. The capacity is managed under the ACI Key Performance Indicator 'Practical Hourly Capacity'.

The following section introduces the relevant international definitions for Capacity, Efficiency and Predictability and then justifies the exclusion of performance area definitions that include delay aspects from this document.

3.1 Capacity:

ICAO generally defines capacity as the number of movements per unit of time that can be accepted during different meteorological conditions. However, ICAO identifies that there are a number of variables in this definition that give rise to key performance capacity indicators such as:

- a. Maximum hourly number of movements possible during visual or low visibility meteorological conditions (VMC/IMC).
- b. Maximum daily number of movements possible between the core hours during visual or low visibility meteorological conditions (VMC/IMC).
- c. Average daily airport capacity measured as a moving average; and so on.

Many other variables also exist that are not mentioned by ICAO such as wind conditions, aircraft mix, systems capability and staffing etc. As such the definition should not be constrained to meteorological condition variations.

Airport Council International defines capacity as "Maximum aircraft movements per hour assuming average delay of no more than four minutes, or such other number of delay minutes as the airport may set". However as concluded in section 3.2 below the inclusion of delay aspects in pure capacity analysis is not recommended.

The notion of a capacity that can be 'sustained' does not appear in either of these two definitions however it is discussed by the FAA sponsored Airport Cooperative Research Program (see section 3.2 below) where the concept of sustained capacity figures are preferred.

¹ ACI, Guide to Airport performance measures, February 2012

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As such the following high level definition of Capacity is used in this guidance document, being the baseline for the three dedicated definitions in section 3.3:

Capacity is defined as the maximum number of sustained movements per unit of time that can be accepted during different local capacity factors (described in Section 4.3)

The question as to whether delay should be included as a factor in capacity assessments or not, is outlined in the following two sections.

3.2 Capacity versus Efficiency

The use of Capacity and Efficiency terms may be confusing. As described previously, to perform an efficiency assessment it is vital to understand what could be the sustained throughput in assumed conditions and compare that to the actual throughput or predicted demand to identify which areas could be improved. The previous section concluded on a definition for Capacity but the question as to the inclusion of assumed or target delay metrics requires additional discussion. The answer lies in the difference between Capacity and Efficiency.

3.2.1 Efficiency

ICAO defines efficiency as comprising both “Temporal Efficiency” (i.e. delay) and “Flight Efficiency” (i.e. trajectory oriented). From an airport perspective the temporal focus area is relevant. The delay aspects cover indicators such as on time departure, average departure delay of delayed flights and so on.

ICAO concludes that predictability indicators are often represented under efficiency indicators related to delay. ICAO states: “In the case of efficiency, delay indicators include all ATM sources of delay. For predictability, only the components of delay that are unknown by a certain event (e.g. at Off Block Time) are considered.”

Efficiency could therefore be seen in both past tense (performance assessment) and future tense (predicted performance). The past tense efficiency performance is not in scope of this guidance material although it is referred to in 4.2.1 as a potential method for calculating capacity. The predicted efficiency performance is in scope, defined as the comparison of predicting demand with assessed capacity. Key Performance Area of efficiency includes an input on assumed future demand. However, this guidance material does not provide a method for predicting demand or setting acceptable delays, it merely assumes this process has been completed to enable a comparison to the capacity.

3.2.2 Demand and Capacity Imbalance

The definition of delay can vary according to the stakeholder. There are ‘acceptable delays’, network or reactionary delays, on-time performance (OTP) delays per flight (gate to gate), average delays over varying periods, arrival

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delays, departure delays, surface taxiing delays and so on. The imbalance between demand and capacity is a key cause of delay².

Delay (actual or predicted) can be used as a performance indicator that highlights an imbalance between demand and capacity. This imbalance can be found across many different domains of the airport, the local airspace (TMA), runways, taxiways and aprons as well as within the landside domain. Measuring capacity enhancements that reduce delay is a method to quantify the effects of those changes in terms of delay cost. That measurement is part of a business case process. Delays caused by systemic landside processes such as baggage, passengers, mobility etc. that affect landside capacity are not in scope of this document but can also be significant causes to delay.

Reported delay metrics do not necessarily quantify an airport's (or network's) true airside performance as inefficient procedures, poor systems or airside design aspects may be impacting delay. The observed delay is actually part of the airport performance strategy. Indeed, an airport can choose whether to set up the constraints at the safe limits of its capacity even if it will lose traffic when the best conditions occur, or to operate at the limit of its capacity preferring potential delays when degraded conditions occur.

The only way to determine the efficiency performance is first to calculate its airside capacity and identify, through analysis, if and where inefficiencies exist that could be removed or reduced. Decisions as to the economics of making improvements is then a business decision supported by a cost benefit case using predicted demand scenarios or planned growth as an economic factor. That cost benefit case will then include delay as well as other metrics.

Airports that already contain an existing imbalance flagged by ATFM or reactionary delays may perform an analysis to achieve an improvement in throughput efficiency as the delay figure itself may be enough to justify the benefit case. This is a reactionary approach as it requires delays to indicate the need for strategic planning. Capacity assessment is part of a proactive approach.

3.2.3 Macro Level Comparison between Demand and Capacity

Figure 3 below illustrates a possible yearly schedule demand scenario, the orange line, compared against a calculated airport airside capacity, the green line. Note that capacity may change on a daily basis, but for simplicity the illustration shows the same daily capacity over the year. The left Y-axis is for demand and the right Y-axis for capacity. At this macro level the airport can see that at varying times of the year demand exceeds capacity and either demand is reduced by negotiation, delay is accepted or capacity enhancement plans are put into place.

² Delays caused by systemic landside processes such as baggage, passengers, mobility etc. that affect landside capacity are not in scope of this document but can also be significant causes to delay.

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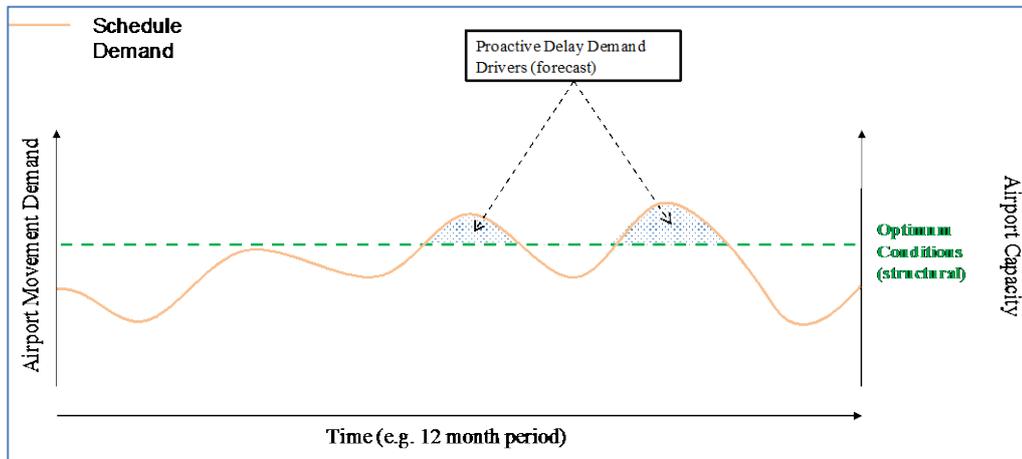


Figure 3: Yearly demand versus yearly capacity

3.2.4 Micro Level Comparison between Demand and Capacity

In the days prior to operation a daily review would normally be performed, as demonstrated in Figure 4 below, where it could be determined that demand exceeds capacity at certain times. On the day of operations (D), capacity constraining conditions (such as weather conditions, staff shortage, equipment failure etc.) may be worse than expected and the capacity falls again. This may result in actual delays rising even higher. Of course the opposite may occur where conditions improve and delay impacts are less than expected.

Figure 4 shows the difference between actual delays versus various airport capacity scenarios. This information can provide a sound basis for strategic performance enhancing decisions.

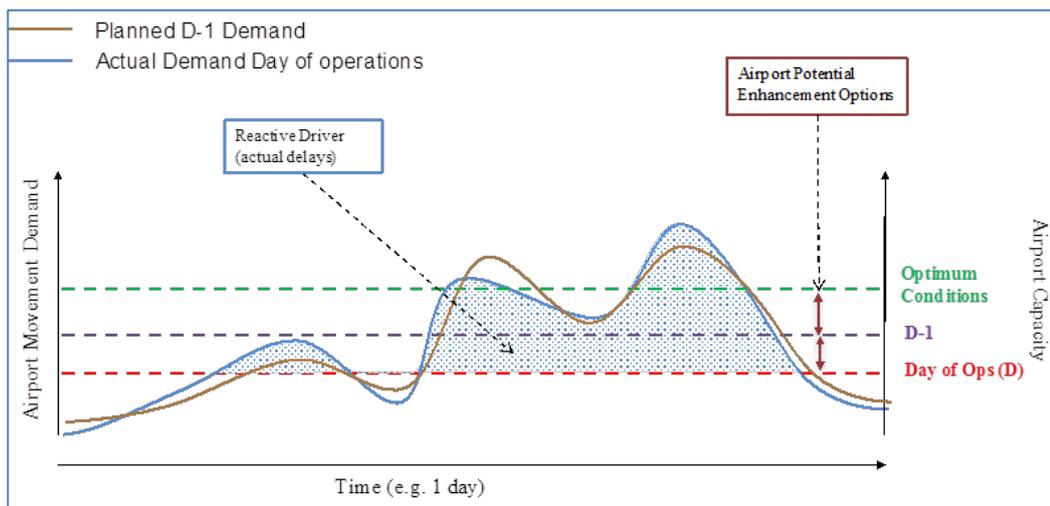


Figure 4: Forecast daily capacity versus demand illustration

For airports that have no current significant delay, i.e. **blue line** regularly remains near or below the (red) **Day of Ops** line, then without a capacity assessment there are no triggers to determine current inefficiencies. Solving these inefficiencies could bring other economic benefits to airport stakeholders. However, if capacity assessments exist but only focus on runway performance then issues in the taxiways, aprons and gates may be overlooked. Note that the

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daily capacity lines may change over time in reality but for simplicity the illustration shows a single daily capacity.

Many airports contain inefficiencies that reduce their airport performance but are not yet impacting delay as no imbalance is actually occurring, although other costs may be impacted for all stakeholders. The complexity is that some airside domains are easier to assign a 'best practice' baseline comparison to e.g. runway occupancy times. Extended taxi in/out times and/or turnaround times, reductions during poor weather and the impact from unsynchronized arrival and departure management are all areas where data from other airports are not easily transferrable for comparison. But there are advantages in sharing best practices in measurements and methodologies across airports.

3.2.5 The United States approach

The Airport Cooperative Research Program (ACRP) is an industry-driven, applied research program that develops practical solutions to problems faced by airport operators. It funds more than 20 research projects a year and is managed by the US Transportation Research Board (TRB) of the National Academies and sponsored by the FAA.

ACRP research provides substantial discussion on the topic of delay and capacity and two reports in particular are relevant for this guidance:

- ACRP Report 104: Defining and Measuring Aircraft Delay and Airport Capacity Thresholds; 2014, and
- ACRP Report 79: Evaluating Airfield Capacity extending the well-known but dated FAA AC 150/5060-5; 2012.

ACRP Report 104 concludes that even though delay metrics are used as part of airport improvement decisions, the way in which delays are reported against scheduled times vary to the way they are normally calculated in simulation modelling where delay is a function of a defined 'normal' travel time. The report also concedes that average delay could mean various things such as average annualized delay or average peak hour delay or even average delay in a particular wind/weather condition for the average-day-peak-month flight demand etc. The use of the term 'acceptable delay' is discouraged.

The report recognises that simulations using predicted flight schedules to calculate delay as an indicator for capacity results in schedules becoming a function of capacity, which they should not.

Both reports conclude that a realistic metric for capacity could be 'sustainable capacity' which is defined by the ACRP as "...a measure of the hourly capacity that can be realistically achieved for several consecutive hours" and is usually less than the saturated capacity.

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3.2.6 Conclusion on delay and capacity

As a conclusion, acceptable delay has not been considered in the scope for this guidance material when referring to capacity assessments. Given differences in how delay is measured and reported across the stakeholders and modelling tools, the lack of standardisation means its use depends on local factors that cannot be included in a generic way.

Additionally, the inclusion of delay into capacity assessment interlinks the assumptions made on flight schedule predictions to the capacity of the airport, which should remain independent. As such a systematic capacity measurement process should not use delay calculations as a means to calculate capacity but more as a means for comparison.

3.3 Three Capacity Definitions

As highlighted in section 1.4 different users will derive different benefits from calculating the capacity. As a result the term 'Capacity' requires to be further defined as a function of time.

The names of each capacity definition have been deliberately changed from those in the NM ATFCM procedures to reduce confusion and misinterpretation.

The following illustration shows how the Network view is mapped onto the capacity phases, which in turn is mapped onto the IATA scheduling process³ and related airport coordination process, where applicable. The Structural Capacity process provides input to early ATFCM processes but is started well before either of the slot processes. The Planned Capacity provides input into the Network Strategic phase and also the initial slot coordination. The Operational Capacity is used as part of the Network Pre-Tactical and Tactical process and during the post IATA conference coordination up to the day of operations.

³ See <http://www.iata.org/policy/infrastructure/slots/Pages/conference.aspx> for more detailed information

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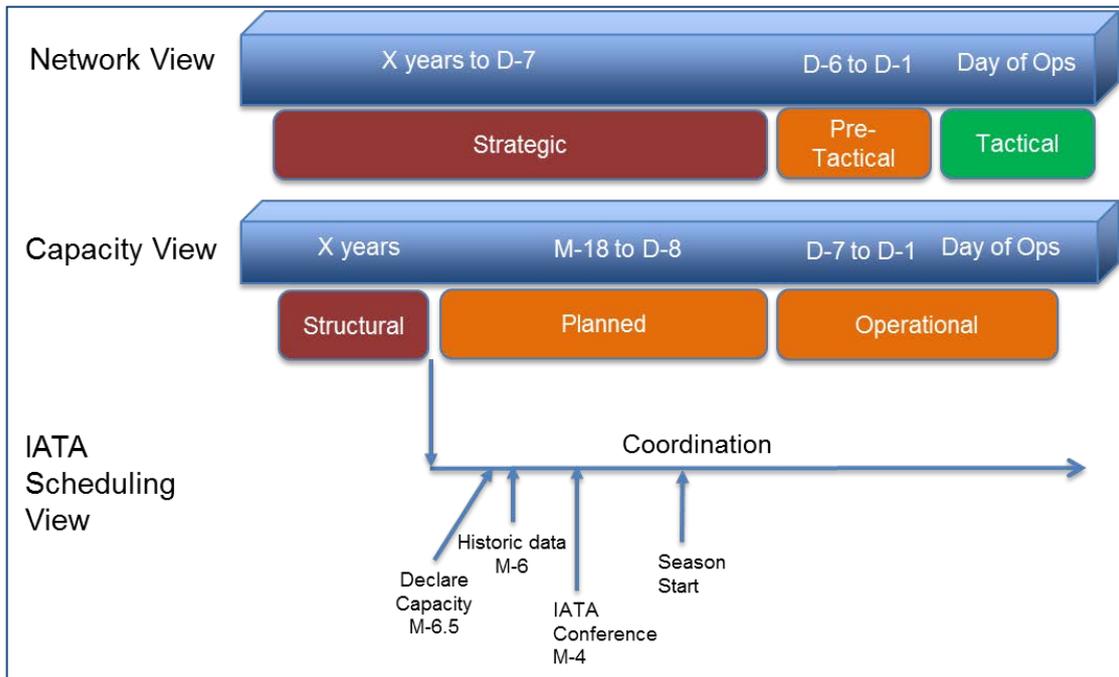


Figure 5: Capacity Definitions compared to ATFCM and Slot processes

The following sections provide a summary of each capacity definition. Section 4 provides more detailed guidance on the recommended methodology for assessing each capacity metric and what constraints should be included.

3.3.1 Structural Capacity – Macro Strategic

Structural Capacity term is a new expression although the practice of longer term planning for airport capacity is not. It is a macro level capacity assessment that assists in identifying an airport’s capacity as a baseline for planning. It disregards certain constraints that are difficult to estimate at long time horizons in the future. Structural capacity should be assessed to establish the airport baseline and be updated when significant changes are expected. Depending on the business model and size of an airport this can range between every 2 to 5 years to an annual basis.

Structural capacity is focussed on the needs of an airport to determine what the infrastructure is capable of in principle and if/when to start the process of infrastructure upgrades and hence is in the multi-year time horizon. This capacity provides the Airport management with its first input for both business case decision making and to identify the requirements for further more detailed Planned Capacity analysis.

3.3.2 Planned Capacity – Strategic

Planned Capacity is calculated in principle prior to the IATA (summer and winter) seasons. Depending if an airport is coordinated, schedules facilitated or not, this can range from more than, but at least, 18 months prior to the season for coordinated airports and closer to the season as identified by the local stakeholders for the other group of airports. Airports that have identified a demand/capacity imbalance should increase the update frequency the closer to the day of operations.

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Planned Capacity is used by all airports for coordination on airline scheduling (with or without the Worldwide Slot Guidelines (WSG) process) and also as input to the strategic flow management processes with the Network Manager. The data provided by the planned capacity metrics enables a detailed comparison to the scheduled demand where collaborative processes may be applied to reduce the imbalance, or to establish contingency plans in the event the detailed constraints eventuate.

Planned capacity is also a critical input into the pre-tactical flow management process with NM ATFCM and DCB (Demand Capacity Balancing) processes and the ongoing schedule coordination with operators (with or without the WSG).

3.3.3 Operational Capacity – Pre-Tactical

Operational capacity is the most detailed capacity assessment performed in the days before and the day of operations. Its objective is to integrate the latest detailed constraint information to update capacity figures.

It is used by all airports to refine any identified demand balancing plans or contingency plans. Operational capacity is also a critical input into the tactical flow management process with NM.

4 Measuring Airport Capacity

The previous chapter outlined three different capacity definitions each of which support various use cases. This chapter identifies where capacity measurement fits within the broader context of performance, the generic methods used to calculate capacity, the kinds of metrics that are needed for each capacity and finally the specific constraints that are recommended to be incorporated into each capacity assessment.

4.1 Capacity Measurement in Context

The capacity assessment methodology is part of a larger process which is mapped onto the structure of the document as illustrated in Figure 6 below. Once the airport has a more clear understanding as to why capacity measurement is an important activity (Section 2), and what the different kind of capacity definitions are (Section 3), the next step is to assess the capacity of the airport (this section).

Once capacity is calculated a comparison can be made with a forecasted demand simulation where the effect on efficiency delay indicators can be assessed. From these effects the airport can decide if enhancement activities are required and, although this guidance does not provide a methodology for this it does provide some examples of enhancement options in Chapter 5.

Whether or not enhancements are needed, the process begins again to ensure the capacity baseline is maintained and the airport remains proactive.

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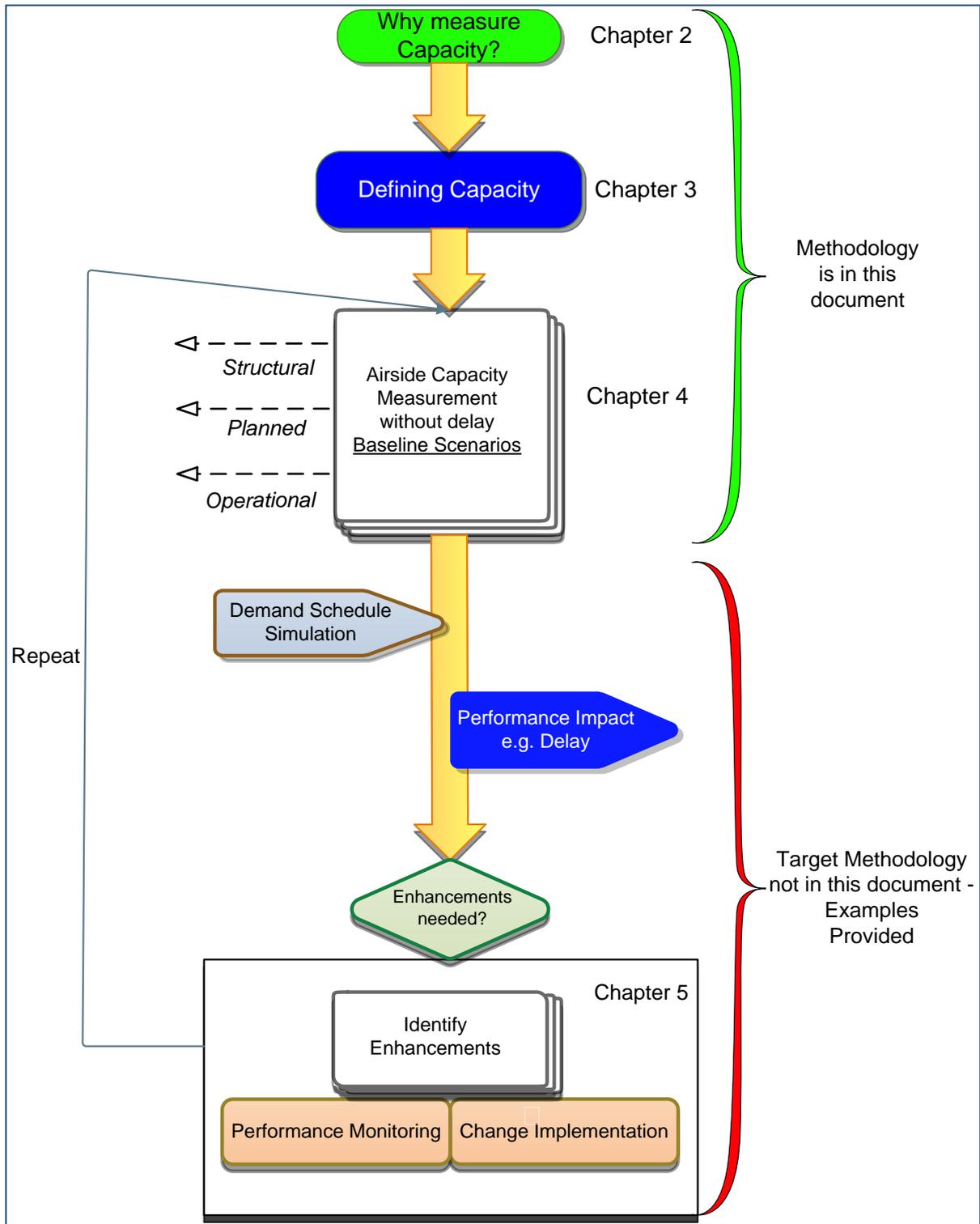


Figure 6: Capacity Assessment in Context

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4.2 Capacity Calculation Methods

The task of calculating capacity varies in terms of effort, data requirements and cost. Each method for calculating capacity also produces different output metrics. There are therefore a range of tools that can be used to support the analysis. This section provides a summary of the main approaches that can be taken from historical data, to spreadsheets or lookup tables to simulations. Given the approach suggested is to analyse capacity without integrating delay performance as a first baseline step, a section is included that discusses Pareto Frontiers as a tool to find the optimum feasible solution.

4.2.1 Historical Throughput Data

Historical data on actual throughput may be considered as an easy way to track the changing performance of the airport and attempt to identify where performance has degraded and if so which factors contributed. This could include changes that occurred when taxiways were closed, during poor weather or staff shortages. Even though it is a reactive method, it provides a pragmatic overview of what has happened, helping identify potential future enhancement to the structural and planned capacity.

As such, historical data provides a relative method for prioritizing those areas for enhancements and an easy method for high level performance checks. The critical aspect is to collect the data in as much detail as possible to ensure correlation can occur between the state of the airport (weather, airspace, runway, taxiways/apron or gates, staffing, system failures etc.) and the performance on the day. This data becomes increasingly valid the more the airport operates under continuous demanding conditions over time.

4.2.2 Look Up Tables and Analytical Models including Spreadsheets

The FAA's advisory circular AC 150/5060-5 (AC) provides an example of a look-up style analysis that can be used for simple hourly capacity and annual capacity. However, it should be noted that the Annual Service Volume (ASV) output also integrates a delay aspect through an estimation of expected demand (to convert hourly figures into a yearly figure). Although this look up table was last updated in 1995, many of the characteristics such as IFR/VFR mix, weighted average runway mode scenarios and runway crossings are still valid in today's airports as a relatively quick starting point.

The numbers in the AC tables do not account for the current state of art operational concepts and applications such as Time Based Separations (TBS), Departure and Arrival Managers, Wake Vortex Re-categorisation (RECAT-EU), standard routing or Follow-the-Greens. They also do not include the impact from advanced tower systems such as A-SMGCS, Electronic Flight Progress Strips (EFPS) and Pre-Departure Clearances over Datalink. Many of Europe's large airports have been refining their operations with these and other enhancements. Hence the numbers in look up tables such as those in the AC should be considered high level starting points.

Various prototyping models or spreadsheet tools have also been developed that expand on the AC to integrate other airport capacity characteristics such as approach separation minima, runway occupancy, the presence of parallel taxiways, aircraft wake pairing etc. They do not normally find it possible to

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incorporate analysis on non-runway related constraints such as taxiway intersections, de-icing bays, gates etc.

The outputs from these tools may vary with relatively small changes in the input assumptions. The capacity values are relatively easy to achieve.

4.2.3 Simulation models

Simulation models are extremely flexible and can incorporate a huge range of characteristics such as:

- The complete airport layout and specific modes relevant for the airport
- ATC procedures (Airspace and Aerodrome related)
- Airport operating procedures
- Simulated runway entry, exit and taxiway paths
- Fleet mix and wake pairing varying over time
- Turn around and queuing algorithms.
- Different systems and technologies and concepts
- Future demand schedule scenarios

These tools however do often involve the setting of an acceptable delay, which as discussed in section 3.2 invariably ties the schedule assumptions to the capacity output even though the two should be independent. They do take a significant amount of time to prepare (could be months) and tune, however for airports that will be using them over a continued period, the setup costs will be spread over time and a local capacity team (see section 5.3) can continue to reuse the tool to run multiple scenarios.

4.2.3.1 Pareto Frontiers

When looking at the extremes of an airports runway capacity capability, balancing arrival rates with departure rates introduces an inverse dependency. Where mixed mode operations are applied for example, to increase the arrival capacity must be balanced with departure capacity. This kind of multi-objective problem is not new in data analysis and the Pareto Frontier is a useful method to find the optimum solution⁴, the optimum being the point where no further improvements can be made in one factor without reducing the other.

When an analysis is attempting to balance multiple objectives where optimization of all objectives is the goal, trade-offs between the target objectives is often necessary. To achieve the trade-off it is necessary to run multiple scenario calculations where the input variables are changed over and over again and the results are plotted against each other to find the most optimal solution. An example of this plot for a two objective problem is shown below and is referred to as a Pareto Frontier. When more than two objectives are conflicting the calculation becomes increasingly complex.

⁴ Named after 19th century Italian engineer Vilfredo Pareto, who investigated a range of economic and social aspects related to inequality and distribution. Many people will recognise his 80/20 principle where approximately 80% of an effect comes from only 20% of the causes.

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The following illustration shows a typical arrival/departure Pareto curve where the maximum values are targeted. The analysis would look to produce one of these for each of the typical influencing factors (see section 4.4) where each run produces a plot where the inputs are varied (wake mix, RET's, intersection departures, conditional clearances, approach spacing, departure SID management etc.). The orange plots are sub optimal lower traffic scenarios, the green plots are the most optimum balance and the red plot is not feasible within the current operation. If enhancements can push the frontier out, then a higher rate could be accommodated.

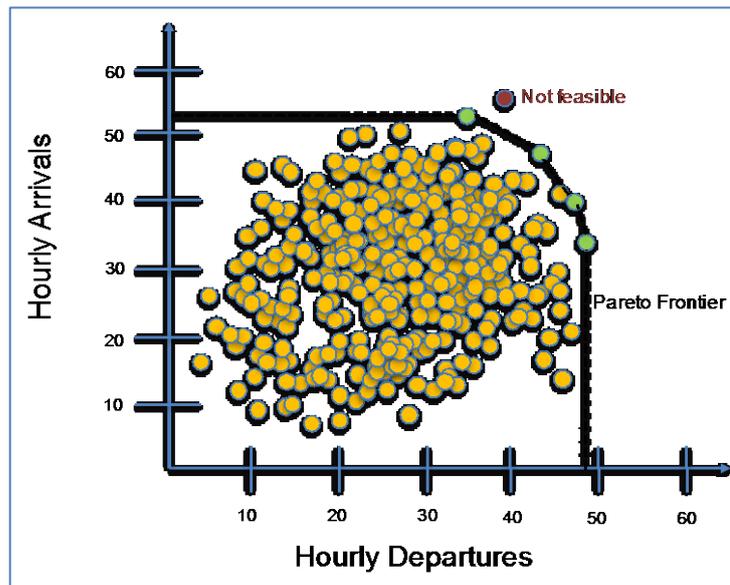


Figure 7: Pareto Illustration for a given runway mode for ARR versus DEP

From the previous capacity methods, the analytical models are the most likely to provide the capability to output a Pareto frontier although some simulation platforms may include this option. For airport runway capacity assessment, the X and Y axis objectives would normally be for Arrivals and Departures. Importantly, given the concept of Pareto optimisation and its attempt to find the absolute feasible limits, target delay is not required.

When looking at the taxiway, instead of arrivals versus departures, an airport might look to maximize the number of aircraft that the taxi system can support, while at the same time minimize the taxi time⁵. Congested taxiways are not good for ATC, flight crews, schedules or the passenger. The shorter and more consistent the taxi time the more efficient the system. However, there is also a limit to the number of aircraft ATC can safely manage at once. The following Pareto Frontier illustration shows how lower taxi times and numbers of aircraft per ATC position are balanced to achieve an optimum. Each plot accounts for the differences in variables such as visibility, aircraft performance, runway exit and gate and route taken.

⁵ It's also worth noting that there is a Pareto frontier for taxi time where shorter times can at the same time produce excessive speeding and braking which results in higher fuel burn. Some routing algorithm studies try to balance these objectives in the speed profile analysis.

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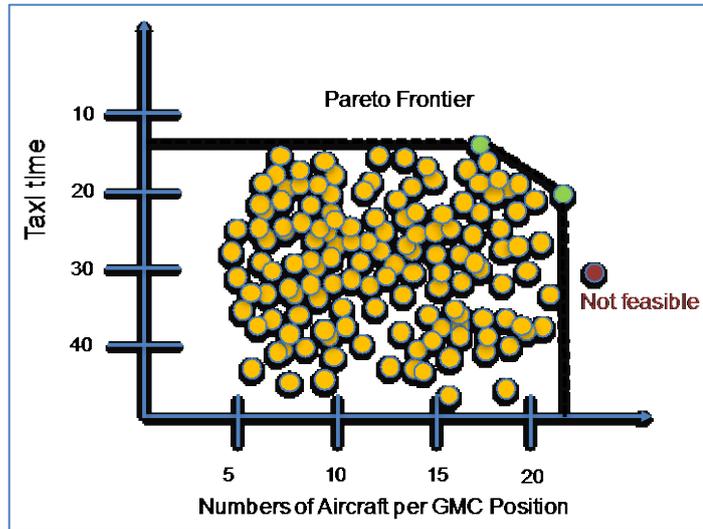


Figure 8: Pareto Illustration for a given GMC position

Likewise, for the apron and gates as one, the shorter the turnaround time, the more aircraft can be accommodated (excluding schedule constraints). The faster turnaround time the costlier that process becomes (staffing, systems, procedures) hence the airport may want to balance the highest turnaround time by varying different turn around operating methods and system support options with the resulting apron throughput for a given apron layout and number of gates in that apron. The following illustrates a Pareto frontier where each plot represents a different mix of aircraft (i.e. ICAO reference codes/wingspan, passenger numbers etc.) visibility and other weather such as de-icing requirements.

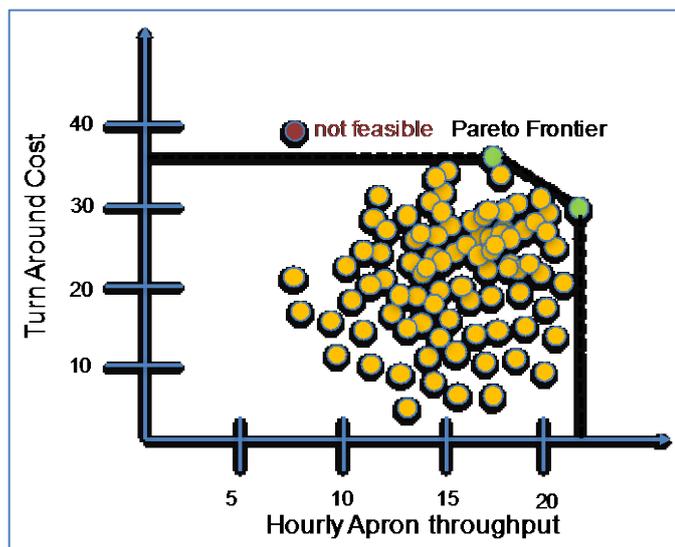


Figure 9: Pareto Illustration for a specific apron turn around versus throughput

Clearly there may be numerous points on the frontiers where an efficient balance can be found depending on the priority of one objective over another, i.e. scheduled peaks in arrivals over departures or visa-versa. The results of a Pareto Frontier essentially output a range of sustainable capacity which has been selected in this document as a preferred metric (Section (3.1)). For each focus area (Runway, Taxi way and Apron/Gates) the calculations are

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performed and assessed together as one to identify bottlenecks and areas of weakness.

4.3 Capacity Metrics

The following provides details on the various metrics that are possible from the methods presented above. Each metric has its own pros and cons towards the users' needs and objectives of the capacity assessment.

- Hourly or less:
 - Usually short enough timeframes to account for the peak and sustainable capacity accounting for effects of fleet mix, runway dependencies, arrival/departure mix and variances in aircraft separations.
 - When requiring capacity data for slot management practices 10 or 15 min time frames may be required.
 - Is preferred metric for most users.
- Daily
 - May average (weighted or not) hourly capacity into a daily figure and as such is seldom used.
 - The usefulness of this metric reduces for airports that have characteristics that impact hourly capacity such as weather, noise abatement procedures etc. in these cases the capacity could increasingly be overstated.
- Annual
 - Primarily used for strategic master planning providing a high level guide for the airports capacity.
 - As for the daily figure, airports that see significant changes in capacity characteristics such as winter and summer weather from visibility to wind will find this metric less useful.
 - Assumptions used in calculating annual capacity must as much as possible be relatively static such as staffing, ATC procedures, and airport layout for the annual figure to be used in master planning.

4.4 Characteristics for each Capacity

Section 3.3 introduced the three capacity definitions recommended by this guidance material each one providing different uses to different target readers.. The following illustration maps a potential alignment between those definitions, the end user in 1.4, the capacity methods in 4.2 and the metrics in 4.3:

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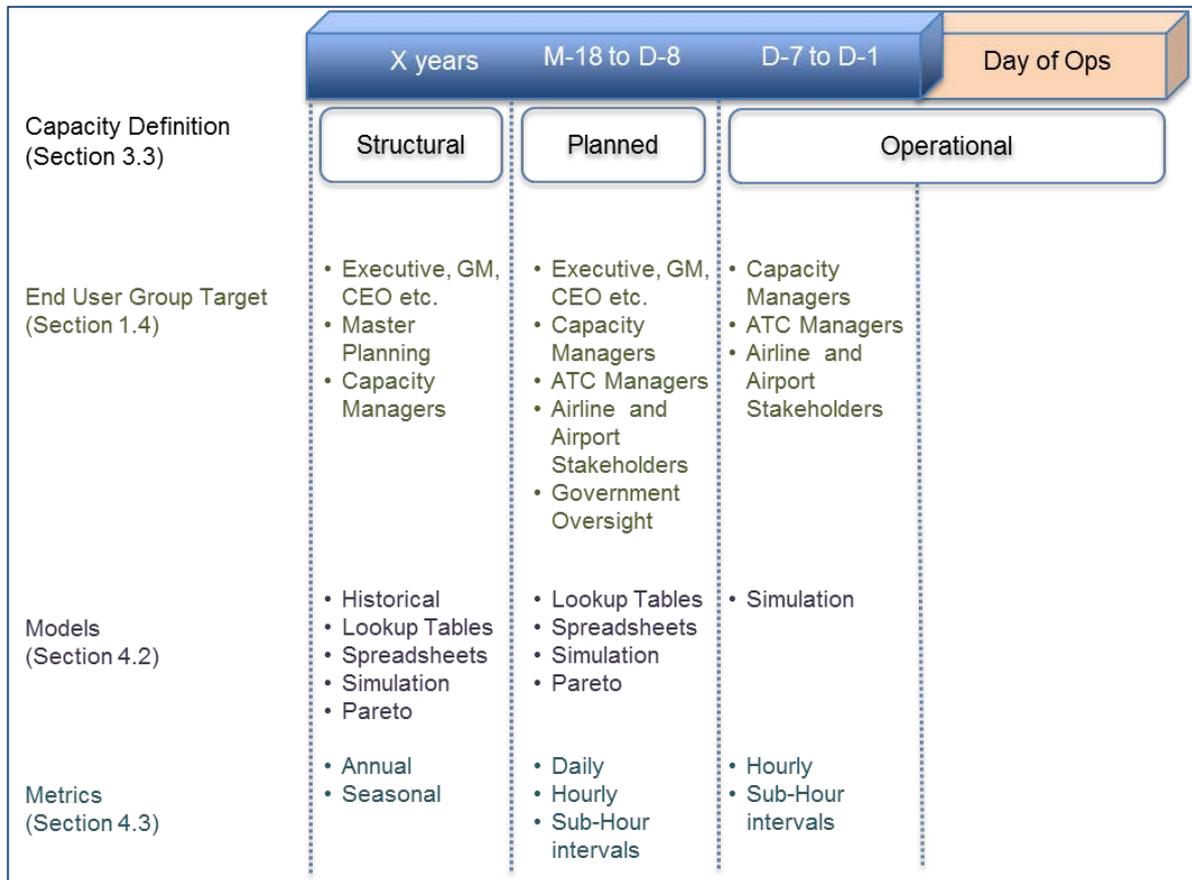


Figure 10: Capacity Definitions Mapped to Users, Models and Metrics

The next section provides a summary of the key characteristics that should be assessed for each capacity.

4.4.1 Structural Airside capacity

Structural capacity is assessed at macro level and assists in identifying an airport’s capacity as a baseline. It deliberately excludes a number of constraints that are either not reliable when forecasting over long periods (weather phenomena) or are considered modifiable in a strategic sense.

The following table is divided into influencing factors and assumptions. Influencing factors are proposed where perhaps different scenarios may be run to analyse the impacts on capacity. The assumptions are not considered as variable but static and are allocated to the influencing factors.

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Influencing factors	Assumptions:
Runway Operations Capacity	
Different Runway Mode Scenarios: Analyse for all modes enabled by the infrastructure.	<ul style="list-style-type: none"> - Global Runway Occupancy Times for arrivals and departures; - Global fleet mix in wake vortex Categories; - No noise abatement restrictions; - No political constraints on movement rates; - No constraints on airspace acceptance and delivery rates; - No constraints on AFL?
Different Weather Scenarios limited to Winter and Summer	<ul style="list-style-type: none"> - Assumed percentage of VMC versus IMC for each season.
Taxi Operations Capacity	
Access to full parallel taxiway for each runway	<ul style="list-style-type: none"> - Sufficient entry/exits to support Runway Occupancy Times.
Runway Crossing operations	<ul style="list-style-type: none"> - Global assumed crossing runway delay time and/or rules for aircraft crossing runways.
Taxiway queuing in IMC and VMC	<ul style="list-style-type: none"> - Sustainable maximum number of aircraft on taxiways during VMC and IMC; - Global taxi time in VMC and IMC; - No constraints on Airfield Lighting.
Apron/Gate Operations Capacity	
Turnaround time	<ul style="list-style-type: none"> - Global turnaround time for all aprons and operators; - No constraints on Ground Handler staffing; - No constraint on Landside capacity.
Stand Compatibility	<ul style="list-style-type: none"> - No constraints on aircraft stand/bridge compatibility.

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Rate Reporting:

The recommended rate for this capacity is an annual or seasonal rate. To obtain this rate the analysis would integrate the above factors and assumptions to produce a global airport hourly VMC and hourly IMC accounting for a balanced arrival and departure rate. When referring to IMC and VMC, the airport could consider any conditions below CAT I as part of IMC as a guide. The conversion from hourly to a yearly figure should include a yearly assumption on IMC versus VMC proportion and should not account for constraints in curfews or staffing or any other factor that reduces the operational availability of the airport. The structural capacity is a best case scenario.

4.4.2 Planned Airside capacity

Planned capacity should be calculated from approximately 18 months in advance to the week prior to the day of operation when more detailed constraints are able to be forecast with reasonable accuracy. This will support the use of this data in the slot coordination process, network manager ATFCM process and internal airport resource planning. Where Structural Capacity analysis data compared to forecast demand data highlights a significant negative gap, planned capacity analysis may occur before the 18-month period to enable a proactive enhancement process to be initiated. Operational procedures and/or systems procurement requirements from that process may require more than 18 months for completing.

The following table is divided into influencing factors and assumptions. Influencing factors are proposed where perhaps different scenarios may be run to analyse the impacts on capacity. The assumptions are not considered as variable but static and are allocated to the influencing factors.

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Influencing factors	Assumptions:
Runway Operations Capacity	
Different Runway Mode Scenarios: Analyse for <u>all</u> modes enabled by the infrastructure	<ul style="list-style-type: none"> - Runway Occupancy Times for arrivals and departures for each mode; - Known Scheduled fleet mix in wake vortex categories; - Seasonal assumed General Aviation / Business Aviation mix; - Noise abatement restrictions included; - Political constraints on movement rates or aircraft types included; - Assumed airspace acceptance and delivery rates (given met conditions as below) covering arrival priority and departure priority scenarios.
Different degraded runway scenarios:	<ul style="list-style-type: none"> - Scheduled Maintenance; - Unscheduled closure (Runway damage, Excursion etc.); - Runway lighting including approach lighting not available; - Surveillance/Navigation System not available.
Seasonal weather scenarios	<ul style="list-style-type: none"> - VMC (i.e. above CAT I); - IMC to include CAT II and III where appropriate; - Adverse weather conditions such as snow, ice, head winds, runway friction etc.

Influencing factors	Assumptions:
Taxi Operations Capacity	
Access to full parallel taxiway for each runway	Specific Arrival Departure Runway Occupancy Times for each runway mode.
Runway Crossing operations	Average delay due to runway crossing (to the crossing aircraft) lapsed for each runway mode.
Taxiway queuing in IMC and VMC	Sustainable maximum number of aircraft on taxiways during VMC and IMC including LVP. <ul style="list-style-type: none"> - Towing procedures to be taken into account; - Average taxi time in VMC and IMC between each apron and runway mode;

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Different degraded taxiway scenarios:	<ul style="list-style-type: none"> - Scheduled Maintenance scenarios on standard taxiway routes and assumed worse case time based on Service Level Agreements (SLA); - Unscheduled closures of main taxiway routes assuming worse case SLA;
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Influencing factors	Assumptions:
Apron/Gate Operations Capacity	
Turnaround time	<ul style="list-style-type: none"> - Average turnaround time for aprons and remote aprons if different accounting for remote stand transport time; - No constraints on Ground Handler staffing Landside capacity constraint scenarios.
Gate availability	<ul style="list-style-type: none"> - Assumed fleet mix and gate compatibility; - Overnight parking and towing operations.

Rate Reporting:

The recommended rate for this capacity is a daily or hourly rate. To obtain a daily rate the analysis would integrate the above factors and assumptions to produce a range of hourly rate scenarios for each mode, meteorological condition, fleet mix variations, arrival priority version departure priority etc. then convert to an average daily rate. The average daily rate should represent a sustainable capacity resilient to a certain assumption to various scenarios. This would aid in identifying characteristics that require additional monitoring or mitigation. For example, some airports have a variable fleet mix which impacts capacity from one hour to another whereas other airports may have a regular fog or headwind issue. Where these factors impact the day’s throughput, they should be reported in a daily capacity also for comparisons.

4.4.3 Operational capacity

Operational capacity is the most detailed capacity assessment performed in the days leading up to the Day of Operation. This is driven by including real time constraints on the day of operation to the planned capacity and how they affect the capacity and varies from hour to hour and day to day.

The following table is divided into influencing factors and assumptions. Influencing factors are proposed where perhaps different scenarios may be run to analyse the impacts on capacity. The assumptions are not considered as variable but static and are allocated to the influencing factors.

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Influencing factors	Assumptions:
Runway Operations Capacity	
Different Runway Mode Scenarios: Analyse for all modes enabled by the infrastructure	<ul style="list-style-type: none"> - Runway Occupancy Times for arrivals and departures for each mode; - Latest/Actual scheduled hourly demand including fleet mix in wake vortex Categories; - Known GA/BA mix based on received FPL data; - Noise abatement restrictions included; - Political constraints on movement rates or aircraft types included; - Actual airspace acceptance and delivery rates (given Met conditions as below) covering arrival priority and departure priority scenarios, staffing issues such as strike action etc; - Known ATC tower staffing constraints); - Other airports/Network constrains affecting the traffic in or out.
Different degraded runway scenarios and recovery times:	<ul style="list-style-type: none"> - Known Scheduled Maintenance; - Unscheduled closure (Runway damage, Excursion etc.); - Runway lighting including approach lighting not available; - Surveillance System not available.
Detailed weather scenarios	<ul style="list-style-type: none"> - Forecast VMC (i.e. above CAT I); - Forecast IMC/LVP to include CAT II and III where appropriate; - Adverse weather conditions such as snow, head winds, runway friction, etc. – weather comment as before.

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Influencing factors	Assumptions:
Taxi Operations Capacity	
Access to full parallel taxiway for each runway	<ul style="list-style-type: none"> - Hourly specific Arrival and Departure Runway Occupancy Times for each runway mode accounting for low Visibility Operations.
Runway Crossing operations	<ul style="list-style-type: none"> - Hourly average crossing runway lapsed time for each runway mode accounting for arrival and departure priority periods.
Taxiway queuing in IMC and VMC	<ul style="list-style-type: none"> - Hourly sustainable maximum number of aircraft on taxiways during VMC and IMC including LVP. Towing procedures to be taken into account; - Known staffing constraints; - Hourly average taxi time in VMC and IMC between each apron and runway mode.
Different degraded taxiway scenarios:	<ul style="list-style-type: none"> - Known Scheduled Maintenance on standard taxiway routes and assumed worse case time alternative; - Unscheduled closures of main taxiway routes assuming worse case SLA; - Taxiway lighting (centre and edge) not available; - Surveillance/Navigation System not available.
Apron/Gate Operations Capacity	
Turnaround time	<ul style="list-style-type: none"> - Average turnaround time for aprons and remote aprons, if different, accounting for remote stand transport time; - Known Ground Handler staffing constraints; - Known and agreed landside capacity.
Gate availability	<ul style="list-style-type: none"> - Scheduled fleet mix and gate compatibility for the various aircraft sizes using the airport; - Known Overnight parking and towing operations.

Rate Reporting:

The recommended rate for this capacity is an hourly rate covering the full operational hours of the day of operations across a number of key scenarios selected where the characteristics result in a significant change in the capacity of the airport.

5 Capacity Enhancements and Monitoring

To release latent capacity an airport has a range of options to choose from depending on the nature of the inefficiency and any budgetary constraints.

1. **Infrastructure and Airspace:** Major **Infrastructure** improvements, such as building new Rapid Exits, runways, or taxiways are often easy to identify yet are expensive and time consuming to implement. **Airspace** is often considered an invisible State asset which brings complexities and often a reluctance to address. Major changes are likely to impact human procedures and ATM systems and may possibly require infrastructure updates to reap maximum benefits.

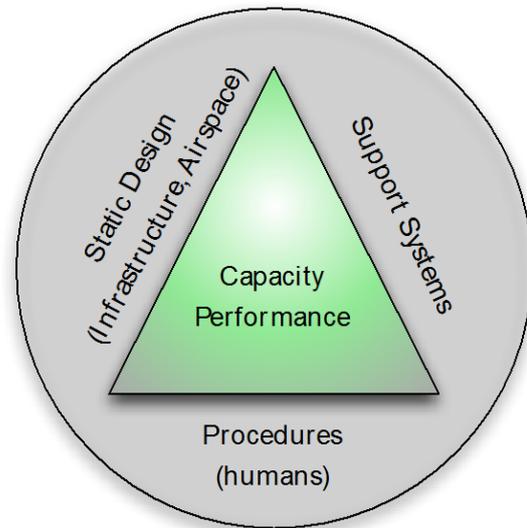


Figure 11: Options for capacity enhancement

Both infrastructure and major airspace changes are long term and are not changed on a regular basis.

2. ATM **systems** improvements may be more complex to identify and implement than major infrastructure and airspace changes, particularly where higher levels of integration and collaboration are necessary. However they might be less costly and less disruptive to the operation and allow for easier incremental upgrades to improve performance provided major infrastructure changes are not also required.
3. Improving **human** performance through changing procedures and operational ATM structure can require intricate change management processes but can deliver significant benefits. Some procedures are extremely static (ICAO requirements or those linked to social aspects such as noise for example), whereas others can be updated and modified more flexibly for quick solutions to problems. In many cases new procedures also are integrated into new infrastructure and ATM systems changes whereas some procedures are independent and require no changes to systems or infrastructure.

5.1 Capacity Enhancement Principles

A fundamental principle of enhancing airside capacity is the need to monitor performance. Only by measuring performance can new measures be assessed and refined. The principle is 'measure to manage' and through various techniques this can be achieved accurately and cost-effectively.

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Adopting standard methods for collecting data gives additional benefits. Operators can develop best practices further by making meaningful comparisons between airports. Underlying the importance of collaboration is the message that “every movement matters”.

Valuable seconds may be gained by good planning, anticipation and timely reaction to clearances among other things. Over many movements, the seconds add up to create additional capacity that in turn can reduce delays or increase resilience.

There are many options for an airport to improve capacity and a selection of examples is shown in section 5.5 and on. These are separated into the three common areas of enhancements mentioned above (Infrastructure, Systems and Humans/Procedures).

5.2 Capacity Enhancement Process

Continuing on from Chapter 4 which provides guidance on the measurement of capacity the next step in the process is to determine if the capacity is sufficient, and if not, how to enhance it. Within the scope of this document the following process is provided as an example and it is not intended to be exhaustive.

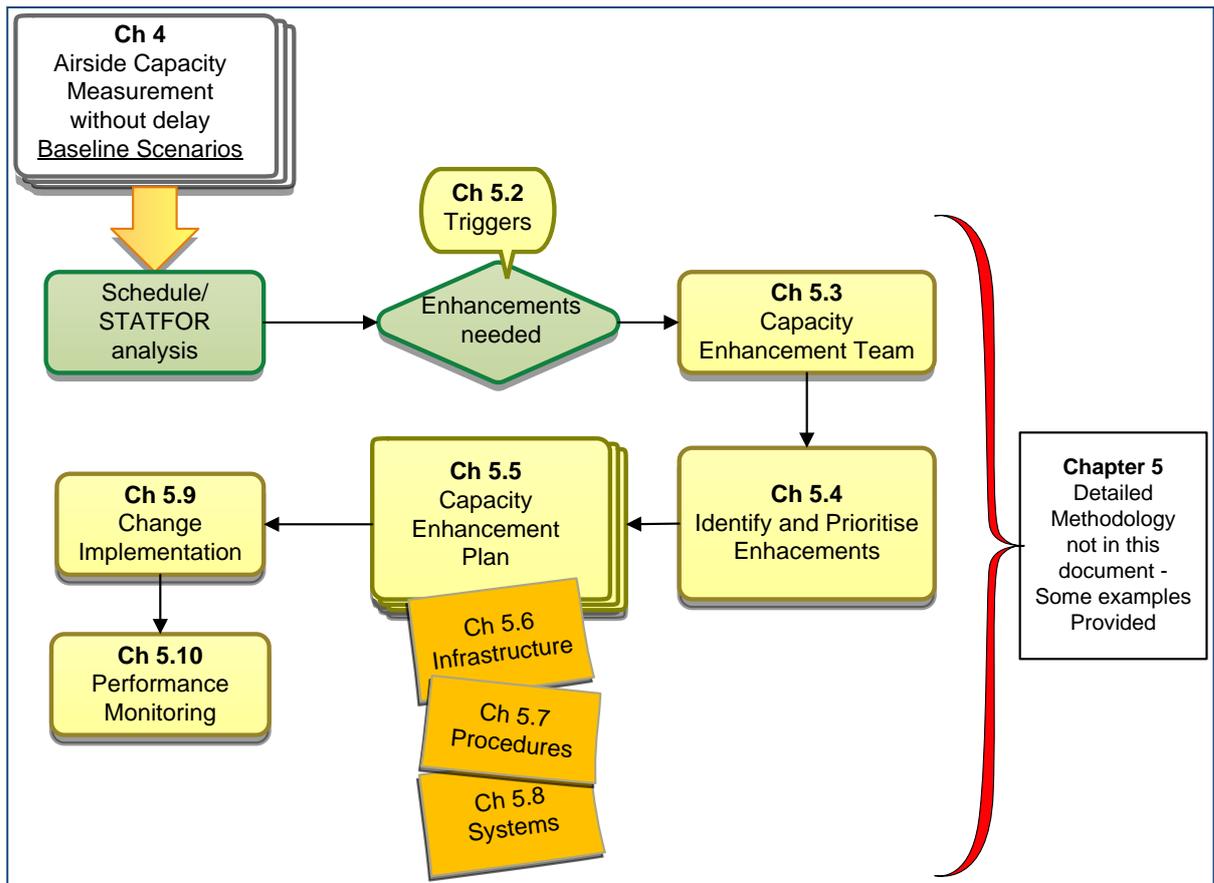


Figure 12: Capacity Enhancement Process

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5.2.1 Potential triggers for enhancement

The decision to commence airside capacity enhancement activities is a local one. Economic factors and executive strategic visions play a significant role. These are normally coordinated decisions that account for Airline Operator views, regional transport strategies, ATC acceptability, landside constraints and ultimately the Airport owners and its Board.

However, from a performance view point there are a number of examples that could be triggers. Supported by ongoing monitoring (Section 5.10), these triggers could provide a useful tool to ensure initiation of activities are not delayed and are based on measurable criteria. The establishment of capacity triggers apply for all sized airports. Some examples are:

- When using baseline capacity assessment as described in section 4 to determine a trigger for enhancements, a slightly different approach could be taken for each one of the three defined assessments.
 - For structural capacity, it could simply be a matter of looking at the scheduled and forecast demand and when it reaches a percentage (defined locally) of the baseline structural capacity across the various 'silos' (Runway, Taxiway, Apron and Gates) and is expected to increase, then enhancement activities may be established or reviewed.
 - When using the planned and operational capacity to compare against, the potential enhancement options become more limited given the shorter time frames involved (i.e. some infrastructure options may not be completed in time). As such more refined triggers may be needed to focus in on the specific constraining areas for targeted enhancement.
- Delay thresholds: Although not recommended as part of the baseline capacity assessment, monitoring delay can be useful when considering business case comparisons. As mentioned in Section 3.2.2, there are various definitions of delay and it would need to be agreed which one/s apply. Then it is a matter of measuring and assessing the current delay performance, and comparing that to predicted performance through simulations to determine which delay trigger/s should be set. The choice of triggers will be based on the strategy of either targeting that full capacity at the risk of generating delay or alternatively avoiding delay in favour of latent capacity.
- Monitoring as described in section 5.10 would then be initiated to validate and if necessary update the predictions at regular intervals as well as flag potential issues. As delay can be assigned a cost factor, CBA's can be a useful tool to balance enhancement costs with delay cost reductions as part of the decision process.

The initiation of an enhancement process (and including the initial capacity assessment) should in best practice be led by the airport operator, but may also be led by the ATC operations depending on the best fit the airport. The decision to create a formal enhancement team is a natural by-product of the capacity assessment process.

5.3 Capacity Enhancement Team

When it has been determined and agreed that a capacity enhancement team is required, the structure of that team must account for all the key stakeholders and enable a clear approach to integrated enhancement selection, prioritization and implementation. The simplest structure is to set up a steering group and an implementation group as described below. More complex arrangements may enable separate implementation sub-groups to be created focusing on specialised enhancement areas.

5.3.1 Capacity Enhancement Steering Group

The role of the Capacity Enhancement Steering Group is to define the capacity enhancement process in terms of:

- *Scope* – what will the capacity enhancement process cover?
- *Targets* – what increases are needed and by when?
- *Method* – what method should be used?
- *Deliverables* – setting priorities and timescales.
- *Team* – who should be appointed to manage the process from ATC, airlines and airport operator?

The Team should consist of ATC Management, Airline Operator Management, Airport Management and the Airport Coordinator if the position exists. It should contain the decision-making authority to commit resources for the implementation of identified enhancements. Each Management position should ensure an integrated safety process is also carried out for any proposed changes.

The Steering Group in turn appoints a team to manage the process. It usually consists of the ATC manager or senior operational controllers, representatives from the operators which may include senior pilots operating at the airport and or relevant operational division heads, and an airport operations manager.

5.3.2 Capacity Enhancement Implementation Group

The Capacity Enhancement Implementation Group is responsible for setting up and managing the component parts of the enhancement process. Team members will also ensure that the capacity enhancement message is introduced with high visibility into their respective organisations.

The team presents the results of the various exercises and initiatives at regular intervals to the Steering Group together with other pertinent issues. It should be composed of ATC Experts, Flight Crew experts, Apron Management and Security experts and data analyst/simulation experts. This may also include other landside experts by coordination or as a member of the team.

5.4 Identifying and Prioritising Enhancements

This part of the process integrates the outputs of the capacity assessment metrics and performance triggers into a structured approach to identify which enhancements are

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likely to increase capacity. Although data will already have been collected to perform the initial baseline capacity assessment, more detailed analysis will be required to narrow down the specific areas where inefficiencies exist. This requires current performance data to be collected.

5.4.1 Data Collection

5.4.1.1 Decide what measurements to make

The team will need to define a measurement exercise, based on the main drivers of airport performance being targeted. These include items such as runway occupancy time, line up times and arrival/departure separations, taxiway patterns, routing, speeds and hotspots and apron gate areas.

The team may already have a good idea of the main drivers, but a systematic approach is recommended to ensure that fundamental factors are not overlooked. This systematic approach should look at each phase of an aircraft's movement in and out of the airport and identify which are the key time intervals. For example, (not comprehensive):

- Runway movements
 - Time between two arrivals at the Final Approach Fix (FAF)
 - Time arriving aircraft touchdown and the line-up clearance for departing aircraft
 - Time between runway vacate and landing clearance for following aircraft
 - Time to line up from clearance
 - Time between the take-off clearance and take-off roll
 - Time between touchdown and vacating of the runway
- Taxiway movements
 - Time held at intersections
 - Taxi time from runway exit A to apron B (and reverse)
 - Time in departure queue
 - Time between estimated or target take-off time and actual
- Apron Movements
 - Time between in block time and off block
 - Time in held in apron waiting for gate to clear
 - Time between start and push approval and off block

5.4.1.2 Run a measurement campaign

The measurements themselves will require a number of activities. The most challenging is to measure runway occupancy times and pilot reaction times, which require either manual or automated techniques. Automated techniques using

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surveillance data is possible however this often also requires correlation with clearance and voice instructions for meaningful data to be extracted. Integration of Electronic Flight Progress Strip actions may also be possible to increase the automation of the analysis. The measurement campaign should observe traffic during peak hours and target at least 20 days to ensure a statistical data sample is collected. There may be differences also observed between winter or summer periods and also in good and poor visibility.

5.4.2 Data Analysis

The amount of sampled data collected should be sufficient to enable the identification of the 'mean' performance so that outliers can be identified and removed. The standard deviation can help determine the performance distribution and the target 'best in class' which the enhancements aim to reach or improve on. The data should enable the team to identify why certain operations achieved higher or lower performance than others.

To evaluate the results, it is necessary to carefully examine the trends and determine what the actual situation really represents. For example, if the difference in the average performance between the best in class and the others is decreasing;

- The others may have improved whilst the best-in-class remained unchanged;
- The performance of the best-in-class may have deteriorated;
- A combination of the two.

5.4.3 Joint Enhancement Development

The next stage is to fully involve pilots and air traffic controllers in developing enhancement ideas further. The Capacity Enhancement Implementation Group may initially discuss the observations with the flight crews and ATC separately in smaller working groups for to allow frank discussions, however a combined approach to these discussions is ultimately required to ensure all parties are able to comment and provide input together as a team.

The results of the measurement exercise and possible solutions are reviewed and discussed at these meetings. Pilots and controllers are invited to discuss capacity issues and suggest ideas or changes to procedures that are believed to bring improvements.

5.4.3.1 Controller meetings

The concept of enhancing airside capacity may involve a number of changes to ATC operations, including a variety of procedures and techniques to support high intensity runway operations. Support and wide buy-in from ATC staff is essential.

Ensuring that controllers attend forums and develop a sense of ownership is the best way to achieve buy-in.

5.4.3.2 Pilot meetings

Capacity enhancement techniques often affect pilots as much as they do controllers. Support and buy-in is therefore, equally important. It should also be remembered that the pilot community is not as homogenous as that of the controllers.

At the very least the slightly different operating procedures of different airlines mean that the capacity enhancement techniques will need subtly different ways of implementing. Common understanding of the issues by all the pilots is therefore absolutely essential.

5.4.3.3 Joint pilot and controller forum

It is essential that ideas and suggestions are openly discussed between the two groups at a joint forum and that local solutions are investigated.

Airlines business preferences must also be properly represented in any forum to ensure buy-in at airline management level. The output from this group should be a joint action plan that addresses the points observed by both parties.

5.4.3.4 Awareness and Training Campaign

The ASG should also plan for an awareness campaign to all stakeholders, particularly Flight Crews and ATCOs to inform them of the benefits, changed procedures (if any), raise awareness and highlight the most prominent capacity enhancement measures to be implemented. The campaign should be clear about when the changes are expected to be applicable.

5.5 Capacity Enhancement Plan

There is no set template for developing an airport capacity enhancement plan; however, it should follow standard project management methodology which details:

1. Why does the airport need to enhance capacity?
2. What capacity enhancements are needed?
3. What budget and timeline is to be met?
4. What expertise and resources are required?
5. How will the project/s be run and organised?
6. When is the project complete and what post implementation monitoring will occur?
7. What is the measure of success?

This guidance provides a significant input towards point 1. The following sections present a few examples to help with point 2 and 6 however the balance of the questions need to be developed locally through a combination of plans and cost benefit assessments.

The following sections provide some capacity enhancement examples divided up into the three main categories of Infrastructure, People and Procedures and Systems. These are not mean to be exhaustive but provide a starting point for local analysis.

5.6 Capacity Enhancement Infrastructure Factors

The following section contains example infrastructure improvements that could be added to a capacity enhancement plan. Even though each of these would also require changes to procedures or systems support, the dominating focus for the change is the infrastructure enhancement. Other procedures or systems dominated enhancements are presented in following chapters.

5.6.1 Runway

The runway is often an obvious target for enhancement where runway occupancy is of particular interest. Other runway enhancements related to enabling it to receive larger aircraft (e.g. strength, width, length, stop ways) are not covered in this document.

5.6.1.1 Visual Aids

Lights, signs and markings employed at an airport play an important role in a pilot's situational awareness (position, speed, direction to follow).

To minimise runway occupancy time, pilots need to identify their nominated exit as early as possible during roll-out so that they can adjust deceleration accordingly or make an early decision to continue to the next exit. Note as some airports flight crews are instructed which exists are to be targeted either on voice or through AIP published procedures.

As soon as possible after touchdown, a pilot needs to:

- Locate the preferred (or nominated) exit;
- Determine the distance to go;
- Assess speed and deceleration.

There is mounting evidence that runway exit visibility may be improved by RETILS - Rapid Exit Taxiway Indicator Lighting System. The use of RETILS is recommended in ICAO EUR Doc. 013 European Guidance Material on Aerodrome Operations under Limited Visibility Conditions.

5.6.1.2 Rapid Exit Taxiways (RET) Design

The design of a RET needs to match consistent performance from a range of aircraft and pilot performance. For example, exits should not be designed and located to match the best performing pilots or aircraft type. Assessing fleet performance should be done with the major aircraft operators, using actual performance data relating to aircraft types, landing weights, operating practices and ambient conditions.

A correctly designed RET is crucial in minimising runway occupancy time.

The ICAO RET design is currently the most widely used, particularly in Europe, but there are other common designs such as the FAA standard as well as site-specific designs such as those to be found at Paris CDG.

RETs should be designed in accordance with ICAO Annex 14 with reference to the ICAO Aerodrome Design Manual (Doc 9157). The European CS ADR-DSN section

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D.295 (e) states that “The intersection angle of a rapid exit taxiway with the runway should not be greater than 45°, nor less than 25° and preferably should be 30°.”

Perpendicular exits may be retained for use by crossing traffic.

Airports should recommend preferred RETs by aircraft type and promulgate it through the AIP. ICAO standard centerline lights and marking should be provided for all RETs.

Distance-to-go information should be provided to the pilot by RETILS for night/reduced visibility and equivalent markings for day/good visibility conditions.

5.6.1.3 Position of RETs

In order for maximum benefit to be derived from the design of a RET, the runway should be equipped with a series of such exits, correctly positioned with respect to the performance characteristics of the expected or ‘design’ traffic mix. The FAA estimates that a 30m reduction in the distance between threshold and exit reduces runway occupancy time by 0.75 seconds. However, the runway occupancy time of an aircraft which overruns an exit increases by 0.75 seconds for each 30m it has to travel to the next exit.

Guidance on the positioning and number of exits is given in ICAO Annex 14, the Aerodrome Design Manual (Doc 9157) and FAA Advisory Circular 150/5300-13 (Airport Design). These documents separate aircraft into four performance bands based on threshold speeds in the case of ICAO and aircraft weight in the case of the FAA. However, a better assessment of the correct position and number of exits could perhaps be obtained through a detailed examination of the performance characteristics of the actual fleet mix expected to use the runway. A third method for determining the optimum position and number of RETs is by computer simulation.

5.6.1.4 Number of RETs

The fleet mix being designed for is the critical factor in determining the number of RETs required. This information can only be obtained locally, through a collaborative process involving the airport and aircraft operators.

The overall aim should be to have a minimum number of exits, positioned so as to ‘capture’ the largest percentage of traffic, with the lowest average runway occupancy time for each category and for the overall runway. With the exception of the final ‘stop end’ exit, all exits to be used by landing traffic should ideally be RETs.

5.6.2 Taxiways

5.6.2.1 Perimeter Taxiway

Where possible, Aerodrome designs should avoid the need to cross a runway to access a taxiway or other part of the Aerodrome. Limiting the number of aircraft crossing an active runway can be achieved through the use of perimeter taxiways. Perimeter taxiways (that run around the runway ends) avoid aircraft having to cross a runway and can reduce runway occupancy times, taxi times and congestion on the maneuvering area.

Runway End Safety Area (RESA) design and protection of the ILS sensitive area need to be taken into account and as such should pass behind the localizer and not between it and the runway.

5.6.2.2 Holding Bays or Areas

A holding bay is a defined area on the manoeuvring area where aircraft can be held or by-passed, to facilitate efficient surface movement.

Holding bays are especially useful for last minute changes to the departure sequence.

5.6.3 Apron/Gates

Where the airport apron area has one main taxiway/lane where aircraft are parked opposite one another tail on, during pushback, two or more aircraft could be headed for the same centre line resulting in a bottleneck. The installation of an Alternative Parallel Taxiway/Taxi Lane (APTL) system may be possible to resolve these issues. Note however that currently ICAO Annex 14 does not yet provide requirements for the use of this concept.

This system however works on a very simple principle and will maximise use of existing taxiway resources. Put simply the APTL consists of three parallel lines, one centre line and two alternative parallel lines, one either side of the centre line. This configuration enables simultaneous pushback or taxi procedures.

The basic rule of thumb dictates that no aircraft on the centre line can overtake, be overtaken by, or be passed by another aircraft on an APTL. A maximum wingspan on each APTL should be declared so that it complies with the ICAO separation distances provisions. The wingspan of the aircraft permitted to use the APTLs should be the same for each alternate taxi lane.

Where airfield lighting is installed, it should support the use of the APTLs at all times and in all weather conditions. Lighting should be standard green for all centrelines (including APTLs). However, where colour coding of APTLs has been used at Paris CDG, Frankfurt and Munich, corresponding blue/green and orange/green lighting has been installed on the APTLs.

5.7 Capacity Enhancement Human and Procedure Factors

5.7.1 ATC Arrival Sequencing

Air traffic controllers influence arrival rates by tactically adjusting the arrival sequence. This may be used either to increase the rate or to create space for departing aircraft. The sequencing of departing aircraft has a similar impact, especially on single runway airports. Tactical arrival and departure management tools can provide significant assistance to ATC in this optimisation as can the Target Start Up Approval Time (TSAT) generator in Airport – Collaborative Decision Making (A-CDM).

The management of the traffic mix is a critical part of sequence optimisation. The traffic mix is defined for a given period (peak hour / day) as the proportion of each aircraft group.

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The group classification scheme is based on factors that affect the required separation between aircraft: wake vortex category, speed profile, SID, runway occupancy time, etc.

The link between traffic mix and sequence can be established from a probabilistic point of view. For a given traffic mix, there are various possible combinations of arrival or departure sequences (AA, ADA, DD, ADDA) and some combinations produce better performance than others across the various traffic mixes.

The capacity analysis presented in Chapter 4 provides a 'near perfect world' baseline, however it is very difficult to estimate a traffic mix and complex hourly sequence distribution in capacity analysis – i.e. on the day of operations schedule delays, changes in aircraft and other unplanned effects have an impact. However, in the constant process of improving throughput efficiency, efforts to tune the departure and arrival sequence should continue.

Depending on the modes of operation and given aircraft mix, the distribution operating under ADA, AA or DD throughout the day will produce different throughputs. Operator flight schedules are designed to accommodate the requirements of the operator and do not account for the integration of schedules from other operators. As such the approach and departure sequences based on schedules may not provide the best aircraft mix to optimise the use of the runway capacity.

Performing an analysis comparing various assumed traffic mixes with various distributions of ADA, AA or DD periods would produce comparative throughputs. The most efficient scenarios can be selected and coordinated with the operators to share best practice. Tactical sequence management can greatly assist in achieving the best mix however the more strategic support that can be achieved from the operators, the more the tactical gains can be found.

In order to consistently achieve minimum spacing, the runway mode of operation and the prevailing traffic must be taken into account.

For example, in mixed mode operations, wake vortex of departing aircraft need not be factored in when there is a gap in departures while minimum spacing based on radar surveillance, consistent with the wake turbulence category of subsequent aircraft, can be maintained at all times for arrival only runways.

An integrated arrival and departure management tool aims to maximise certain efficient sequences more often thus providing a sustainable capacity increase (see Section 5.7.6).

5.7.1.1 Parallel Runway Modes

Practice has shown that maximum aerodrome capacities can be achieved by using parallel runways in a mixed mode operation. In many cases, however, other factors such as the landside/airside infrastructure, the mix of aircraft types, and environmental considerations result in a lower achievable capacity.

Other factors such as non-availability of landing aids on one of the parallel runways or restricted runway lengths may preclude mixed mode operations at a particular aerodrome.

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Because of these constraints, maximum runway capacity may, in some cases, only be achieved by adopting a fully segregated mode of operation, i.e. one runway is used exclusively for landings while the other is used exclusively for departures.

The advantages to be gained from segregated parallel operations as compared to mixed parallel operations are as follows:

- Separate monitoring controllers are not required.
- No interaction between arriving and departing aircraft on the same runway and a possible reduction in the number of [missed approaches.](#)
- A less complex ATC environment overall for both approach and aerodrome controllers;
- A reduced possibility of pilot error following undetected selection of the wrong ILS.

5.7.1.2 Speed Control

This is essential for the optimum use of the runway and available airspace as well as to enable terminal area and aerodrome controllers to accurately assess the intervals between aircraft. Controllers must provide pilots with information on distance to touchdown (preferably within +/- 5NM accuracy) during sequencing in order that crews can plan energy management during descent and comply with ATC speed restrictions.

Use of standard speeds and continued instruction (once a speed restriction has been applied during the approach) on speed required until reaching the outer marker/4NM point aids efficiency and removes unpredictability for both pilot and controllers.

5.7.1.3 Time Based Separation (TBS)

When there are strong headwinds, aircraft ground speed is reduced on final approach. This results in a reduced landing rate, causing delays and even flight cancellations.

TBS aims at reducing the gap in landing rates in light and strong headwind conditions. It can help maintain airport capacity at the same level in all wind conditions.

The concept of time separation takes advantage of wake vortex quick dispersion in strong headwinds: this fact makes it possible to reduce the ground distance between landing aircraft. Consequently, airports are able to operate with the same landing and capacity rates as in light wind conditions.

As the wake strength impacting on aircraft is lower when there are heavy winds, safety levels will be maintained even if the distance between the pair of aircraft is minor.

Other additional parameters (e.g. the aircraft's final approach speed and deceleration profile) for keeping the right distance have also been identified.

TBS uses a new Human-Machine Interface (HMI) for delivering the required separation minima between aircraft. The Human-Machine Interface displays customised information for approach and control towers. Target distance indicators are displayed on the extended runway centreline of the final approach controller's radar display and the tower runway controller's air traffic monitor display.

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TBS does not change the absolute distance based wake turbulence minima of 3nm (i.e. aircraft pairs where wake vortex minimum applies will never be closer than 3nm) or the appropriate distance based non-wake minima (e.g. 2.5nm between a leading Medium and following Heavy on final approach).

5.7.2 Flight Crew Arrival Planning

Of the elements that affect airside capacity, the time spent by aircraft on the runway is often the most critical. Known as 'Runway Occupancy Time', or ROT, it depends on pilot and controller performance, infrastructure, procedures used and the prevailing meteorological conditions. Runway capacity can be increased by around 5 to 15 % (at single runway and multiple runway airports respectively) by reducing ROT.

On landing, pilot attention is focused on performing a smooth touch down and deceleration. The type and degree of braking employed will depend on the surface conditions and landing weight, taking into account also passenger comfort considerations.

Good planning by the flight crew can make a big difference in arrival ROT. Based on inflight landing performance calculations with current gross weights and meteorological conditions, the crew should choose the most appropriate rapid exit taxiway. Familiarity with the location of these RETs is essential in order to select a sensible exit point. While excessive deceleration is to be avoided, braking to achieve the selected exit taxiway will help reduce the ROT. Note in some cases aircraft with a relatively short turn-around may apply brakes less optimally to ensure they cool sufficiently for departure (e.g. A380 aircraft).

Enhancing the Auto-Brake function to enable the flight crew to pre-set the target runway exit on approach, allows the aircraft systems to automatically optimise the aircraft's deceleration after touchdown. Where this function is available arrival runway occupancy performance would improve and could be coupled to published AIP preferred exits for early planning for the flight crews approach.

In some aircraft the pilot may select an auto-brake setting, based on a preferred or instructed exit, during the approach preparations. Having an alternate exit taxiway is also recommended practice.

5.7.3 Taxi-in/out

5.7.3.1 One-way system

Where the taxiway infrastructure allows, a one-way system should be introduced on the taxiways. This makes orientation easier and taxiing safer, ensuring a swifter flow of traffic.

5.7.3.2 Standard Taxi routes

Implementation of fixed taxi routes allows the use of a consistent system utilising the taxiways in the most efficient order. Having a predictable flow of traffic has proven to increase the efficiency, reduce delays and allow controllers extra thinking time to concentrate on other elements such as optimum departure order. It also helps flight crew to prepare their navigation around the airport. Radio traffic is minimised by simplifying the messages passed by the controller.

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Variations to the standard fixed taxi routes can be given when required but experience has shown that, once introduced, both controllers and pilots prefer to use the standard procedure whenever possible.

5.7.4 Gate Operations

Replacing voice with digital link to deliver routine messages (e.g. pre-departure clearances) has been shown to be a very effective capacity enabler. However, implication upon situational awareness of other airfield users should be assessed prior to any such implementation.

Parking stands are a valuable finite resource, wasted when used to absorb Calculated Take Off Time (CTOT) or other operational delay. Remote holding areas have no function (or associated equipment) other than to allow the freeing of (fully equipped) parking stands on the airport terminal area. Agreement is required between ATC, Airlines and Airport Operator to adopt this procedure.

Remote holding areas must be pre-determined and then managed by ATC in co-operation with the airport operations unit. This procedure may not be applicable to all airfield layouts since it requires sufficient space to safely hold aircraft prior to departure without encroaching on runways, taxiways, etc.

Minimum safe separation distances must be maintained at all times.

Adequate separation must also be maintained to ensure that ground crew and other airfield users do not suffer from jet blast and engine ingestion at any time during the tactical pushback.

However, remote holding has a counter effect such as higher fuel consumption and emissions, an effect that is less and less desired. Processes within A-CDM provide the means for more effective management of ground traffic and delivery to the runway.

5.7.4.1 Ground Holding

Ground holding is an air traffic management tool used at airports to balance capacity with demand when necessary.

Unavoidable ground holding provides a further opportunity for air traffic control to optimise the departure sequence, e.g. by pushing back some aircraft ahead of others to separate them along the same departure route, or to ensure a departure can be achieved between two arrivals.

Ground delay processes can be optimised by introducing A-CDM and implementation of a departure sequence management tool.

5.7.5 Runway Line up and entry

The procedures used by ATC and flight crews regarding runway entry and line up clearances can have a substantial effect on departure runway occupancy.

5.7.5.1 Runway Holding Point

If instructed to wait at a runway holding point, pilots should complete as many take off checks as possible while waiting. This saves valuable time once line-up is authorised. It is essential that pilots are made aware of their position in the departure sequence.

A procedure for multiple line-ups on the same runway may be employed where ATC instruct pilots to line up and wait after a departing aircraft. ICAO⁶ contains procedures and requirements (such as phraseology, visibility, jet blast or prop wash, frequency etc.) to be met when applying this procedure. The European Action plan for the Prevention of Runway Incursions (currently EAPRI Edition 2.0) also refers to this procedure however it specifically refers to aircraft departing from different points on the same runway and not the same intersection however this is not precluded from ICAO.

This procedure ensures that an aircraft will be fully lined-up and ready to depart as soon as the take-off clearance is given. Priority is always given to ensure that unnecessary delays do not occur in issuing clearance to line up.

Obliquely angled taxiways, which limit the flight crew's ability to see the runway threshold and final approach area, should be avoided when using this technique.

Local procedures may allow for multiple line ups from the same intersection however a local safety case should be performed to ensure no risk of confusion or other safety effects (jet blast etc.) exists.

5.7.5.2 Conditional Clearances

Conditional clearances expedite traffic by allowing pilots to proceed immediately after the condition has been satisfied instead of having to wait for the controller to issue the clearance.

The use of conditional clearances must at all times be in accordance with the applicable ICAO provisions both in terms of procedure and phraseology.

The wording of the clearance must leave no ambiguity as to the identity of the aircraft that the clearance is dependent on.

The procedure requires the controller to issue the restriction and the identity of the restricting traffic before the clearance.

Issued in this order, the possibility of the Clearance being heard and then responded to whilst the Controller is adding a restriction to the Clearance (causing a 'blocked' dual transmission by Flight Crew and Controller) is removed.

Conditions specific to each situation where a conditional clearance may be used further reduces the potential for confusion.

For example, an aircraft can be issued with a runway line-up, entry or crossing clearance that is conditional upon one other movement only, be that a landing or a departing aircraft.

⁶ ICAO Doc 7030 EUR 6-4, section 6.5.3 "Multiple Line-ups on the same runway", as well as ICAO Doc 4444 Chapter 12.3.4.10 under "Preparation for Take-off".

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If the movement concerned is a landing aircraft, then that aircraft must be the first aircraft on approach. In the case of multiple departures, a conditional clearance is only issued subject to the aircraft that is immediately ahead in the departure sequence. Other important aspects are the physical conditions of the airfield and the meteorological conditions in so far as their effect on visibility for flight crews, drivers and controllers.

In the case of runways, visibility must be such that the controller can clearly and continuously see the aircraft that is being given the conditional clearance and the aircraft or vehicle that the clearance is conditional upon. The visibility and physical conditions of the airfield shall also be such that the flight crew, in receipt of a conditional clearance, can clearly and continuously be able to see the aircraft or vehicle upon which the clearance is conditional.

Obliquely angled taxiways that limit the ability of the flight crew to see the runway threshold/final approach area should be avoided also when using conditional clearances.

5.7.6 Departure

The period between take-off clearance and starting the take-off roll is not a time to be rushing. The priority for pilots is to ensure that the aircraft is correctly configured, that ATC clearances are understood and complied with, and that the position and activity of other relevant aircraft are known.

Once on the runway, pilots complete their final checks in readiness for take-off. At this point the aim is to react promptly to the take-off clearance. Here seconds really do count. Good awareness of the traffic sequence can be used to anticipate the take-off clearance.

The average reaction time to the take-off clearance at major European airports is 11 seconds. Studies have shown that by reducing this to 7 seconds could add 2 extra departure slots per hour. Sequences that allow the aircraft not to stop on the runway not only save time, but also fuel and emissions.

5.7.6.1 Intersection Departure

An aircraft may be instructed to line up and take off from a point on the runway other than the beginning of the runway. Such intersection departures decrease taxi times and improve the management of the departure sequence.

An intersection take-off sign should be provided when there is an operational need to indicate the remaining Take-Off Runway Available (TORA) for intersection Take-Off. The TORA value should also be published in the AIP for all intersections from which intersection take-offs may be authorised.

Obliquely angled taxiways, that limit the ability of the flight crew to see the runway threshold/final approach area, should be avoided when using this procedure.

5.7.6.2 Departure Clearance

Issuing the line-up and take-off clearance as early as possible prompts pilots to complete all necessary checks and move from the taxiway to the runway without

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stopping. This can save valuable time, especially if coupled (at the discretion of flight crews) with a rolling take-off.

The possible introduce a mixed time and distance-based separation procedure to optimise the Minimum Departure Interval (MDI) could be assessed. The procedure works through the use of a simple system of aircraft categorisation, based on aircraft climb speed and published in tabular format, to determine recommended departure intervals for various aircraft combinations, runways and departure routes.

Following safety assessment, local regulatory approval and controller training, it is possible for runway controllers to assess the actual spacing being achieved by application of the speed table departure intervals. The controller can then adjust the time based interval by observing the preceding departure passing the point on the radar display at which time the succeeding aircraft should be cleared for take-off in order to achieve the minimum permissible departure intervals.

Departure intervals between all IFR flights are determined by the category of the aircraft involved. If a subsequent departing aircraft is in the same locally published performance group as the previous there is a predetermined separation, usually two minutes. An extra minute is added to this basic separation for each performance group lower by which the previous departure is classified.

If the departing aircraft type is not listed in the locally published table, then individual co-ordination is required between tower and departure radar controllers.

Where approved, tower controllers may optimise these pre-determined intervals by the use of radar derived information. Minimum vortex separation requirements must be adhered to at all times.

5.7.6.3 Early Turns After Departure

Instructing departing aircraft to turn away from runway heading as soon as possible after take-off allows the number of subsequent departures in a given period of time to be maximised.

Standard Instrument Departures (SIDs) should be designed with tracks diverging as soon as possible after departure. Local noise abatement requirements may however not allow aircraft departure route to be amended below certain altitudes.

5.7.6.4 Aircraft Type Specific SIDs

SIDs may be developed for aircraft meeting specified noise level requirements and/or light aircraft, facilitating their speedy departure.

These may be used in conjunction with early turn departure and visual separation techniques.

5.7.6.5 Visual Separation After Departure

In good weather conditions, pilots may be instructed to maintain their own separation from other traffic immediately after take-off. This technique is particularly useful when used in conjunction with early turn departures or diverging SID routes and enables shorter intervals between departures, hence increasing capacity.

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5.7.7 Promising Procedural Best Practices

The following are a selection of suggested best practice procedures for capacity enhancements.

1. Provision and use of multiple holding points to enable flexible and efficient runway use.
2. Introduction of procedures enabling an aircraft to overtake the No 1 aircraft in the sequence to achieve the most efficient departure order.
3. Not issuing start-up clearance unless sure that the aircraft can make the departure slot time (CTOT).
4. Enhance runway efficiency by allocating different holding points for use by aircraft on specific SIDs.
5. The sequence of aircraft presented at the runway holding points should take into consideration wake vortex categories, aircraft speed and SIDs.
6. Use of a Coordinator/Watch Manager role enables the wider airfield picture to be seen by the Tower and can be particularly useful for planning during busy periods.
7. Use of airport surveillance systems can assist with the efficiency of taxiing and can also have safety benefits.
8. Use of conditional clearances to expedite aircraft line-ups and taxiing. The use of a separate Clearance Delivery Controller and radio frequency as appropriate. Phraseology for this procedures can be found in ICAO Doc 4444 Section 12 and the EAPRI Edition 2.0.

5.8 Capacity Enhancement System Factors

Often both infrastructure and procedures enhancements include an update to the system capabilities. For airside capacity these are often related to ATC systems although not exclusively. One particular area where system tools are increasingly being implemented to increase capacity is that related to A-SMGCS, Arrival Managers and Departure Managers.

5.8.1 Advanced Surface Movement Guidance & Control System (A-SMGCS)

A-SMGCS (Advanced Surface Movement Guidance & Control System) is a system providing routing, guidance and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rates under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety (ICAO Doc 9830: Advanced Surface Movement Guidance and Control Systems (A-SMGCS) Manual).

A-SMGCS is a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstances with respect to traffic density and complexity of aerodrome layout, taking into account the demanded capacity under various visibility conditions.

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A-SMGCS is more than just a set of systems, it also includes complementary procedures and at the lower levels of implementation aims to deliver improved [situational awareness](#) to controllers. Higher levels of implementation deliver [safety nets](#), conflict detection and resolution as well as planning and guidance information for pilots and controllers.

One such higher level of A-SMGCS is the Follow-the-Green (FtG) application validated by SESAR⁷. The concept is explained by its name, in that the green runway exit or taxiway centreline lights are displayed for the flight crew to follow to their destination (gate or runway). However, there are a number of variations that have developed ranging from basic versions to more advanced versions including those that work within current ICAO procedures to those suggesting new procedures.

All FtG concept variations share a common 'routing' or 'surface manager' feature, as the lighting system requires knowledge of each aircraft's surface route to be able to light the way. The routing capability varies from manual systems (i.e. the human creates and activates the route) to fully automated ones (i.e. system automation using surveillance and electronic flight progress strip data with the human in the loop).

Other enablers are required to achieve higher levels of automation such as surveillance systems, advanced human machine interfaces, electronic strips, advanced Visual Docking Guidance Systems integration and more.

5.8.2 Arrival Manager (AMAN)

AMAN systems are designed to provide automated sequencing support for the ATCOs handling traffic arriving at an airport, continuously calculating arrival sequences and times for flights, taking into account the locally defined landing rate, the required spacing for flights arriving to the runway and other criteria.

AMANs are also used as "metering" tools, assisting in regulating the flow of traffic into the TMAs surrounding busy airports.

Helping to make best use of the available capacity at an airport combined with a more efficient, and predictable, arrival management process can assist in reducing low-level holding and tactical intervention by the ATCO, leading to lower fuel consumption, less noise and pollution.

5.8.3 Departure Manager (DMAN)

An advanced ATC tool for optimizing runway throughput thus increasing runway and airport capacity is the DMAN. It assists ATC in managing departure traffic, by providing takeoff sequences as well as optimised departure trajectories, in order to achieve optimal use of runway capacity and TMA airspace. The DMAN is often integrated into an A-CDM application to link target or calculated take off times and off block times (also TSATs) at the gate to the turnaround process.

⁷ SESAR VP-649 in 2013 and VP-759 in 2015 performed by the SESAR European Airports Consortium (SEAC) and VP-761 in cooperation with Latvijas Gaisa Satiksme and Eurocontrol

5.9 Change Implementation

Change Implementation at an airport is a complex task as most enhancements affect multiple stakeholders with different objectives. As the changes become more complex, the level of innate knowledge shared by all stakeholders' decreases and a program of education and shared understanding is critical to ensure all parties are clear about what is being achieved or targeted by the change.

There are numerous project management methodologies associated with initiating and managing a change however they are not in scope of this guidance material. Most airports will have a set style of project management however this may differ from those used by the Operators or the ATC operational organisation and as such a tailoring process should be run to find the most suitable approach.

Change management is not only about project management but also cultural changes, training and communication, timing and sharing of benefits and a clear joint agreement on what the change is and why the change is necessary. If applied through a capacity team environment across all stakeholders, this guidance material provides a methodology to assist in collaborative understanding of why and what changes are needed. The implementation and monitoring process should continue that collaborative approach.

5.10 Performance Monitoring

Once a change has been implemented, sustaining that change and integrating it into the ongoing operational paradigm is critical to ensure the capacity of the airport is positively impacted. As defined in Section 3.1 capacity is about what can be sustained as opposed to short-term peak management. Additionally, returns on investment targets also normally require a post implementation assessment on how the project did compared to estimated benefits so lessons can be learnt.

When running a performance monitoring program, it is important to understand what performance indicators are being targeted. Chapter 3 provides details on the current main performance areas for the airside and concludes on Capacity as opposed to delay related areas such as Efficiency and Predictability. In total there are 11 KPA's defined by ICAO Doc 9883 that cover such areas as cost effectiveness the environment and so on which are not in scope of this guidance.

In regards to monitoring performance, its relationship to day of operations throughput is a key focus area. It is therefore vital that the real time external environment is monitored and recorded (weather, system failures etc.) as well so that correlations can be performed when trying to understand why throughput was lower than expected during heavy demand periods. The overall aim is to achieve the baseline capacity as much as possible.

In addition to comparing to day of operations data, a constantly reviewed baseline capacity assessment should be performed to update the comparative model and ensure the throughput figures are being compared to the best-in-class that the airport can achieve. This is highlighted in Figure 12.

6 LOCAL AIRPORT EXAMPLES

The following examples have been provided to show how the capacity assessment methodology as presented in this guidance material, and in particular the three capacity definitions (see Section 3), have been applied in practice at European airports. Also of particular relevance is the important role the baseline capacity assessment plays in terms of enhancement selection, business case derivation and performance monitoring.

6.1 London Heathrow

For many years Heathrow's capacity modelling experts have worked closely with NATS Analytics to use fast time simulation tools and analysis to test and optimise designs for new infrastructure, determine the runway capacity available each season, as well as to assess and minimise the impact of closing parts of the airfield for maintenance. NATS ATC are involved by providing technical advice and validate all results.

The first stage in any simulation modelling is to create a baseline model that mirrors the current situation. Sharing this model with all relevant airport stakeholders and getting their agreement that this represents reality is a worthwhile step and generates trust for the forthcoming simulation results.

As well as allowing different design options to be evaluated by comparing output metrics, fast time simulation allows different traffic schedules to be modelled and modified designs to be reassessed quickly and consistently. Modelling outputs also prove to be useful tools for communication and discussion with stakeholders assisting the decision making process.

Heathrow's airfield modelling assesses runway throughput as well as considering taxiways and stands. For large infrastructure projects landside capacity is modelled separately but results are shared and cross checked by project teams to ensure results are aligned.

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6.1.1 LHR Structural Airside Capacity – Terminal 2

Background	<p>The original Terminal 2 building opened in 1955 and during its 55 years of operation over 300 million passengers passed through it. It closed in November 2009 and was demolished to make way for the construction of a new terminal designed around the passenger experience – continuing the airport transformation that began with the opening of Terminal 5 in 2008. The new Terminal 2, The Queen’s Terminal, opened in June 2014.</p>
Purpose	<p>Simulation modelling was completed in advance of the new terminal being built to:</p> <ul style="list-style-type: none"> • validate the location and design of the new terminal; • validate that the number and size of stands was suitable for current and future traffic demand; • identify any bottlenecks either around the terminal or the airfield, • indicate that ATC workload would be acceptable.
How we did it?	<p>Once the design was completed, an airfield layout was drawn which included the locations and sizes of the stands as well as likely aircraft routings. At the same time assumptions were agreed for use of the stands and the terminal and current and future schedules were provided to test the model.</p> <p>Fast time simulation models were then used to compare different configuration options. Each model was validated by NATS ATC and provided a range of output metrics including taxi time, delay and workload figures. The models proved that the concept of operations for the new terminal would be effective and that airside performance would achieve the required standards.</p>
Who was involved?	<p>Heathrow ATM; Heathrow Master Planning; NATS Analytics; NATS ATC Stakeholders from airline and ground handler community.</p>
Collaboration	<p>At each stage internal and external stakeholders were kept up-to-date and involved with progress. Airlines were involved in assessing design options and had a forum for airing ideas and concerns.</p> <p>The results were validated by ATC.</p>

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<p>Communication</p>	<p>Communication was critical at all stages and was achieved through Steering Groups and Working Group involving both internal stakeholders and key partners.</p> <p>As it was a large scale project, the simulation modelling formed one part of a much wider programme and as such the communication was centralised across the airport.</p>
<p>Challenges</p>	<ul style="list-style-type: none"> • Assumptions changing to reflect amended design details; • Accounting for airline / alliance preferences; • Time and cost pressures; • Ensuring the appropriate interpretation of modelling outputs.
	

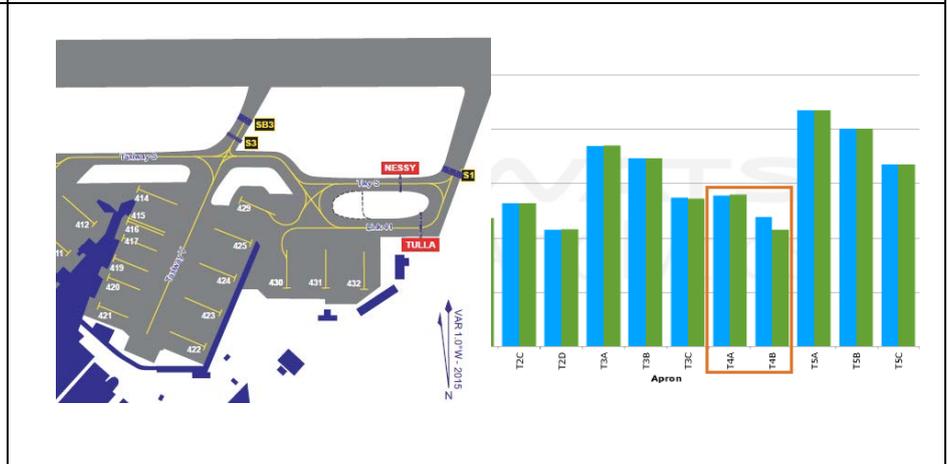
AIRPORT CAPACITY ASSESSMENT METHODOLOGY

6.1.2 LHR Planned Airside Capacity – Taxiway Sierra Closure

Background	<p>A section of Taxiway Sierra had to be closed for approximately 10 months in order for it to be repaired. During this period as well as losing part of the taxiway, certain stands had to be closed and access to the runway was affected. It was important to understand the impact on the airfield of carrying out this repair so mitigations could be made where possible and stakeholders communicated with.</p>
Purpose	<p>Simulation modelling was carried out on what was considered to be the most constraining mode of operation (27L departures) to:</p> <ul style="list-style-type: none"> • estimate the impact on the whole airport operation in terms of runway throughput as well as any increase in delay; • identify any localised impacts of this closure – including certain times of day, access to certain stands or certain parts of the airfield.
How we did it?	<p>The issue was prioritised by the Airfield Transformation team who established, owned and managed the airfield infrastructure programme of works. It was their responsibility to eliminate and de-conflict the risks and issues associated with this critical work.</p> <p>Fast time simulation models were used to assess the effects of the taxiway closures. The models were validated by NATS ATC and provided a range of output metrics, including taxi time and delay figures. The models proved that the effects of the taxiway closure could be managed in such a way to minimise disruption to the operation.</p>
Who was involved?	<ul style="list-style-type: none"> • Heathrow ATM; • Heathrow Transformation Manager; • NATS Analytics; • NATS ATC • Stakeholders from airline and ground handler community.
Collaboration	<p>The Airfield Transformation Manager engaged with the airline community to eliminate and de-conflict risks and issues as well as ensuring the work was completed safely, efficiently and to plan.</p> <p>Due to the cost and long timescale involved it was necessary to communicate widely within Heathrow to ensure support did not wane over time.</p> <p>As the closure affected ATC operations it was important to involve them both to define alternative routes and to guarantee that the temporary procedures in place while the repairs were underway</p>

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	were manageable.
Communication	As certain airlines were likely to be more impacted than others it was necessary to work more closely with them to run through a variety of scenarios to allay specific concerns.
Challenges	<ul style="list-style-type: none"> to complete on time and to budget; to ensure any impacts of the taxiway closure were shared across the operation rather than affecting any airline in particular.



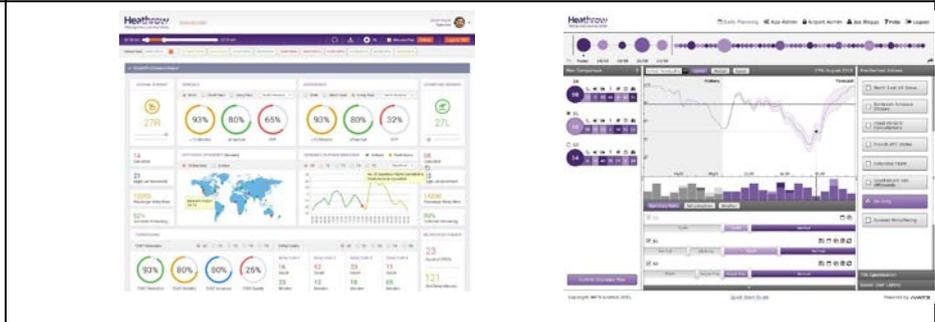
AIRPORT CAPACITY ASSESSMENT METHODOLOGY

6.1.3 Operational Capacity – Demand Capacity Balancing

Background	<p>The daily operation at Heathrow does not always run to schedule as airline performance is affected by a number of external factors - in particular weather (locally or en-route), industrial action across Europe and congestion.</p> <p>This uncertainty in the operational performance is heightened because in a high-intensity operation demand and capacity are intrinsically linked.</p>
Purpose	<ul style="list-style-type: none"> • To predict operational performance more accurately and precisely during and prior to the day of operation. • To improve all operational areas that directly affect punctuality and efficiency by generating a balanced plan with the aim of reducing departure route congestion and inbound stacking. • To share the plan with the airport operational stakeholders (including airlines, ground handlers, Airport Operations Centre (APOC)).
How we did it?	<p>Building a demand and capacity balancing system starts by predicting the situation before considering flow management. Initially a plan for a day is generated by balancing aircraft demand (predicting arrival and departure times) with airport capacity.</p> <p>The first step to predicting the operation is to understand the factors that drive performance changes (e.g. en-route winds, local weather, airline behaviour etc.). The schedule is also a key component as combinations of aircraft type, SID routes etc. can all influence capacity. These factors were used to build simulation models and create a more realistic prediction of how the operation changes from day-to-day. The same simulation models are then used to test alternative strategies and develop optimal solutions that balance the needs of all stakeholders.</p> <p>Such tactical processes build and extend upon the strategic capacity declaration and airfield master planning as well as the SESAR APOC concept.</p>
Who was involved?	<ul style="list-style-type: none"> • Heathrow Airfield Flow Managers; • APOC Members; • Heathrow IT; • NATS Analytics; • NATS ATC • Stakeholders from airline and ground handler community.

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<p>Collaboration</p>	<p>Collaboration is critical to the success of Demand and Capacity Balancing. As the outcomes may directly affect ground staff (e.g. re-fuelling personnel, stand planners) and passengers it is vital that implications are understood and principles agreed.</p> <p>Airport, ATC and Ground resource all need to be aligned for this to work.</p>
<p>Communication</p>	<p>As this affects all stakeholders at the airport it is absolutely critical to communicate frequently and honestly and to develop open channels of communication.</p>
<p>Challenges</p>	<ul style="list-style-type: none"> • developing the model for this is a new concept ensuring the factors are relevant and predications are accurate; • managing expectations of stakeholders; • combining outputs from live data feeds • ensuring the appropriate interpretation of modelling outputs by users and stakeholders.



6.2 Geneva

Geneva Airport, with its 15 Million annual passengers and 190,000 annual single runway movements has been growing for the past years at an annual rate of 5% in terms of passengers and of 2% for movements.

Operational airside complexity reduces capacity and stems in part from general aviation which represents 20% of aircraft movements and operates on a “volatile” schedule, using all types of aircraft (single engine, turboprops and jets). The remaining aircraft movements are scheduled traffic, this includes a mix of aircraft types ranging from Dash 8’s, category C aircraft (80%) up to category E aircraft.

Lack of land space makes for tight restrained areas to exit the runway, manoeuvre and park.



Figure 13: Stands have become a scarce resource during peak hours

Terrain is another factor reducing airside capacity. The Jura Mountains peaking at 1,600m that border the airport along the north and the Alps border the southern part with the Mont Blanc towering at 4,810m making for restrained approach and departure routes. Peak traffic for many years has been the winter ski weekends clogging up terminal space and using all the available aircraft stands.

Landside capacity problems stem from the terminal that was built in 1968 and planned to accommodate 5 Million passengers per year which was achieved in 1986.

6.2.1 Structural Capacity – Macro Strategic

Master Planning was for many years based on “feeling” and historical data as opposed to forecasted figures.

The Airport Capacity Enhancement (ACE) program was implemented in 2009 and provided the necessary structure to analyse and improve airside capacity. It targeted mainly runway capacity and addressed 3 domains: systems, procedures and Infrastructure.

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Driven by the airport and working hand in hand with the ANSP, two home based airlines and local handling companies, many capacity improvements were initiated and completed as shown in the figure below.

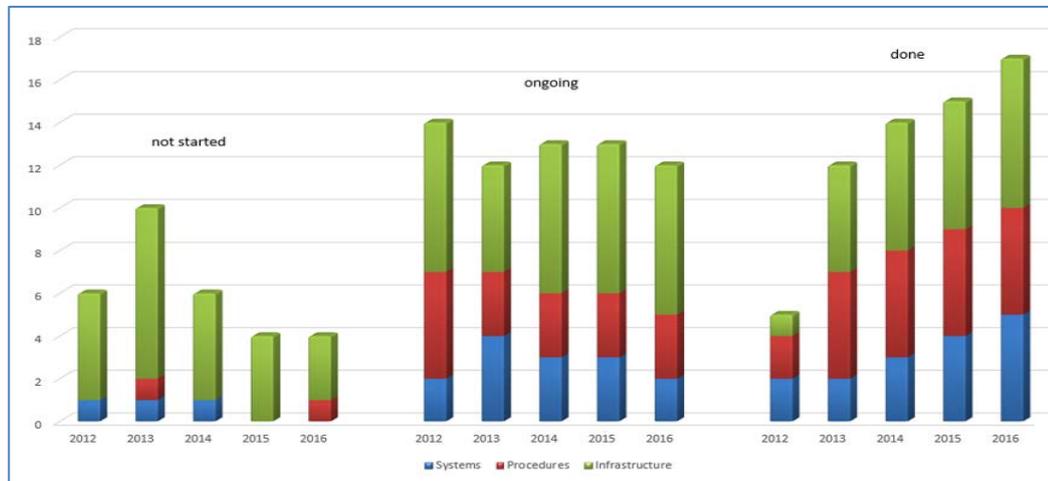


Figure 14: Airside capacity enhancement projects per year at Geneva Airport

As an example, with the help of EUROCONTROL's PIATA+ analysis tool and airside data collection the baseline capacity was calculated and the team identified that adding a rapid exit taxiway on runway 05 would reduce the runway occupancy time and increase capacity. Fast time simulation was used to see the effect on the departing and arriving traffic flow including potential taxiway bottlenecks. This was also consistent with the recent master plan work that determined runway capacity would have to increase from the current 40 movements per hour to 47 in 2030. Other solutions such as Time Based Separation for arrival traffic needs to be explored to help increase runway capacity in the future.

The ACE program and its potential enhancement projects are now coordinated with higher level roadmap discussions that involve the civil aviation authority and the ANSP. We are also trying to initiate a Landside Capacity Enhancement program to convince stakeholders the benefits it would bring.

6.2.2 Planned Capacity – Strategic

Meetings are held twice a year (6 months prior to season) with the national coordinator, marketing department, Airport Operations Centre, and local ANSP to determine next season's capacity constraints. Currently, historical capacity figures are used for the terminal (no greater than 3,000 passengers per hour arrivals or departures) and for airside (36 movements per hour, 4 reserved for general aviation, maximum of 21 arrivals per hour). Stakeholders agree that this method is not appropriate anymore considering the shortage of gates and stands during peak Schengen/non-Schengen flights. **For many years the peak winter season was planned with pure local knowledge estimations however, it has become more complex and a systematic approach is required.**

Recently during the capacity process accuracy issues were identified in the scheduling from one of the airport's largest carriers (40% market share) and analysis was needed to work out the gap in pre-tactical planning.

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The airside has been a major focus in past years however now there are new problems arising landside, most recently in security check delays and terminal bottlenecks.

Since security planning is the big issue due to expensive sub-contracts with third parties for human resources, with the help of a third party specialist, planning is done for the next 365 days and checks are done to see if KPIs are met. Extensive analysis has been done to determine and improve the baseline capacity per security lane (throughput) to better plan when to open more lanes based on forecasted passenger throughput.

6.2.3 Operational Capacity – Pre-tactical

No specific plan is made before the day of operations. Certain airlines that have several flights to the same destination will spontaneously combine 2 flights into 1 if possible to reduce the number of movements. However, one drawback is evening delayed flights that end up operating during later noise-sensitive time frames.

The airport has started work on determining capacity contingency plans based on worse case scenarios triggered by the weather (TCU's, fog or snow), industrial action or a potential closed runway.



Figure 15: Snow removal and winter operations

6.2.4 Lessons learned and way forward

Whether you are experiencing delays or not, the airport has gained valuable assistance from performing a detailed analysis of the various airport processes to see what baseline capacity is. Data collection is a good start.

Depending on how critical delays, saturation and financial aspects become in the different airport processes, “coping” is not a viable solution and capacity planning needs to be initiated. **However, getting the corporate culture to adopt this new mind-set takes time and determination ... and budget.** However, these costs are small compared to the costs to the operators, the airport and the passengers.

Addressing current procedures to increase capacity can easily turn out to be a quick win and not as expensive as improving infrastructure.

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Figure 16: Check-in hall during a weekend ski season

Geneva airport is committed to capacity assessment as part of total airport planning in the future.

7 ACRONYMS and REFERENCES

7.1 REFERENCES

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7.2 ACRONYMS

Abbreviations and acronyms used in this document are available in the EUROCONTROL Air Navigation Inter-site Acronym List (AIRIAL) which may be found here:

[AIRIAL \(Air Navigation Inter-Site Acronym List\)](#)

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