RUNWAY OPERATIONS: Computing Runway Arrival Capacity

SYST 560/460

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

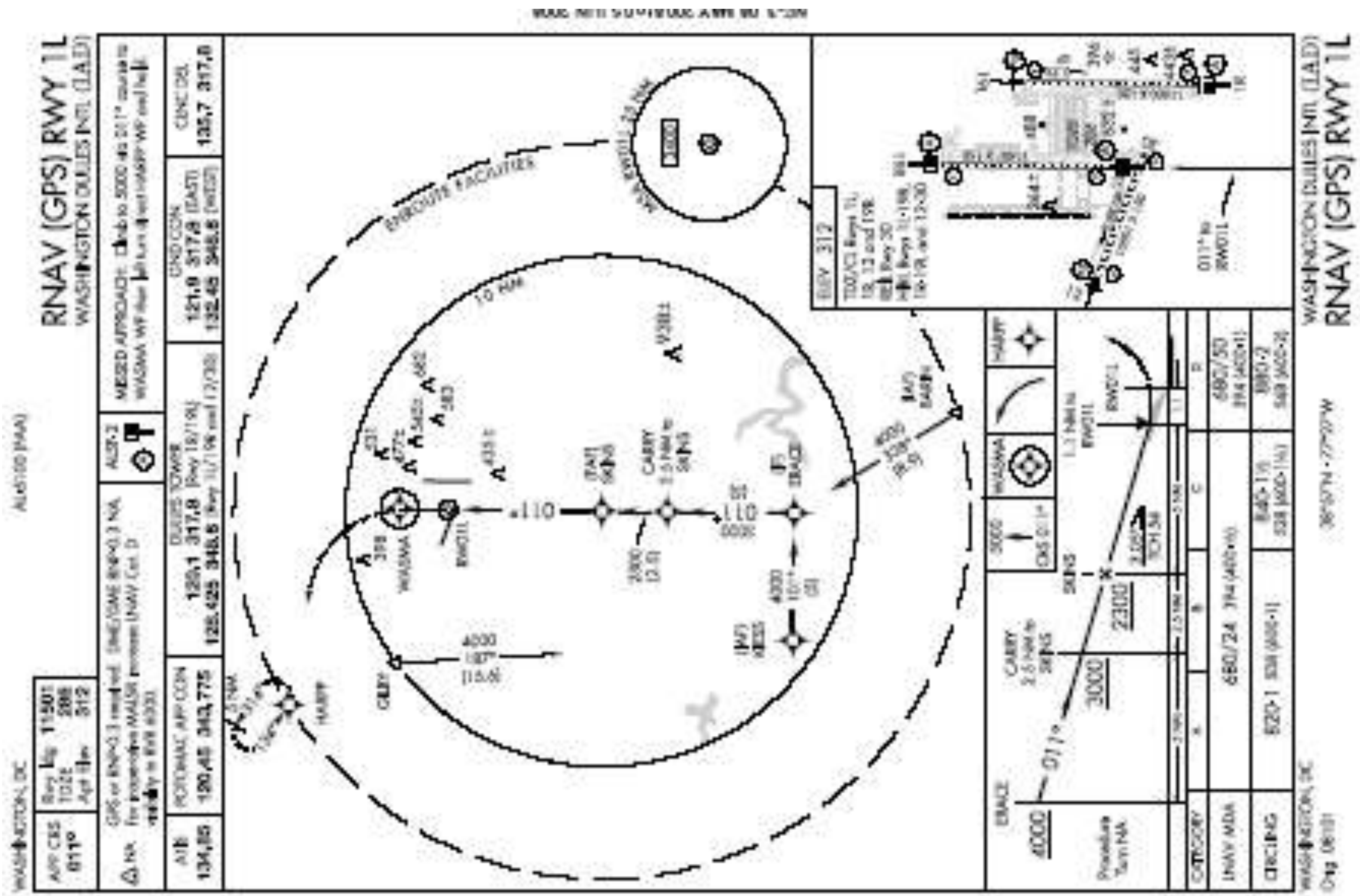
	Definition	Assumptions and Notes	% of MTC
Maximum Throughput Capacity (MTC)	•Expected number of movements performed in 1 hour	•Does not violate ATC separation rules •Continuous Demand •No limits on delays	
Practical Hourly Capacity (PHCAP)	•Expected number of movements performed in 1 hour •Delay set to average 4 min delay per vehicle	•Avg of 4 min delay, means some vehciles >> 4 mins •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 •100% of MTC with bad weather MTC

See deNeufville/Odoni (2004) pages 370 to 374

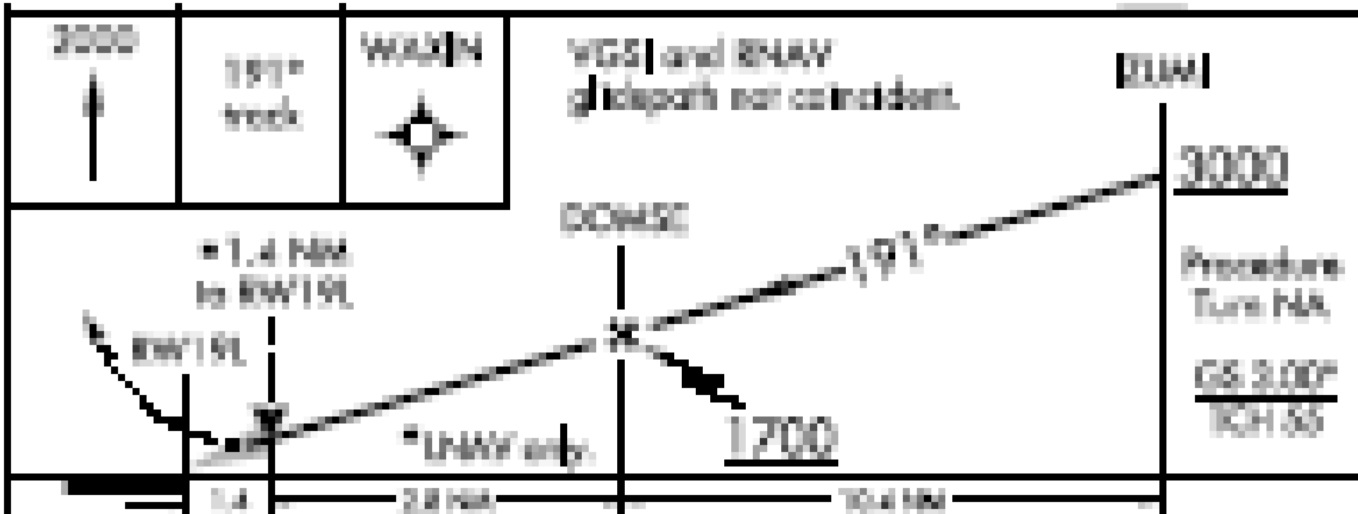
Runway Operations

- 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)

Runway Arrivals



Runway Arrivals



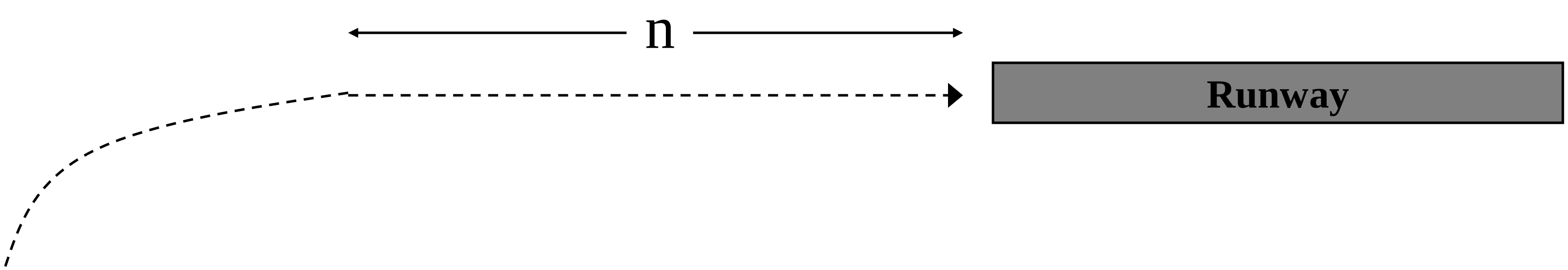
CATEGORY	A	B	C	D
LPV DA	595/24 292 (300-½)			
LNAV/VNAV DA	829/60 527 (600-1¼)			
LNAV MDA	820/24 518 (600-½)		820/50 518 (600-1)	820/60 518 (600-1¼)
CIRCLING	1000-1 698 (700-1)		1000-2 698 (700-2)	1000-2¾ 698 (700-2¾)

38°57'N - 77°27'W

WASHINGTON DULLES INTL (IAD)

RNAV (GPS) Y RWY 19L

Model for Runway Arrivals



n – length of final approach

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

V_i – landing speed of aircraft type i (defined as speed on the ground)

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

Homogeneous Fleet

$MCT = 3600/ROT$ (Simultaneous Runway Occupancy – SRO)

$MCT = 3600/(S_{i,j}/V_j)$ (Wake Vortex Sep Distance)

$MCT = 3600/[(S_{i,j}/V_j) + b]$ (Wake Vortex + ATC Buffer)

Non-Homogeneous Fleet Mix

$MCT = 3600/E[ROT]$ (Simultaneous Runway Occupancy – SRO)

$E[ROT] = \Sigma_i \Sigma j \ (p_{ij} * ROT_i)$

$MCT = 3600/E[T_{i,j}]$ (Wake Vortex Sep Distance)

$E[T_{i,j}] = \Sigma_i \Sigma j \ (p_{ij} * (S_{i,j}/V_j))$

$MCT = 3600/E[T_{i,j}]$ (Wake Vortex + ATC Buffer)

$E[T_{i,j}] = \Sigma_i \Sigma j \ ((p_{ij} * (S_{i,j}/V_j)) + b)$

Separation Distance (nm)

		Follow (Approach Speed)			
Lead (Approach Speed)		H (150)	L (130)	M (110)	S (90)
	H (150)	4	5	5	6
	L (130)	2.5	2.5	2.5	4
	M (110)	2.5	2.5	2.5	4
	S (90)	2.5	2.5	2.5	2.5

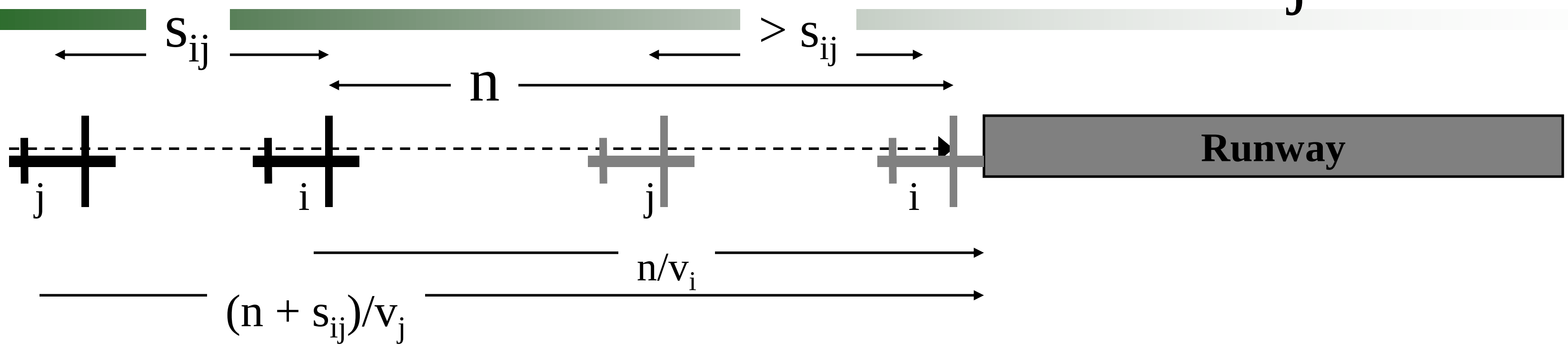
Separation (Expanding, Decreasing)

	Follow				
Lead		H (150)	L (130)	M (110)	S (90)
	H (150)	Same	Expanding	Expanding	Expanding
	L (130)	Decreasing	Same	Expanding	Expanding
	M (110)	Decreasing	Decreasing	Same	Expanding
	S (90)	Decreasing	Decreasing	Decreasing	Same

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

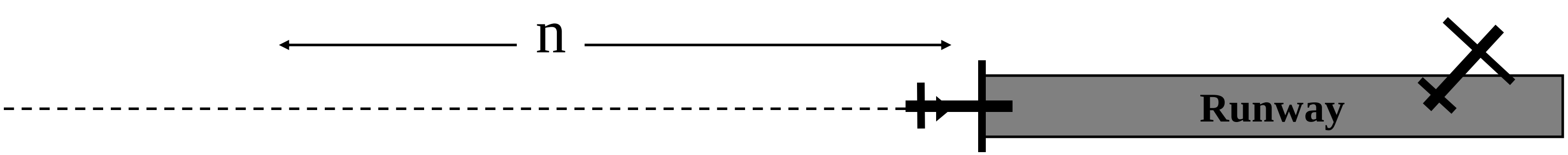
Expanding Separation ($v_i > v_j$)



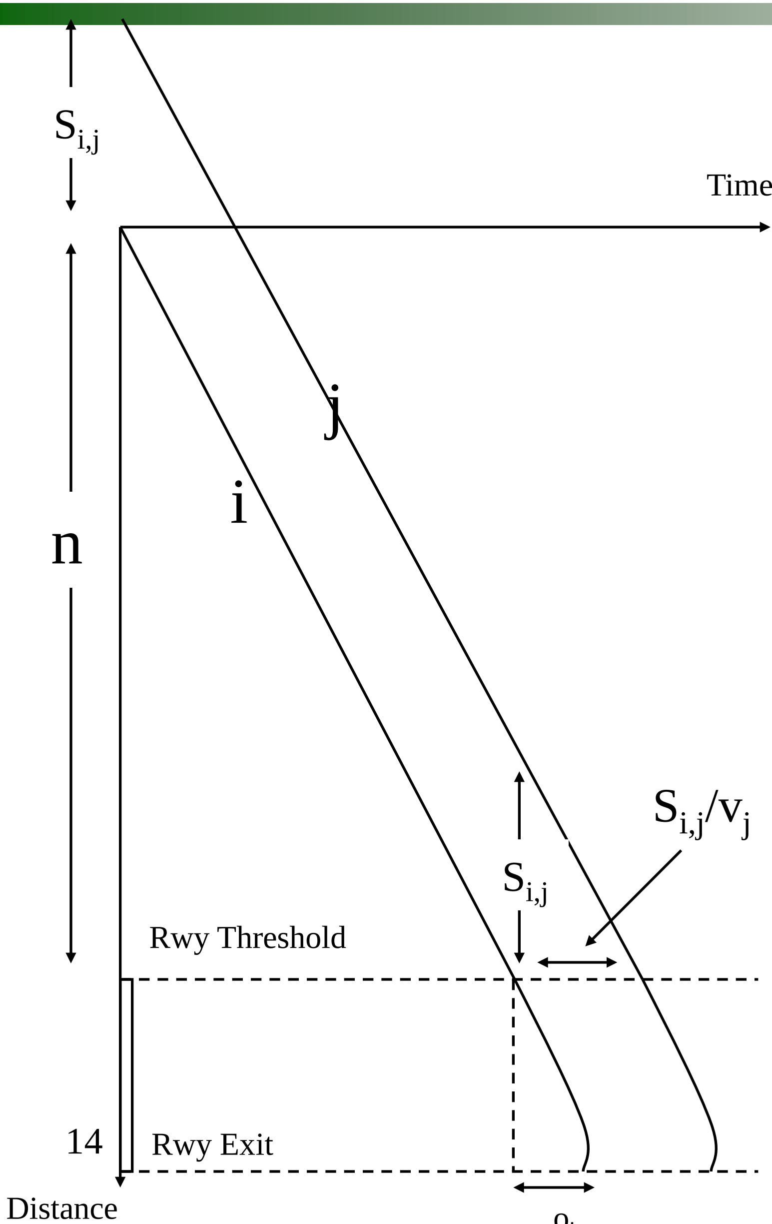
T_{ij} = Minimum Acceptable Time Interval between successive Arrivals

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*

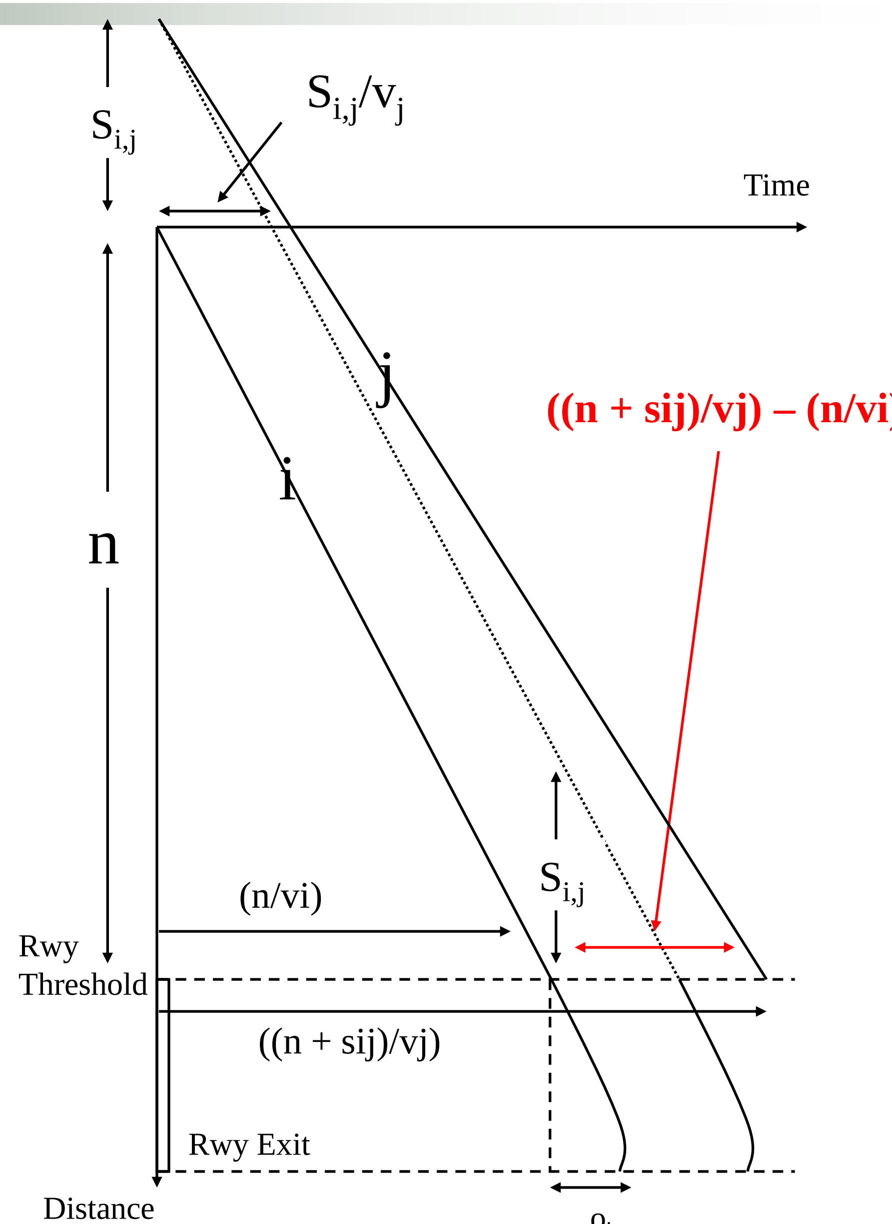


Constant Separation ($v_i = v_j$)

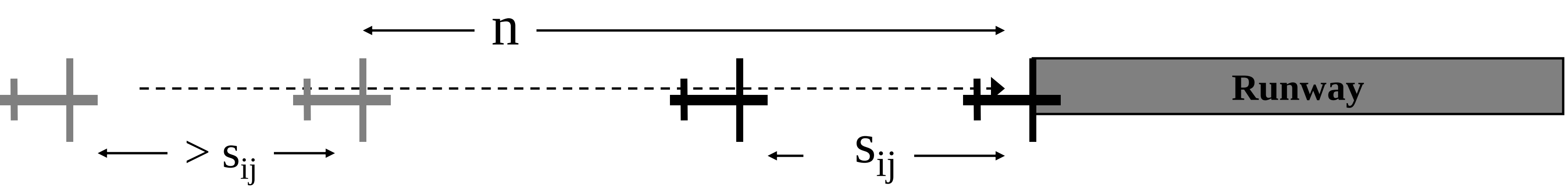


NOT DRAWN TO SCALE

Expanding Separation ($v_i > v_j$)

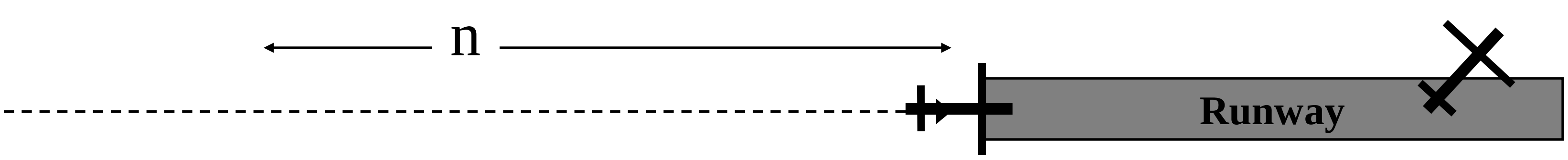


Decreasing Separation ($v_i < v_j$)

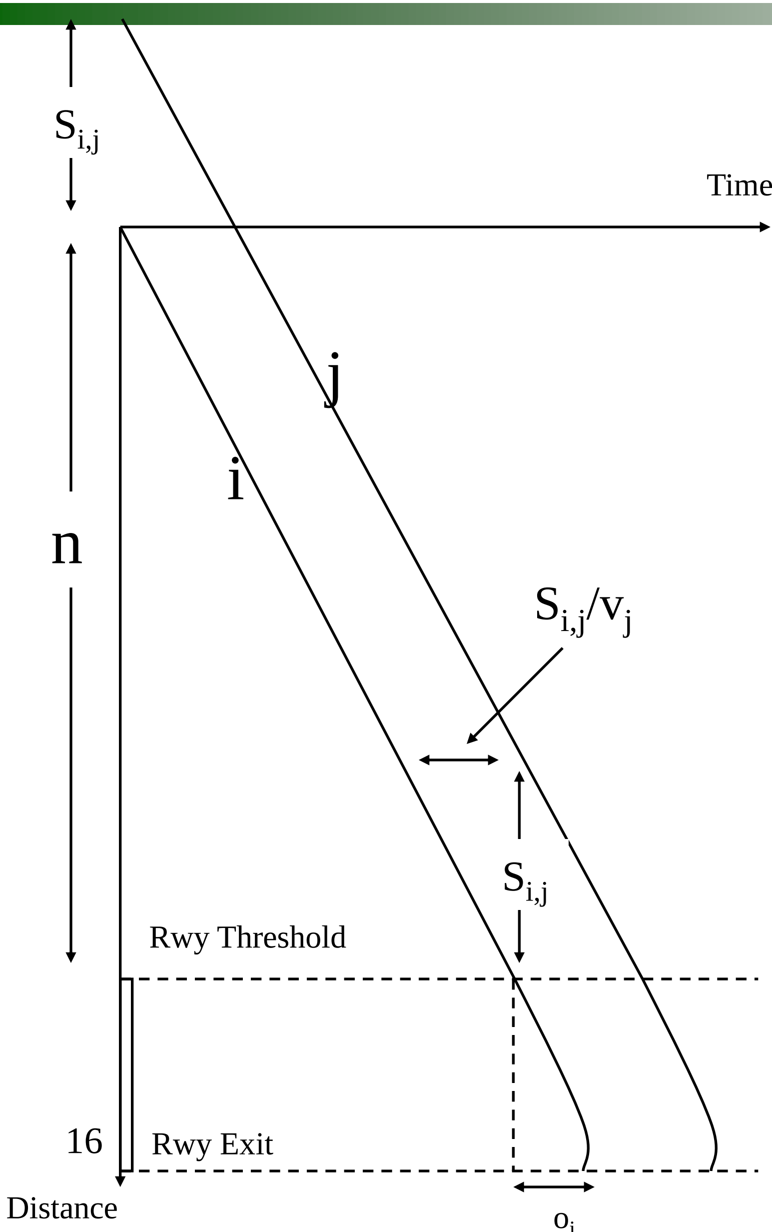


T_{ij} = Minimum Acceptable Time Interval between successive Arrivals
max of

1. (s_{ij}/v_j)
   – *(time for faster 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*

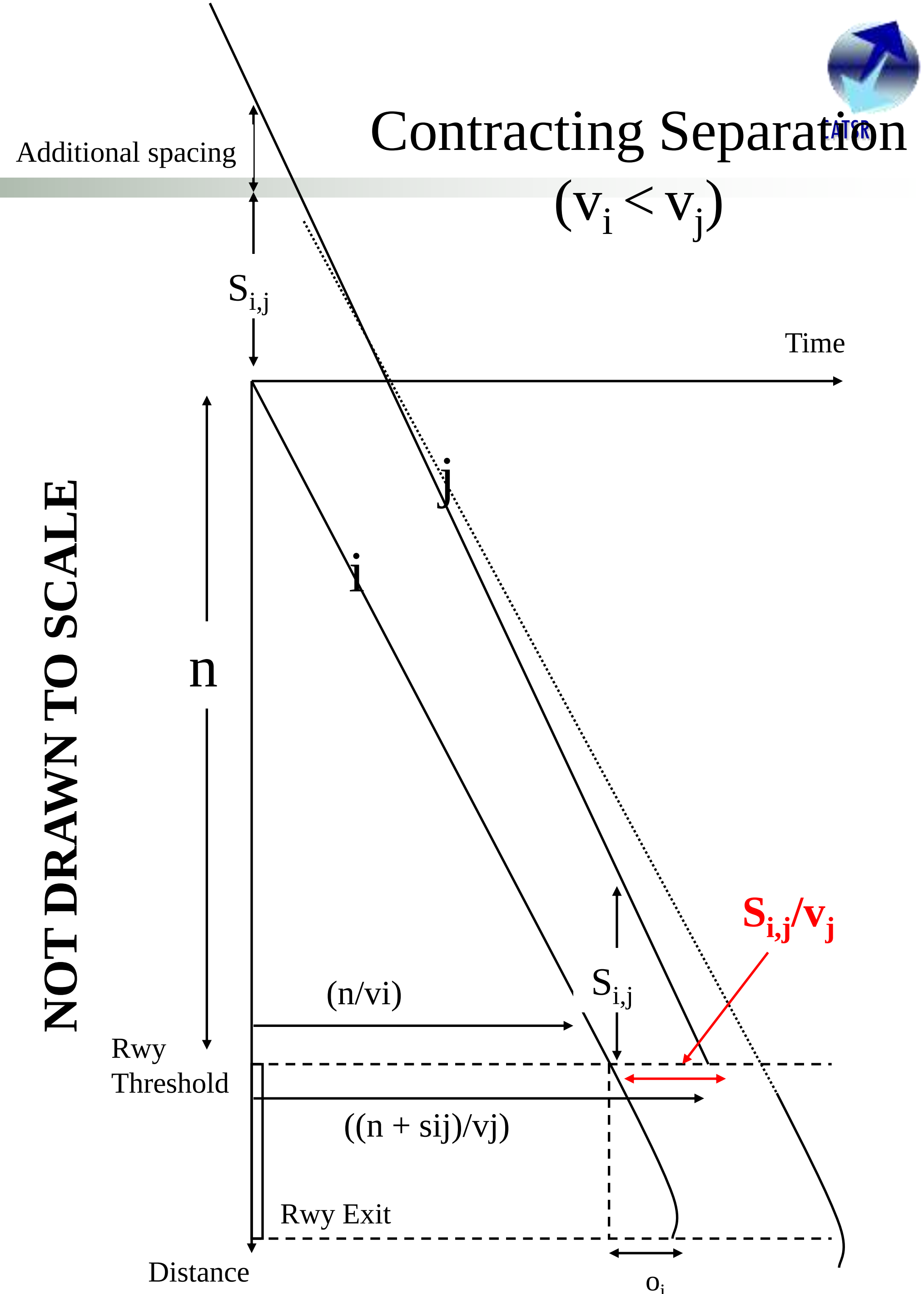


Constant Separation ($v_i = v_j$)



NOT DRAWN TO SCALE

Contracting Separation ($v_i < v_j$)



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

Mixed Fleet Arrivals

- Average Minimum Acceptable Inter-arrival Time

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

  - 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 = $1/E[T_{ij} + \delta]$

  - δ = 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

δ = 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