# RUNWAY OPERATIONS: Computing Runway Arrival Capacity

OR750 /SYST660

USE Runway Capacity Spreadsheet

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# Background

- Air Transportation System Infrastructure is composed of:
  - Airports
    - "Airside" (runways, taxiways, ramps, …)
    - "Landside" (terminals, passenger lounges, access roads, rental cars, busses, parking,
  - Air Traffic Control
    - Tower
    - Terminal Area
    - En-route

# Runway Capacity

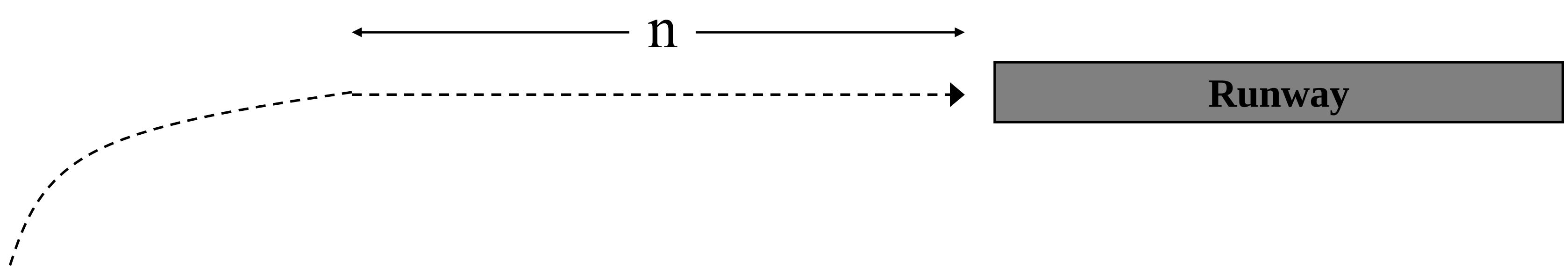
| | Definition | Assumptions and Notes | % of MTC |
|---|---|---|---|
| **Maximum Throughput Capacity (MTC)** | •Expected number of movements performed in 1 hour | •Does not violate ATC separation rules<br>•Continuous Demand<br>•No limits on delays | |
| **Practical Hourly Capacity (PHCAP)** | •Expected number of movements performed in 1 hour<br>•Delay set to average 4 min delay per vehicle | •Avg of 4 min delay, means some vehciles >> 4 mins<br>•Runway capacity achieved when avg delay = 4 mins | 80-90% of MTC |
| **Declared Capacity** | •Number of movements per hour at a reasonable LOS (i.e. delay minutes = 3 min) | •Used for "Schedule Coordination" (in Europe). Sets limit on scheduled arrivals/departures | 85-90% of MTC |
| **Sustained Capacity** | •Number of movements per hour than can be reasonably sustained over period of several hours | • Split in Airport Arrival Rate (AAR) and Airport Departure Rate (ADR) | •90% of MTC with good weather MTC<br>•100% of MTC with bad weather MTC |

See deNeufville/Odoni (2004) pages 370 to 374

# Runway Operations

- Arriving aircraft land
- Departing aircraft takeoff
- Runway capacity determined by:
  - Separation distance between arriving aircraft
    - Separation Distance Violation
  - Separation distance between departing aircraft
    - Separation Distance Violation
  - Only **one** aircraft on runway at any time
    - Simultaneous Runway Occupancy
- Separation distance and Runway Occupancy Time (ROT) determined by aircraft type (weight/lift, landing speed, …)
  - Heavy (e.g. 747-400)
  - Large (e.g. 777, 767)
  - Medium (e.g. 737)
  - Small (e.g. RJ)

# Model for Runway Arrivals




n – length of final approach

i(j) – type of leading (trailing) aircraft

$V_i$ – ground speed of aircraft type i

$O_i$ – runway occupancy time of aircraft type i

$S_{ij}$ – minimum separation distance between two airborne aircraft i and j

$T_{ij}$ – minimum acceptable time interval between successive arrivals at runway of aircraft type i and type j

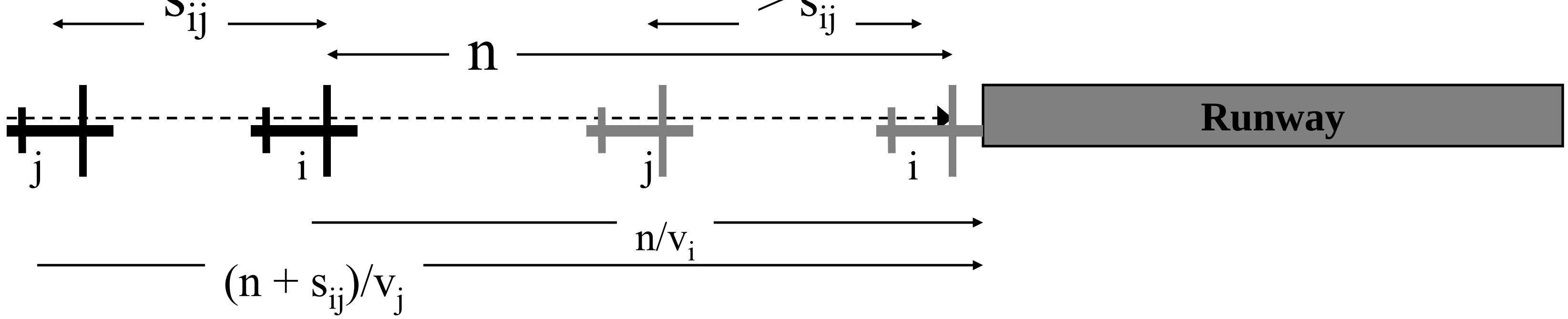
# Minimum Time Separation Between 2 Aircraft

- Runway can only have single aircraft at a time
- Minimum separation distance between arriving aircraft must be maintained at all times
- $T_{ij} > O_i$
  - minimum acceptable time interval between successive arrivals at runway of lead aircraft type i and follow aircraft type j > runway occupancy time of aircraft type i

# Arrival Two Cases

- Lead aircraft of type i is *faster* than follow aircraft of type j
  - Case: Expanding Separation
- Lead aircraft of type i is *slower* than follow aircraft of type j
  - Case: Decreasing Separation

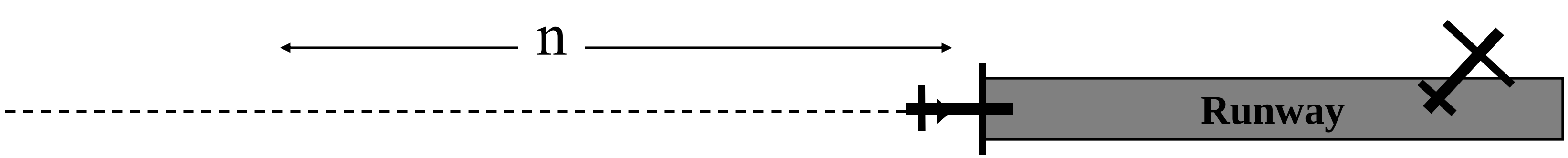
# Expanding Separation ($v_i > v_j$)



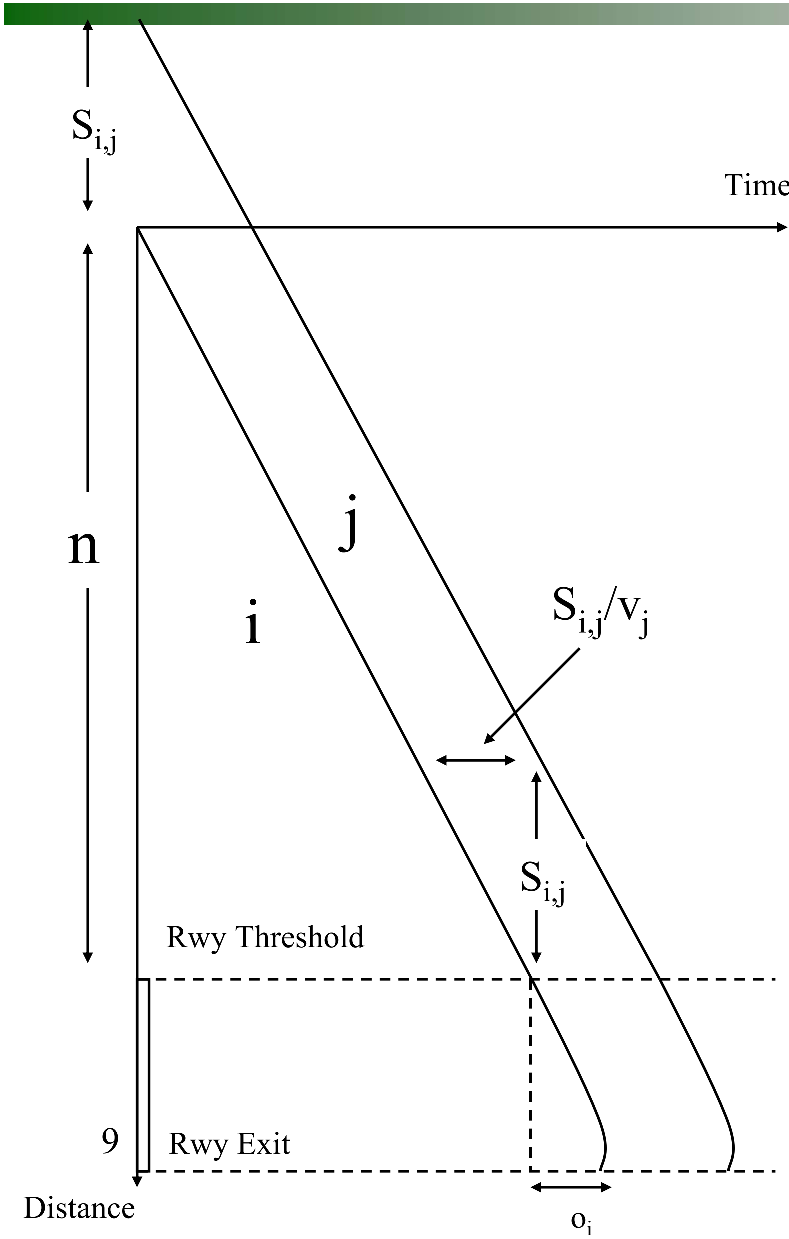

$T_{ij}$ = Minimum Acceptable Time Interval between successive Arrivals

max of

1. $((n + s_{ij})/v_j) - (n/v_i)$
   – *(time for follow aircraft (j) to fly separation distance plus final approach path) – (time of lead aircraft (i) to fly final approach path)*
2. $o_i$ *occupancy time of lead aircraft*

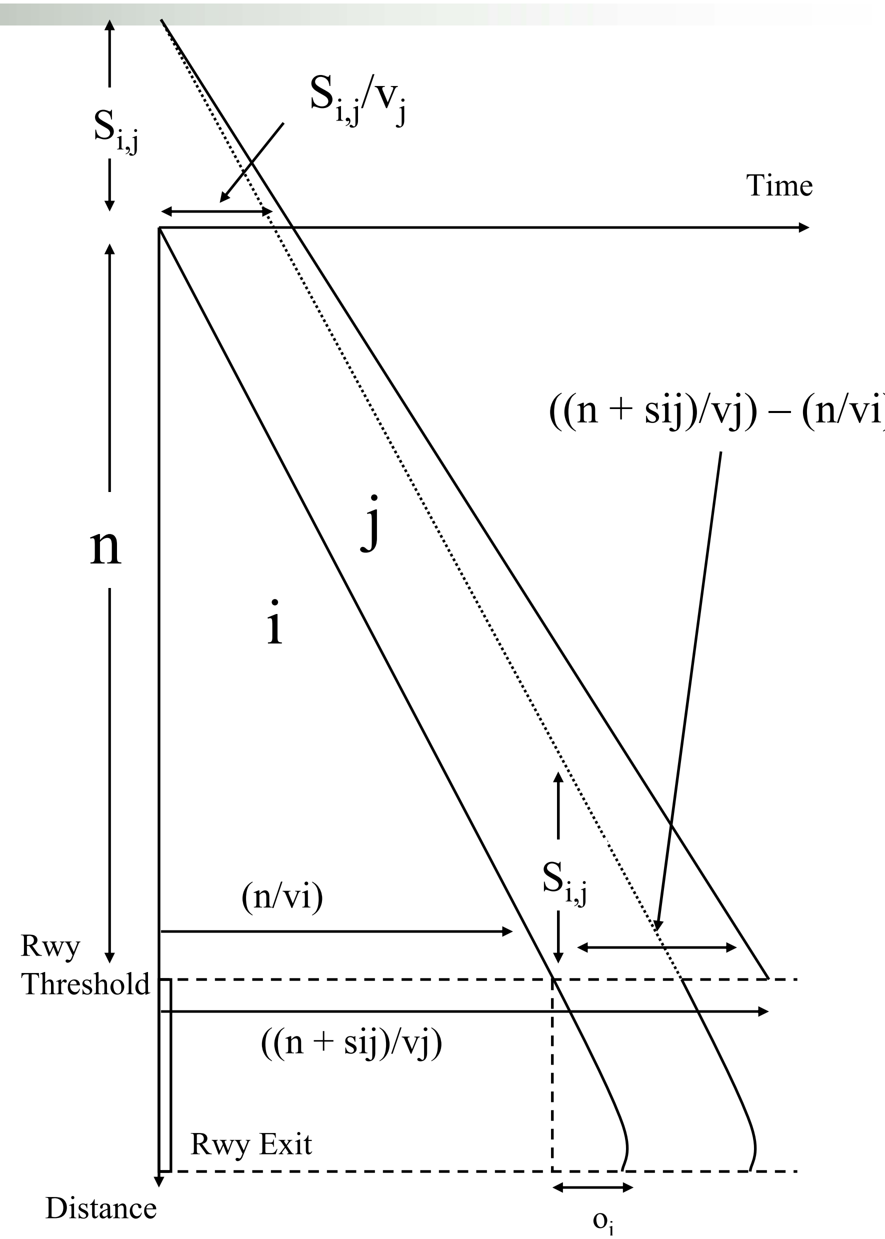


## Constant Separation ($v_i = v_j$)

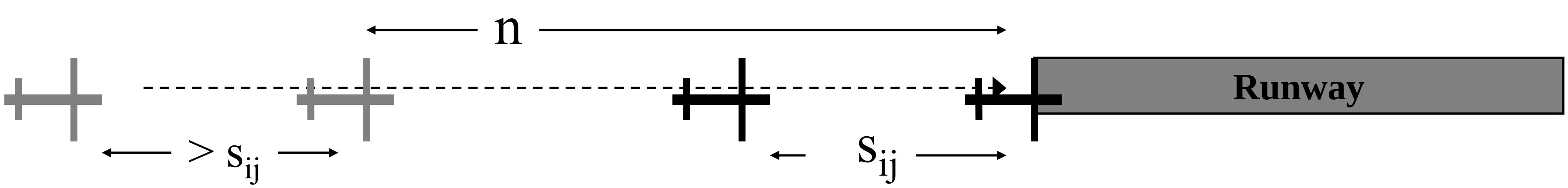



**NOT DRAWN TO SCALE**

## Expanding Separation ($v_i > v_j$)

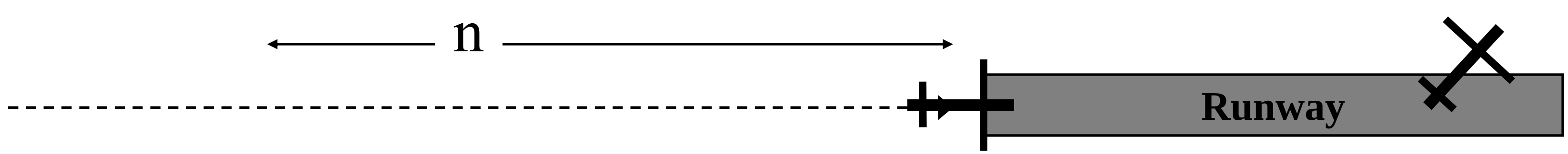


# Decreasing Separation ($v_i < v_j$)

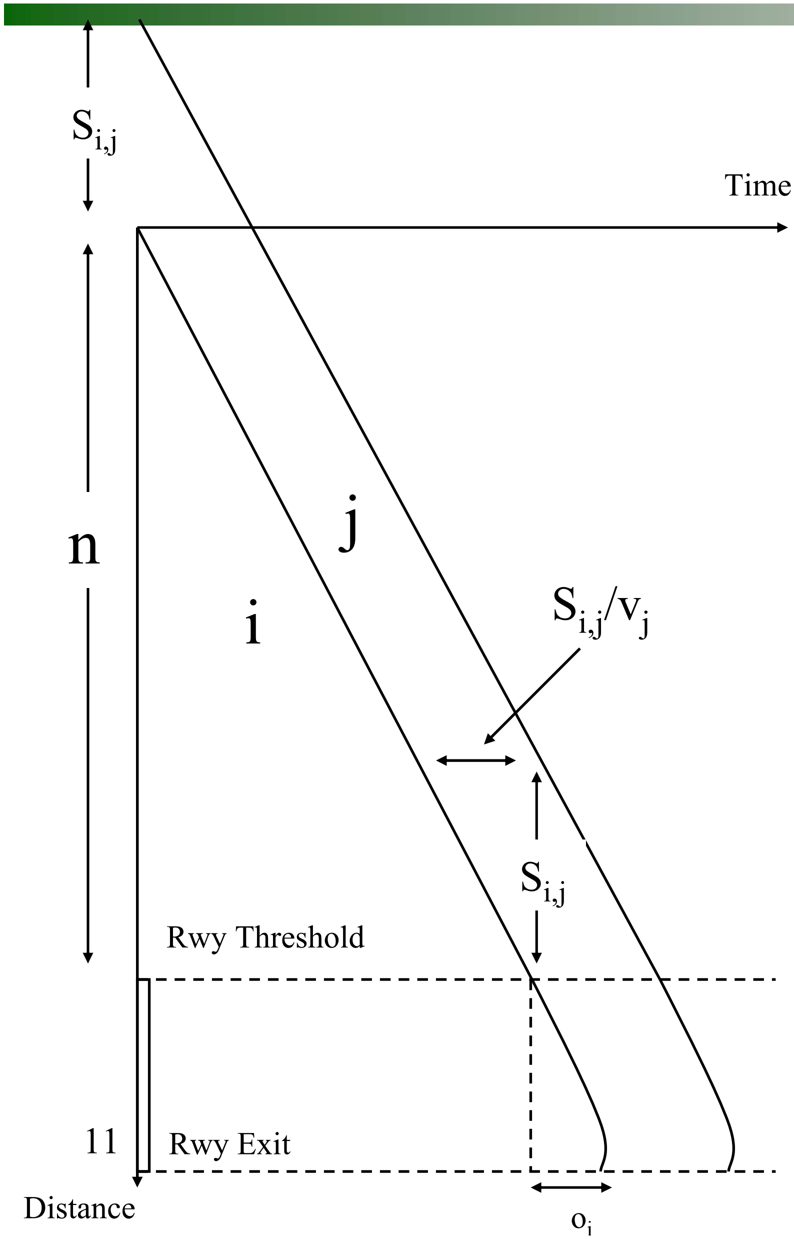



$T_{ij}$ = Minimum Acceptable Time Interval between successive Arrivals
max of

1. $(s_{ij}/v_j)$
   - *(time for <u>faster</u> follow aircraft (j) to fly separation distance) – (time of lead aircraft (i) to fly final approach path)*
2. $o_i$ *occupancy time of lead aircraft*

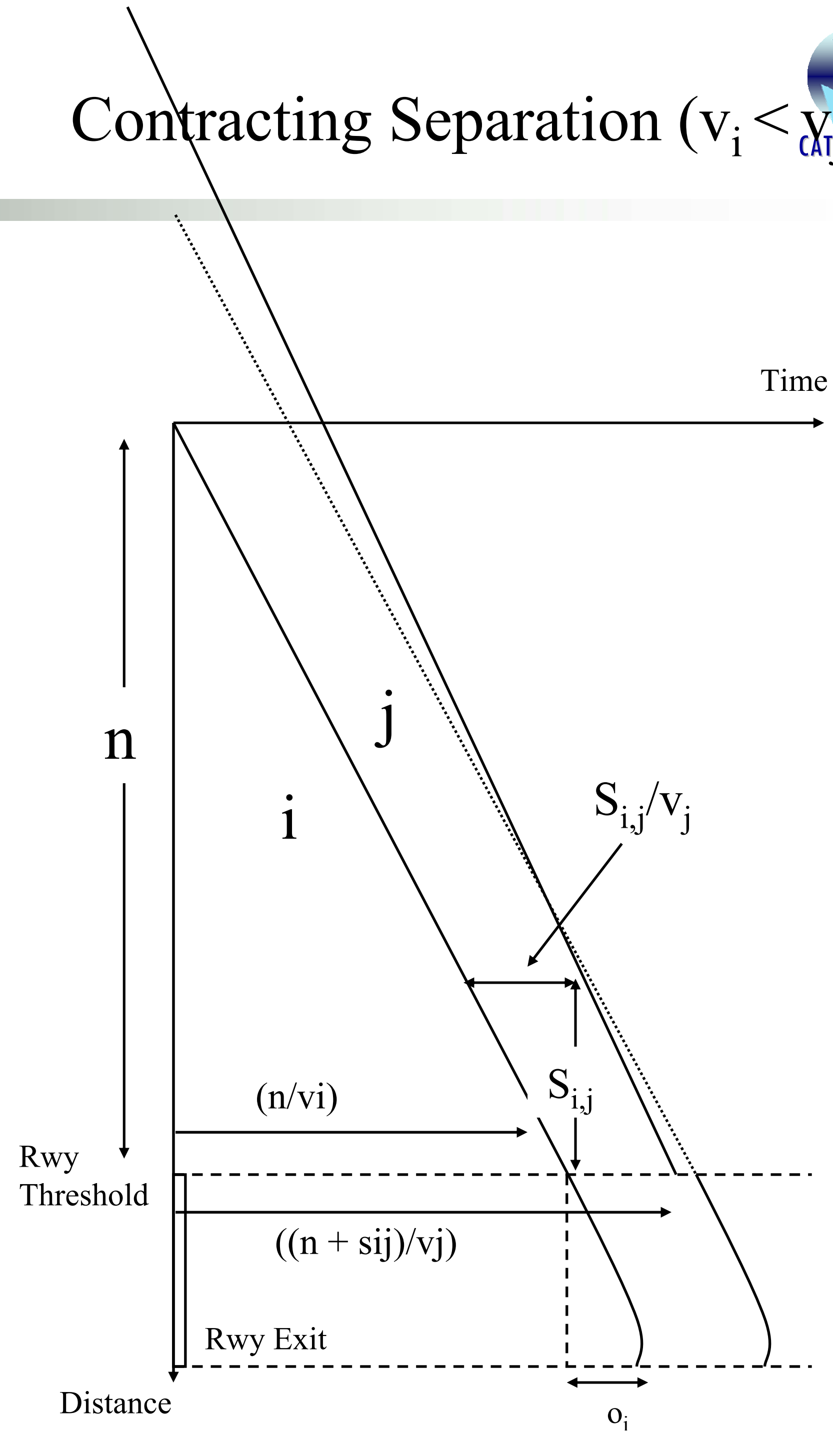


## Constant Separation ($v_i = v_j$)




NOT DRAWN TO SCALE

## Contracting Separation ($v_i < v_j$)



# Mixed Fleet Arrivals

- Average Minimum Acceptable Inter-arrival Time

$$E[T_{ij}] = \Sigma^{i \text{ to } K} \Sigma^{j \text{ to } K} p_{ij} \cdot T_{ij}$$

  - K – number of aircraft types
  - $K^2$ – number of aircraft type i followed by aircraft type j (pairs)
  - $p_{ij}$ – probability of aircraft type i followed by aircraft type j

- **Maximum Capacity Throughput (MCT)** = arrivals/hour = $1/E[T_{ij}]$
  - Assumes continuous supply of arriving aircraft
  - Assumes no arrival queueing delays

- **Sustained Capacity Throughput (SCT)** = arrivals/hour = $1/E[T_{ij} + \delta]$

  - $\delta$ = 10 secs = additional distance (padding) used by Air Traffic Controllers to avoid violating separation distance

# Example

| Aircraft Type i | $p_i$ | $v_i$ | $o_i$ |
|---|---|---|---|
| H | 0.2 | 150 | 70 |
| L | 0.35 | 130 | 60 |
| M | 0.35 | 110 | 55 |
| S | 0.1 | 90 | 50 |

S =

| Lead (i) | Follow (j) H | L | M | S |
|---|---|---|---|---|
| H | 4 | 5 | 5 | 6 |
| L | 2.5 | 2.5 | 2.5 | 4 |
| M | 2.5 | 2.5 | 2.5 | 4 |
| S | 2.5 | 2.5 | 2.5 | 2.5 |

P =

| Lead (i) | Follow (j) H | L | M | S |
|---|---|---|---|---|
| H | 0.0 4 | 0.07 | 0.07 | 0.02 |
| L | 0.07 | 0.1225 | 0.1255 | 0.035 |
| M | 0.07 | 0.1225 | 0.1255 | 0.035 |
| S | 0.02 | 0.035 | 0.035 | 0.01 |

$\delta = 10$ secs

E[Tij] = 116.3

Sustained Capacity Throughput (Arrivals/Hour) = 30.9 aircraft/hours

# Limitations of Model

- Model assumes:
  - independent runway (no intersections or parallel)
  - Landing aircraft only
  - Wind speed and direction
  - $v_i$ and $o_i$ should be random variables
  - Separation distance should be random variables

CATSR

# END

# Homework: Runway Operations - Arrivals

Use Runway Operations – Arrival Spreadsheet

1. Plot a graph with Max # Arrivals/Hour on y-axis, Aircraft Type (i,j) on the x-axis ( H-H, L-L, M-M, S-S).
   - What aircraft type pairing generates the highest number of operations?
   - What aircraft type pairing generates the highest number of operations?

- Plot a graph with Total # Seats on y-axis, Aircraft Type (i,j) on x-axis (H-H, L-L, M-M, S-S). Assume seats for aircraft type as follows: H=524, L=304, M=44, S=36.
  - What aircraft type pairing generates the highest number of seats for arrivals?
  - What aircraft type pairing generates the lowest number of seats for arrivals?