Airfield Design Specifications

Prof. Amedeo R. Odoni

Airport Systems Course
Massachusetts Institute of Technology
Fall 2004

Airfield Design Specifications

Objective:

- To outline briefly the fundamental ideas behind the design specifications of airfields

Topics:

- Principal sources
- ICAO and FAA reference codes
- Airport/aircraft compatibility issues

Reference: Chapter 9

Airport Design Specifications

- **The two most-commonly used sources of geometric specifications for airfield design are:**
  1. **ICAO Annex 14 ("Aerodromes") and associated supplements and manuals**
  2. **FAA Advisory Circular 150/5300-13 ("Airport Design")**
- **FAA updates of specifications are usually developed earlier than updates to ICAO Annex 14 (e.g., Group VI standards)**

Classification (FAA)

Aircraft Approach Category

- **A: Speed < 91 knots**
- **B: [91 - 121) knots**
- **C: [121 - 141) knots**
- **D: [141 - 166) knots**
- **E: Speed 166+ knots**

Airplane Design Group

I: Wing < 49 ft (15 m)

II: [49 - 79) ft (15-24 m)

III: [79 - 118) ft (24-36)

IV: [118 - 171) ft (36-52)

V: [171 - 214) ft (52-65)

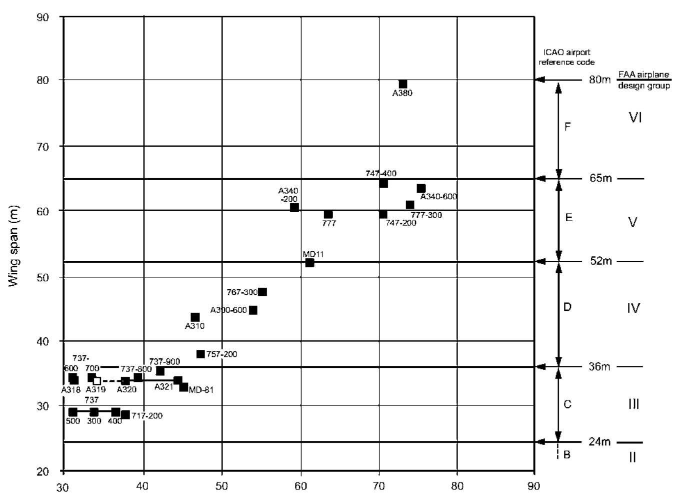
VI: [214 - 262) ft (65-80)

Airport Reference Codes (ICAO)

Code #	Field length	Code letter	Wing span	Main gear wheel span
1	Up to 800 m	A	Up to 15 m	Up to 4.5 m
2	800-1200 m	B	15 – 24 m	4.5 – 6 m
3	1200-1800 m	C	24 – 36 m	6 – 9 m
4	1800 m +	D	36 – 52 m	9 – 14 m
		E	52 – 65 m	9 –14 m
		F	65 – 80 m	14 –16 m

Remarks re ICAO and FAA Airport Reference Codes

- **Essentially all major commercial airports are in ICAO Code #4**
- **Main gear wheel span (ICAO) is "dominated" by wing span**
- **ICAO Code Letters A-F wing spans correspond *exactly* to FAA Airplane Design Groups I-VI wing spans**
- **Most geometric specifications for airports are determined by the wing span of the most demanding (or "critical") aircraft (>500 operations per year)**



Airport/Aircraft Compatibility

- **Problems with the 747-400**
  - **Civilian aircraft with 64.9 meter wingspan**
    - **-- Outside Group V and Code 4E when introduced**
  - **Changes in Group V, Code 4E definitions were made as a result**
- **Problems with new, larger aircraft**
  - **When specifications are not met, airport may be unable to accommodate aircraft or special procedures may be required (possibly resulting in congestion or under-utilization)**

A380 vs. B747-400

Airbus A380	vs.	Boeing747
Length: 72.2m		Length: 70.7m
Wing span: 79.8m	4:3	Wing span: 64.9m
Height: 24.1m		Height: 19.4m
Weight: 560 tons		Weight: 396 tons
Passengers: 555		Passengers: 416

Runway Separations for Aircraft Approach Cat. C-D

Runway Centerline To...	AIRPLANE DESIGN GROUP					
	I	II	III	IV	V	VI
	NON-PRECISION INSTRUMENT AND VISUAL					
Hold Line	250 ft 75 m	250 ft 75 m	250 ft 75 m	250 ft 75 m	250 ft 75 m	250 ft 75 m
Taxiway Centerline	300 ft 90 m	300 ft 90 m	400 ft 120 m	400 ft 120 m	400/450/500 120/135/150	600 ft 180 m
Parking Area	400 ft 120 m	400 ft 120 m	500 ft 150 m	500 ft 150 m	500 ft 150 m	500 ft 150 m
	PRECISION INSTRUMENT					
Hold Line	250 ft 75 m	250 ft 75 m	250 ft 75 m	250 ft 75 m	280 ft 85 m	325 ft 98 m
Taxiway Centerline	400 ft 120 m	400 ft 120 m	400 ft 120 m	400 ft 120 m	400/450/500 120/135/150	600 ft 180 m
Parking Area	500 ft 150 m	500 ft 150 m	500 ft 150 m	500 ft 150 m	500 ft 150 m	500 ft 150 m

Airfield Capacity

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Airfield Capacity

- **Objective**
  - To summarize fundamental concepts re. airfield capacity
- **Topics**
  - Definitions of capacity
  - Factors affecting capacity
  - Separation requirements
  - A simple model for a single runway
  - Capacity envelopes and capacity coverage chart

Reference: Chapter 10

Capacity Measures

- **Maximum-Throughput Rate**
  - **Average number of demands a server can process per unit of time when always busy**
    - **μ = maximum throughput rate**
    - **E(t) = expected service time**

$$\mu = \frac{1}{E(t)}$$

- **Level of Service (LOS) related capacity**
  - **Number of demands processed per unit of time while meeting some pre-specified LOS standards (must know μ to compute)**

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 ATC rules, assuming continuous aircraft demand.

- **Declared Capacity**

  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 apron capacity and terminal capacity

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

Less Common LOS-Related Capacity Definitions

- **Practical Hourly Capacity**

  The average number of operations that can be performed in one hour on a runway (or, more generally, a system of active runways) with an average delay per operation of 4 minutes.

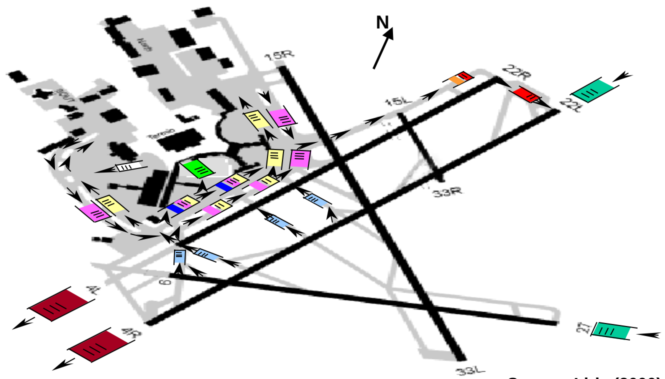
- **Sustained Capacity**

  The average number of operations per hour that can be "sustained" for periods of several hours; vaguely-defined, typically workload-related.

Factors Affecting 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**

Configuration 22L/27 - 22R/22L



Source: Idris (2000)

Role of ATC Separation Requirements

- **Runway (and airfield) capacities are constrained by ATC separation requirements**
- **Typically aircraft are separated into a small number (3 or 4) of classes**
- **Example: FAA classification**
  - Heavy (H): 255000 lbs < MTOW
  - Large (L): 41000 lbs < MTOW < 255000 lbs
  - Small (S): MTOW < 41000 lbs
- **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 S"**

IFR Separation Requirements: Single Runway (USA)

Arrival-Arrival:

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

		Trailing aircraft		
		H	**L or B757**	**S**
Leading aircraft	**H**	**4**	**5**	**5/6***
	B757	**4**	**4**	**5**
	L	**2.5 (or 3)**	**2.5 (or 3)**	**3/4***
	S	**2.5 (or 3)**	**2.5 (or 3)**	**2.5 (or 3)**

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

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

IFR Separation Requirements: Single Runway (USA) [2]

Departure-Departure (approximate, in seconds)

		Trailing aircraft		
		H	L + B757	S
Leading aircraft	H	90	120	120
	B757	90	90	120
	L	60	60	60
	S	45	45	45

Arrival-Departure and Departure-Arrival

- **Leading aircraft must be clear of runway at the instant when trailing aircraft starts takeoff roll or touches down on the runway, respectively. In D-A case, trailing arrival must also be at least 2 nmi from runway when takeoff run begins**

Separation Requirements (Italy; until recently)

Arrival/Arrival
(in nautical miles)

$$\begin{array}{c} \\ H \\ M/L \\ S \end{array} \begin{array}{c} \begin{array}{ccc} H & M/L & S \end{array} \\ \begin{bmatrix} 5 & 5 & 7 \\ 5 & 5 & 5 \\ 5 & 5 & 5 \end{bmatrix} \end{array}$$

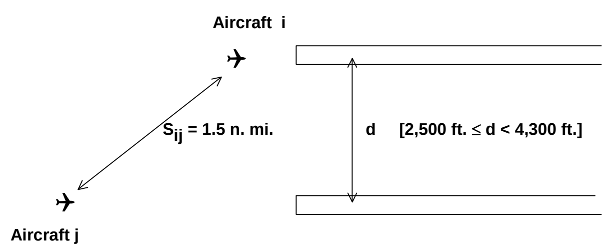
Departure/Departure
120 seconds between successive departures

Departure/Arrival
Arrival must be at least 5 n.mi. away from runway threshold

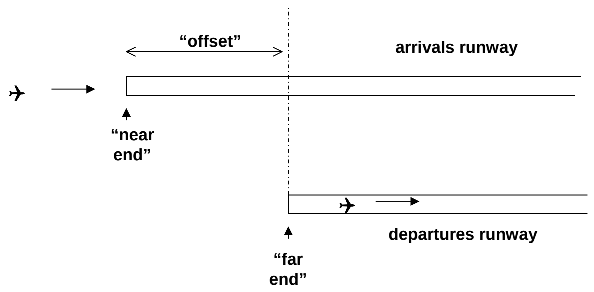
Parallel Runways (IFR): USA

Separation between runway centerlines	Arrival/ arrival	Departure/ departure	Arrival/ departure	Departure/ arrival
700-2499 ft	As in single runway	As in single runway	Arrival touches down	Departure is clear of runway
2500- 4300 ft	1.5 nmi (diagonal)	Indep'nt	Indep'nt	Indep'nt
4,300 ft or more	Indep'nt	Indep'nt	Indep'nt	Indep'nt

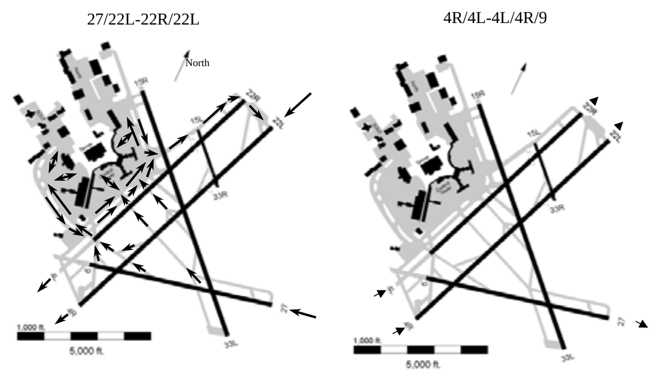
The diagonal separation between two aircraft approaching medium-spaced parallel runways



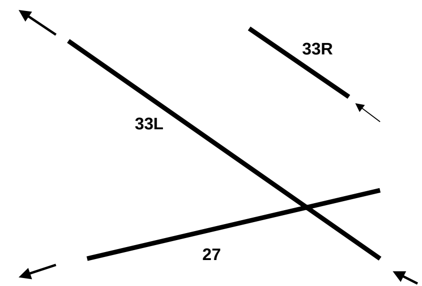
Staggered parallel runways; the "near" runway is used for arrivals and the other for departures



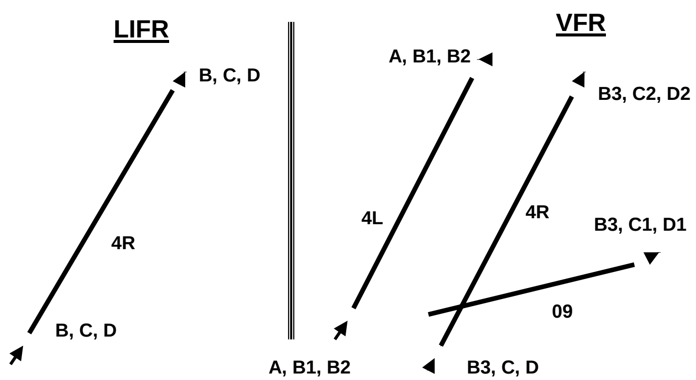
Two high-capacity configurations in opposite directions at Boston/Logan (VMC)



A low- capacity configuration in VMC at Boston Logan



Configurations: Same Direction, Different Weather Conditions



Typical Approach for Estimating Airside Capacity

1. **Compute average time interval for all possible aircraft class pairs i, j**

   t_{ij} = average time interval between successive movements of a pair of aircraft of types i and j (i followed by j) such that no ATC separation requirements are violated

2. **Compute probability for all i, j**

   p_{ij} = probability of occurrence of the pair of aircraft types i and j (i followed by j)

3. **Compute overall average service time**

$$E(t) = \sum_i \sum_j p_{ij} \cdot t_{ij} \qquad \mu = \frac{1}{E(t)}$$

Numerical Example

Given: Single Runway (Arrivals Only: IFR)

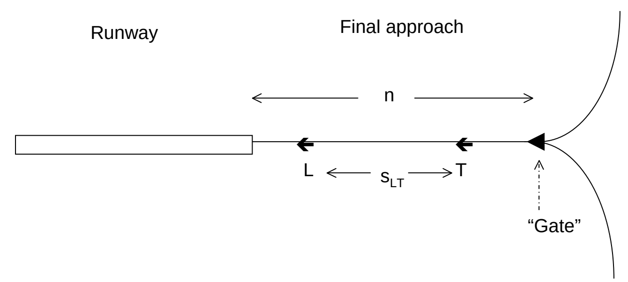
n = 5 N. Miles

Aircraft Types			
Type	Mix (%)	Approach Speed (kts)	Runway Occupancy Time (secs)
Heavy (1)	20	140	60
Large (2)	50	120	55
Small (3)	30	100	50

$$[s_{ij}] = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{ccc} 1 & 2 & 3 \\ 4 & 5 & 6^* \\ 3 & 3 & 4^* \\ 3 & 3 & 3 \end{array}$$

* Applies only with lead aircraft at threshold (all other separations apply throughout final approach).

A simple representation of a runway used for arrivals only under IFR



Single Runway Model: Arrivals Only

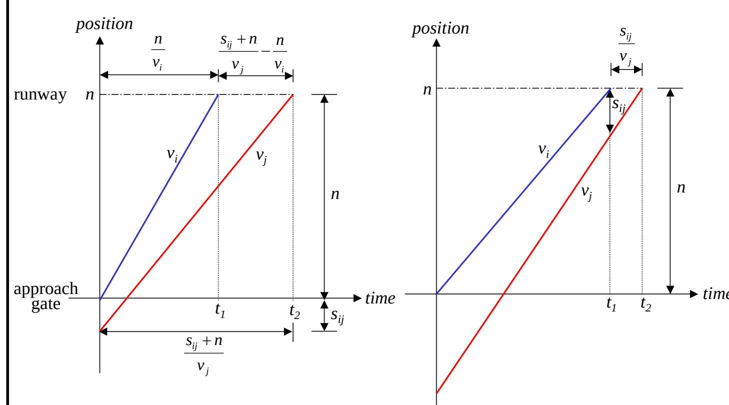
- **Consider two aircraft, i and j. Let**
  - **n = length of final approach (typically 5-8 n.mi.)**
  - **s_{ij} = separation in air between i and j**
  - **v_i, v_j = approach speed of i, j**
  - **o_i, o_j = runway occupancy time of i, j**
  - **$T_{i,j}$ = min. time separation between i and j at runway**
- **Assume $v_i > v_j$**
  - **<u>Opening Case</u>: Aircraft i precedes j**

$$T_{ij} = \max\left(\frac{n + s_{ij}}{v_j} - \frac{n}{v_i}, o_i\right)$$

  - **<u>Closing Case</u>: Aircraft j precedes i**

$$T_{ji} = \max\left(\frac{s_{ji}}{v_i}, o_j\right)$$

Graphical Description of the Model



Effect of Airborne Separation Requirement

✈ **Closing Case**

- **Second aircraft is faster, and must have required separation distance from first aircraft at runway threshold; separation at merge area (beginning of final approach) is greater than minimum**

✈ **Opening Case**

- **Second aircraft is slower, and must meet separation requirement from first aircraft in merge area when approach is initiated; separation at runway threshold is greater than minimum**

Matrix of Minimum Separations

✈ The number T_{ij} in row i and column j is the minimum separation(sec) for the case of aircraft type i followed by type j

$$T_{ij} = \begin{bmatrix} 103 & 171 & 216 \\ 77 & 90 & 144 \\ 77 & 90 & 108 \end{bmatrix}$$

- **Opening Case**

$$T_{12} = \max\left(\frac{10\,\text{n.mi.}}{120\,\text{knots}} - \frac{5\,\text{n.mi.}}{140\,\text{knots}},\ 60\,\text{sec}\right)$$

$$= \max(171\,\text{sec},\ 60\,\text{sec}) = 171\,\text{sec}$$

Matrix of Minimum Separations [2]

- **Closing Case**

$$T_{31} = \max\left(\frac{3\,\text{n.mi.}}{140\,\text{knots}},\ 50\,\text{sec}\right)$$

$$= \max(77\,\text{sec},\ 50\,\text{sec}) = 77\,\text{sec}$$

- **Stable Case**

$$T_{22} = \max\left(\frac{3\,\text{n.mi.}}{120\,\text{knots}},\ 55\,\text{sec}\right)$$

$$= \max(80\,\text{sec},\ 55\,\text{sec}) = 80\,\text{sec}$$

- **"Special" Case (also T_{23})**

$$T_{13} = \max\left(\frac{6\,\text{n.mi.}}{100\,\text{knots}},\ 60\,\text{sec}\right)$$

$$= \max(216\,\text{sec},\ 60\,\text{sec}) = 216\,\text{sec}$$

Safety Buffer

- **In practice, a safety buffer is added to the minimum separations between aircraft, to make up for imperfections in the ATC system**
- **Allow a buffer of an additional *b* = 10 seconds between each aircraft for safety (10 seconds implies about 1/3 n. mi. longitudinal separation)**

Matrix of Average Time Separations

The t_{ij} indicate the average separation (sec) between an aircraft of type i and a following aircraft of type j.

$$t_{ij} = T_{ij} + b$$

$$t_{ij} = \begin{bmatrix} 113 & 181 & 226 \\ 87 & 100 & 154 \\ 87 & 100 & 118 \end{bmatrix}$$

Matrix of Pair Probabilities

- Let p_{ij} = probability that an aircraft of type i will be followed by one of type j
- Assume first-come, first-served (FCFS) runway service

$$p_{ij} = \begin{bmatrix} 0.04 & 0.1 & 0.06 \\ 0.1 & 0.25 & 0.15 \\ 0.06 & 0.15 & 0.09 \end{bmatrix}$$

Example

- **20% of aircraft are Type 1, 50% are Type 2**
- **Therefore, the probability of a Type 1 followed by a Type 2 is: p_{12} = (0.2)*(0.5) = 0.1**

***Note*: This is valid only for an FCFS system; no sequencing.**

Numerical Example [2]

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

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

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

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

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 on the runway in question.**

That is:

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

★ **E(t) = 124 seconds**

Numerically:

$$E(t) = (0.04)(113) + (0.1)(181) + (0.06)(226) + (0.1)(87) + (0.25)(100) + (0.15)(154) + (0.06)(87) + (0.15)(100) + (0.09)(118)$$

Saturation Capacity $= \dfrac{3600 \text{ seconds}}{124 \text{ seconds}} =$ **29 aircraft**

Numerical Example [4]

- The variance (a measure of variability) of the service times (intervals between successive landings in this case) can also be computed from:

$$\sigma_t^2 = \sum_i \sum_j p_{ij} \cdot [t_{ij} - E(t)]^2$$

- Or,

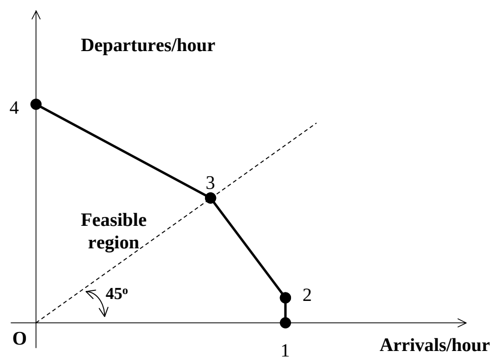
$(0.04)(113\text{-}124)^2 + (0.1)(181\text{-}124)^2 + \ldots + (0.09)((118\text{-}124)^2$
$= 1542 \text{ sec}^2$

- The standard deviation, $\sigma_t = \sqrt{1542} = 39$ seconds

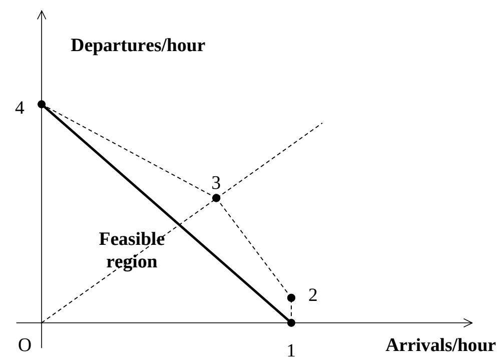
Sensitivity of the model

- The model (and the runway's arrival capacity) is sensitive to
  - Airborne separation requirements (regular and wake-turbulence related)
  - Runway occupancy times
  - Final approach speeds of aircraft
  - Length of final approach
  - Safety-related margins (buffers) allowed by air traffic controllers
  - Mix of traffic (homogeneity)
  - Sequencing of aircraft

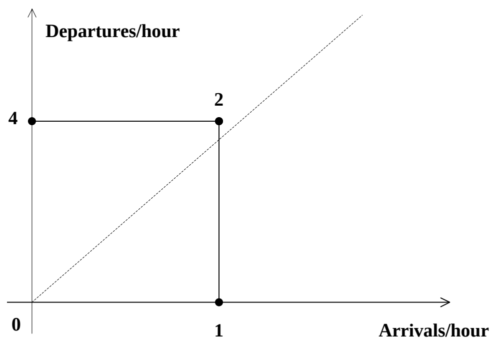
A typical capacity envelope for a single runway



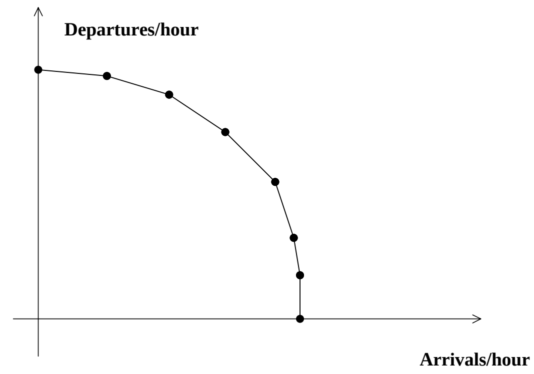
Capacity envelope when operating with strings of arrivals and departures



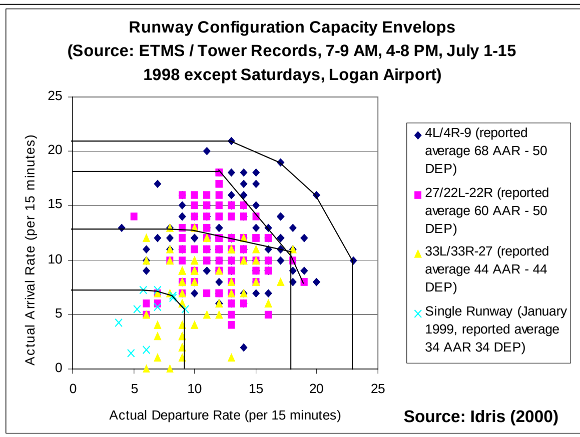
Capacity envelope for two parallel runways, one used for arrivals and the other for departures



A hypothetical capacity envelope for a multi-runway airport with mixed use of the runways



Runway Configuration Capacity Envelopes

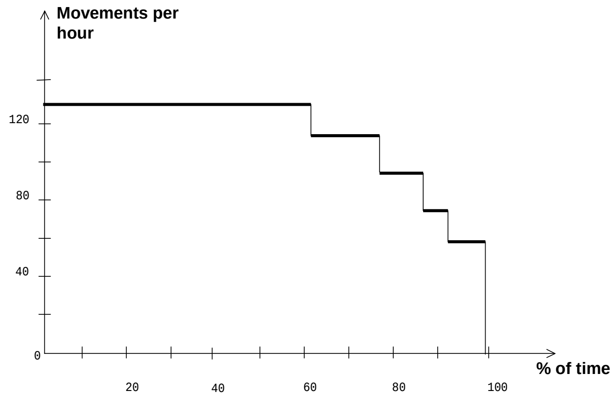


Capacity Coverage Chart

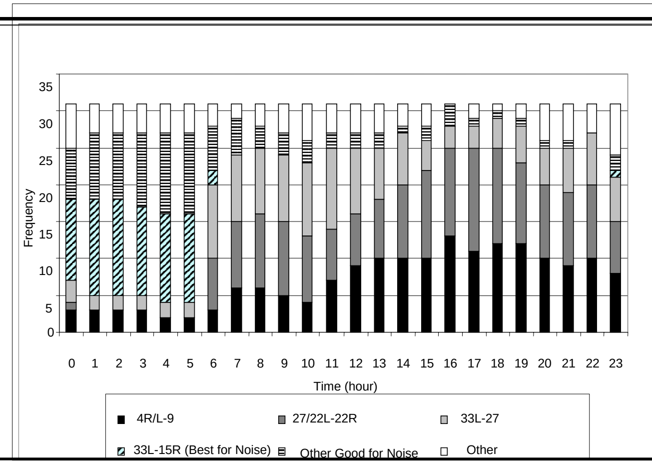
- **CCC shows how much capacity is available for what percentage of time**
- **Assumptions:**
  - **airport will operate at all times with the highest capacity configuration available for prevailing weather/wind conditions**
  - **the capacity shown is for a 50%-50% mix of arrivals and departures**

  Note: Neither of these assumptions is necessarily true in practice (e.g., noise may be principal consideration in selecting configuration during periods of low demand)

Annual Capacity Coverage Chart: Boston/Logan



Runway configuration usage at Boston/Logan, January 1999 (from Logan FAA tower logs)



Capacity Coverage Chart [2]

- **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

Range of Airfield Capacities

- **The capacity of a single runway varies greatly among airports, depending on local ATC rules, traffic mix, operations mix, local conditions and the other factors identified earlier (12 – 60+ movements per hour is possible)**
- **At major commercial airports, in developed countries, the range is 25 – 60 movements per hour for each runway**
- **Depending on the number of runways and the airport's geometric configuration, total airfield capacity of major commercial airports ranges from 25 per hour to 200+ per hour**

Airport Capacity: US vs. Non-US

- **FAA capacity benchmarks (2001): 31 busiest airports**
  - **24 of 31: VMC capacity > 100/hour; range: 50 – 270**
  - **16 of 31: IMC capacity > 100/hour; range: 45 – 184**
  - **14 of 31: Plan a new runway by 2010 (none of the 7 most congested); capacity benefits of 17 – 50%**
  - **Capacity benefits due to ATM by 2010: 0 – 17% (mostly 3 – 13%)**
  - **www.faa.gov/events/benchmarks/**
- **Airports elsewhere enjoy a significant advantage in average aircraft size and serve fewer aircraft operations for same number of annual passengers …but this may be diluted by deregulation and by growth in regional services**
- **Only three non-US airports with capacity > 100/hour (!)**