

RUNWAY OPERATIONS: Computing Runway Arrival Capacity

SYST 560/460

USE Runway Capacity Spreadsheet

Fall 2008

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CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH



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

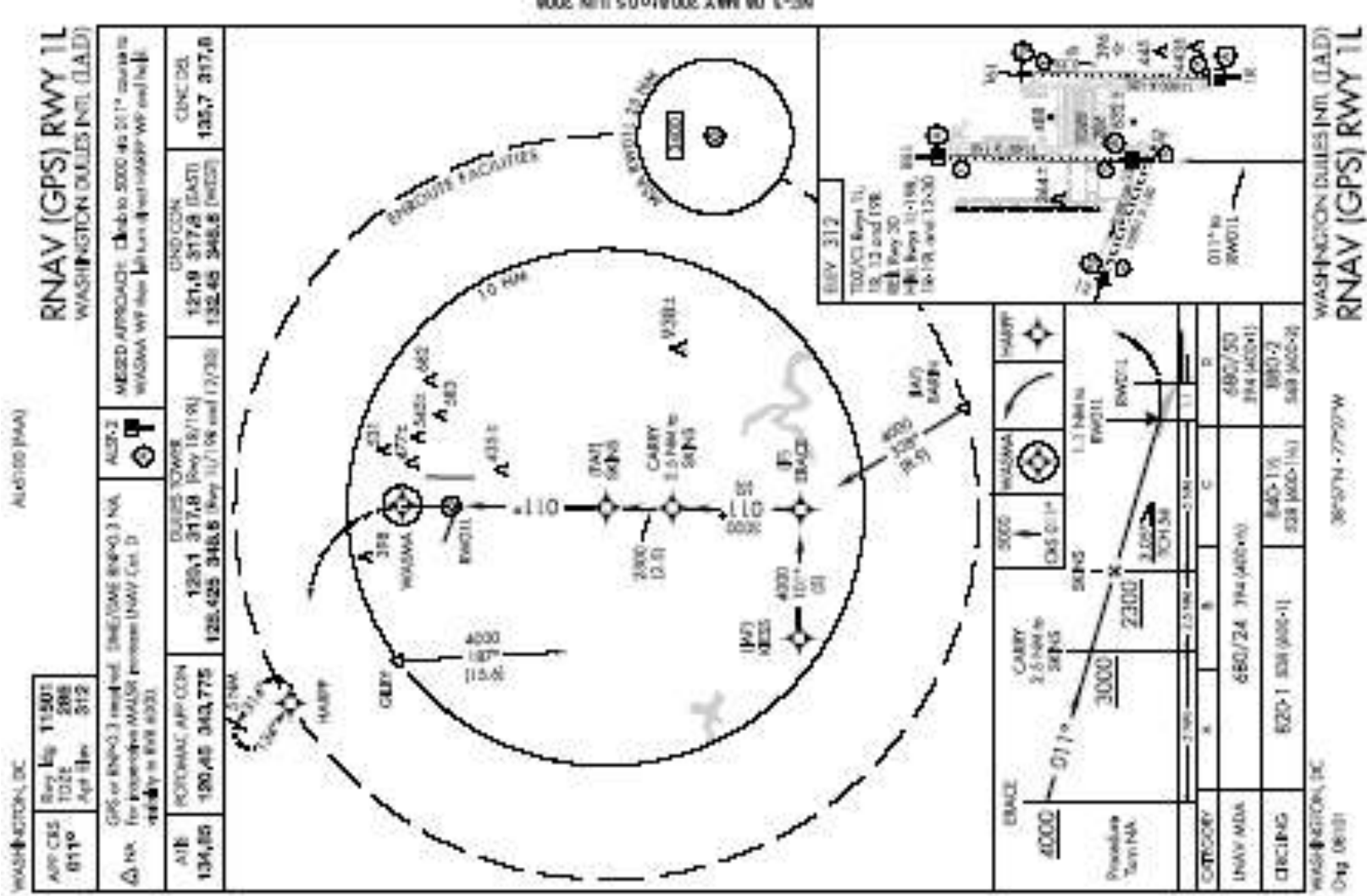
	Definition	Assumptions and Notes	% of MTC
Maximum Throughput Capacity (MTC)	<ul style="list-style-type: none"> Expected number of movements performed in 1 hour 	<ul style="list-style-type: none"> Does not violate ATC separation rules Continuous Demand No limits on delays 	
Practical Hourly Capacity (PHCAP)	<ul style="list-style-type: none"> Expected number of movements performed in 1 hour Delay set to average 4 min delay per vehicle 	<ul style="list-style-type: none"> Avg of 4 min delay, means some vehicles >> 4 mins Runway capacity achieved when avg delay = 4 mins 	80-90% of MTC
Declared Capacity	<ul style="list-style-type: none"> Number of movements per hour at a reasonable LOS (i.e. delay minutes = 3 min) 	<ul style="list-style-type: none"> Used for “Schedule Coordination” (in Europe). Sets limit on scheduled arrivals/departures 	85-90% of MTC
Sustained Capacity	<ul style="list-style-type: none"> Number of movements per hour than can be reasonably sustained over period of several hours 	<ul style="list-style-type: none"> Split in Airport Arrival Rate (AAR) and Airport Departure Rate (ADR) 	<ul style="list-style-type: none"> 90% of MTC with good weather MTC 100% of MTC with bad weather MTC

See deNeufville/Odoni (2004) pages 370 to 374

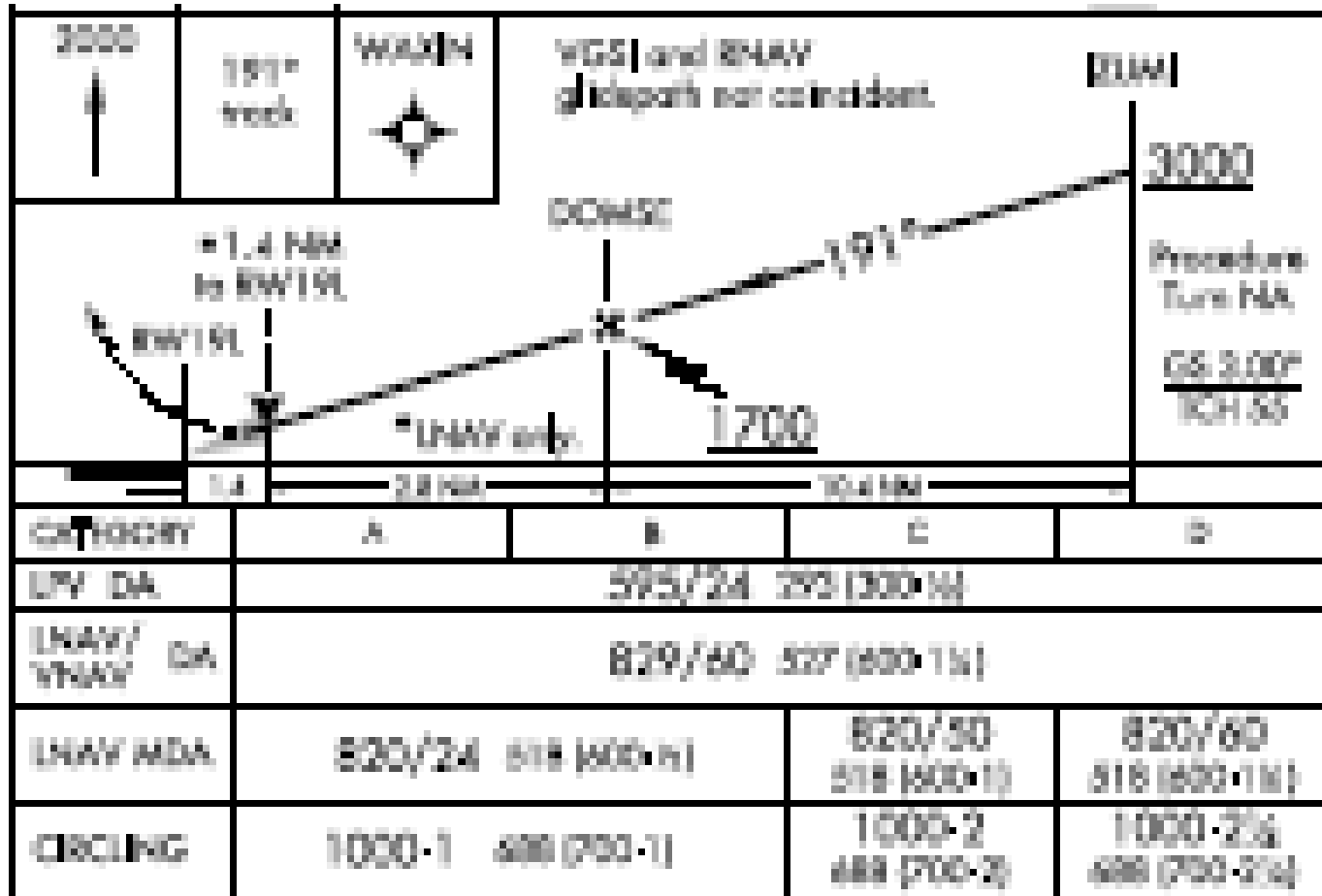
Runway Operations

- 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

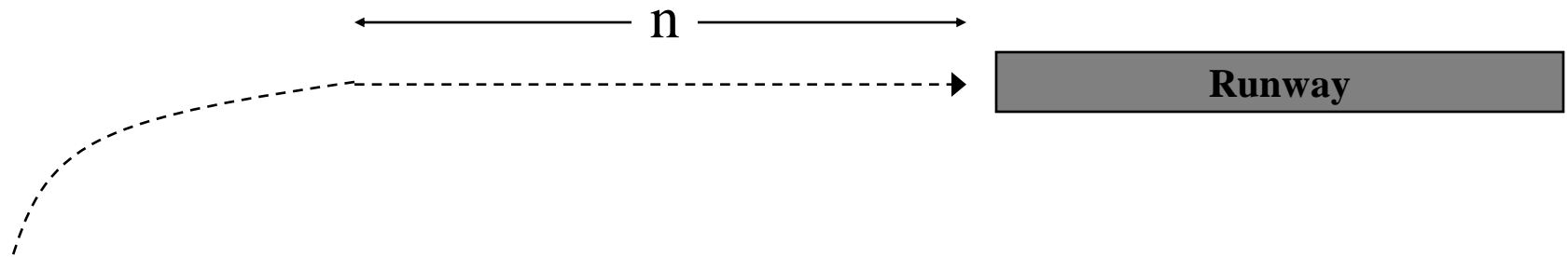


Runway Arrivals



WASHINGTON DULLES INTL (IAD)
 38°52'N · 77°22'W
 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

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)

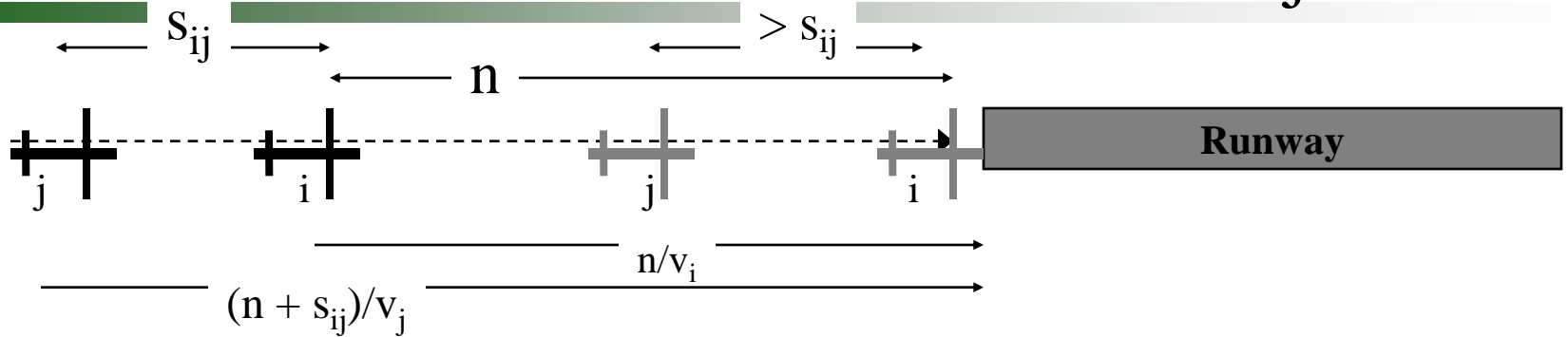


	Follow				
Lead		H (150)	L (130)	M (110)	S (90)
	H (150)	Same	Expanding	Expanding	Expanding
	L (130)	Decreasing	Same	Expanding	Expanding
	M (110)	Decreasing	Decreasing	Same	Expanding
	S (90)	Decreasing	Decreasing	Decreasing	Same

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

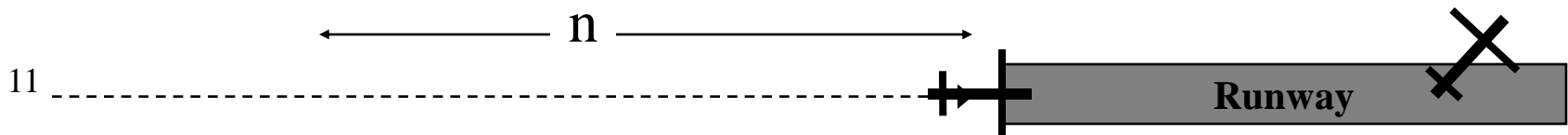
Expanding Separation ($v_i > v_j$)



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

max of

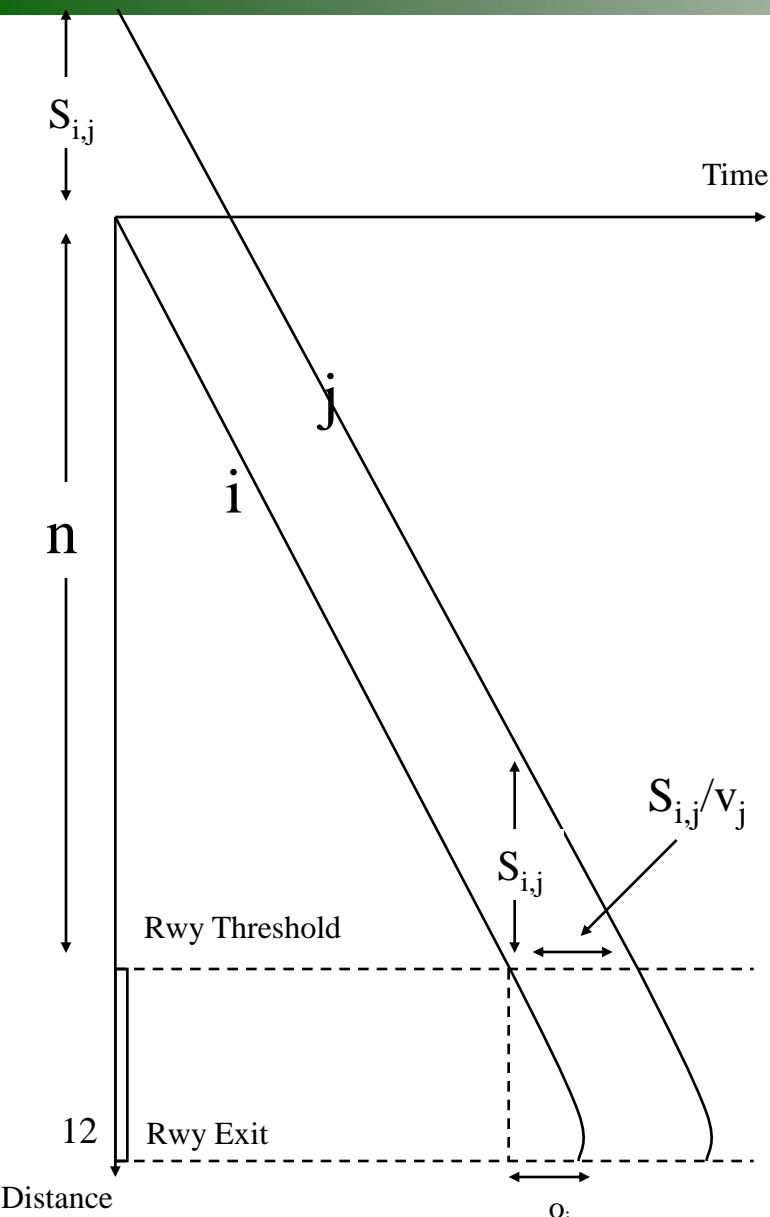
1. $((n + s_{ij})/v_j) - (n/v_i)$
 – (time for follow aircraft (j) to fly separation distance plus final approach path) – (time of lead aircraft (i) to fly final approach path)
2. o_i occupancy time of lead aircraft



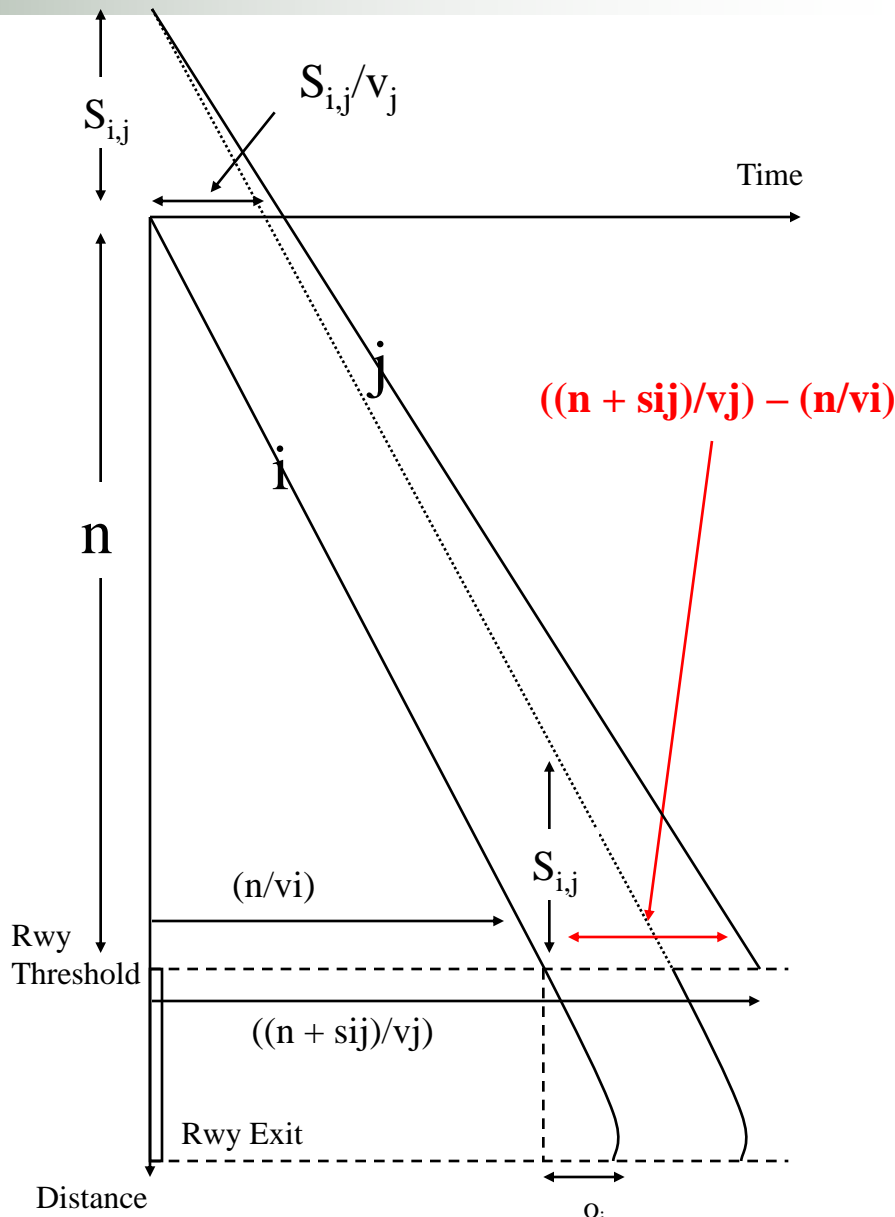


Constant Separation ($v_i = v_j$)

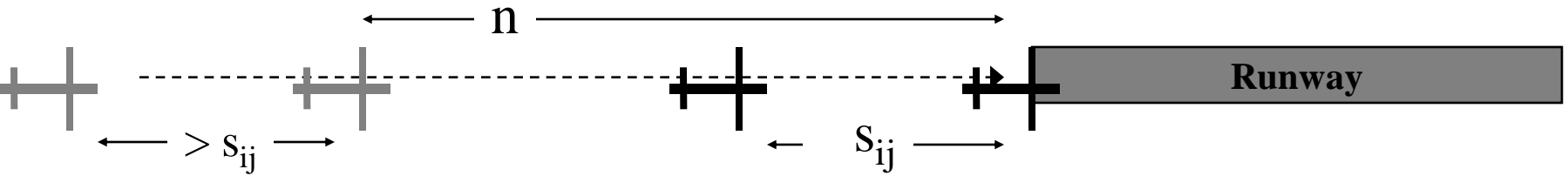
Expanding Separation ($v_i > v_j$)



NOT DRAWN TO SCALE

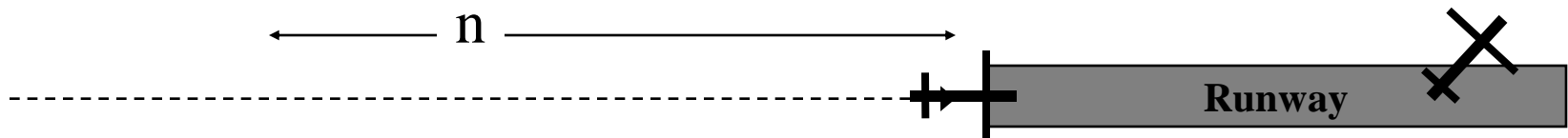


Decreasing Separation ($v_i < v_j$)



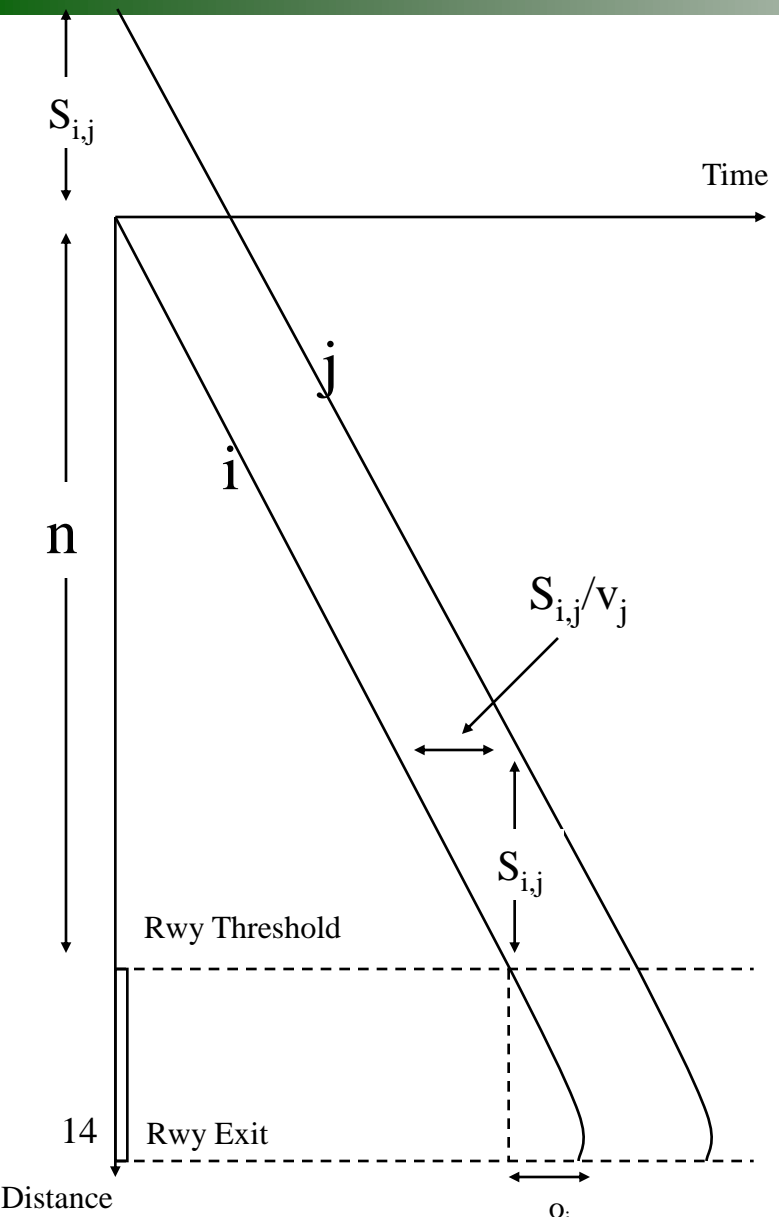
T_{ij} = Minimum Acceptable Time Interval between successive Arrivals
 max of

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





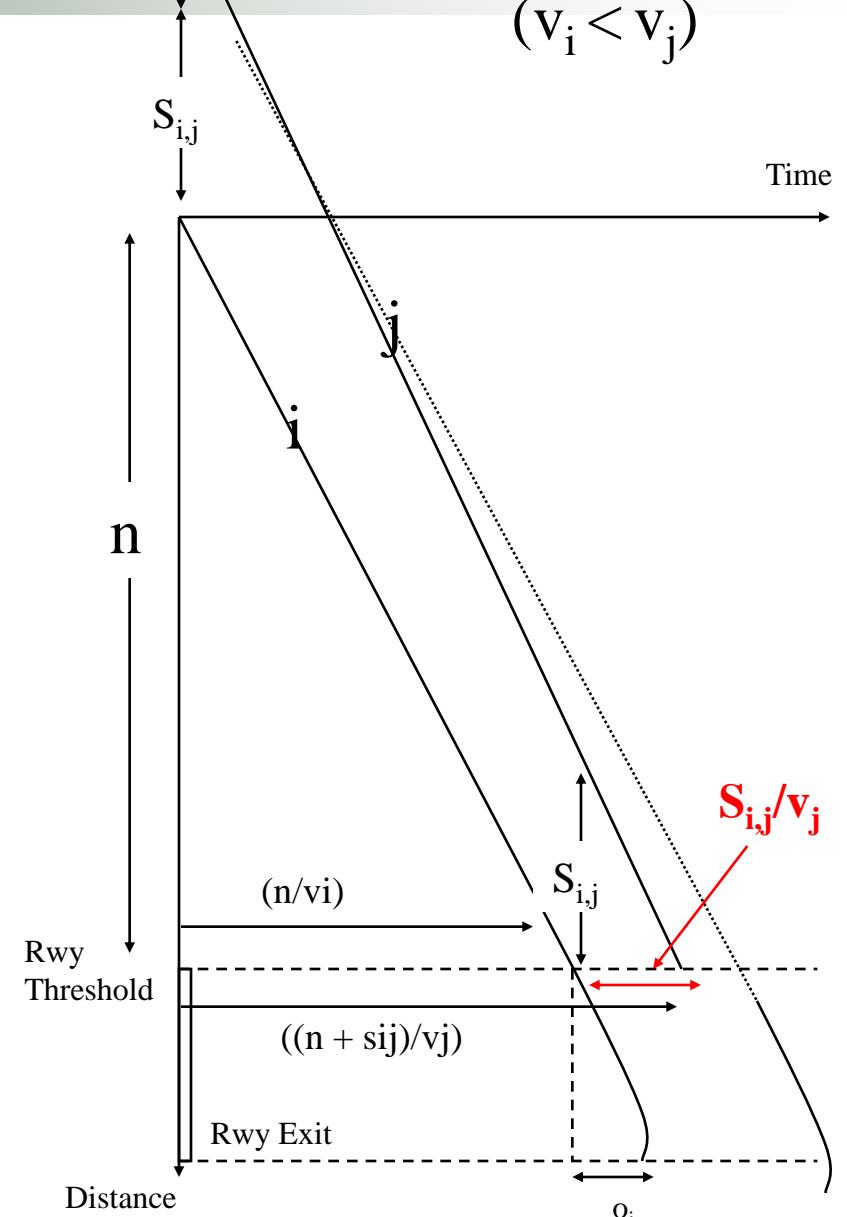
Constant Separation ($v_i = v_j$)



Additional spacing

Contracting Separation ($v_i < v_j$)

NOT DRAWN TO SCALE



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

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

- 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	0.04	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

$$\delta = 10 \text{ secs}$$

$$E[T_{ij}] = 116.3$$

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