Airfield Capacity

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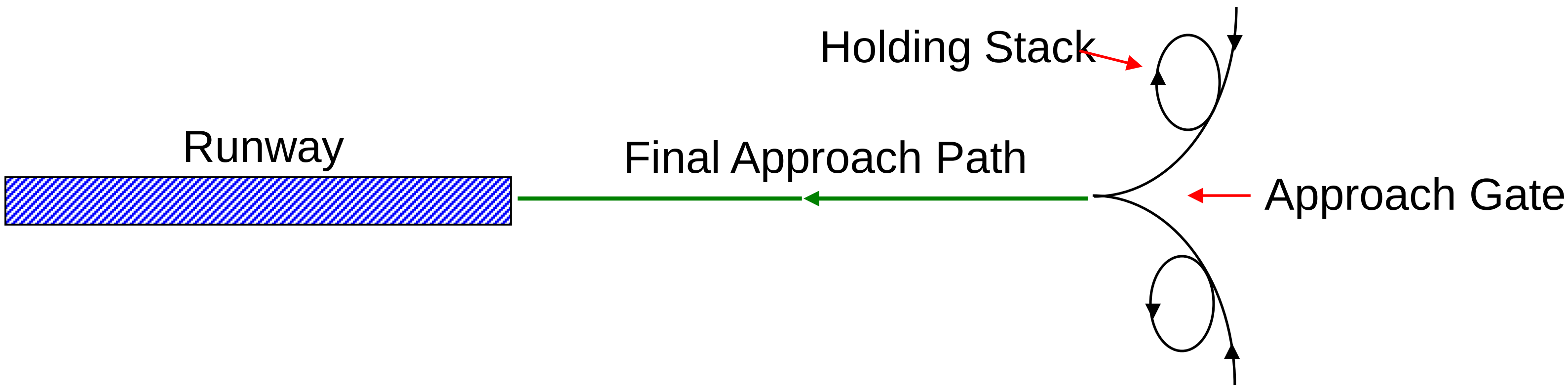
Airfield Capacity

- **Objective:**
  - To summarize fundamental concepts re. airfield capacity and related issues
- **Topics:**
  - Definitions of capacity
  - Factors affecting capacity
  - Separation requirements
  - Capacity envelopes and capacity coverage charts
  - Declared capacity and slot coordination

Reference: Chapter 10, de Neufville and Odoni

The Principal Bottleneck



- The runway systems of the world's busiest airports act usually as the principal bottlenecks of the air transport system's infrastructure
- While other components of infrastructure may also occasionally act as bottlenecks, the capacity of runway systems is the **most "resistant to expansion"**

Definitions: Runway Capacity*

- *Maximum Throughput (or Saturation) Capacity*

  The expected ("average") number of runway operations (takeoffs and landings) that can be performed in one hour without violating air traffic management (ATM) rules, assuming continuous aircraft demand.

- *Declared Capacity* [tied to *Level of Service* (LOS)]

  The capacity per hour used in specifying the number of slots available for schedule coordination purposes; used extensively outside US; no standard method for its determination; no generally accepted LOS; ***typically set to about 85-90% of saturation capacity***; may be affected by stand/gate capacity, passenger terminal capacity, etc.

** These definitions can be applied to a single runway or to the entire complex of runways at an airport.*

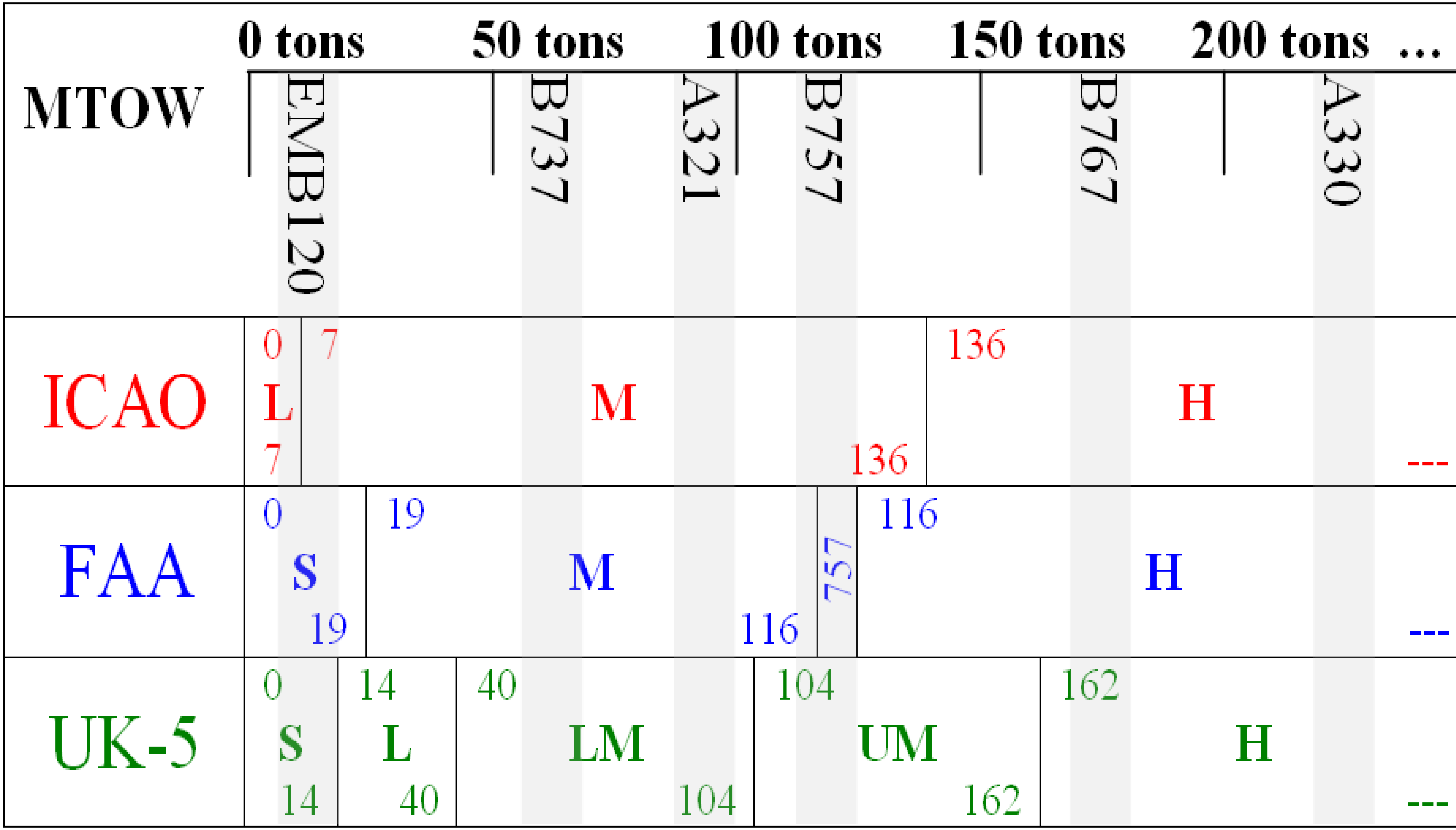
Factors Affecting Runway Capacity

- Number and layout of active runways
- Separation requirements (longitudinal, lateral)
- Weather (ceiling, visibility)
- Wind (direction, strength)
- Mix of aircraft
- Mix and sequencing of operations (landings, takeoffs, mixed)
- Quality and performance of ATM system (including human factor -- pilots and controllers)
- Runway exit locations
- Noise considerations

Role of ATM Separation Requirements

- Runway (and airfield) capacities are constrained by ATM separation requirements
- Typically aircraft are separated into a small number (4 or 5) of classes according to their maximum takeoff weight (MTOW)
- Example: ICAO classification
  - Super Heavy (SH): Airbus 380 [560 tons], Boeing 747-8
  - Heavy (H): 136 tons ≤ MTOW [and <SH]
  - Medium (M): 7 tons ≤ MTOW < 136 tons
  - Light (L): MTOW < 7 tons
- Required separations (in time or in distance) are then specified for every possible pair of aircraft classes and operation types (landing or takeoff)
- Example: "arrival of H followed by arrival of M requires 5 nautical miles of separation on final approach"

Aircraft Classes for Terminal Area ATM Purposes



"Super Heavy": A380 (560 tons), B747-8 (448 tons)

ICAO Recommended Separations*: Arrival - Arrival

	TRAILING A/C			
LEADING A/C	Super Heavy	Heavy	Medium	Light
Super Heavy	4	6	7	8
Heavy	4	4	5	6
Medium	3	3	3	5
Light	3	3	3	3

* Separations shown in n. miles (1 n.mile =1.852 km)

- **In addition, leading aircraft must be safely out of runway before the trailing aircraft can touch down on the runway**
- **Separations behind SH and H aircraft are greater because of the "wake vortex" (or "wake turbulence") effects**

ICAO Recommended Separations*: Departure - Departure

	TRAILING A/C			
LEADING A/C	Super Heavy	Heavy	Medium	Light
Super Heavy	150	150	180	180
Heavy	90	90	120	120
Medium	90	90	90	90
Light	90	90	90	90

*** Approximate separations in seconds (vary according to national practices)**

Numerical Example: Inputs

Aircraft Characteristics			
Type	Mix (%)	Approach Speed (knots)	Runway Occupancy Times (sec)
Heavy (1)	20	140	60
Medium (2)	50	120	55
Light (3)	30	100	50

Single Runway; Arrivals only

Length of Final Approach = 5 n. miles

Separation Requirements

	Trailing Aircraft			
Leading Aircraft		1	2	3
	1	4 n.m.	5 n.m.	6 n.m.
	2	3 n. m.	3 n.m.	4 n.m.
	3	3 n.m.	3 n.m.	3 n.m.

Numerical Example [2]

Matrix of average time intervals, t_{ij} (in seconds), for all possible pairs of aircraft types:

$$[t_{ij}] = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 113 & 181 & 226 \\ 87 & 100 & 154 \\ 87 & 100 & 118 \end{bmatrix} \end{array}$$

Matrix of probabilities, p_{ij}, that a particular aircraft pair will occur:

$$[p_{ij}] = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 0.04 & 0.1 & 0.06 \\ 0.1 & 0.25 & 0.15 \\ 0.06 & 0.15 & 0.09 \end{bmatrix} \end{array}$$

Numerical Example [3]

- By multiplying the corresponding elements of the matrices [p_{ij}] and [t_{ij}] we can compute the average separation (in seconds) between a pair of aircraft at the runway in question.

That is: Numeri

$$E(t) = \sum_i \sum_j p_{ij} \cdot t_{ij}$$

$E(t) = (0.0\ )\ 14\ () + (0.3\ )\ 1\ () 8 + (0.0\ )\ 26\ () 2$
$+ (0.1)\ 8\ ) + 7 (0.2\ )\ 15\ () 0 + (0.01\ )\ 15\ () 5$
$+ (0.0\ )\ 26\ ) + 7 (0.1\ )\ 15\ () 0 + (0.0\ )\ 9\ ()$

↑ E(t) = 124 sec

- Max throughput/saturation capacity typically stated as no. of aircraft per hour

Saturation Capacity = 3600 / 124 sec = 29

The Concept of the "Runway Configuration"

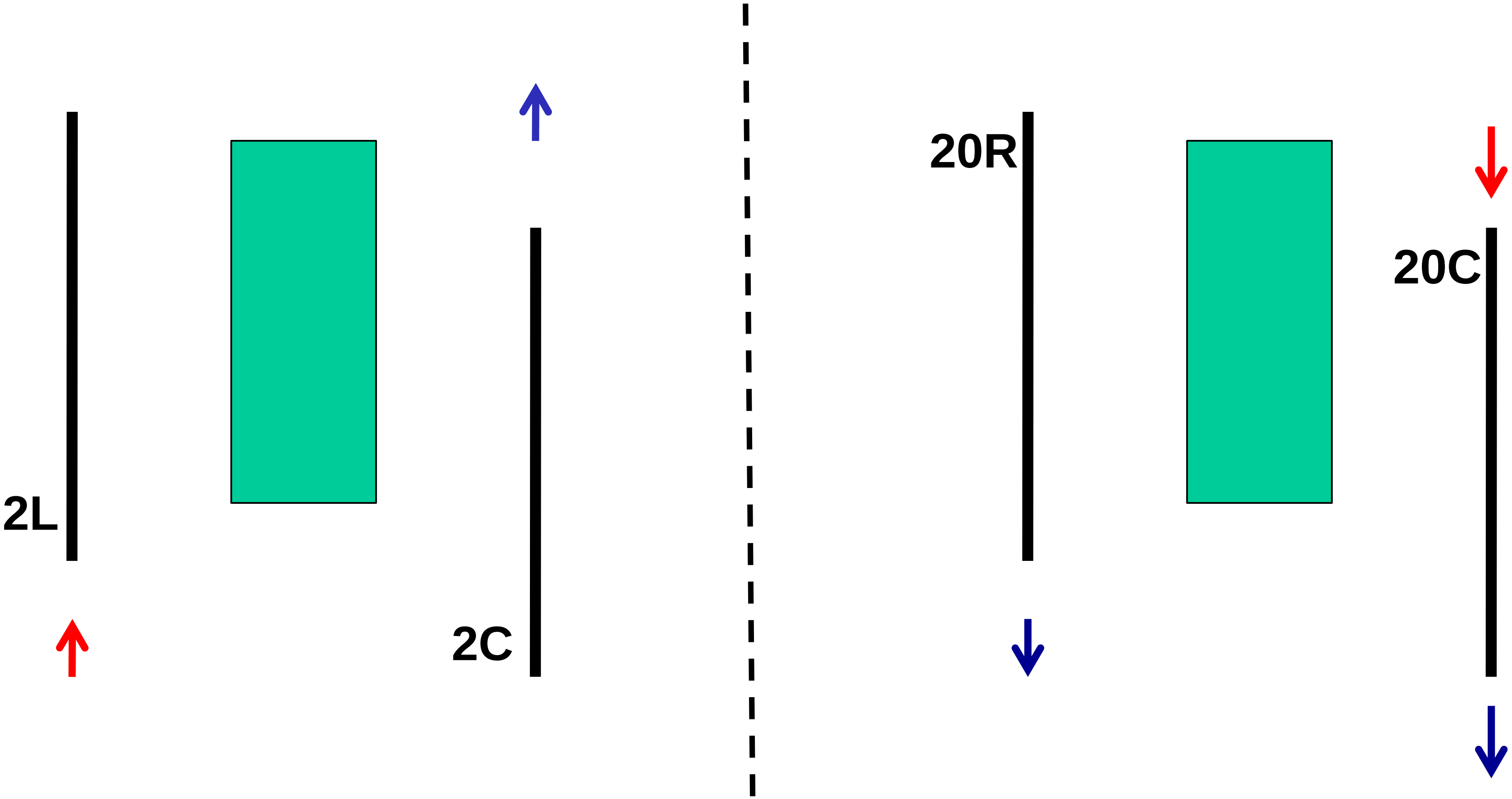
- Multi-runway airports can operate in any one of many possible "configurations".
- Each configuration is described by:
  - The set of runways which are active
  - The type of operations (arrivals only, departures only, or mixed) assigned to each of the active runways
- Example: A possible configuration at IST consists of "05 for arrivals, 35L for departures" (denoted as "05|35L")
- Weather and wind direction and strength play a major role in the selection of a configuration – occasionally allowing a single choice only
- But air traffic managers often have the option of selecting among many alternative configurations (e.g., in calm winds)

Capacity Varies with Runway Configuration

- The capacity of a runway system depends on the runway configuration in use, which, in turn, depends on weather conditions and wind
  - At many airports, where weather is variable airside capacity can also be highly variable and difficult to predict even a few hours in advance

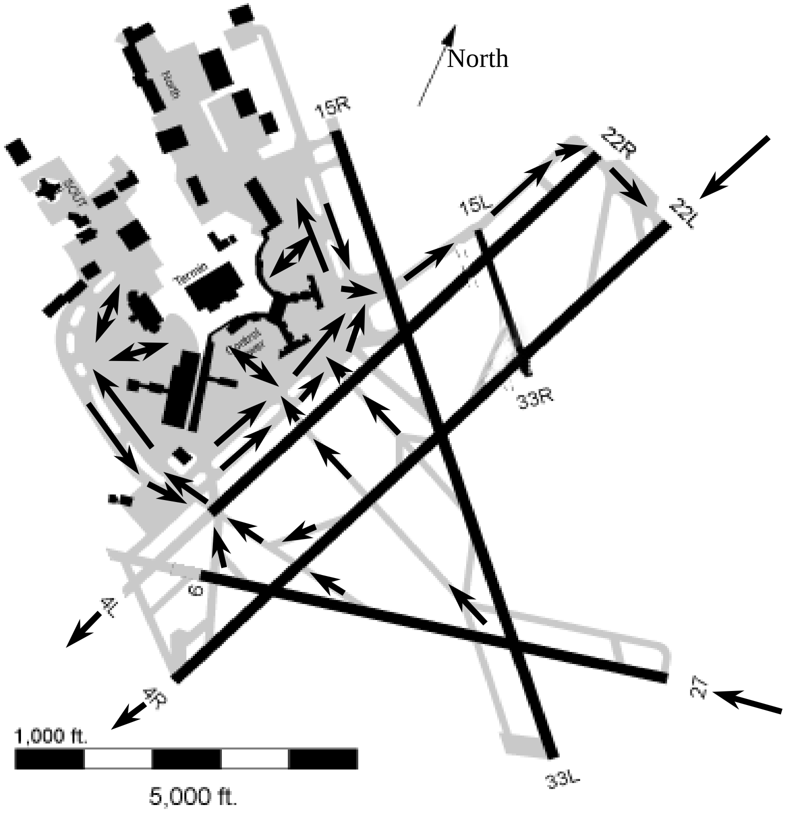
Istanbul Atatürk (IST) Airport

Singapore: Example of Two Configurations

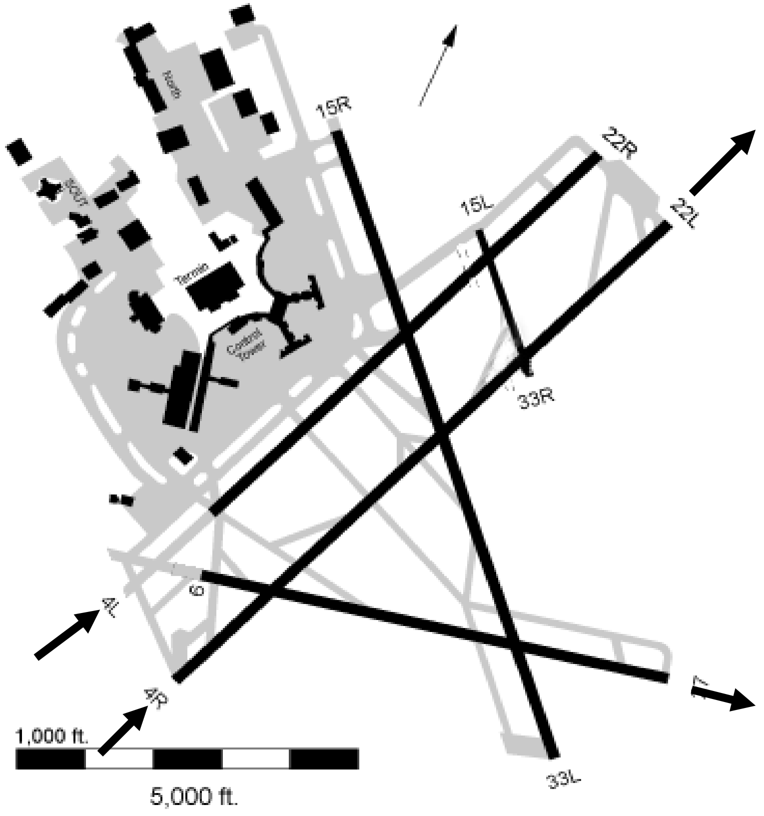


High-capacity configurations in opposite directions, Boston/Logan (VMC)

27-22L | 22R-22L



4R-4L | 4R-4L-9



Parallel Runways (IFR)

Separation between runway centerlines	Arrival/ arrival	Departure/ departure	Arrival/ departure	Departure/ arrival
Closely-spaced 700/1200 – 2500 ft (213/366 – 762 m)	As in single runway	As in single runway	Arrival touches down	Departure is clear of runway
Medium-spaced 2500 – 5000* ft (762 – 1525* m)	1.5 nmi (diagonal)	Indep’nt	Indep’nt	Indep’nt
Independent > 5000* ft (> 1525* m)	Indep’nt	Indep’nt	Indep’nt	Indep’nt

* 3400 ft (1035 m) or 4300 ft (1310 m) are alternative limits; 3000 ft (915 m) stated as feasible by ICAO and FAA, subject to conditions

Toronto Lester B. Pearson International

LBPIA: Single-Runway and Dedicated Two-Runway Capacities

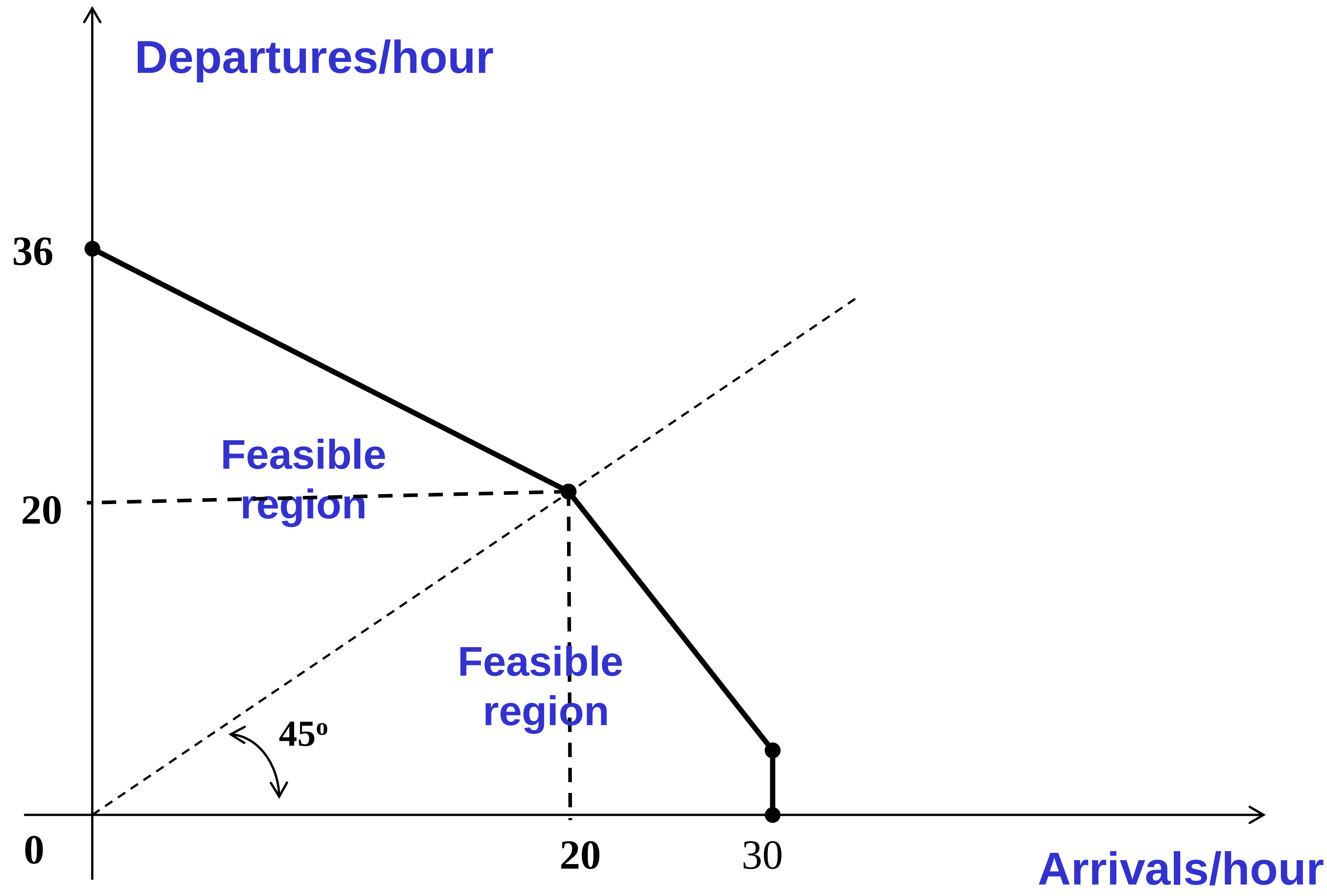
Type of Operation	Example Runway Configuration	IMC	VMC
Single Runway, Mixed Operations	Arr 05, Dep 05	48	56
Dedicated Dependent East/West Operations	Arr 06R, Dep 06L	60	70
Dedicated Independent North/South Parallel Operations	Arr 15R, Dep 15L	63	65
	Arr 33L, Dep 33R	68	75
Dedicated Independent East/West Parallel Operations	Arr 05, Dep 06L	80	82
	Arr 23, Dep 24L	80	82

Summarizing Runway System Capacity

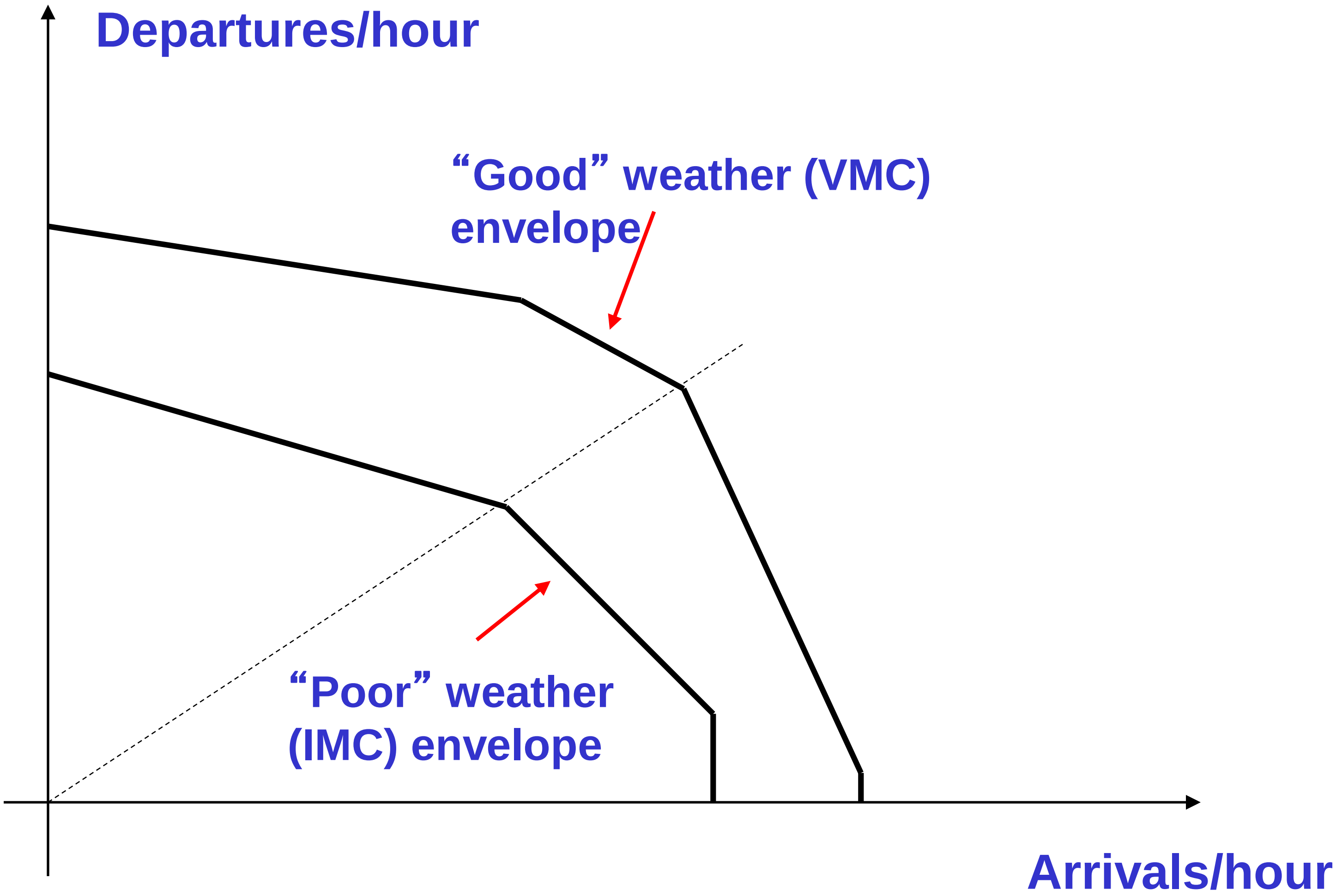
- Capacity envelopes: For a specified runway configuration, show what combinations of arrivals and departures are feasible to perform per hour or per 15 minutes

- Capacity coverage charts: For a specified long period of time (one year, one month) show how much total capacity is available at the airport for what percentage of time

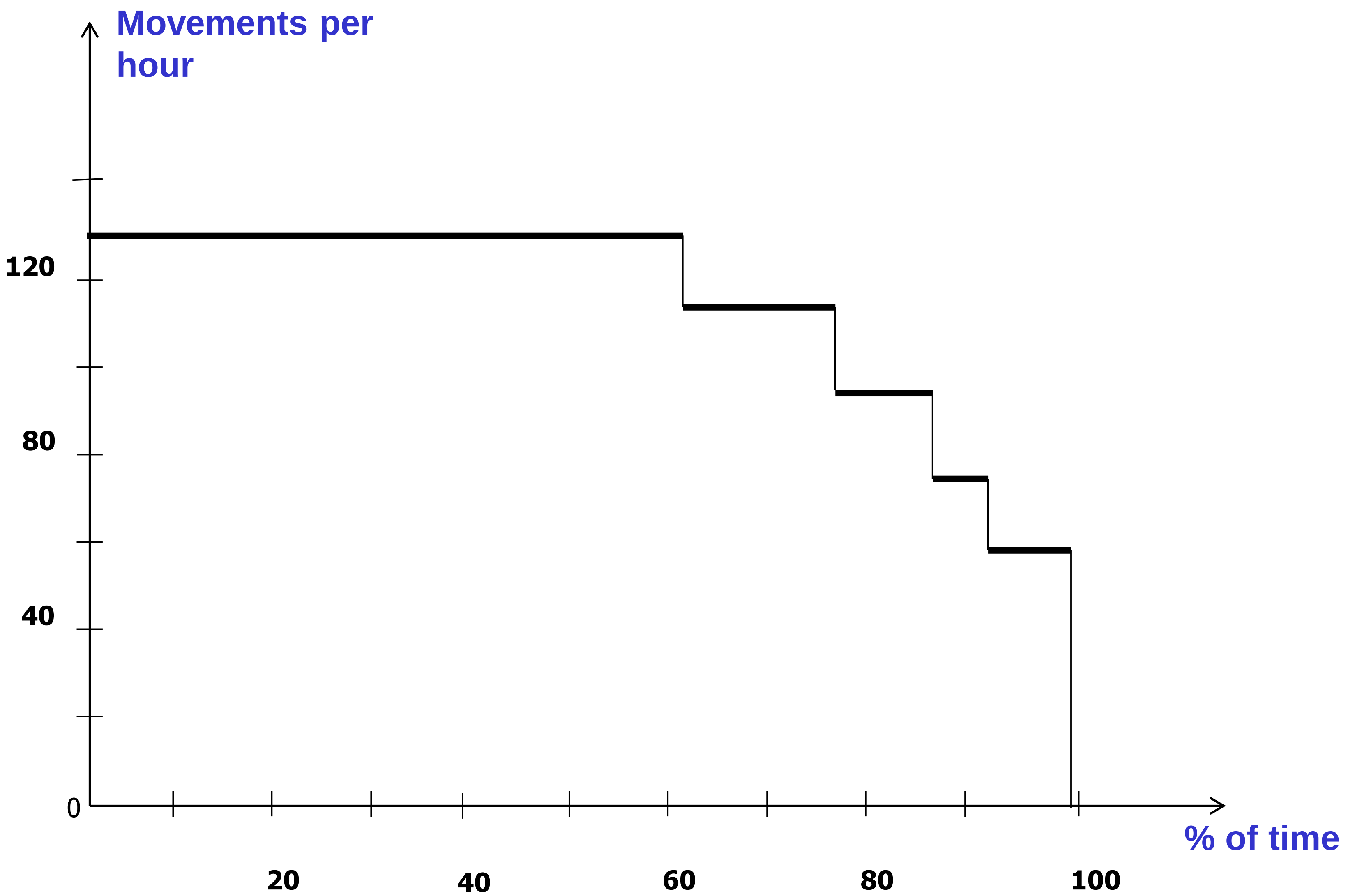
Typical capacity envelope ("Pareto envelope") for a single runway



Visual Meteorological Conditions (VMC) vs. Instrument Meteorological Conditions (IMC)



Annual Capacity Coverage Chart: Boston/Logan



Capacity Coverage Chart (CCC)

- The CCC summarizes statistically the supply of airside capacity
- CCC requires a capacity analysis for all weather/wind conditions and runway configurations
- “Flat” CCC implies predictability and more effective utilization of airside facilities
  - Operations (takeoffs and landings) can be scheduled with reference to a stable capacity level
  - Fewer instances of under-utilization and over-utilization of facilities

Increasing Runway Capacity

- At high levels of utilization, even small increases in the capacity of the runway system can have a large impact on air traffic delays
- This is the motivation behind many of the current efforts of airport operators and of ANSPs (e.g., NextGen and SESAR)
  - Reducing, even marginally, separation requirements (e.g., at many US and several European airports)
  - Improved precision in separations, especially on arrival
  - Sequencing of landing aircraft to minimize the use of wake vortex separations (e.g., LHR, Denver, Dallas/Ft. Worth)
  - Intersection departures to reduce separations between departures (e.g., Munich, LHR)
  - Time-based inter-arrival separations in headwinds (LHR)
  - Re-definition of aircraft classes (RECAT)

IFR Separation Requirements: Single Runway (USA)

Arrival-Arrival:

(1) Airborne separations on final approach (nmi):

Trailing aircraft

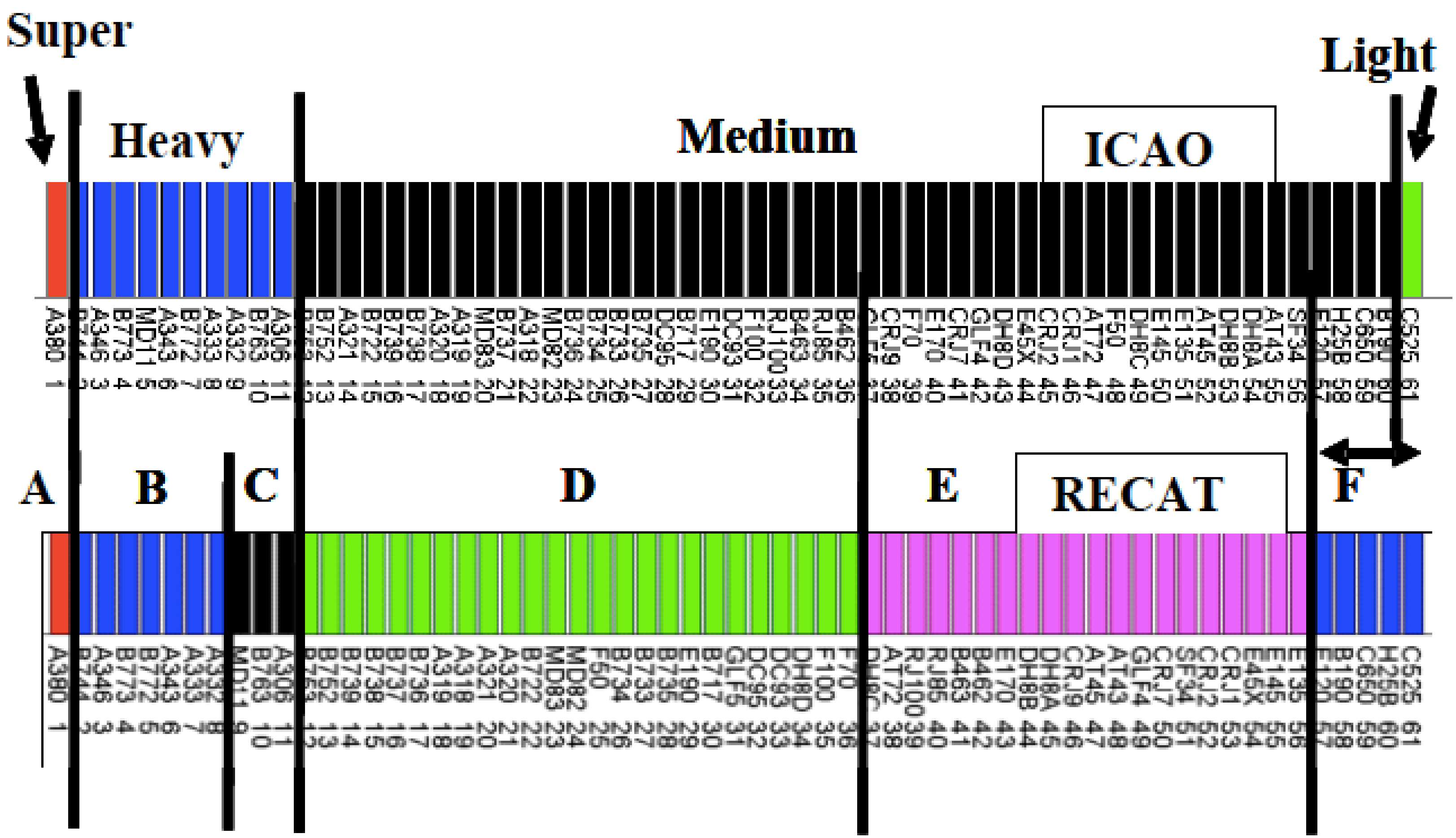
Leading aircraft

	H	L or B757	S
H	4	5	6*
B757	4	4	5*
L	2.5	2.5	4*
S	2.5	2.5	2.5

** Applies when leading aircraft is at threshold of runway*

(2) Leading aircraft must be clear of the runway before trailing aircraft touches down

Current ICAO vs. Proposed RECAT Classes



Need for More Capacity

- ATM innovations will result in only limited increases in *runway system* capacity at the busiest airports [e.g., +10% – 20%(??) over 20 years]
- Quantum increases in capacity can only come from new airports or new runways at existing airports
- Practically no new primary airports planned in North America and Western Europe; several in Asia (India, China, Middle East)
- New runways are planned at a very few busy airports in Europe and US and at many major airports in Asia

Range of Airfield Saturation Capacities

- The saturation capacity of a single runway varies greatly among airports, depending on ATM rules and performance, weather conditions, traffic mix, operations mix and other factors identified earlier
- At major commercial airports, in developed countries, the typical range per runway in good weather conditions is
  - 25 – 44 arrivals per hour for arrivals-only operations
  - 30 – 55 departures per hour for departures-only ops
  - 30 – 56 movements per hour for mixed ops
- Depending on the number of runways and the airport's geometric configuration, total airfield capacity of major commercial airports ranges from 30 per hour to 260+ per hour

Capacity of Taxiways

- The capacity of the taxiway system is rarely, if ever, the capacity bottleneck of major airports
- However, some specific parts of the taxiway system may consistently act as “hot spots” (points of congestion), especially at older, limited-area airports
- Local geometry and traffic flows determine the location of these hot spots
- The blocking of groups of stands by a single lane passage is one of the most common examples of such taxiway hot spots
- Much more common problem: long taxiing times (15+ minutes) associated with surface movements, as the airfields and runway systems of busiest airports become ever more expansive and complex

Madrid Barajas Airport (MAD)

Capacity of Aprons/Stands

- Often a tough problem!
- Different stands can accommodate different sizes of aircraft
- Remote vs. contact stands
- Shared use vs. exclusive use (airlines, handlers)
- Dependence among neighboring stands
- Static capacity: No. of aircraft that can be parked simultaneously at the stands. (Easy!)
- Dynamic capacity: No. of aircraft that can be accommodated per hour. (Can be difficult to compute.)

Stand Blocking Time (SBT)

- Scheduled occupancy time (SOT) [30 minutes to 4 hours, except for overnight stays]
- Positioning time (PT) [5 – 20 min for in-and-out]
- Buffer time (BT) [can be more than 1 hour at some locations]

$$SBT = SOT + PT + BT$$

No. of aircraft served by a single gate rarely exceeds 6 – 7 per day and can be significantly less for gates serving long-range flights

Questions? Comments?