# AIRPORT CAPACITY RESILIENCE: Capacity Symmetry

## Purpose of the study

The airport capacity declaration and associated scheduling process entails high complexity as it is influenced by many different factors.

Airport Airside Capacity refers to the ability of the airport runway/taxiway/apron system to handle a given demand of flights within a specified time period, incurring an acceptable level of delay (to be determined by the airport stakeholders). It is defined by the International Civil Aviation Organisation (ICAO) as the ‘number of movements per unit of time that can be accepted during different meteorological conditions’ [1], whilst Airport Council International defines it in terms of ‘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’ [2].

Airport capacity is a combination of the available infrastructures, the existing ATM systems and the capabilities of human actors. On the infrastructures side, capacity could by increased by extension works on the airside area. Investments in the runway system are usually the most expensive, so the capacity at the apron, taxiway system and terminal should always be adapted to get the most out of the runway system, being this the determining factor for overall capacity. Additionally, new technology and reduction in aircraft sequencing could result in an airport capacity growth when accounting for the operational side.

Among all factors affecting the runway system capacity, the runway configuration is considered as the most relevant. While some airport layouts allow for very similar operation conditions in one runway configuration or another, resulting in equal or similar capacities for all possible runway configurations, other layouts do not offer that “symmetric capacity” as the different configurations might have very different operating conditions, dependencies and limitations.

This study analyses **the potential difference in capacity depending on the runway configuration, associated with the probability of each configuration**. Runway configurations are analysed for 16 European airports every 15 minute intervals, together with their peak service rate and their percentage of usage in order to determine their imbalance associated risk.

There are therefore 2 main elements to investigate:

* Capacity per runway configuration: understood as the peak service rate of each configuration and calculated as the 99th percentile of the peak throughput in 1h intervals.
* Runway configuration use: understood as the percentage of time each configuration is in use at each airport during the period being analysed.

## The interdependency triangle

Airport capacity, demand and delay are three elements that influence each other (see Figure 1). Capacity refers to the theoretical traffic density the airport can serves while the demand corresponds to the airline scheduled operations in correspondence to the theoretical capacity. Both elements are linked by the delay which results from the demand/capacity imbalance. If one of them changes, the other 2 elements might be affected (so if we allow more delay, we might be able to handle more demand).

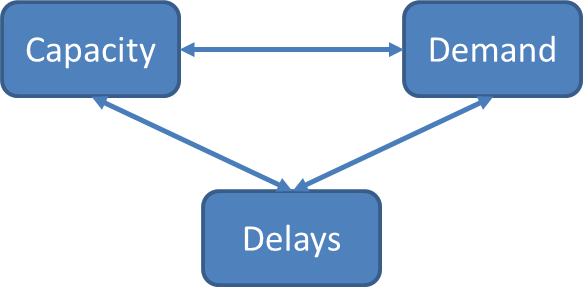


Figure 1: The interdependency triangle

In the case of a change in the runway configuration that reduces the capacity, different scenarios are possible:

* If the change is unforeseen, the demand is unlikely to be adapted to this reduction in capacity. If that demand is higher than the new capacity, there will be an impact on the airport performance and related delays.
* If the change is unforeseen but the demand remains below the new capacity, the airport system should cope without an impact on performance.
* If the change is foreseen (i.e. night runway configurations), demand should be adapted without an impact on delays. The chance for demand/capacity imbalance is kept to a minimum but still can exist.

## Capacity analysis

One of the main difficulties found while developing the present study deals with the calculation of the airport capacity, as there is no universal method for this calculation. Although all methods might take into account similar factors, there are different approaches. Among the elements used in such studies are: structural layout (runway, taxiway, apron, gates, terminals, local airspace); environmental impact and economic factors.

The analysis and methodologies will also depend on the time horizon for which the capacity calculation is being made, serving different purposes in the airport capacity plans, as shown in Figure 2



Figure 2: Airport capacity planning phases.

An example of capacity calculation methodology would follow these steps:

1. Historical throughput data (track performance & areas to prioritize)
2. Tables & analytical models (high level starting point)
3. Simulation models (fast time and real time)
4. Pareto frontiers (optimum solution)

Nevertheless, as previously mentioned, not all airports do regular capacity studies or follow the same steps. At the moment the only common information repository including airport capacity is Eurocontrol’s Airport Corner [3] where airports can report their capacities on a voluntary basis. Ideally, this information is provided per runway configuration. However, many airports do not provide any information in this regard. Even when the information is available, the differences between methodologies and recurrence in the capacity studies for airports across Europe makes very difficult to have a consistent capacities database.

## Runway configuration

The preferable runway direction is related to **the wind conditions (direction and speed)** but the choice of runway configuration (OPS) also depends highly on other factors:

* **Demand**. Arrival and departure demand play a key role in configurations selection, especially in high demand situation when high capacity configurations are preferred to serve incoming traffic.
* **Meteorology (ceiling & visibility + wind gusts)**. Besides wind speed and direction, other meteorological conditions are of great importance for runway configuration, such as visibility and cloud ceiling and wind gusts that can cause serious harm to aircraft on its vicinity.
* **Noise abatement procedures**. Noise abatement procedures are used at most major airports in order to reduce noise impact on neighbor communities and are normally active at night and early morning period.
* **Inertia (controllers’ preference)**. Air traffic controllers tend to prefer certain runway configurations or to remain in a same runway configuration in order to avoid changes, so it has an important factor on configuration selection.
* **Time of the day (curfews)**. The time of the day influences the staff availability and the range of possible runway configurations that can be selected.
* **Coordination (TMA/airport)**. Flows in and out the airport need to be coordinated, especially in multi airport Terminal Maneuver Areas.
* **Other factors:** Unavailability of runways (works in progress, maintenance, …)

Research studies on runway configuration are mainly focused on configuration selection process prediction. These investigations are based on two types of models: prescriptive & descriptive:

* Prescriptive models: Look for an optimal solution (accounting different factors)
* Descriptive models: Conduct historical data analysis

Examples on configuration prediction models include a data-driven model using discrete choice modeling framework which computes configuration prediction in every next 15 min interval, extended to 3h probabilistic forecast. Case studies performed in LGA and SFO airports in USA reveal an accuracy of ≈80% [4] Another example is a decision-tree based model to predict airport acceptance rate used as a decision support tool in Ground Delay Programs (GDPs) [5].

## Available data

Given the lack of consistent capacity data, the approach will focus on the available data in the Airport Operator Data Flow managed by the PRU.

The Airport Operator Data Flow is established for 81 airports (status as end 2018) and it includes, amongst other extensive data for every flight, the runway time (that is, take off time for departures and landing time for arrivals) for every movement, the type of movement (arrival or departure) and the runway used.

The data is provided monthly by the airport operators and integrated in a common database after data quality checks.

A total of 16 airports among the 81 available are selected for the purpose of these studies. The airports are: Brussels (EBBR), Frankfurt (EDDF), Munich (EDDM), Helsinki (EFHK), Manchester (EGCC), London Heathrow (EGLL), Amsterdam (EHAM), Copenhagen (EKCH), Oslo (ENGM), Warsaw (EPWA), Barcelona (LEBL), Paris Charles de Gaulle (LFPG), Milano Malpensa (LIMC), Roma Fiumicino (LIRF), Lisbon (LPPT) AND Zurich (LSZH).

Data for the feasibility analysis consists on a case study for five airports: EGCC, EDDM, LEBL, EGLL and EPWA. The converage of their runway usage (share) as per the threshold of 5% is as follows:

|  |  |
| --- | --- |
| **AIRPORT** | **SHARE** |
| EGCC | 99,1% |
| EDDM | 98,3% |
| LEBL | 96,8% |
| EGLL | 94,2% |
| EPWA | 93,0% |

The study is conducted for the calendar year 2018, covering the time window between 6 and 23h Local Time.

## Analysis

The APDF data allows for a post-ops data driven analysis covering the runway use. The objective is to extract the runway system configurations based on the historic data. In parallel, as a proxy for capacity, the peak service rate (that is, the percentile 99 of the hourly throughput) will be calculated for each of these runway configurations.

 Figure 3: Steps of the analysis.

For each airport the analysis involves the following steps:

1. Establish the time intervals that will be used for identification of the runway configuration. Normally these will be 15 min intervals, but might be extended depending on complexity of the runway system to allow for identification of all active runways.
2. Identification of active runways and type of movement (Arr/Dep) in each time interval using each runway.
3. Identification of runway configuration for each time interval and calculation of the time share for each runway configuration. To identify typical configurations, a minimum share of 5% of the analysed time has been considered. 5% proves to be a reasonable threshold to discard non-representative configurations but still cover more than 90% of the operations in 2018 for the tested airports.

The time window considered is 6 to 23h local time to discard night operations where the demand is normally too low to consider the peak service rate as a proxy for capacity and the configurations that are mainly related to environmental constrains.



Figure 4: Identification of runway configuration.

1. The calculation of the peak service rate requires first the calculation of the throughput for each time interval (resulting in 15 minutes rolling hours’ throughput)
   1. For each 15 min time interval (i), check configurations in the following 45 min [(ii), (iii), (iv)]. If the configuration observed in (i) is also observed in at least 2 of the next 3 intervals [(ii), (iii), (iv)], the hourly throughput is considered valid for that configuration (TRUE), calculated (Arrivals, Departures and Total) and associated to the time interval (i).

The reason to allow 1 in 4 time intervals to correspond to another configuration is to allow for some unexpected movement that does not purely fit with the runway configuration (in the example below, the use of runway 25R for a departure of a Heavy aircraft, although that was not the active runway for departures in that hour).



Figure 5: Calculation of peak throughput.

* 1. For all valid throughputs calculated (that is, for configurations that are sustained in 3 of 4 consecutive time intervals), calculation of the percentile 99 (peak service rate) for each runway configuration with a representative share (>5%).



Figure 6: Representative runway configurations and peak service rates.

1. Once both the chance of a certain runway configuration and the corresponding peak service rate have been established, the capacity resilience for a given configuration, *conf* *i*, will be calculated as:

Where:

1. Finally, the airport capacity resilience:

## Results

TO BE DEVELOPED. PRELIMINARY RESULTS FOR 16 AIRPORTS INCLUDED ON ANNEX I.

Results for the feasibility analysis for the five selected airports, sorted by resilience percentage from largest to smallest:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **AIRPORT** | **CONFIGURATION** | **P99 TOTAL THROUGHPUT** | **PROBABILITY** | **CAPACITY REDUCTION** | **RESILIENCE** |
| EGCC | ARR:23R - DEP:23L | 52 | 48,71% | 0% | 100% |
| EGCC | ARR:05R - DEP:05L | 51 | 12,21% | 2% | 100% |
| EGCC | ARR:05L - DEP:05L | 40 | 10,71% | 23% | 98% |
| EGCC | ARR:23R - DEP:23R | 40 | 27,48% | 23% | 94% |

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| --- | --- | --- | --- | --- | --- |
| **AIRPORT** | **CONFIGURATION** | **P99 TOTAL THROUGHPUT** | **PROBABILITY** | **CAPACITY REDUCTION** | **RESILIENCE** |
| EDDM | ARR:26L - ARR:26R - DEP:26L - DEP:26R | 89 | 52,87% | 0% | 100% |
| EDDM | ARR:08L - ARR:08R - DEP:08L - DEP:08R | 88 | 45,43% | 1% | 99% |

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| --- | --- | --- | --- | --- | --- |
| **AIRPORT** | **CONFIGURATION** | **P99 TOTAL THROUGHPUT** | **PROBABILITY** | **CAPACITY REDUCTION** | **RESILIENCE** |
| LEBL | ARR:25R - DEP:25L | 70 | 72,76% | 0% | 100% |
| LEBL | ARR:07L - DEP:07R | 70 | 14,19% | 0% | 100% |
| LEBL | ARR:02 - DEP:07R | 56 | 9,81% | 20% | 98% |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **AIRPORT** | **CONFIGURATION** | **P99 TOTAL THROUGHPUT** | **PROBABILITY** | **CAPACITY REDUCTION** | **RESILIENCE** |
| EGLL | ARR:27R - DEP:27L | 91 | 31,31% | 0% | 100% |
| EGLL | ARR:27L - DEP:27R | 91 | 30,65% | 0% | 100% |
| EGLL | ARR:09L - DEP:09R | 90 | 32,29% | 1% | 100% |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **AIRPORT** | **CONFIGURATION** | **P99 TOTAL THROUGHPUT** | **PROBABILITY** | **CAPACITY REDUCTION** | **RESILIENCE** |
| EPWA | ARR:33 - DEP:29 | 43 | 49,69% | 0% | 100% |
| EPWA | ARR:11 - DEP:15 | 42 | 43,26% | 2% | 99% |

In EDDM and EGLL the capacity reduction is of 1 movement from the capacity reference configuration to the minimum resilience configuration, so it should be further research the impact of the 1 movement reduction in airport performance.

## Conclusions

TO BE DEVELOPED

## Annex I: Preliminary results for 16 airports



## References

1. ICAO. *Doc 9883 “Manual on Global Performance of the Air Navigation System”*, 1st Edition (2009).
2. ACI. *“Guide to Airport Performance Measures”*, (2012).
3. EUROCONTROL Airport Corner. *(*[*https://www.eurocontrol.int/articles/airport-information-management*](https://www.eurocontrol.int/articles/airport-information-management)*).*
4. Avery, Jacob, and Hamsa Balakrishnan. *"Predicting airport runway configuration: A discrete-choice modeling approach"* (2015).
5. Jones, James C., et al. "*Predicting & quantifying risk in airport capacity profile selection for air traffic management*" *14th USA/Europe Air Traffic Management Research and Development Seminar (ATM2017), Seattle, USA*. (2017).