Runway Capacity Examples: Two Dependent Runways and 3 Runways

CEE 5614
Analysis of Air Transportation Systems

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Professor

Example:
Two Dependent Parallel Runways

Problem Statement

- An airport has two parallel runways separated 800 meters away form each other (oriented 090-270 degrees)
- The following parameters are known for this airport

Technical Parameters (inputs)	Parameter	Values
Dep-Arrival Separation (nm)	δ	2
Common Approach Length (nm)	γ	8
Standard deviation of Position Delivery Error (s)	σ	20
Probability of Violation	Pv	5

- The airport operates under IFR conditions with the following separation matrices:

Minimum Separation Matrix (nm)			Arrivals-Arrivals
		Trailing	
	Small	Large	Heavy
Small	3	3	3
Large	5	3	3
Heavy	6	5	4

Arrival-Arrival

Problem Statement

- Departure-Departure Separations

Departure-Departure Separation Matrix (seconds)			
		Trailing	
	Small	Large	Heavy
Small	60	60	60
Large	90	90	90
Heavy	120	120	120

Departure-Departure

- Other parameters

	Small	Large	Heavy
ROT (s)	46	52	60
Percent Mix	30	40	30
Vapproach (knots)	100	140	150

Questions

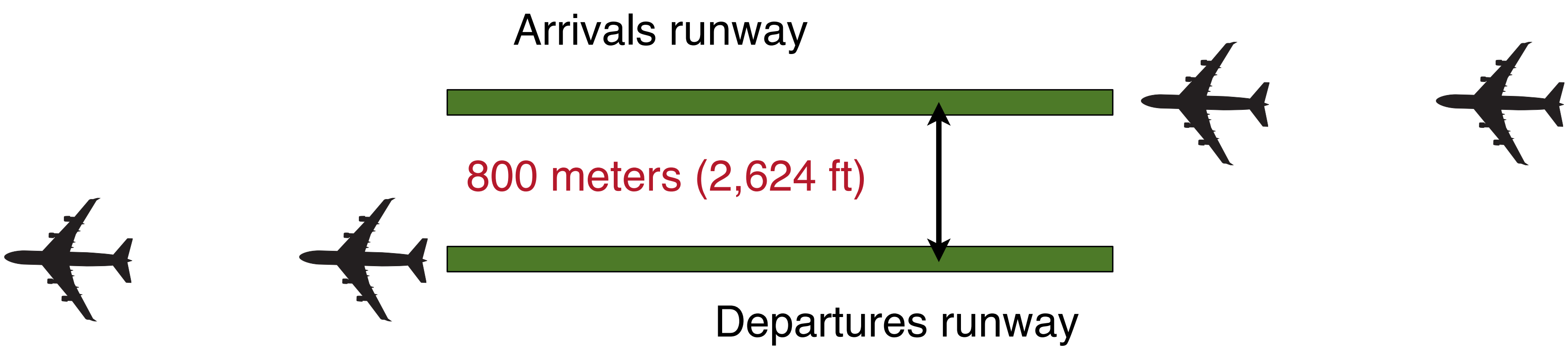
- Draw the Pareto capacity diagram for the airport if one runway is used for arrivals and one for departures
- Draw the Pareto capacity diagram for the airport if both runways are used in mixed operations mode (i.e., arrivals and departures on both runways). Do the analysis for IFR operations.

Solution

Using the Excel Spreadsheet for Calculations

Airport Runway Segregated Operations

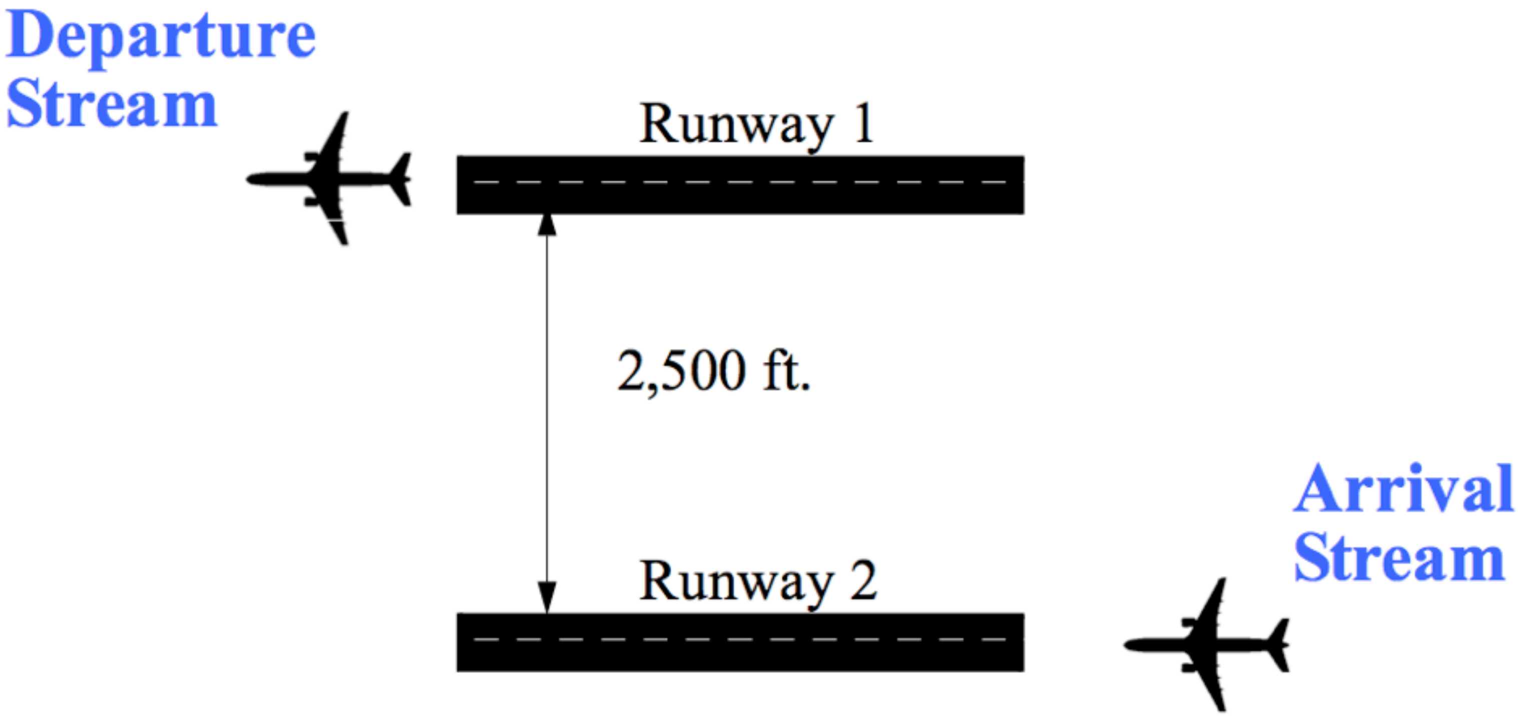
- Two parallel runways spaced 800 meters away (2,624 feet)
- Recall: FAA requires minimum of 2,500 feet and an airport surveillance radar system to allow one runway for arrivals and its parallel one for departures



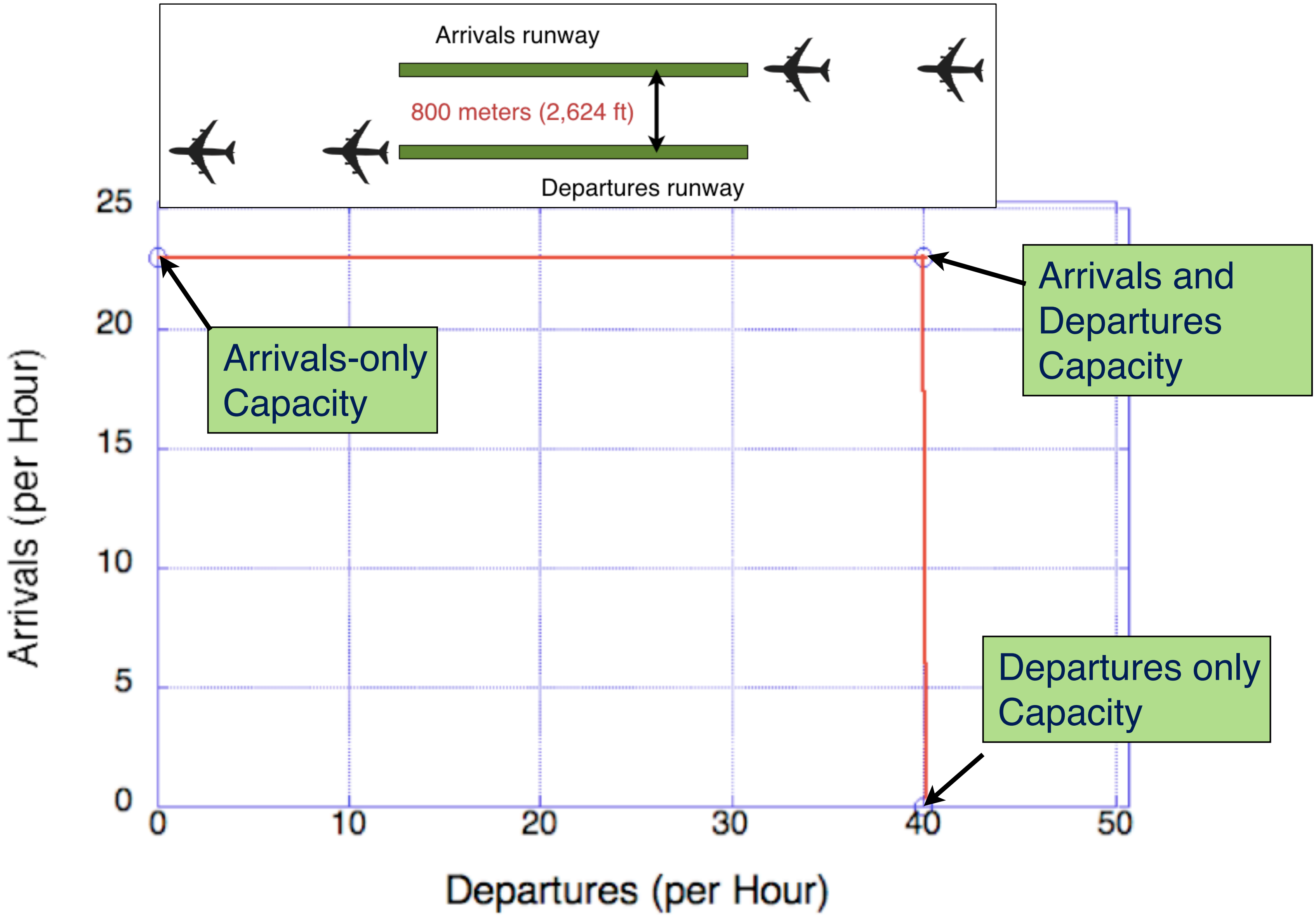
FAA Rule for Segregated Operations (see Notes # 5 Runway Separations)

When a surveillance radar is available at the airport,

- Simultaneous departures and arrivals can be conducted if two parallel runways are located 2,500 ft.

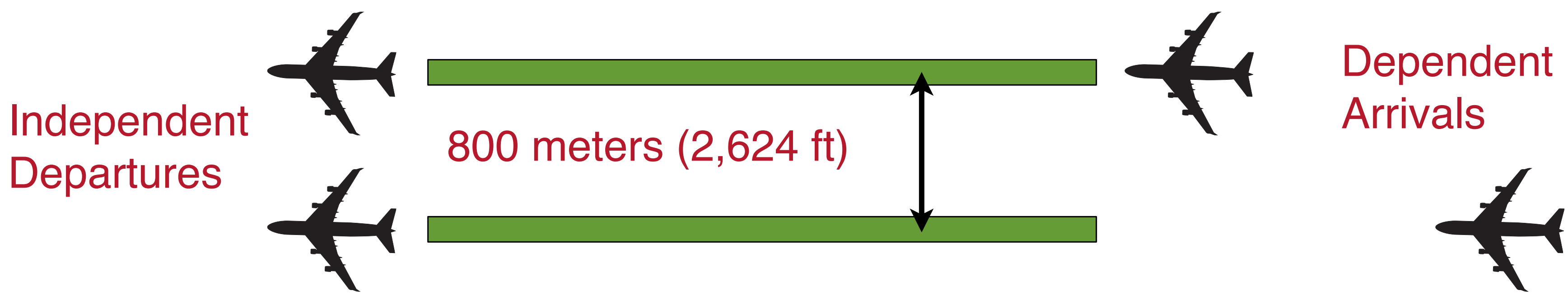


Pareto Diagram for Segregated Operations



Airport with Both Runways under Mixed Operations

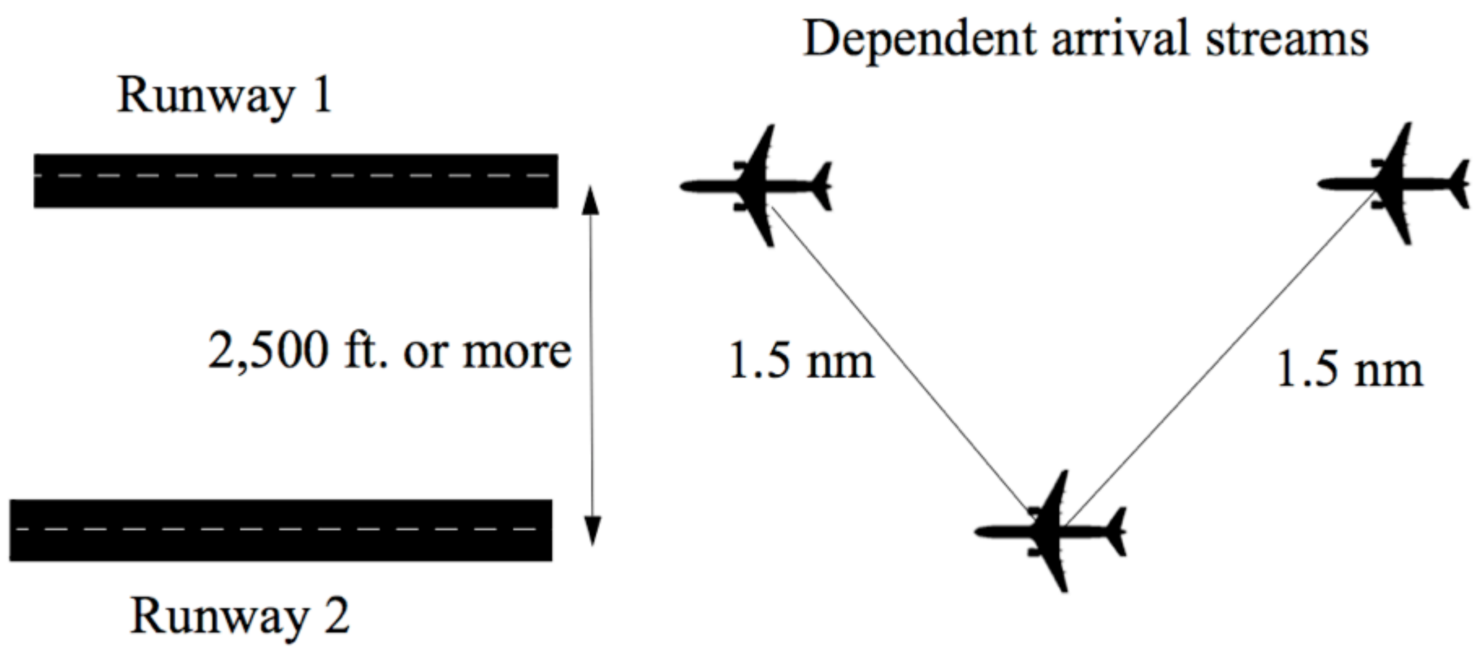
- Two parallel runways spaced 800 meters away (2,624 feet)
- Recall: FAA requires minimum of 3000 feet and a PRM (Precision Runway Monitor) system to allow simultaneous independent parallel approaches
- Therefore: runways are operated **with dependent arrivals but independent departures (2 rules)**



FAA Rule for *Dependent Runway Arrival* Operations (see Notes # 5 Runway Separations)

When a surveillance radar is available at the airport,

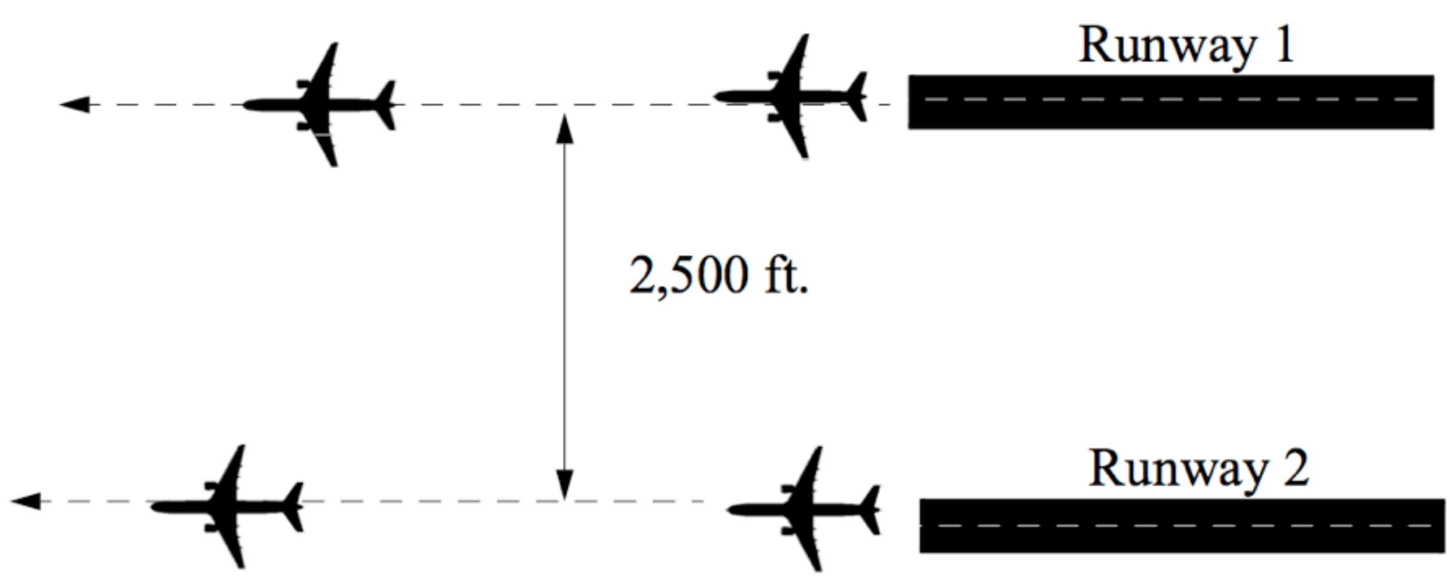
Procedures exist to conduct dependent arrivals when runway separation is below 4,300 ft. and above 2,500 ft. (standard radar).



FAA Rule for *Independent Runway Departure* Operations (Notes # 5 Runway Separations)

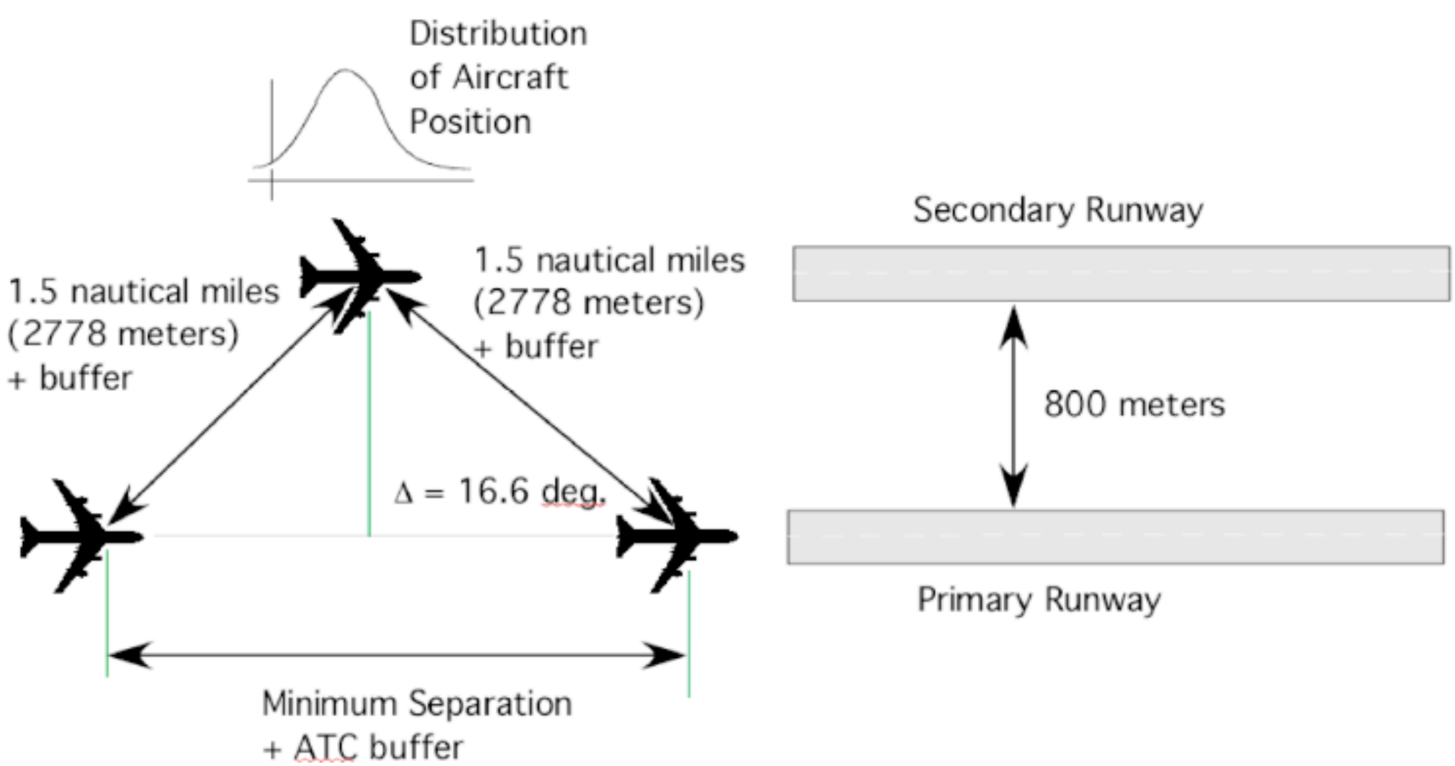
When a surveillance radar is available at the airport,

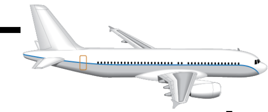
- Simultaneous departures can be conducted if two parallel runways are located 2,500 ft.



Solution for Dependent Arrivals

- Arrival to both runways are dependent
- Select a primary runway for analysis and then select the runway that is dependent on the primary runway (called secondary runway)





Solution and Analysis

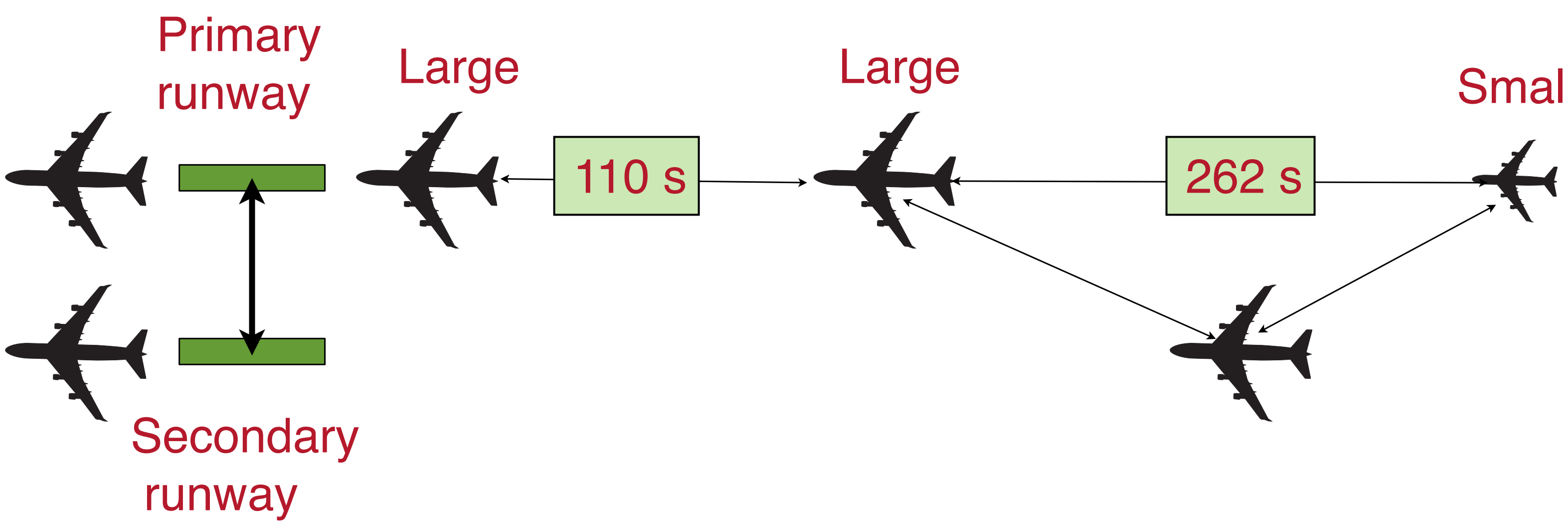
- Lets add two buffers of 33 seconds to simulate probability of violations of 5% (consistent with human factor studies)
- This brings the minimum gap for an arrival on the second runway to be : 147 seconds
- Now lets find gaps between successive arrivals on the primary runway with at least a gap of 140 seconds. The matrix of successive arrivals on the primary runway is shown below

49						
50	Augmented Matrix					
51			Trailing			
52		Small	Large	Heavy		Expected Value
53	Small	141.00	110.14	105.00		E(Tij) + B(Tij)
54	Large	262.29	110.14	105.00		156.75
55	Heavy	312.00	166.71	129.00		

Example Interpretation of Analysis

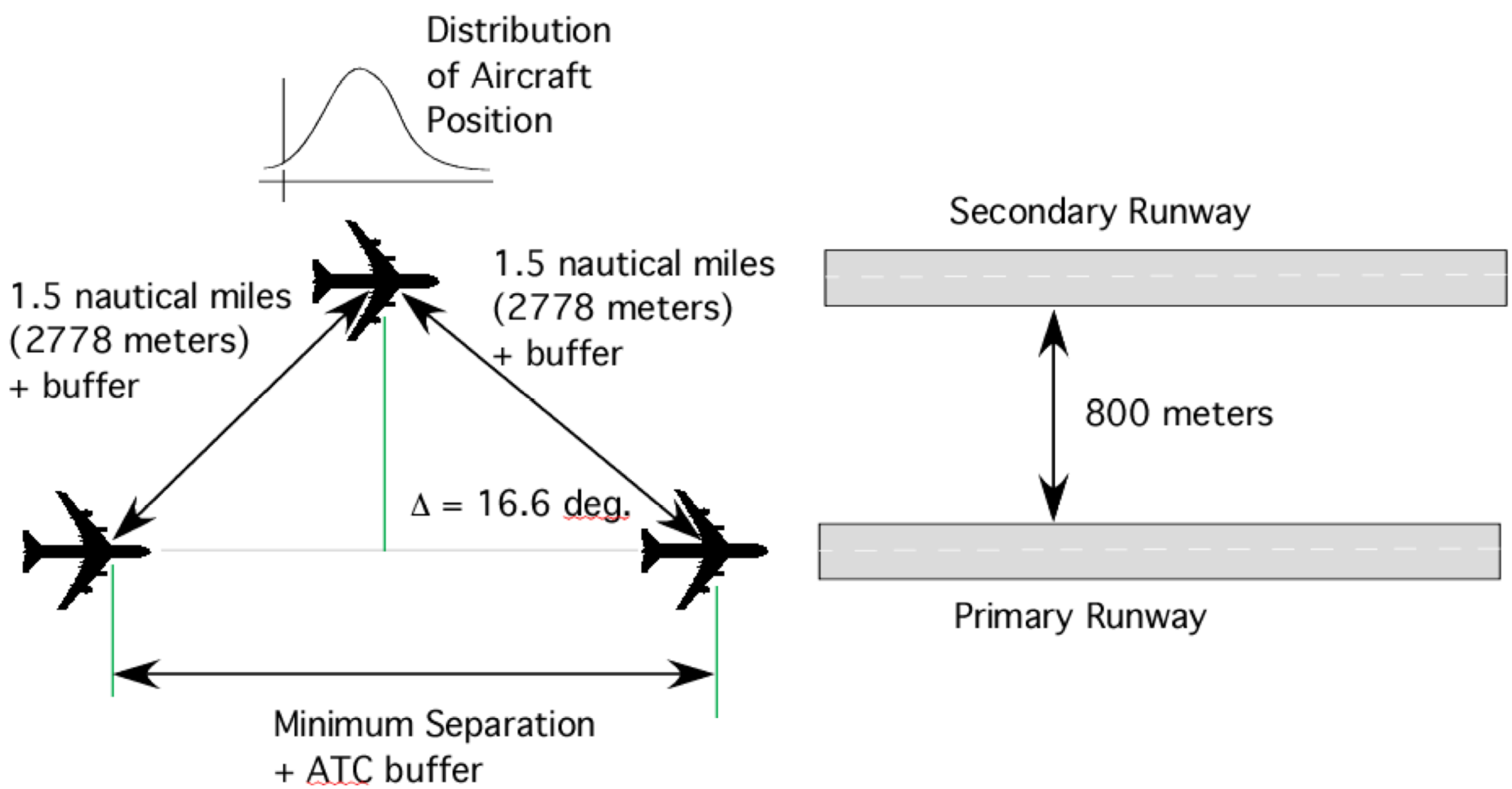
- When a **large-large** sequence exists, the arrival gap (110 seconds) is not large enough to allow a diagonal separation of 1.5 nm for an arrival on the secondary runway
- When **large-small** sequence exist, the arrival gap allows an arrival on the secondary runway

50	Augmented Matrix			
51			Trailing	
52		Small	Large	Heavy
53	Small	141.00	110.14	105.00
54	Large	262.29	110.14	105.00
55	Heavy	312.00	166.71	129.00



Solution for Diagonal Arrivals

- This solutions uses the rule that 1.5 nm is needed between diagonally operated tracks



Solution Ideas

- Note that for each arrival on the secondary runway we need to account for possible buffers (or position errors) since controllers do not have a fast update of the aircraft position in their radar scopes. The aircraft landing in the secondary runway thus pose a higher challenge to the air traffic controller because they require two buffers computed between arrivals in the primary runway.
- The minimum expected gap without buffers allowing an aircraft arrival on the secondary runway is calculated to be 5,320 meters (using simple geometry).

Solution

- A 5,320 meters distance translates into the following headways for each one of the three aircraft groups operating at this facility:
- T_{gap} – heavy = 69 seconds
- T_{gap} – large = 74 seconds
- T_{gap} – small = 103 seconds
- The expected headway for minimum gap (no buffers) is : (0.3) 103 + (0.4) (74) + (0.3) (69) = 81 seconds.

Diagonal Separation Solution

- Lets add two buffers of 33 seconds to simulate probability of violations of 5% (consistent with human factor studies)
- This brings the minimum gap for an arrival on the second runway to be : 147 seconds
- Now lets find gaps between successive arrivals on the primary runway with at least a gap of 140 seconds. The matrix of successive arrivals on the primary runway is shown below

Solution

- Lets add two buffers of 33 seconds to simulate probability of violations of 5% (consistent with human factor studies)
- This brings the minimum gap for an arrival on the second runway to be : 147 seconds
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54	Large	262.29	110.14	105.00		156.75
55	Heavy	312.00	166.71	129.00		

Solution

84	Arrivals on Secondary Runway per Gap				
85			Trailing		
86		Small	Large	Heavy	
87	Small	0.00	0.00	0.00	
88	Large	1.00	0.00	0.00	
89	Heavy	2.00	1.00	0.00	
90					

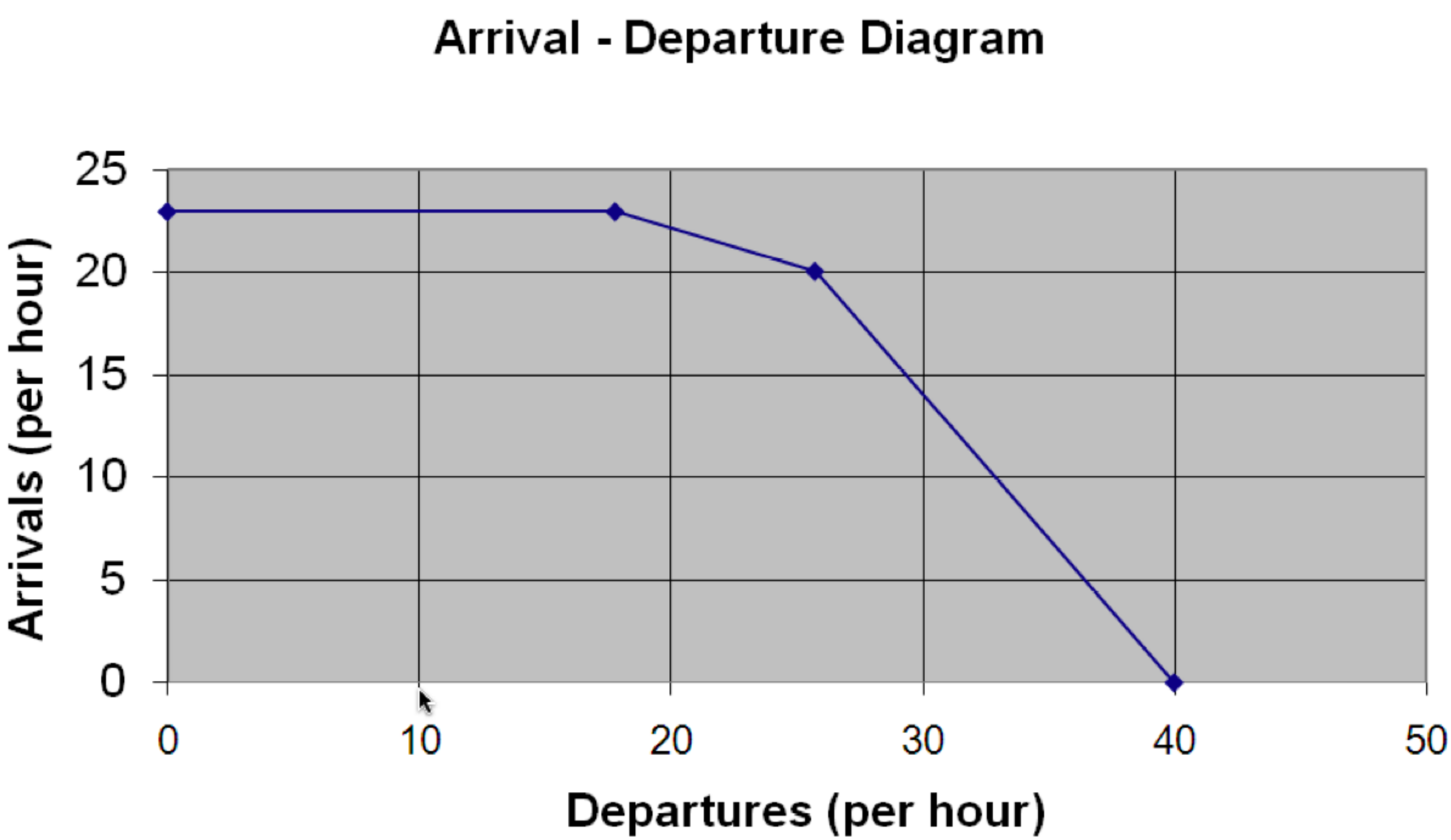
93			Trailing				
94		Small	Large	Heavy		Expected Value	
95	Small	0.00	0.00	0.00		0.00	
96	Large	2.64	0.00	0.00		2.64	
97	Heavy	3.95	2.64	0.00		6.59	
98						9.23	Total Arrivals on Secondary
99							

Solution

- Knowing the probability matrix for both runways, we can estimate the number of gaps where sufficient headway exit allowing and arrivals on the secondary runway

- The approach is similar to that explained in class and executed in the Excel program to estimate departures in the mixed mode case (see rows 93-97 in the Excel spreadsheet)

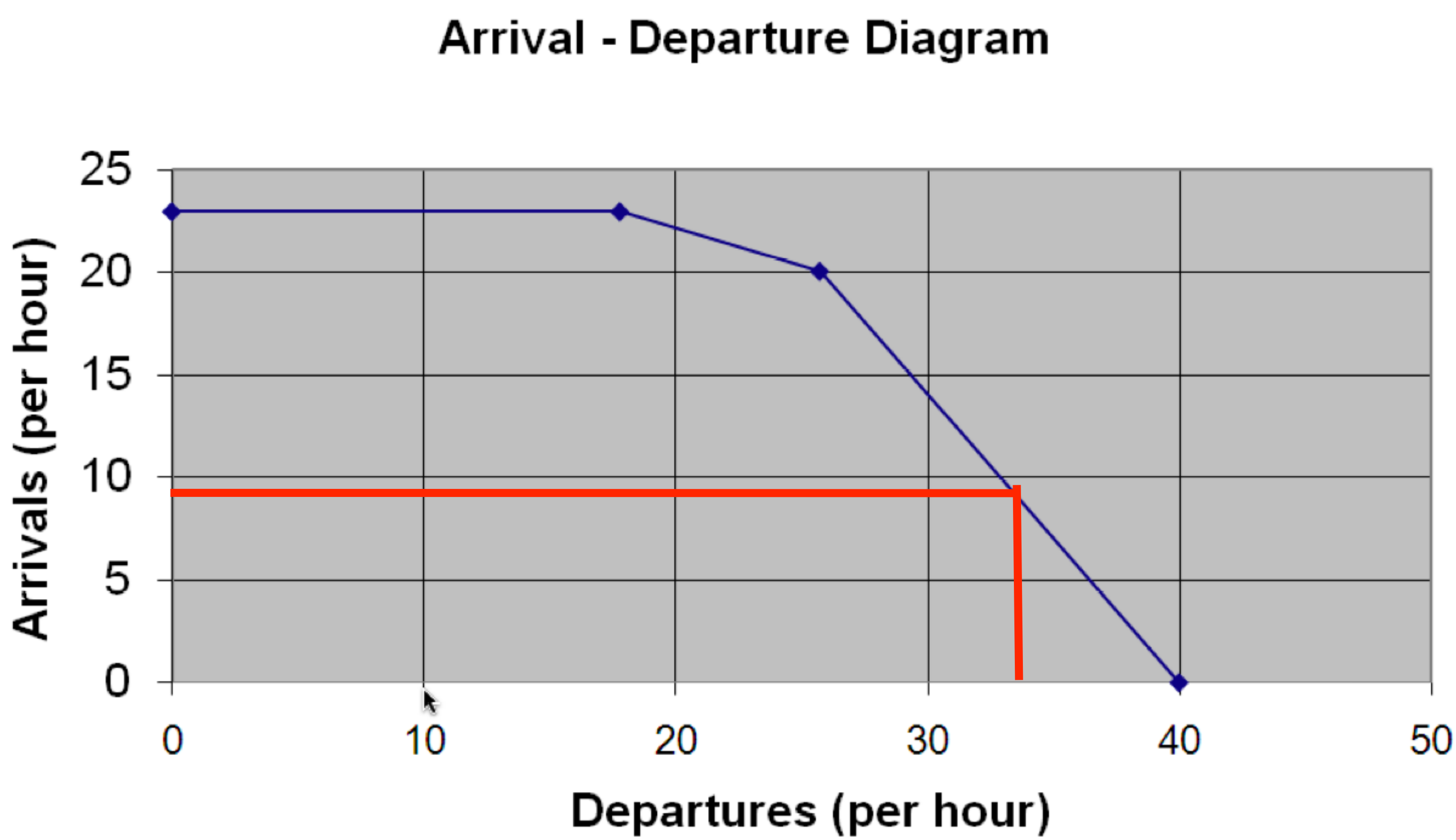
Solution for Primary Runway



Remarks

- If all conditions are met as stated, the airport can process 23 + 9 = **32 arrivals per hour** under the strategy that one runway is used at the saturation level and the second one is only used when available gaps on the primary allow arrivals in the secondary runway.
- To estimate the number of departures when the arrivals is 9.2 per hour we turn our attention to the original Pareto diagram for the primary runway only.
- The figure suggests that if arrivals are processed at a rate of 9/hr, we could process 33 departures/hr on the same runway.

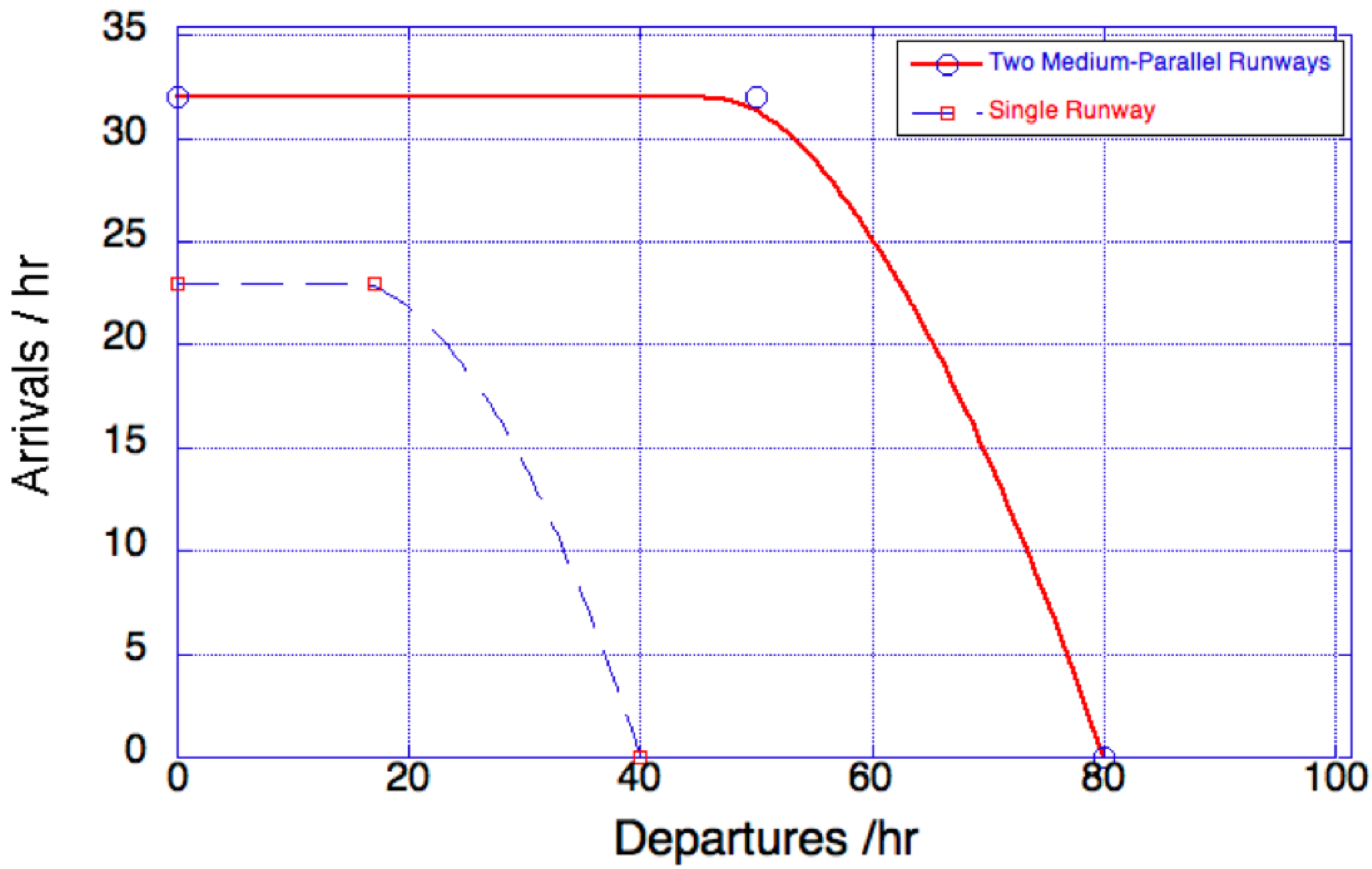
Remarks


Arrival - Departure Diagram
Arrivals (per hour)
25
20
15
10
5
0
0
10
20
30
40
50
Departures (per hour)

Remarks

- This provides a first estimate of the number of departures on the secondary runway when 9 arrivals are processed in the same runway
- The primary runway handles 17 departures and 23 arrivals per hour
- Therefore, the new close-parallel configuration will handle (17 + 33 = 50) departures and 32 arrivals on two runways
- When only departures are allowed, the number of departures just doubles compared to the single runway case (i.e., 80 departures per hour as shown in the Pareto diagram)

Final Solution



Example:
Three Dependent Runways

Problem Description

- The airport to be studied in this problem is shown in Figure 1
- The airport has two 9,000 foot runways with a configuration shown in the Figure 1 (see Page 5)
- The airport has an airport surveillance radar (ASR) which tracks aircraft up to 60 miles form the airport site
- Tables 1 and 2 show the typical ATC separations at the airport under IMC conditions
- Tables 3 and 4 show the separations under VMC conditions
- The airport has the following technical parameters: a) in-trail delivery error of 16 seconds, b) departure-arrival separation for both VMC and IMC conditions is 2 nautical miles, c) probability of violation is 5%
- Arriving aircraft are “vectored” by ATC to the final approach fix (see Figure) located 7 miles from the runway threshold

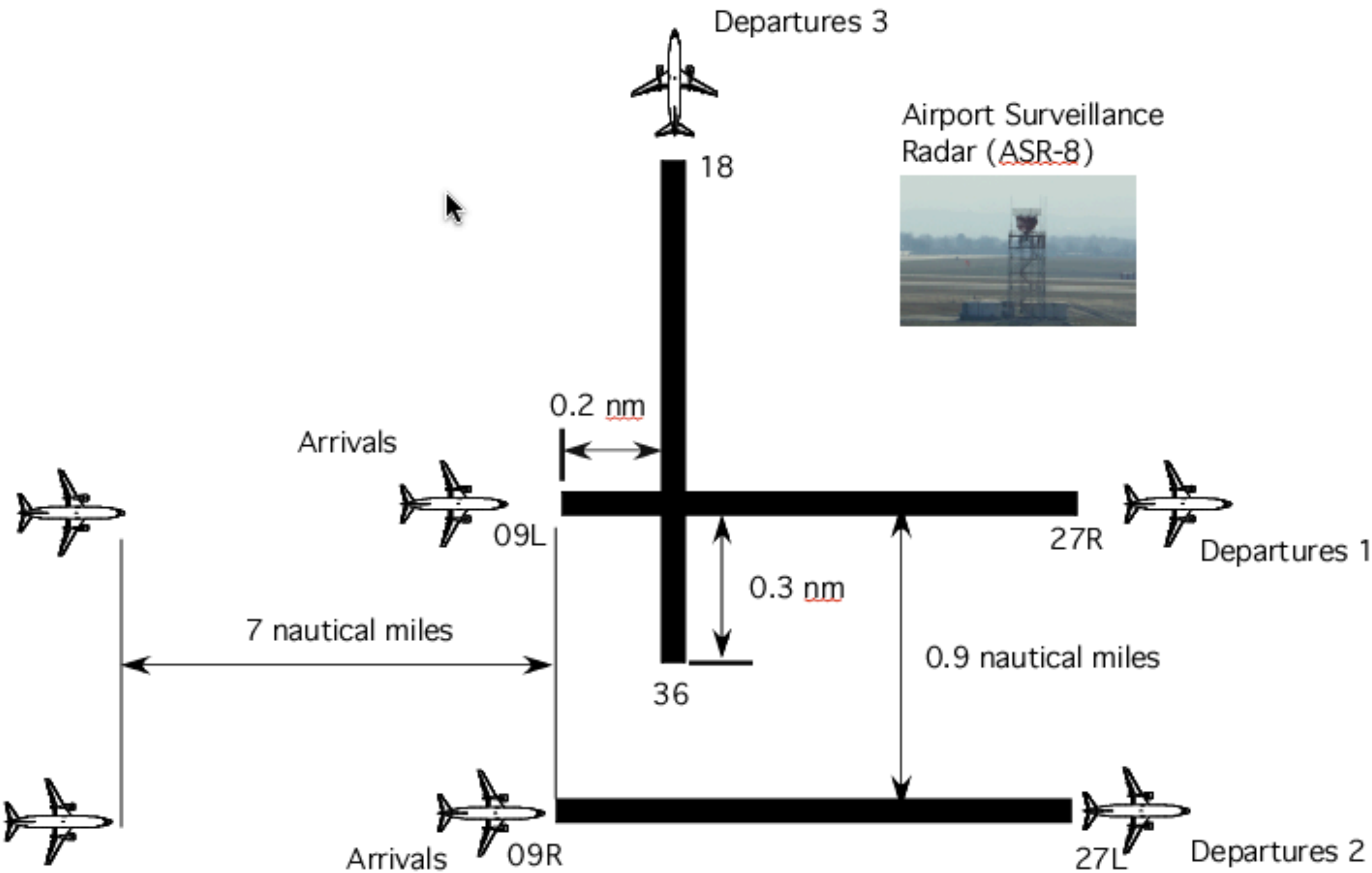
Problem Description

- The airport has an aircraft fleet mix made up of 10% small, 65% large and 25% heavy wake class aircraft
- The characteristics of the aircraft are given in Table 5
- Observed runway occupancy times in the field are: 48, 55, and 62 seconds for small, large and heavy aircraft, respectively
- Assume the 3-point runway deceleration calculation method applies to this problem to estimate the time to cross the intersection

Problem Description

- In your analysis assume departing aircraft accelerate on the runway at a constant rate of 2.2 m/s^2
- Assume that ATC controllers release departures on runway 18-36, around 10 seconds after an arriving aircraft crosses the intersection between runways 09L-27R and 18-36
- Arrivals and departures are not airborne at the intersection
- For departures on runway 18-36 to occur, it is desired that when the departing aircraft is released from the takeoff position, the next arrival to runway 09L be no less than 2.0 nm from the arrival threshold
- This rule is used by ATC controllers to schedule departures on runway 36

Problem Description



Problem Description (IFR Separations)

Table 1. Minimum arrival-arrival separations under IMC conditions. Values in are nautical miles.

Minimum Separation Matrix (nm)			Arrivals-Arrivals
Lead		Trailing	
	Small	Large	Heavy
Small	3	3	3
Large	5	3	3
Heavy	6	5	3

Table 2. Minimum departure-departure separations under IMC conditions. Values in are in seconds.

Departure-Departure Separation Matrix (seconds)			
Lead		Trailing	
	Small	Large	Heavy
Small	60	60	60
Large	60	60	90
Heavy	120	120	120

Problem Description (VFR Separations)

Table 3. Minimum arrival-arrival separations under VMC conditions. Values in are nautical miles.

Minimum Separation Matrix (nm)			Arrivals-Arrivals
Lead		Trailing	
	Small	Large	Heavy
Small	2.4	2.4	2.4
Large	5	2.4	2.4
Heavy	6	4	2.7

Table 4. Minimum departure-departure separations under IMC conditions. Values in are in seconds.

Departure-Departure Separation Matrix (seconds)			
Lead		Trailing	
	Small	Large	Heavy
Small	50	50	50
Large	50	50	75
Heavy	90	90	90

Problem Description (Runway Performance)

Table 5. Runway Performance Data.

Aircraft Group	Parameters	Representative Aircraft
Small aircraft	Approach speed = 125 knots Touchdown location = 1,200 feet Average deceleration = -4.2 ft/s^2 Free roll time = 2.0 seconds (after touchdown and before braking)	Cessna Citation 560, Citation 500, Beechcraft Jet 400
Large aircraft	Approach speed = 145 knots Touchdown location = 1,300 feet Average deceleration = -4.2 ft/s^2 Free roll time = 2.0 seconds	Boeing 737-400 (B-737-400), Airbus A320 (A-320-200)
Heavy aircraft	Approach speed = 155 knots Touchdown location = 1,400 feet Average deceleration = -4.2 ft/s^2 Free roll time = 2.0 seconds	Boeing 747-400, Airbus A340-600

Questions

1. Calculate the arrival-departure saturation capacity diagram (Pareto diagram) under IMC conditions for this airport
2. Calculate the arrival-departure saturation capacity diagram (Pareto diagram) under VMC conditions for this airport

- State all your assumptions in your calculations

Solution Steps to the Problem

- Start with a single runway analysis for IMC conditions
- Identify interactions between runways
- Use the principle of superposition whenever possible (i.e., study independent runways and then add their capacity)
- Set-up a manual simulation scheme to look at various operational strategies for the airport

Single Runway Analysis (Arrival Operations)

- Use the spreadsheet program provided in class or your own manual calculations

Pij Matrix			
		Trailing	
	Small	Large	Heavy
Small	0.010	0.065	0.025
Large	0.065	0.423	0.163
Heavy	0.025	0.163	0.063

IFR Conditions

Augmented Matrix (Tij + Bij)			
		Trailing	
	Small	Large	Heavy
Small	112.80	100.88	96.08
Large	178.34	100.88	96.08
Heavy	211.82	153.74	96.08

Arrivals-Only Capacity 30.98 per hour

Single Runway Analysis (departure operations)

Pij Matrix			
	Trailing		
	Small	Large	Heavy
Small	0.010	0.065	0.025
Large	0.065	0.423	0.163
Heavy	0.025	0.163	0.063

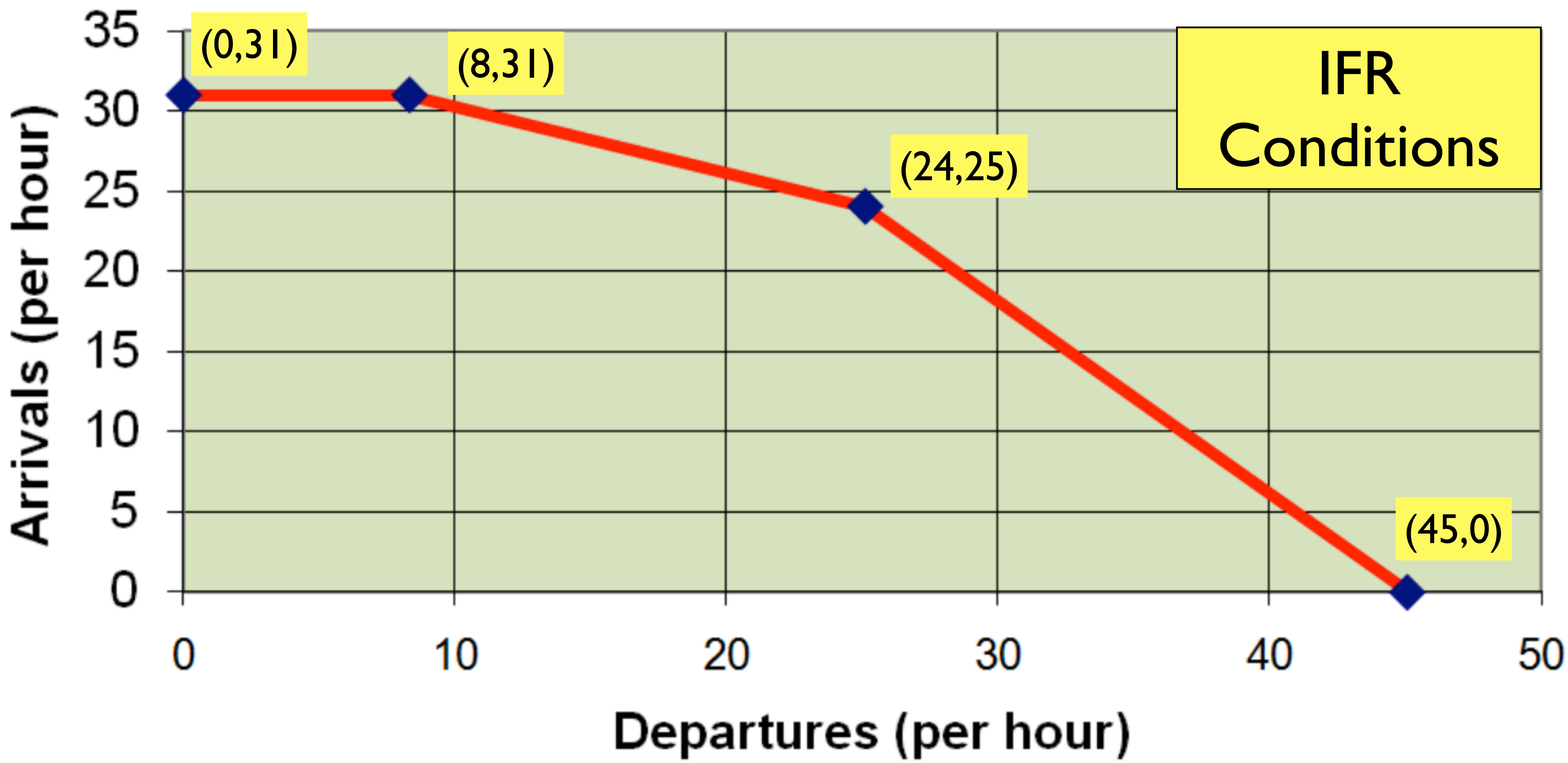
IFR Conditions

Departure-Departure Separation Matrix (seconds)			
	Trailing		
	Small	Large	Heavy
Small	60	60	60
Large	60	60	90
Heavy	120	120	120

Departures-Only Capacity 45.07 per hour

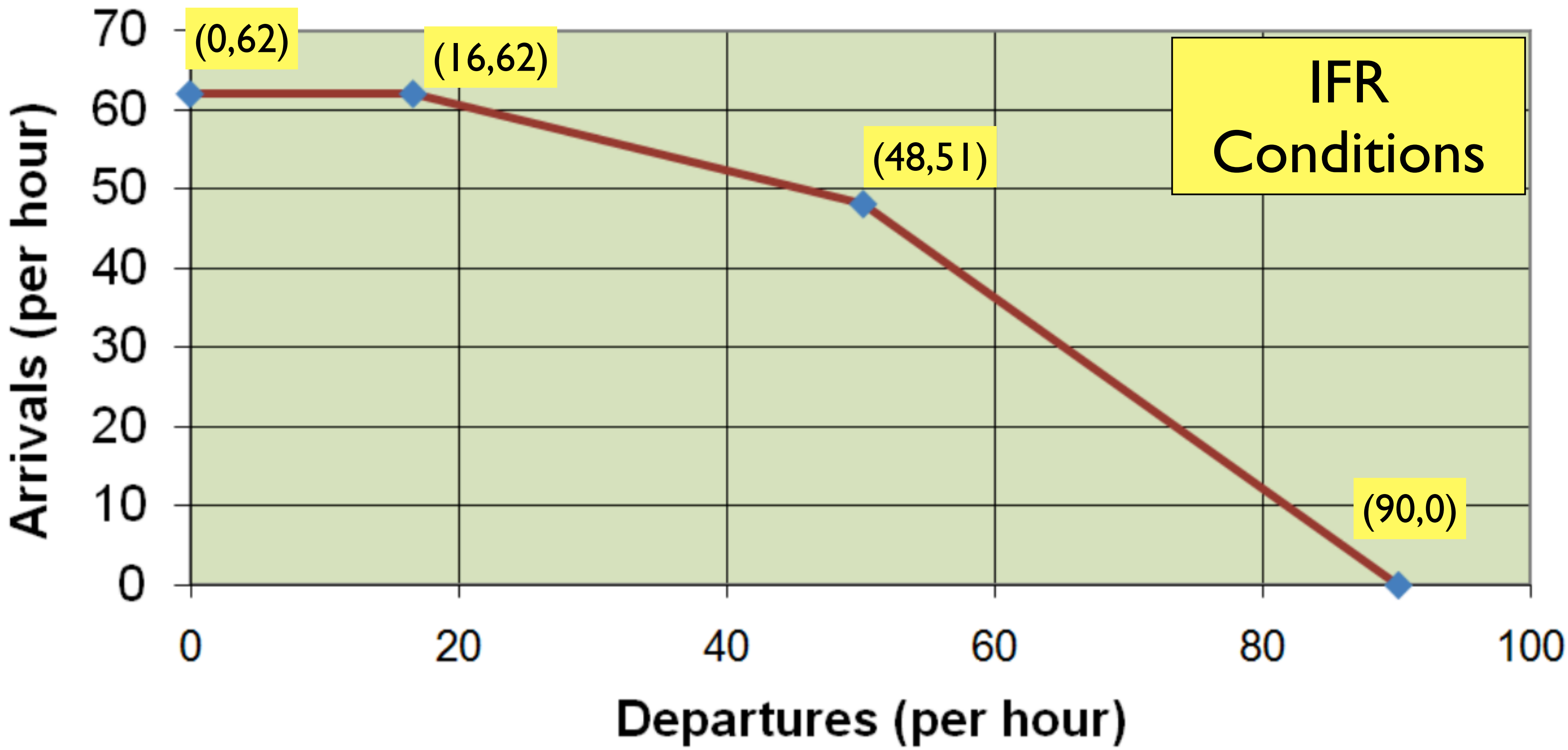
IFR Capacity Pareto Diagram (Single Runway Analysis)

Saturation Capacity for a Single Runway at the Airport under Various Operational Conditions. The diagram applies to one runway (either 09L-27R or 09R-27L)



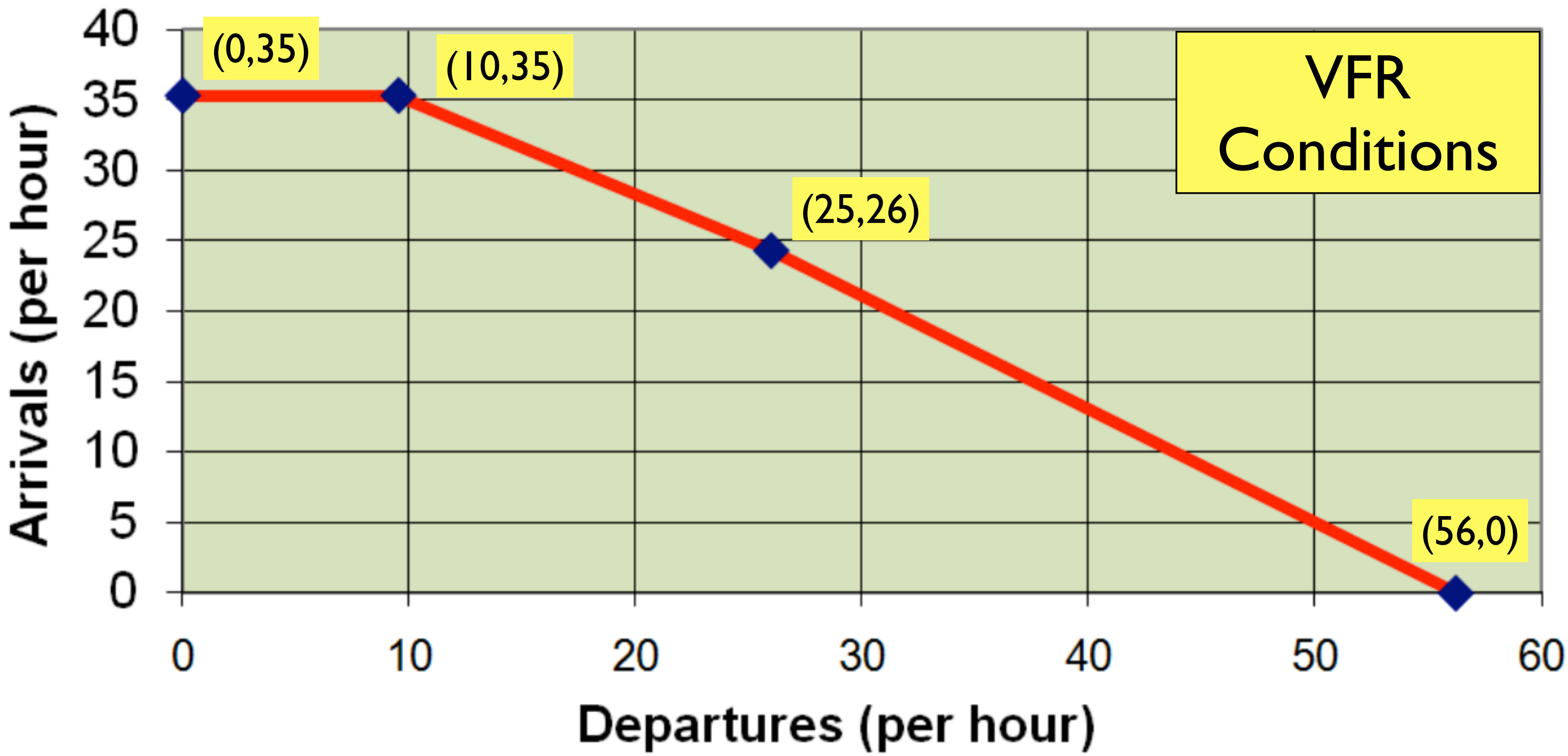
IFR Capacity Pareto Diagram (Two Parallel and Independent Runways)

Saturation Capacity for two runways at the Airport under Various Operational Conditions. The diagram applies to one runway (either 09L-27R or 09R-27L)



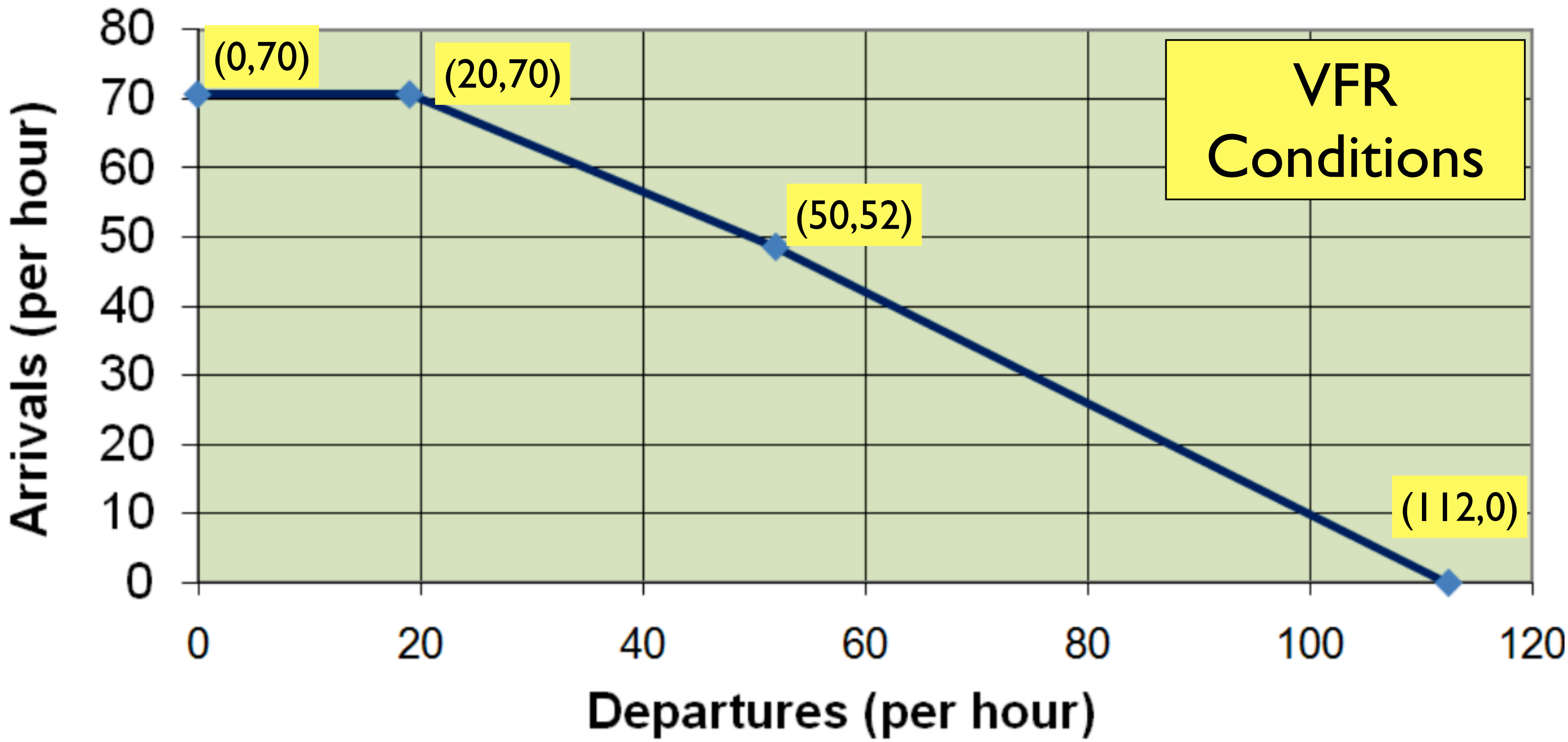
VFR Capacity Pareto Diagram (Single Runway Analysis)

Saturation Capacity for a Single Runway at the Airport under Various Operational Conditions. The diagram applies to one runway (either 09L-27R or 09R-27L)



VFR Capacity Pareto Diagram (Two Parallel and Independent Runways)

Saturation Capacity for a Single Runway at the Airport under Various Operational Conditions. The diagram applies to one runway (either 09L-27R or 09R-27L)



Observations

- Arrivals on runways 09L and 09R are independent (> 4300 ft separation) (radar available)
- The Pareto diagram found for one runway replicates for the second parallel runway (also used in mixed operations mode)
- The arrivals-only saturation capacity of the two-runway system is 62 per hour
- The departures-only saturation capacity for two parallel runways is 90 per hour

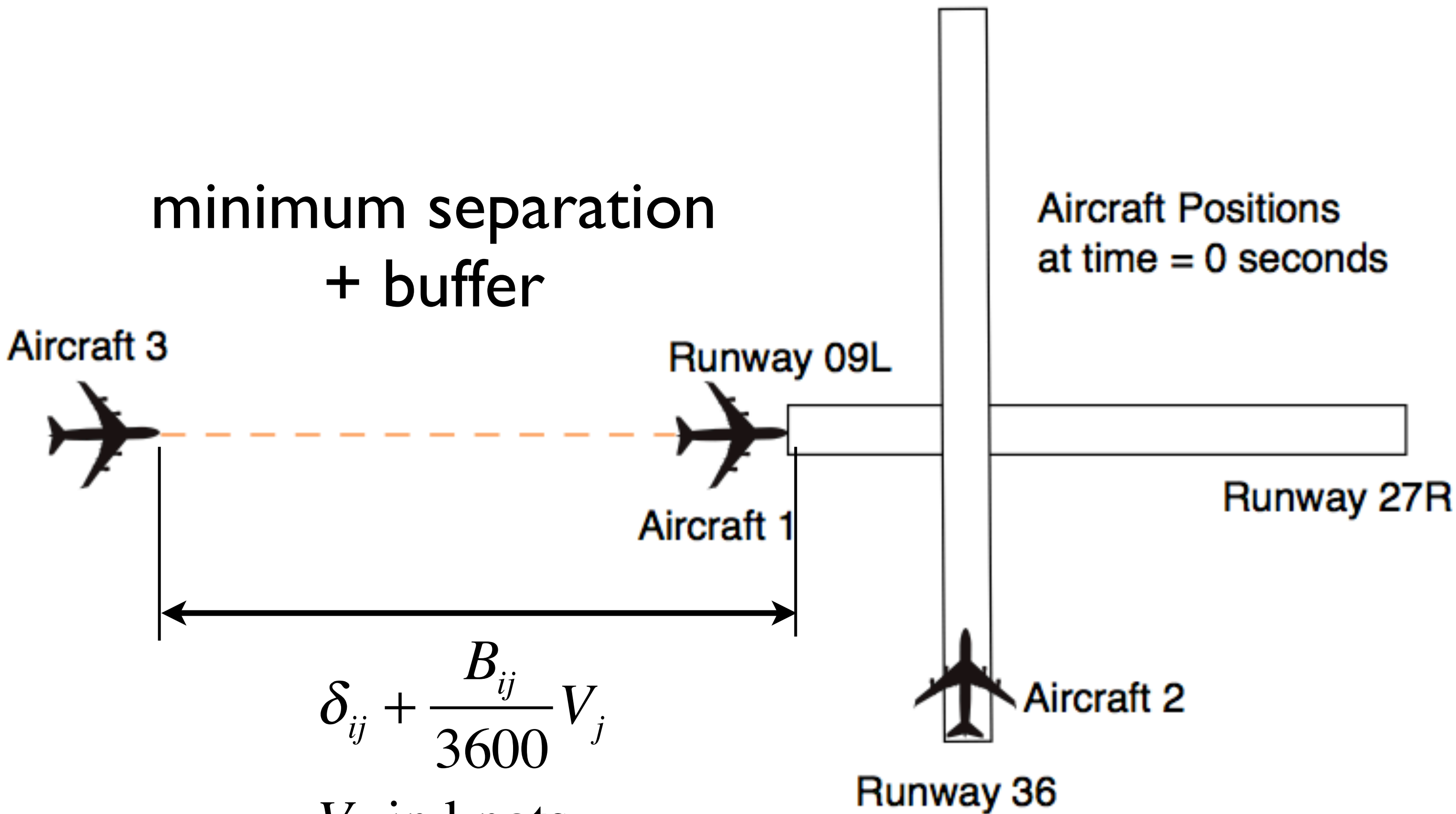
Detailed Analysis for Intersecting Runways

- The intersecting runway is treated as another asset at the airport
- Need to answer the fundamental questions:
- Are there any gaps left by successive arrivals (do nothing) allowing departures from runway 36?
- Quantify the capacity benefit for IFR conditions

Approach

- Visualize the situation by drawing various operations
- Determine the added number of departures on runway 36 allowed with the “natural” arrival gaps on runway 09L
- Assume that departures on runway 09L are not processed since runway 36 offers clear advantages
- The diagrams that follow illustrate various steps in the sequence of events likely to happen at the airport **as “closing” case, pairwise arrival sequences**

Aircraft Positions at Time t = 0 s



$$\delta_{ij} + \frac{B_{ij}}{3600} V_j$$

V_j in knots

B_{ij} in seconds

Aircraft 1 crosses runway 09L threshold . Aircraft 3 follows in-trail at the required separation behind aircraft 1

Calculations of Travel Time for Landing Aircraft to Cross Runway Intersection

- Calculation of the travel times from threshold crossing point to runway intersection point
- The travel times to cross the intersection of runway 18-36 (as the aircraft lands on runway 09L) are: 5.8, 5.0 and 4.6 seconds for small, large and heavy aircraft, respectively
- These travel times influence the ATC tower controller (i.e. local controller) decision on when to clear a departure on the crossing runway

Calculations of Travel Time to Cross Runway Intersection for Departing Aircraft on Runway 36

$$S = V_i t + \frac{1}{2} a t^2$$

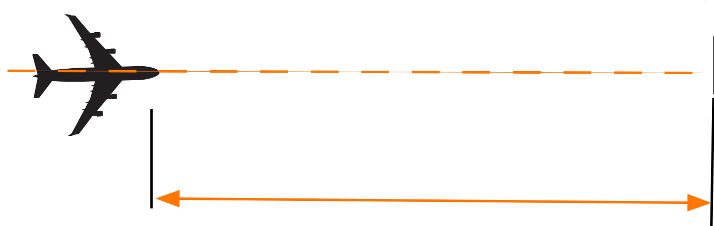
$$t^2 = \frac{2S}{a}$$

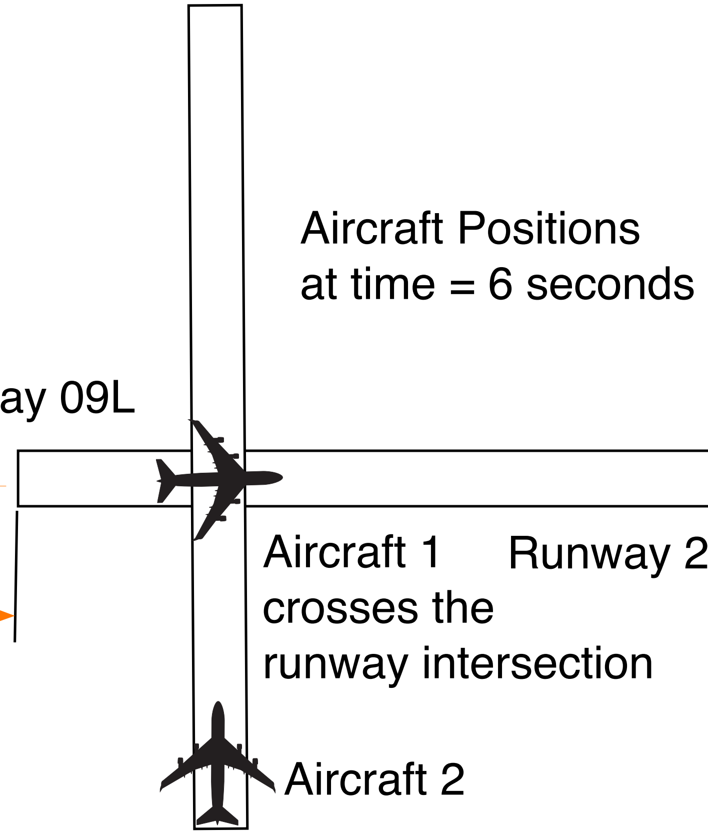
$$t = \sqrt{\frac{2S}{a}}$$

$$t = \sqrt{\frac{2S}{a}} = \sqrt{\frac{2(555.6\ \text{m})}{2.2\ \text{m/s}^2}} = 22.5\ \text{seconds}$$

Aircraft departing runway 36 take ~23 seconds to cross the runway intersection

Aircraft Positions at Time t=6 s





$$\delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{6}{3600}(V_j)$$

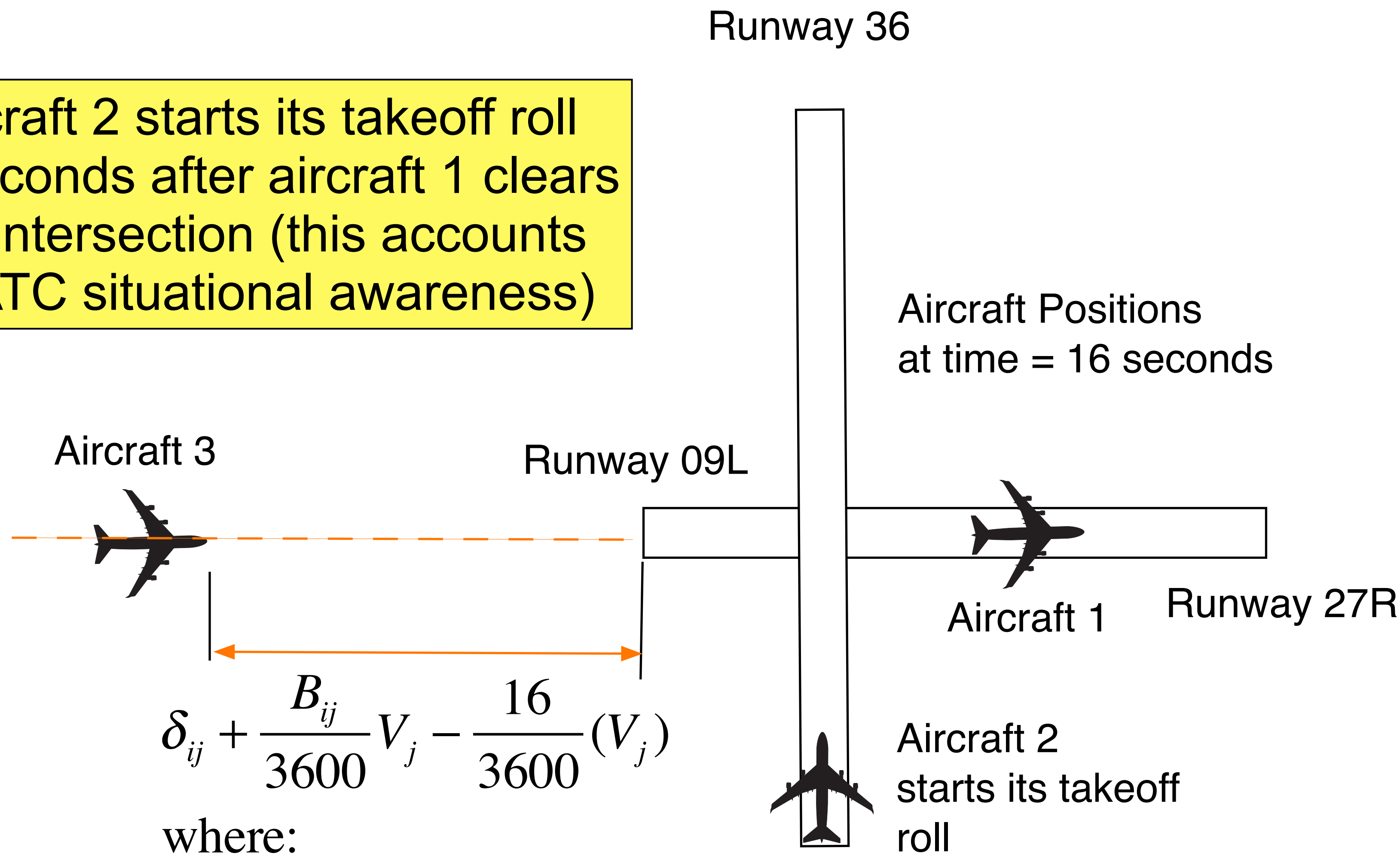
where:

B_{ij} is the buffer time in seconds

V_j is the following aircraft speed in knots

Aircraft Positions at Time t=16 s

Aircraft 2 starts its takeoff roll 10 seconds after aircraft 1 clears the intersection (this accounts for ATC situational awareness)



$$\delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{16}{3600} (V_j)$$

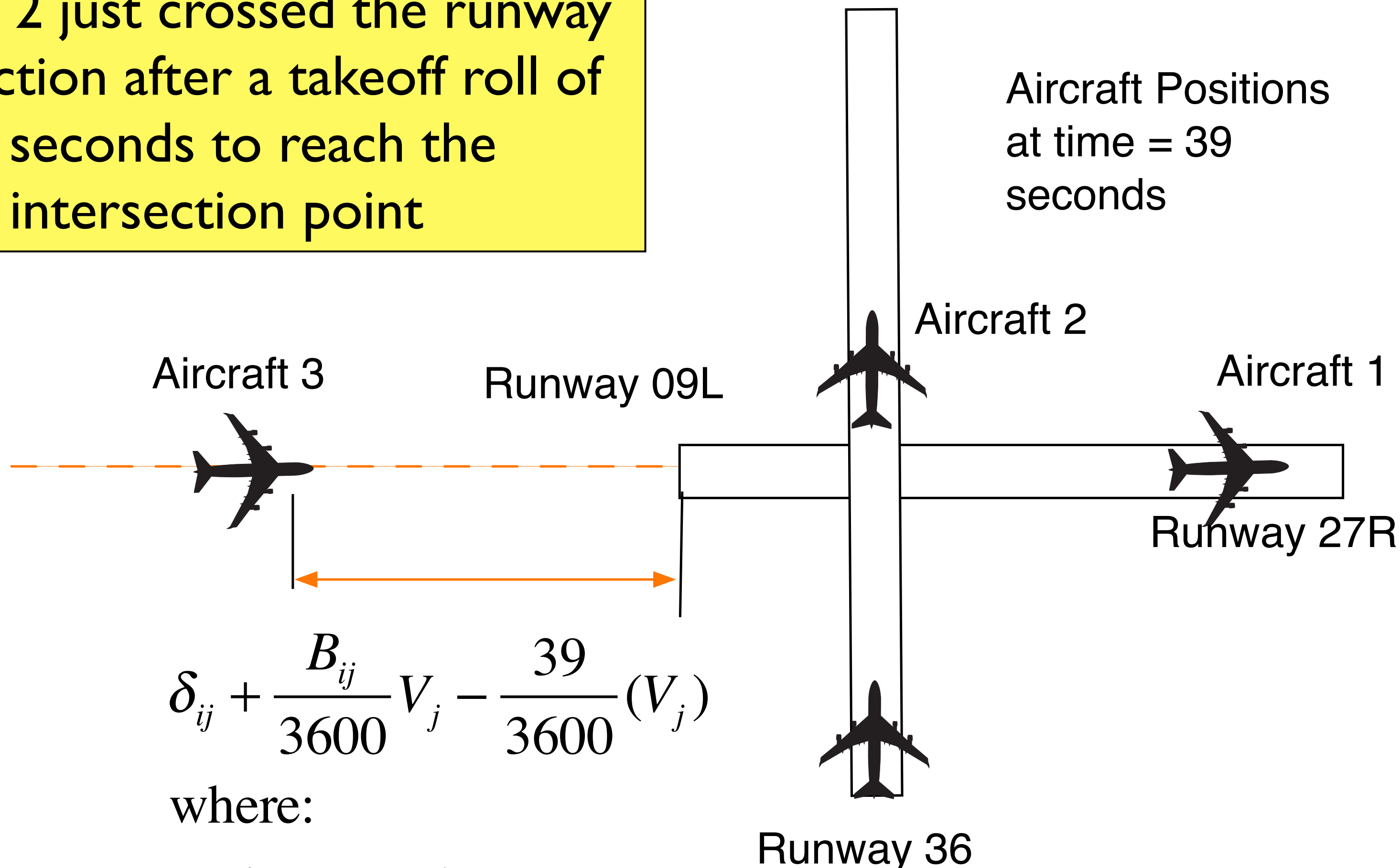
where:

B_{ij} in seconds

V_j in knots

Aircraft Positions at Time t = 39 s

Aircraft 2 just crossed the runway intersection after a takeoff roll of 23 seconds to reach the intersection point



$$\delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{39}{3600}(V_j)$$

where:

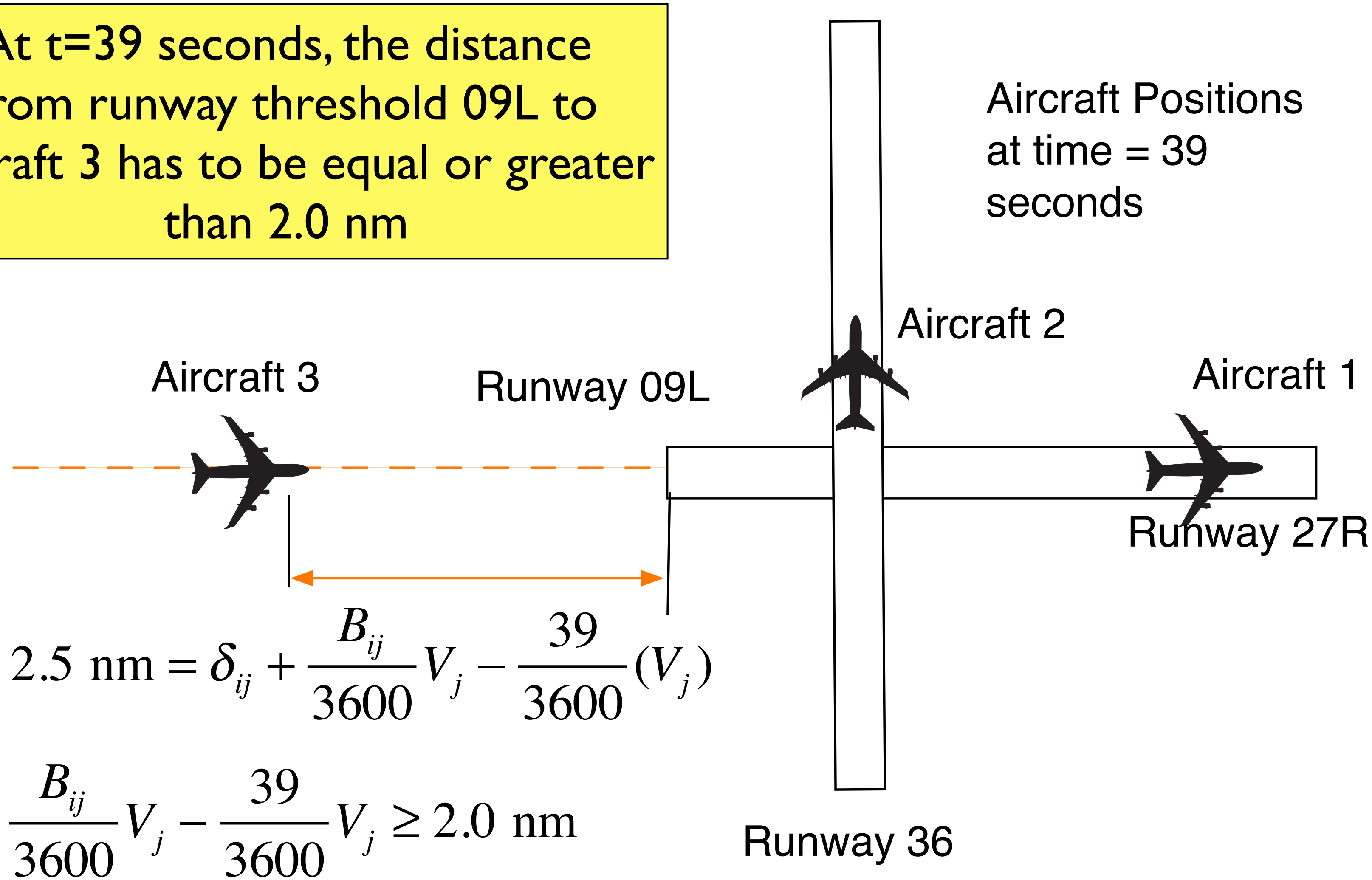
B_{ij} in seconds

V_j in knots

Critical Distance at t = 39 s

At t=39 seconds, the distance from runway threshold 09L to aircraft 3 has to be equal or greater than 2.0 nm

Aircraft Positions at time = 39 seconds



$$\delta = 2.5 \text{ nm} = \delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{39}{3600}(V_j)$$

$$\delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{39}{3600} V_j \geq 2.0 \text{ nm}$$

Condition to release a departure between arrival gaps

General Observations

- The time period between the leading aircraft arrival (i) on runway 09L and a single departure on runway 36 is around 39 seconds. Define,

$$t_{n-36} = \text{time for n departures on runway 36}$$

$$t_{1-36} = 39 \text{ seconds}$$

$$t_{2-36} = (39 + 80) = 119 \text{ seconds}$$

$$t_{3-36} = (39 + 80 + 80) = 199 \text{ seconds}$$

$$t_{n-36} = 39 + E(t_d)(n-1) \text{ seconds}$$

where:

$n =$ number of departures on runway 36 per arrival gap on runway 09L

$E(t_d) =$ expected value of time between successive departures on runway 36

General Observations

$$t_{n-36} = \text{time for n departures on runway 36}$$

- For each successive pair of arrivals on the primary runway (runway 09L-27R), we would have to subtract (t_{n-36}) seconds and check the suitability of each natural gap to release n departures on runway 36
- The procedure is analogous to a single runway with mixed operations

Analysis of Crossing Runway Operations (IFR Case)

Augmented Matrix (Tij + Bij)			
		Trailing	
	Small	Large	Heavy
Small	112.80	100.88	96.08
Large	178.34	100.88	96.08
Heavy	211.82	153.74	96.08

Arrival-arrival matrix (Tij+Bij)

- 39 seconds

Time remaining on following aircraft approach segment (seconds)			
n=1		Trailing	
	Small	Large	Heavy
Small	73.80	61.88	57.08
Large	139.34	61.88	57.08
Heavy	172.82	114.74	57.08

Time left for following aircraft to reach runway 09L threshold

Analysis of Crossing Runway Operations (IFR Case)

Distance left between following aircraft and runway threshold (nm)			
n=1		Trailing	
	Small	Large	Heavy
Small	2.56	2.49	2.46
Large	4.84	2.49	2.46
Heavy	6.00	4.62	2.46

Distance between following aircraft on runway 09L to runway threshold

verify

$$\delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{39}{3600} V_j \geq 2.0 \text{ nm}$$

Number of Departures on runway 36 per arrival gap on 09L			
n		Trailing	
	Small	Large	Heavy
Small	1.00	1.00	1.00
Large	2.00	1.00	1.00
Heavy	2.00	1.00	1.00

Potential departures on runway 36 per arrival gap on runway 09L

Analysis of Crossing Runway Operations (IFR Case)

Pij Matrix (dim)			
		Trailing	
	Small	Large	Heavy
Small	0.010	0.065	0.025
Large	0.065	0.423	0.163
Heavy	0.025	0.163	0.063

Number of Departures on runway 36 per arrival gap on 09L			
n		Trailing	
	Small	Large	Heavy
Small	1.00	1.00	1.00
Large	2.00	1.00	1.00
Heavy	2.00	1.00	1.00

$$ED_{g-ij} = P_{ij} DG_{ij} TG$$

ED_{g-ij} = equivalent departures per gap between aircraft i and j

P_{ij} = probability of i following j

DG_{ij} = Departures per gap between i and j

TG = total gaps per hour

Sample calculation

$$ED_{s-s} = 0.010 * 1.0 * (30.97 - 1) = 0.3$$

Number of departures on runway 36			
n		Trailing	
	Small	Large	Heavy
Small	0.30	1.95	0.75
Large	3.90	12.67	4.87
Heavy	1.50	4.87	1.87
Sum of departures on runway 36			32.68

Total departures on runway 36 considering all arrival gaps on runway 09L

Preliminary Conclusions

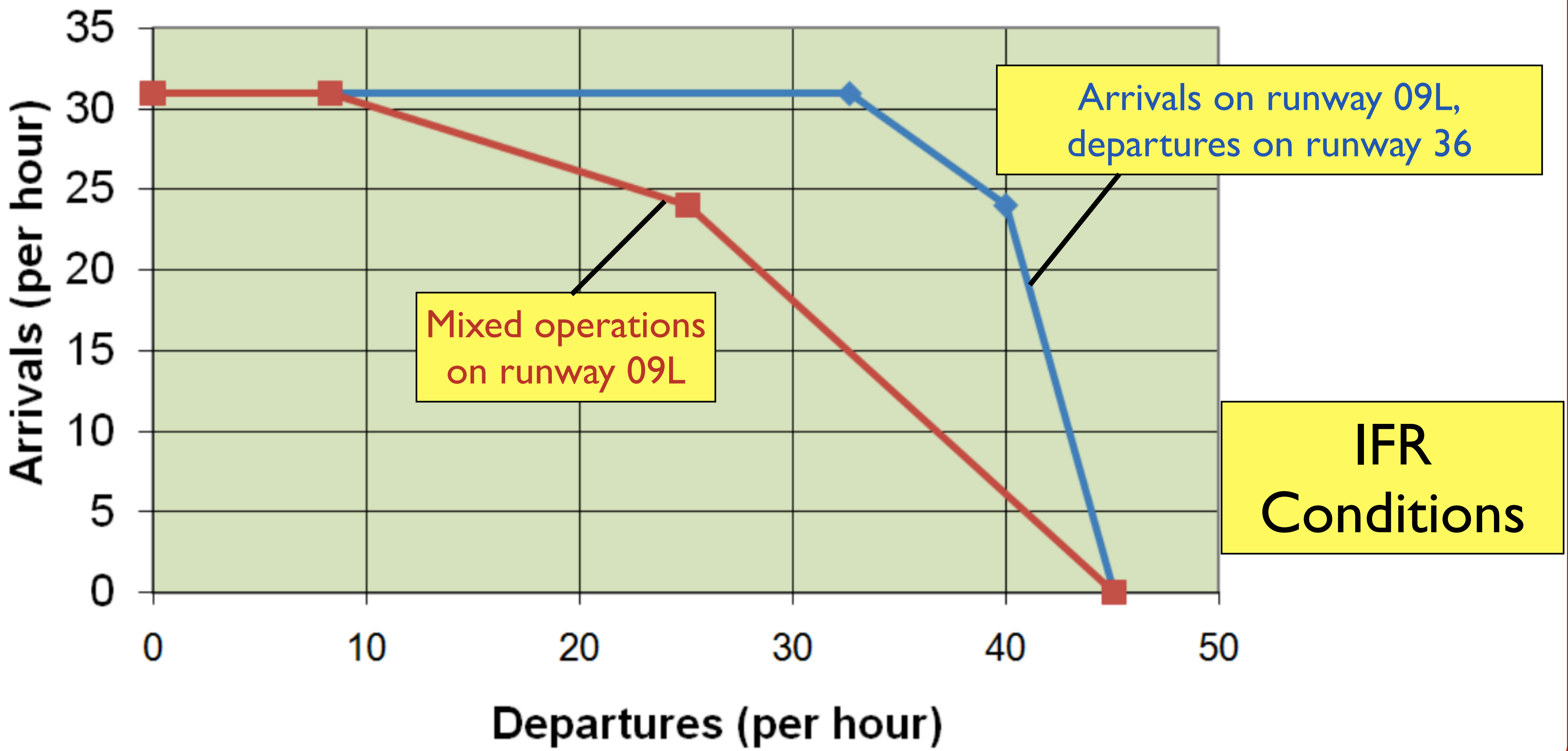
- The total number of departures on runway 36 is estimated to be **33 per hour**
- This is slightly more than the number of arrivals on the primary runway (09L)
- Processing departures on runway 36 is advantageous:
  - 8 departures on runway 09L-27R per hour
  - 33 departures on runway 36-18 per hour
  - Both results assume arrival priority on runway 09L-27R

Extending the Analysis for Runway 09L and 36 as Dependent Pair

- It is clear that departures operations on runway 36 are clearly coupled to arrivals to runway 09L
- Now we study the situation where arrival gaps on runway 09L are increased allowing more departures on runway 36
- As arrival gaps grow to infinity, the number of departures on runway 36 increase to 45 per hour
- The advantages in the Pareto diagram are shown in the next page

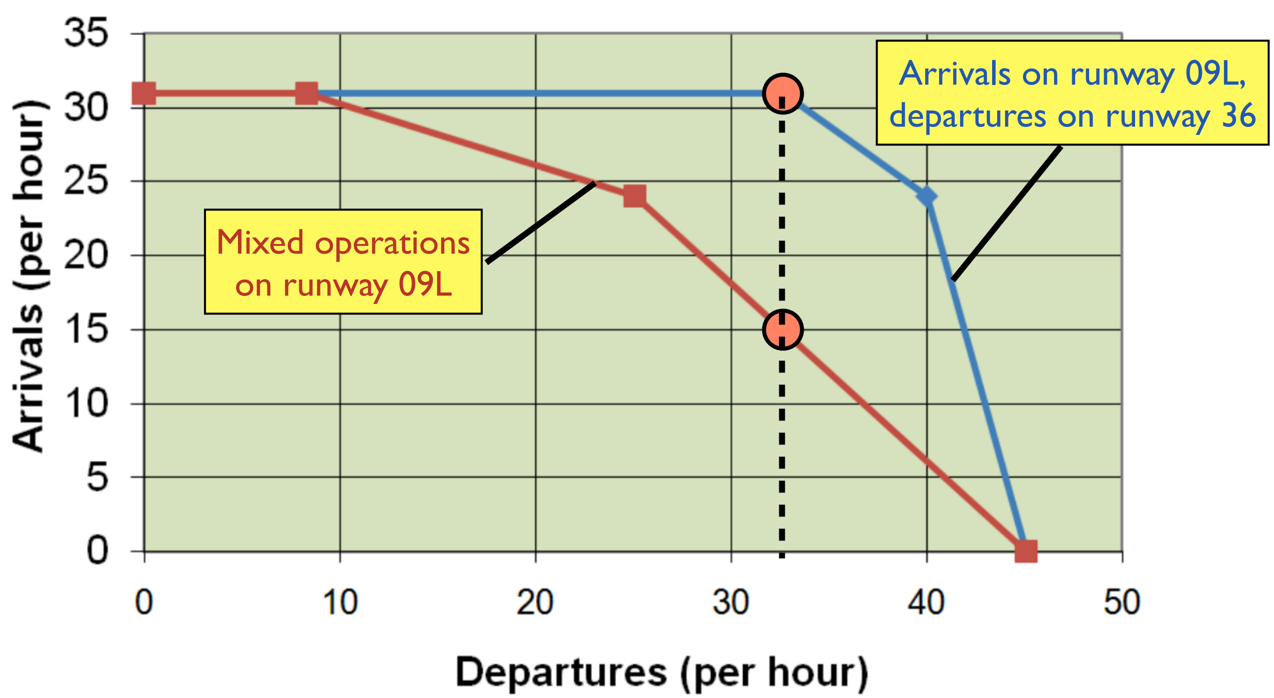
IFR Capacity Pareto Diagram (Runways 09L and 36 as Coupled Pair)

Saturation capacity for two runways operated with dependent operations. Arrivals on runway 09L, departures on runway 36.



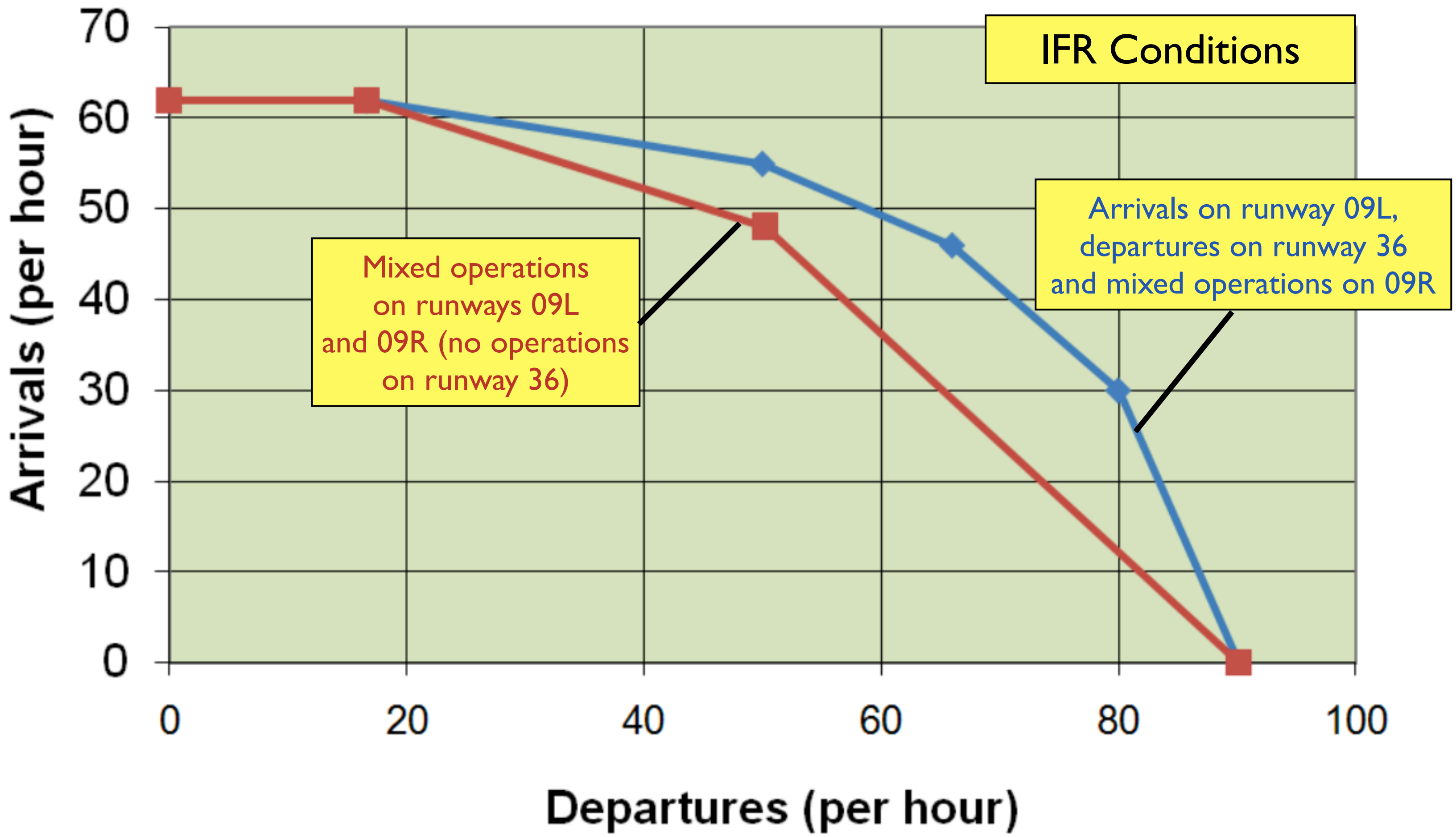
Capacity Benefits

- It is clear that an expansion of the Pareto diagram is a benefit to the capacity of the airport
- Consider an operating point where the coupled runway pair handles 33 departures and 31 arrivals, the single runway 09L in mixed operations can only process 33 departures and and 15 arrivals



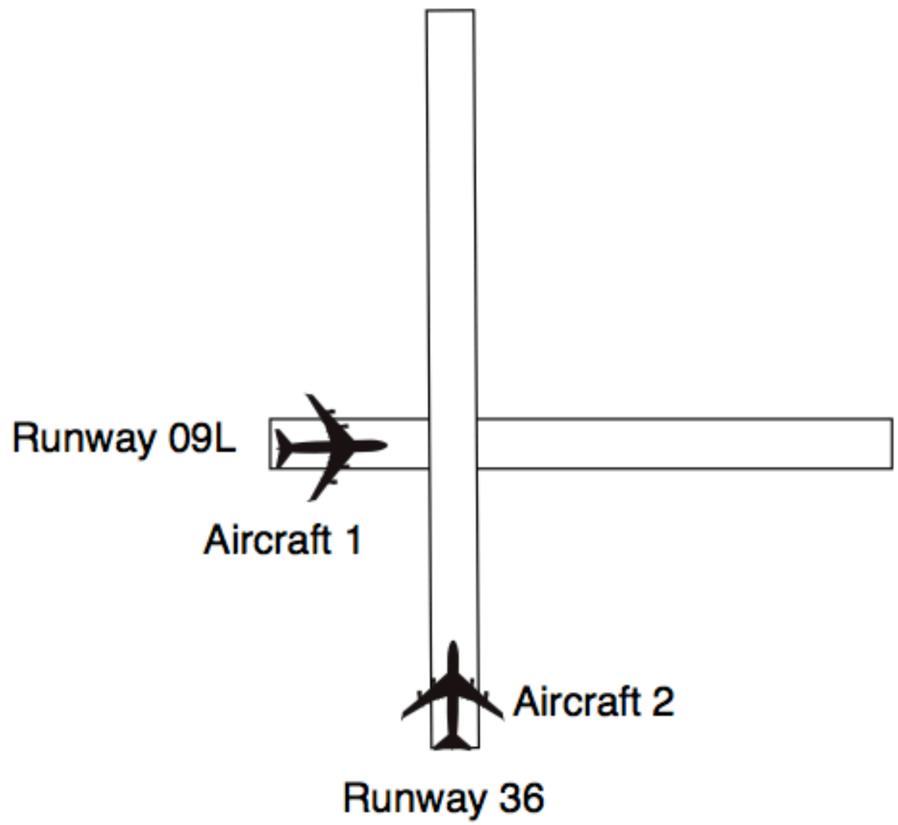
IFR Capacity Pareto Diagram (Coupled Runway Pair 09L / 36 + Runway 09R)

Saturation capacity for three runways (coupled pair + single runway). Arrivals on runway 09L and 09R, departures on runway 36 and 09R.



Final Twist on Departure Capacity

- As the arrivals on runway 09L are reduced to zero (allowing more departures on runway 36 during departure rush periods) it is clear that substantial departure capacity gains are possible operating the coupled pair with sequenced departures (as shown)
- You can show that the departure saturation capacity of the coupled pair is ~80 per hour
- This in the end increases the departure capacity of the airfield to 125 per hour



Capacity Diagrams for Various Airports

CEE 5614/4674
Analysis of Air Transportation Systems

Dr. Antonio A. Trani
Professor

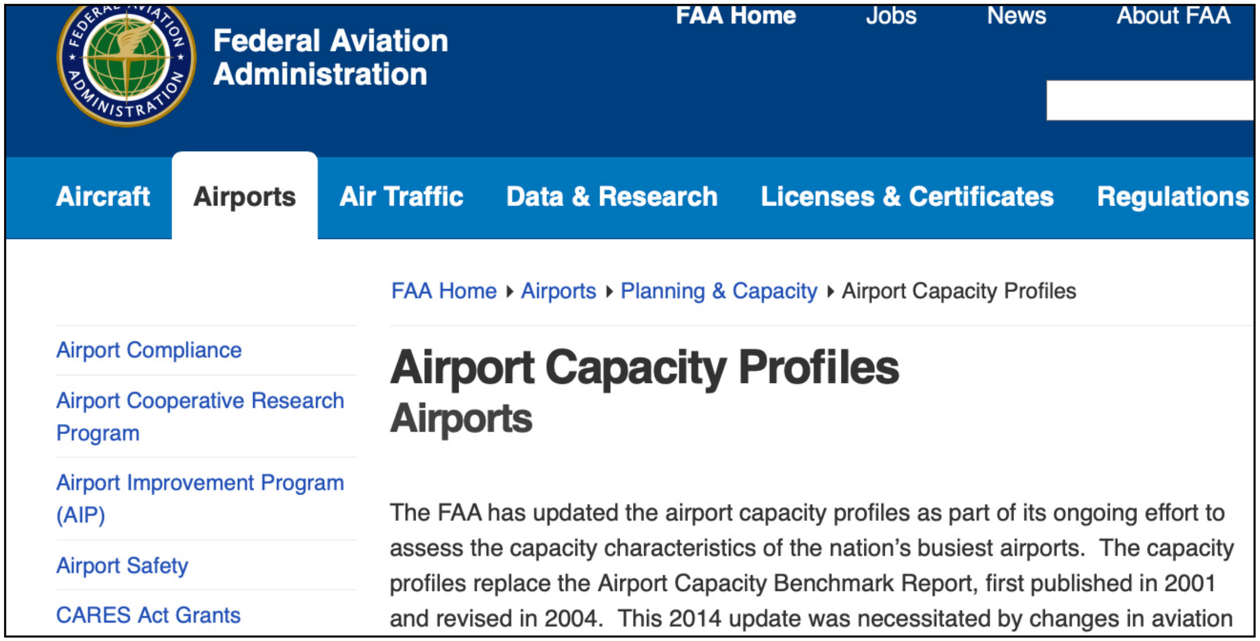
FAA Airport Capacity Benchmarks

- The FAA has conducted detailed capacity studies for the top 30 U.S. airports to determine their VFR and IFR hour capacities
- The details are included in the FAA Airport Capacity Profiles report
- Document: https://www.faa.gov/airports/planning_capacity/profiles/media/Airport-Capacity-Profiles-2014.pdf

Important Considerations

- FAA continues to develop new runway operational procedures
- Wake vortex mitigation - improves runway capacity
- Converging runway operations - decreases runway capacity

For the most up-to-date information consult the FAA Airport Capacity Profiles web site.



https://www.faa.gov/airports/planning_capacity/profiles/

Runway Capacity Factors Considered

- Capacity is affected by:
  - Runway configuration
  - Weather
  - Aircraft fleet mix

Weather Assumptions

Because capacity changes in response to weather and operational conditions, a capacity rate range was developed for each of three weather conditions--visual, marginal, and instrument. The three weather conditions are defined as follows:

- **Visual**: Ceiling and visibility allow for visual approaches, which are specific to each airport.
- **Marginal**: Ceiling and visibility are below visual approach minima, but better than instrument conditions
- **Instrument**: Ceiling less than 1,000 feet or visibility less than 3 statute miles.[4] Instrument Flight Rules (IFR) apply and radar separation between aircraft is required.

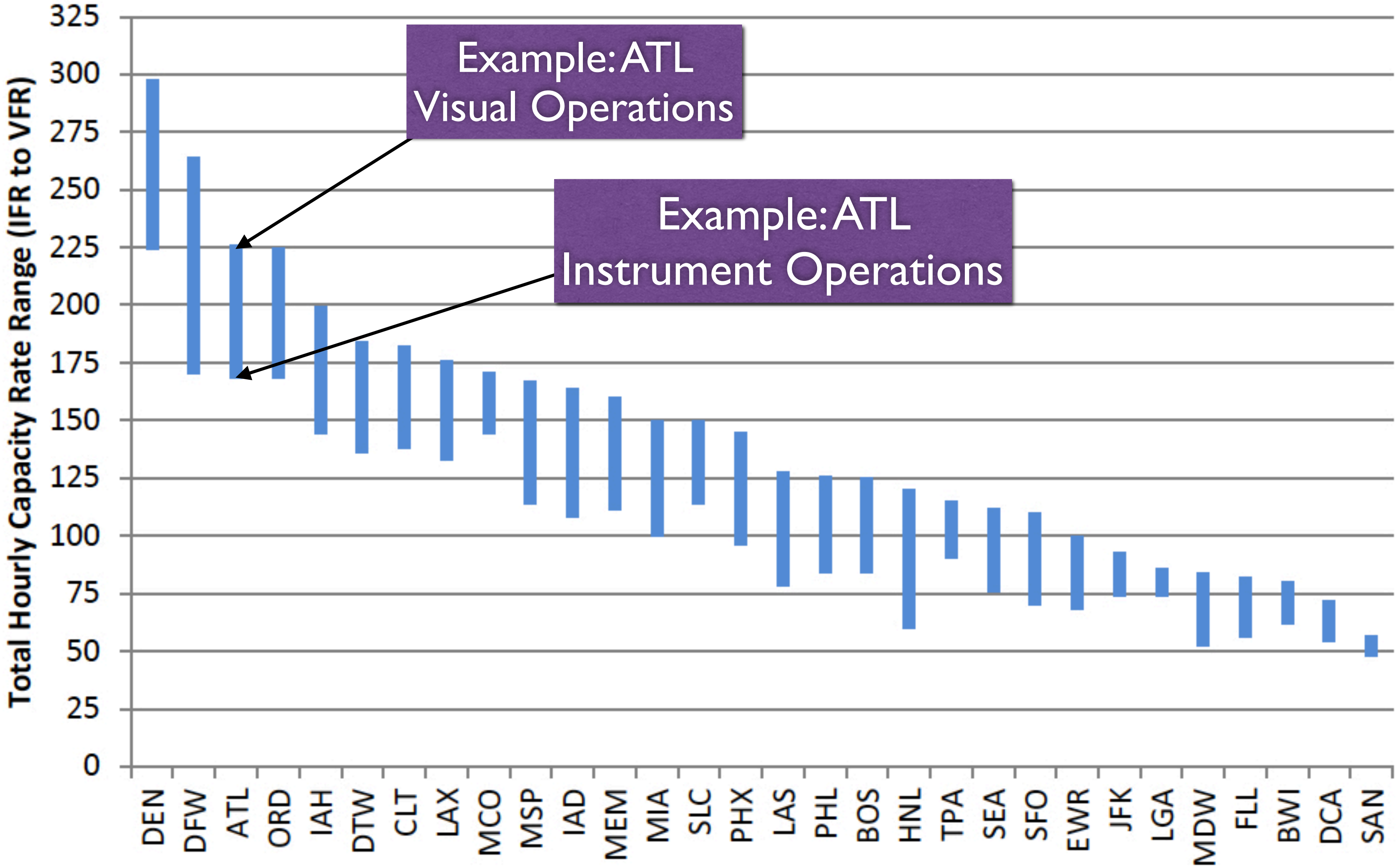
Source: FAA Airport Capacity Profiles (2014)

Example Summary Runway Capacity Information

Airport Identifier and Name		Aircraft Operations (Arrivals and Departures) per Hour		
		Visual	Marginal	Instrument
ATL	Hartsfield-Jackson Atlanta International	216-226 (AP) 219-222 (DP)	201-208 (AP) 206 (DP)	175-190 (AP) 183-186 (DP) 168-169 (LIMC - AP) 168-179 (LIMC - DP)
BOS	Boston Logan International	116-125	109-112	84-86
BWI	Baltimore-Washington Thurgood Marshall International	68-80	64-80	62-64
CLT	Charlotte/Douglas International	176-182	161-162	138-147
DCA	Ronald Reagan Washington National	69-72	69-72	54-64
DEN	Denver International	262-266 (AP) 266-298 (DP)	224-279	224-243
DFW	Dallas/Fort Worth International	226-264	194-245	170
DTW	Detroit Metropolitan Wayne County	178-184	163-164	136
EWR	Newark Liberty International	94-99 (AP) 94-100 (DP)	76-84	68-70
FLL	Fort Lauderdale-Hollywood International	74-82	66-72	56-66
HNL	Honolulu International	117-120	91-105	60-77
IAD	Washington Dulles International	150-159 (AP) 156-164 (DP)	112-120 (AP) 136-145 (DP)	108-111 (AP) 125-132 (DP)
IAH	Houston George Bush Intercontinental	172-199	152-180	144-151
JFK	New York John F. Kennedy International	84-87 (AP) 90-93 (DP)	85-86	74-84

Source: FAA Airport Capacity Profiles (2014), Table 1.

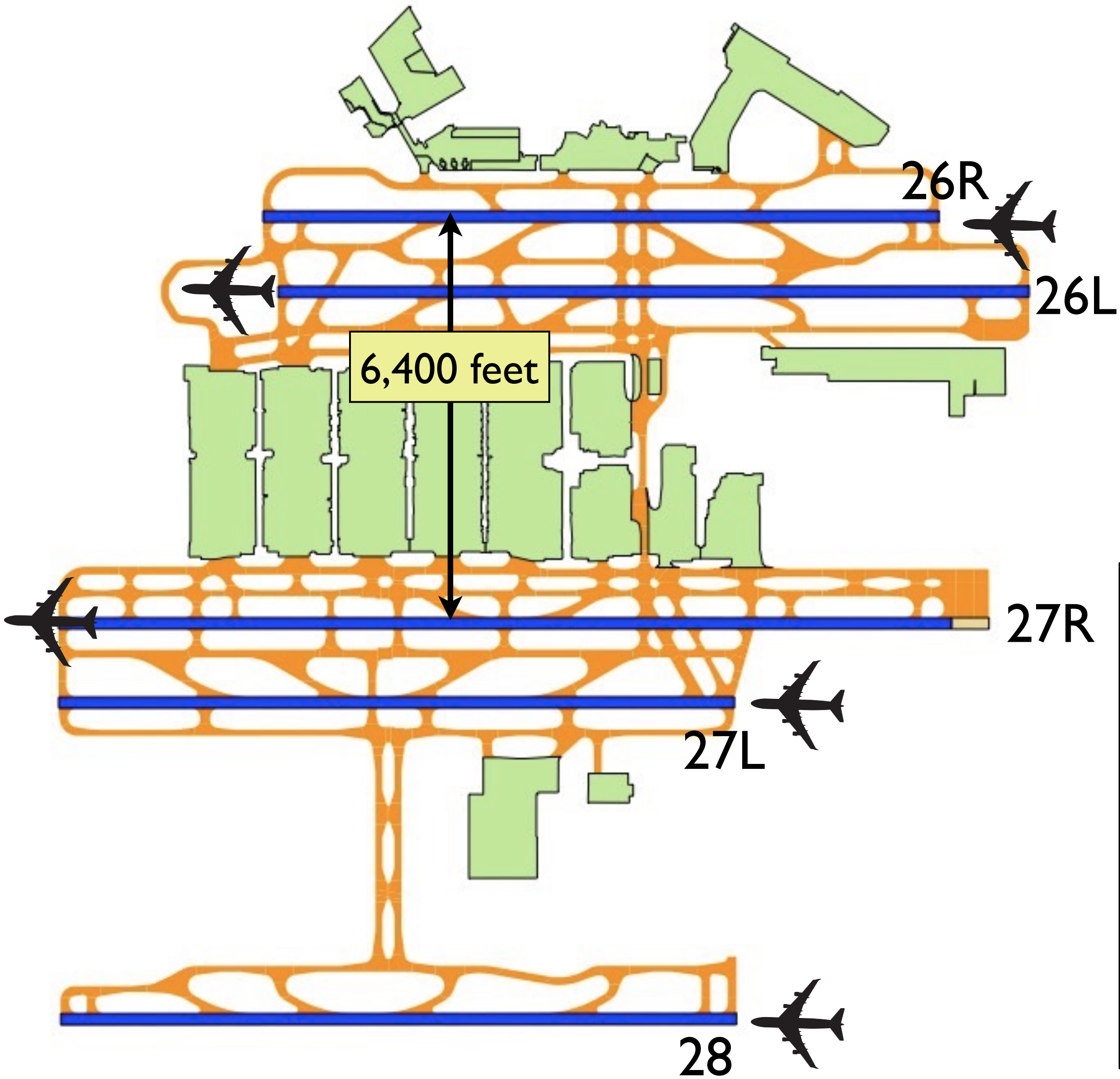
Runway Capacity Rate Information



Source: FAA Airport Capacity Profiles (2014), Figure 1.

Airport # 1: Atlanta Hartsfield-Jackson

- The busiest airport in the World in terms of passengers

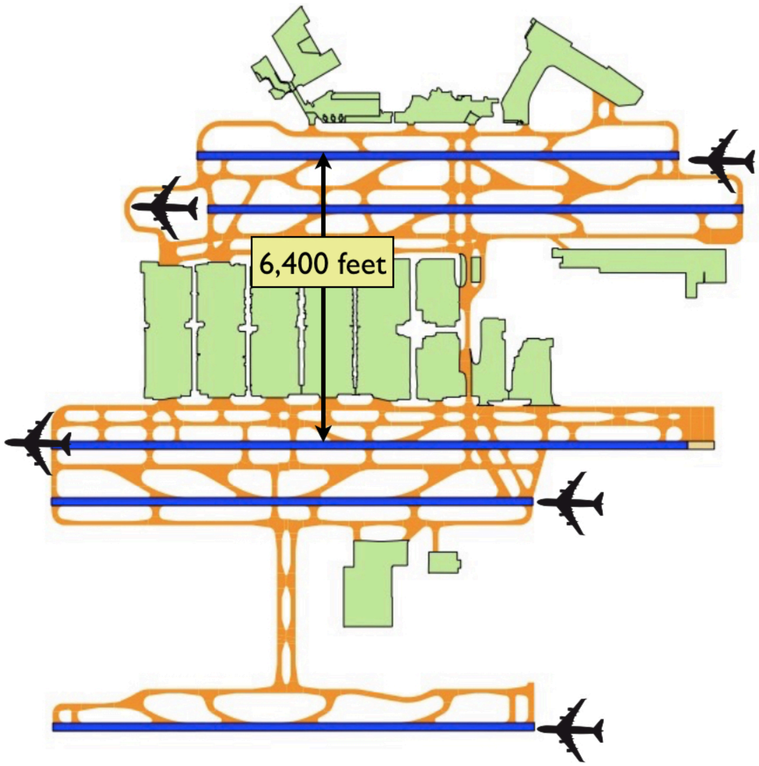


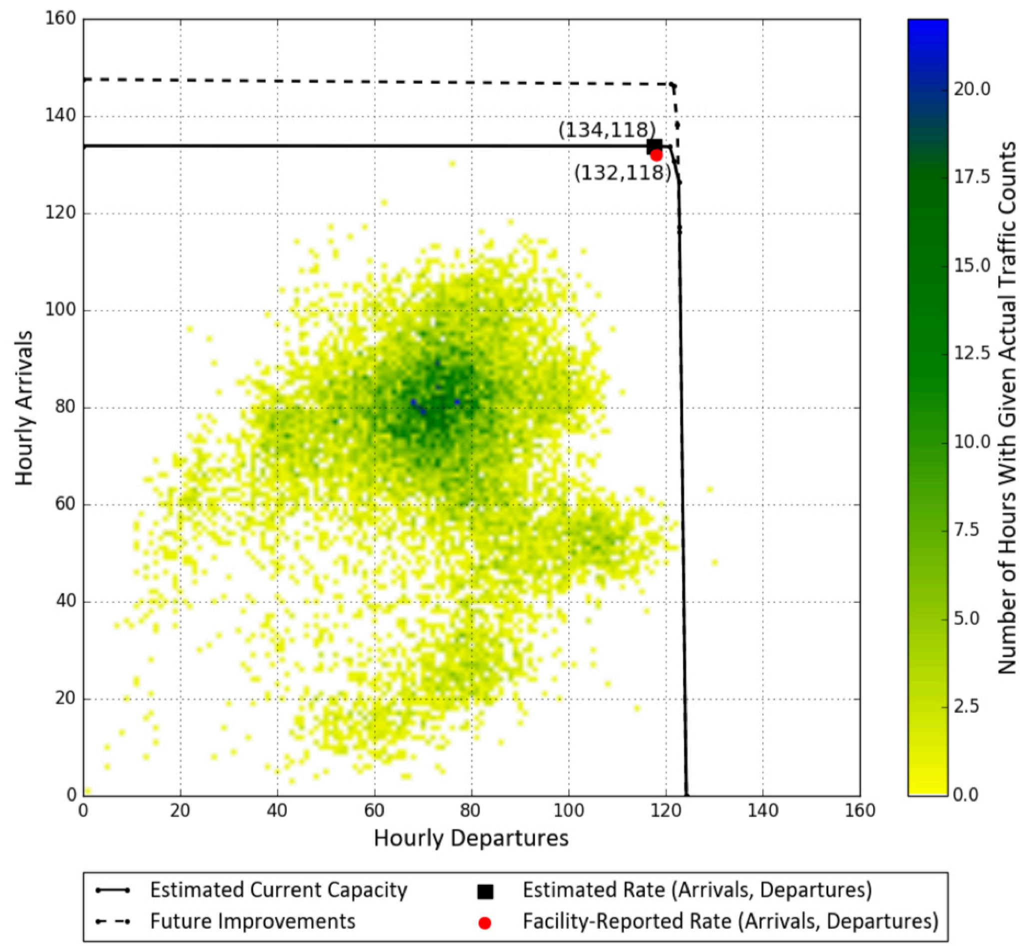
Aircraft Class	% Mix
Small	2.3
Large	78.5
B757	12
Heavy	7.4

Condition	Hourly Capacity
Visual (VMC)	216-226
Marginal VMC	201-208
Instrument (IMC)	165-190

Airport # 1: Atlanta Hartsfield-Jackson

Visual Weather Conditions



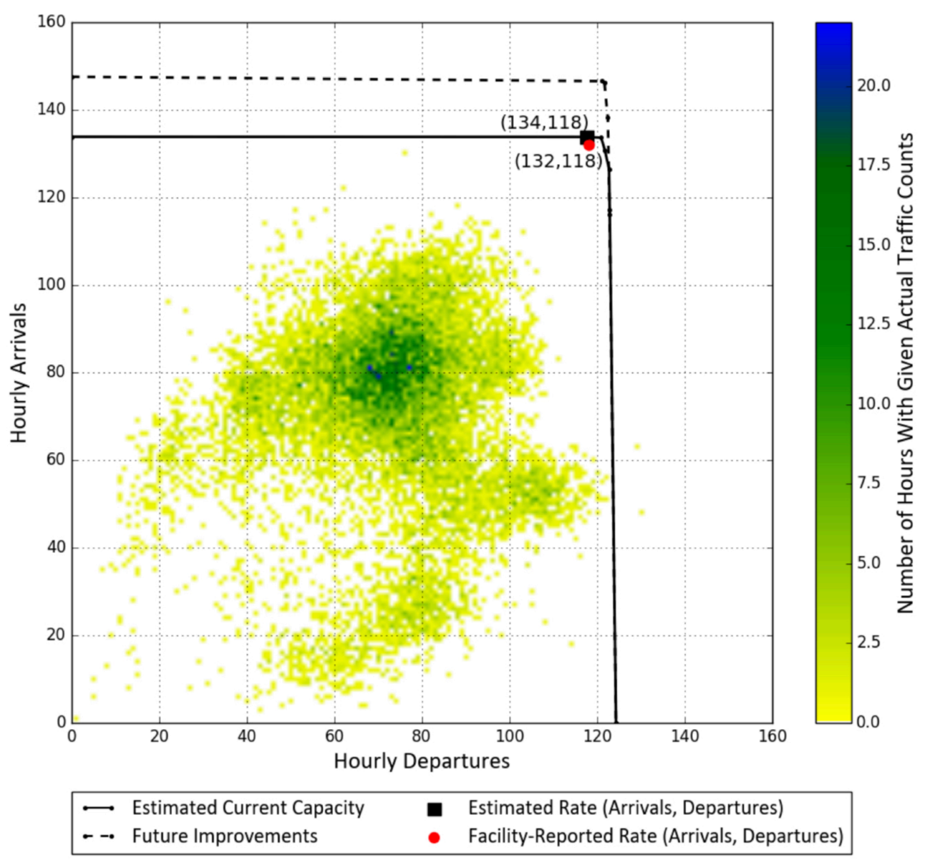


source: https://www.faa.gov/airports/planning_capacity/profiles/media/ATL-Airport-Capacity-Profile-2018.pdf

Atlanta Hartsfield-Jackson (Visual Weather Conditions)

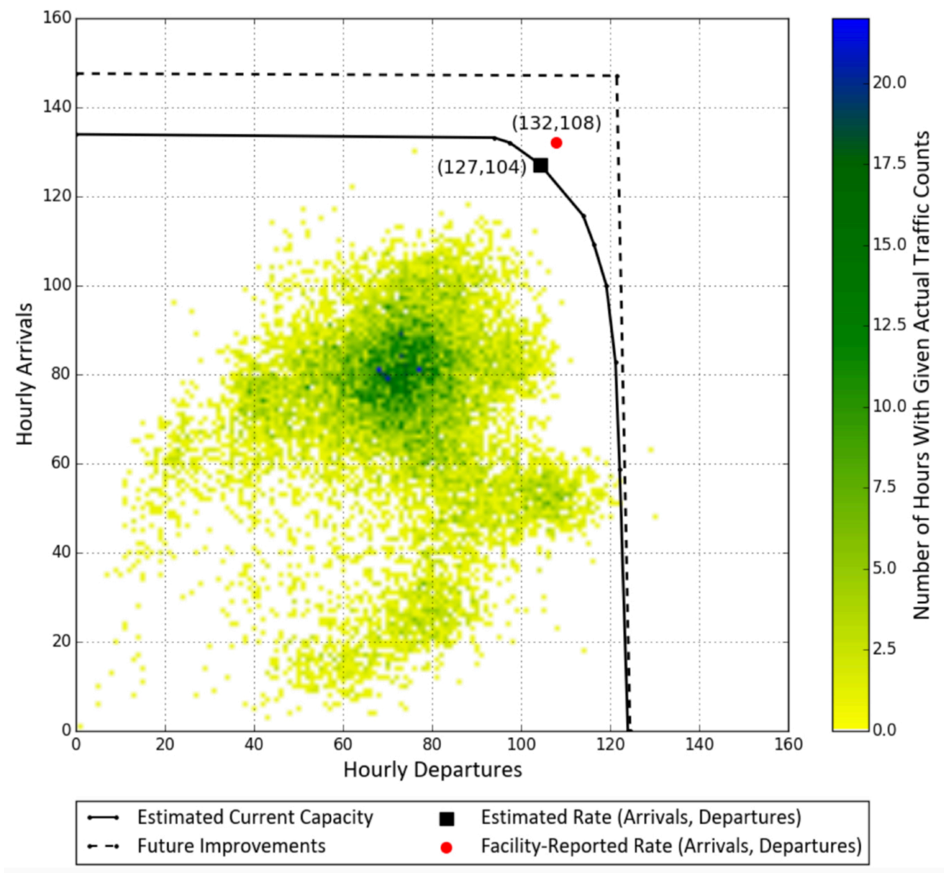
East flow operations

Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
CURRENT OPERATIONS	08L,09R,10	08R,09L	250	252
FUTURE IMPROVEMENTS	08L,09R,10	08R,09L	N/A	260



West flow operations

Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
CURRENT OPERATIONS	26R,27L,28	26L,27R	240	231
FUTURE IMPROVEMENTS	26R,27L,28	26L,27R	N/A	268

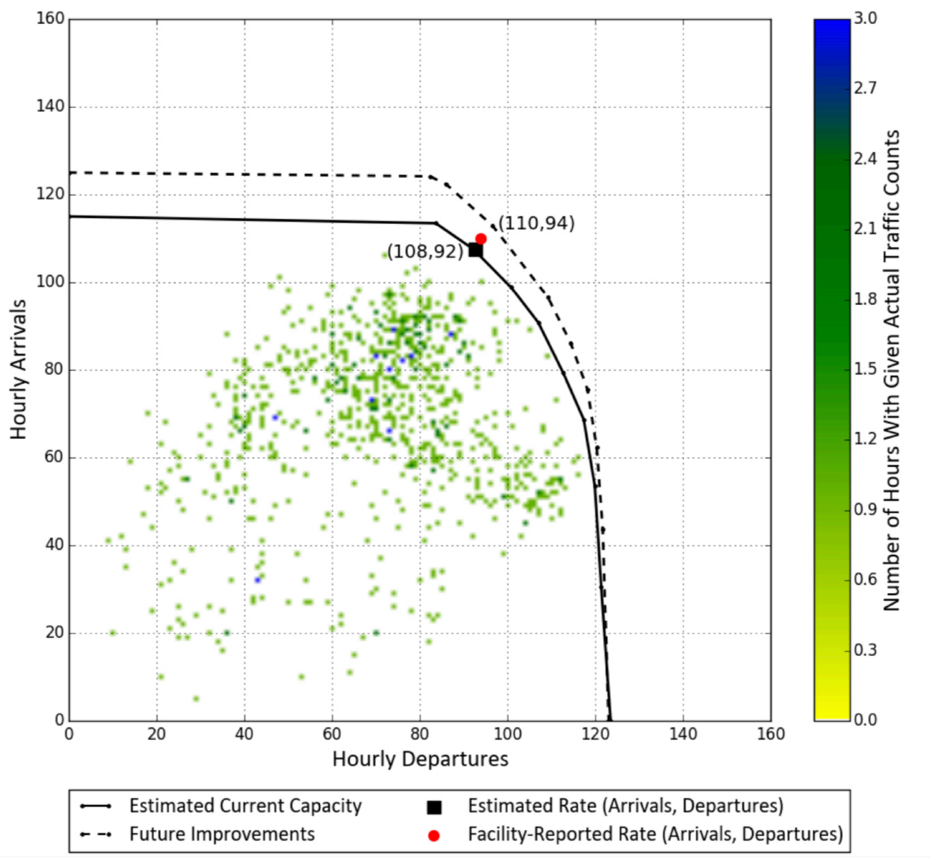


source: https://www.faa.gov/airports/planning_capacity/profiles/media/ATL-Airport-Capacity-Profile-2018.pdf

Atlanta Hartsfield-Jackson :Instrument Weather Conditions

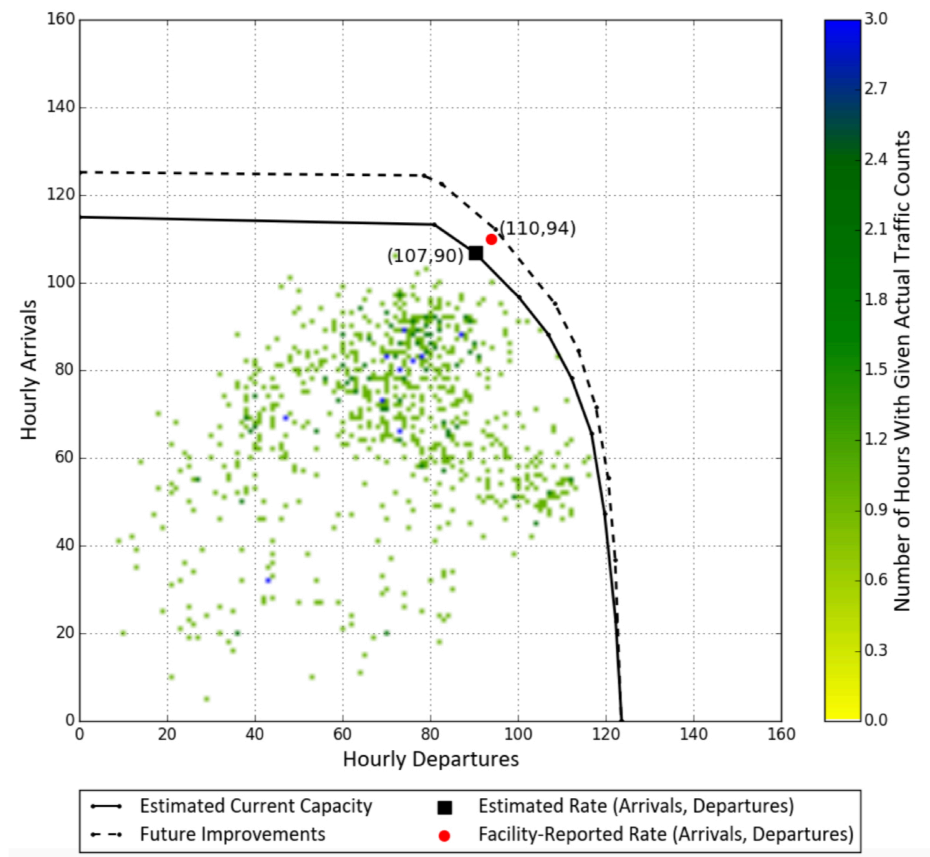
East flow operations

Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
Current Operations	08L,09R,10	08R,09L	204	200
Future Improvements	08L,09R,10	08R,09L	N/A	210



West flow operations

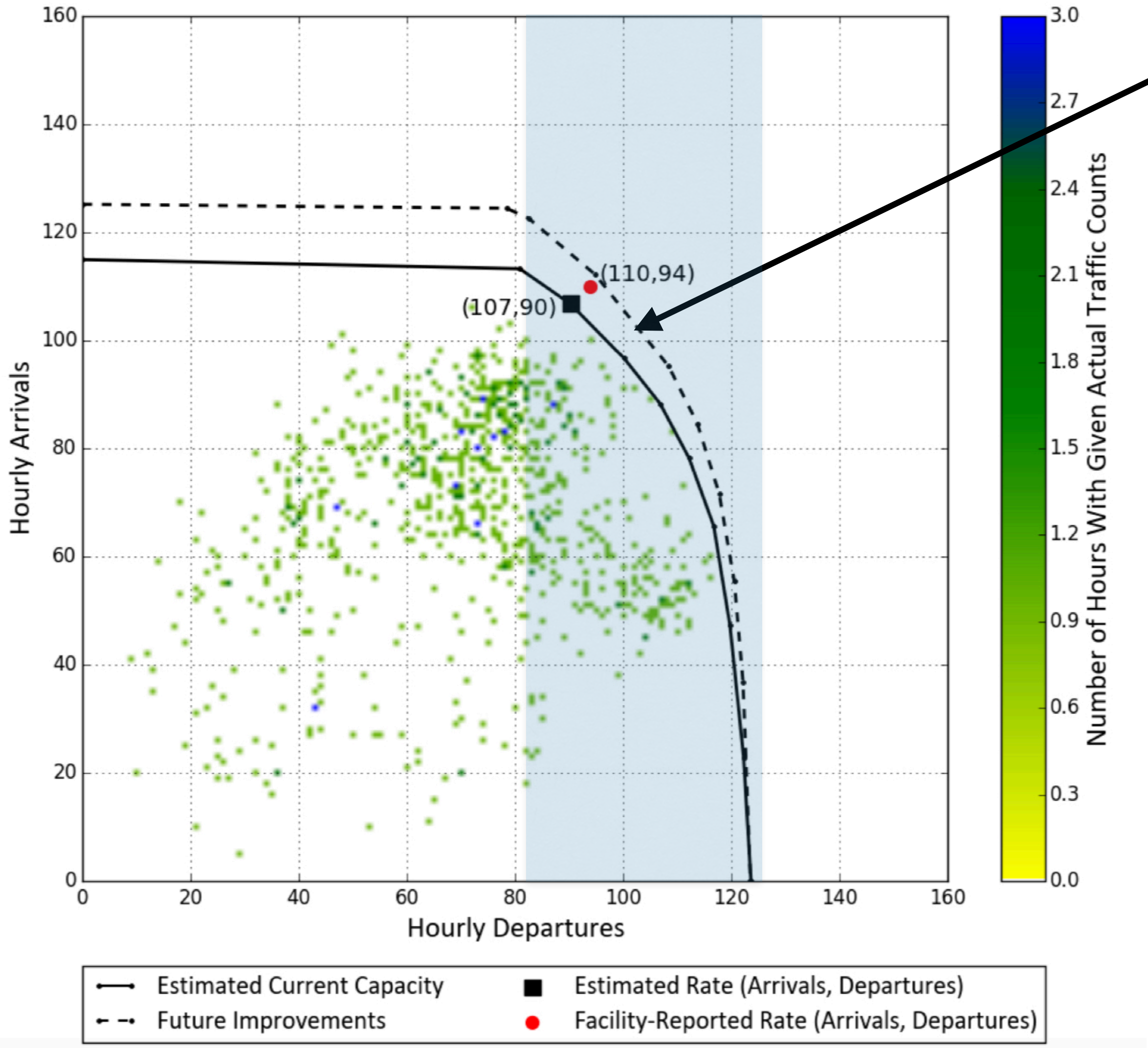
Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
Current Operations	26R,27L,28	26L,27R	204	197
Future Improvements	26R,27L,28	26L,27R	N/A	207



source: https://www.faa.gov/airports/planning_capacity/profiles/media/ATL-Airport-Capacity-Profile-2018.pdf

Atlanta Hartsfield-Jackson :Instrument Weather Conditions

West flow operations

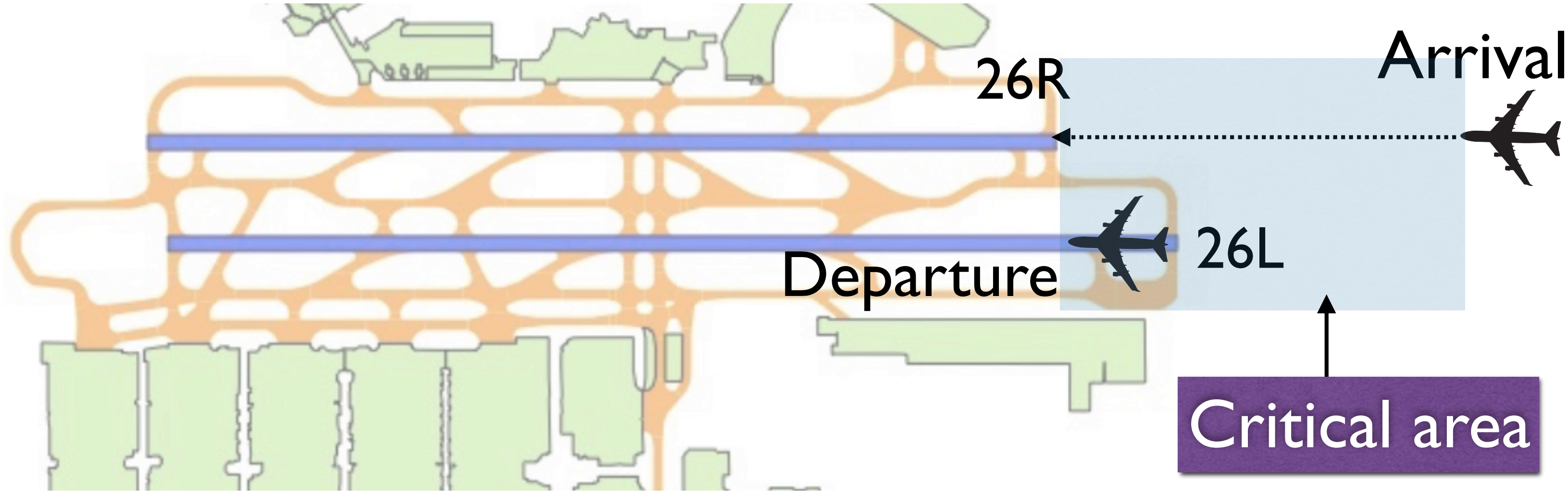


- Note the moderate dependence between arrivals and departures under IFR conditions
- Departures wait for arrivals to reach a safe condition (i.e., reaching the runway threshold)

source: https://www.faa.gov/airports/planning_capacity/profiles/media/ATL-Airport-Capacity-Profile-2018.pdf

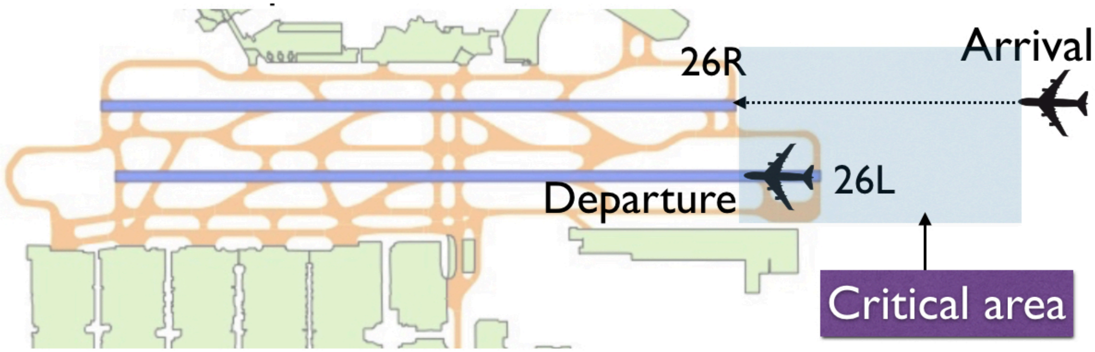
Consider the Northern Runways at ATL under Instrument Weather Conditions

West flow operations



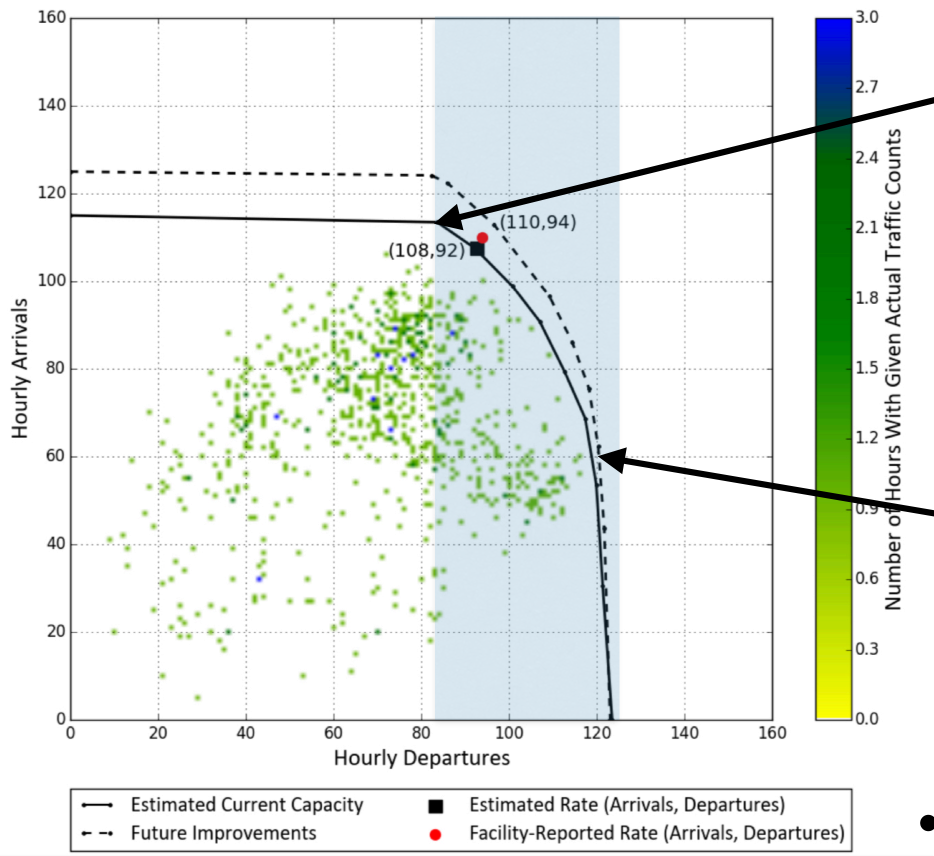
ATC controllers time the departure operations (26L) to avoid a simultaneous go-around of the arrival on runway 26R and a departure climbing out of runway 26L

Consider the Northern Runways at ATL under Instrument Weather Conditions



- Example: assume the critical area is 1.25 nm long (protection to avoid simultaneous operations on parallel runway in IMC conditions)
- According to the FAA/VT landing events database B738/A320 have typical approach speeds ~145 knots on final
- The ***arrival takes 31 seconds to "fly" the critical area***. This implies runway 26L is blocked for 992 seconds of every hour (28% of the time)
- If the arrival capacity is 32 operations/hour (31 gaps), the departure runway is "blocked" 28% of the time
- Typical departure capacity at ATL is 50 operations/hour
- **Reduced departure capacity for runway 26L in IMC is then (50*(1-0.28)) = 39 operations/hour**

Departure Runway Capacity at ATL under Instrument Weather Conditions



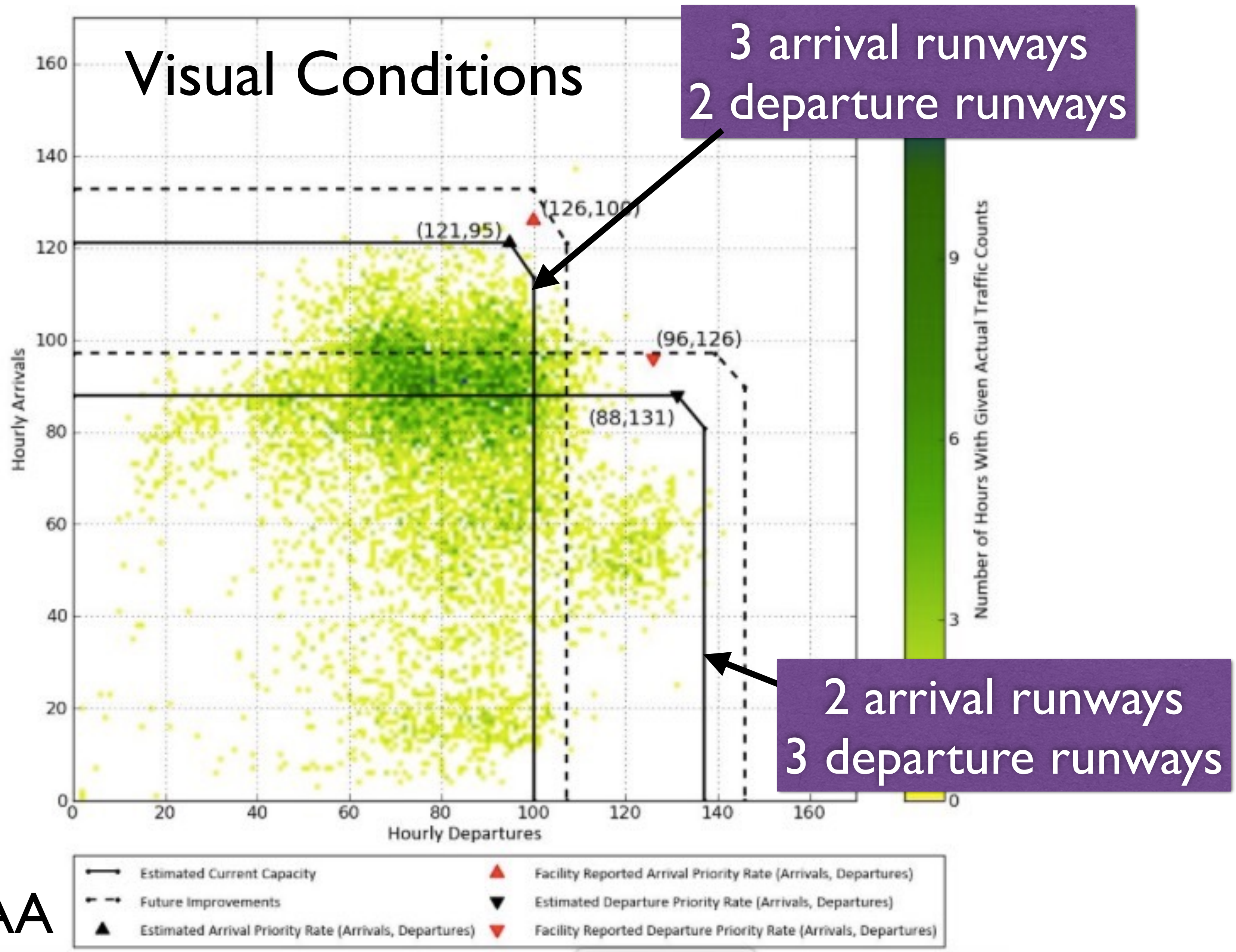
40 departure capacity reduction while maintaining 100% arrival priority

55 arrival capacity reduction allowing 120 departures/hour

- FAA analysis shows 124 departures/hour
- Is this possible in IMC with two runways? Discuss in class.

source: https://www.faa.gov/airports/planning_capacity/profiles/media/ATL-Airport-Capacity-Profile-2018.pdf

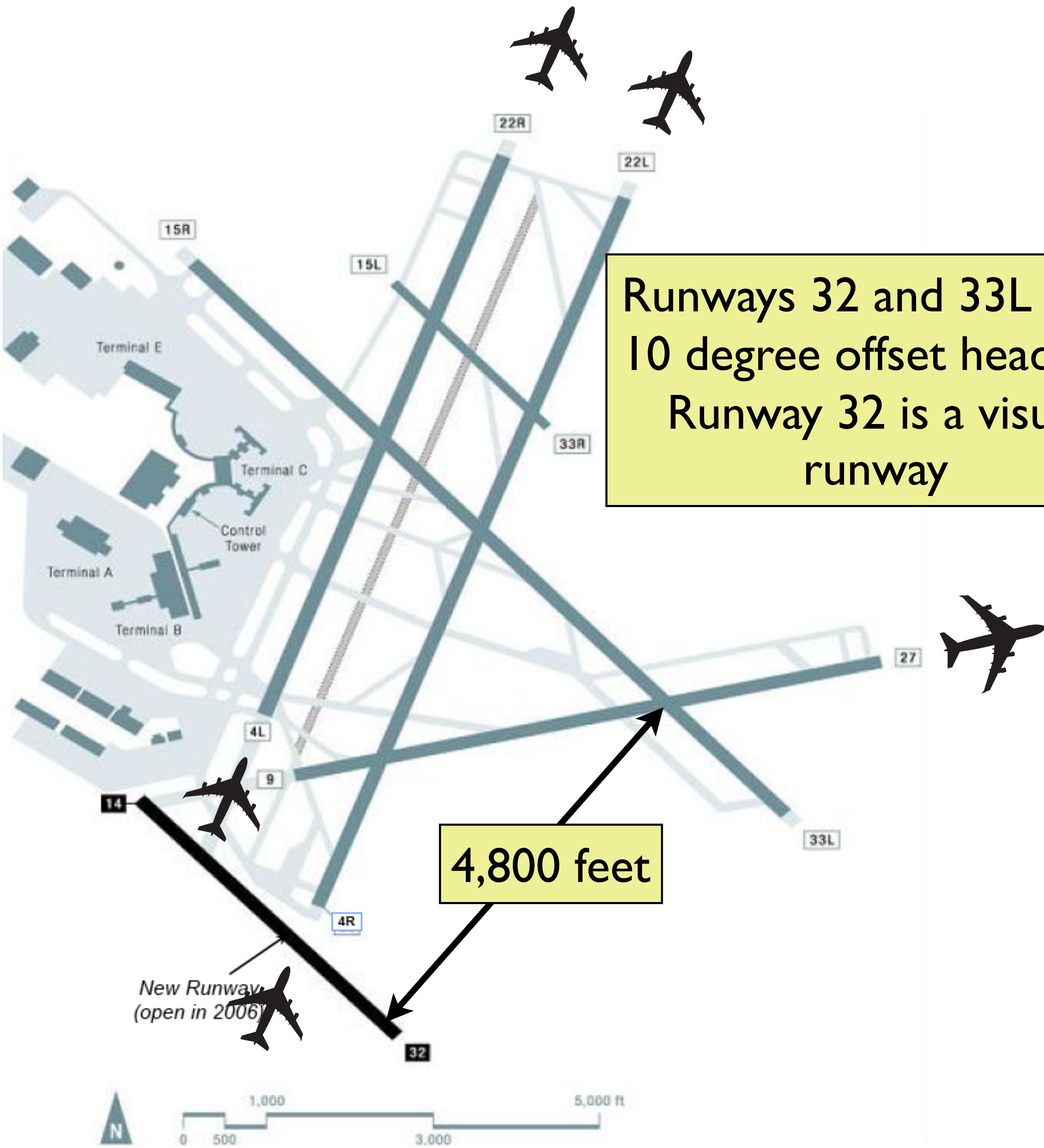
Atlanta International Airport



source: FAA

VirginiaTech Invent the Future

Airport # 2: Boston Logan



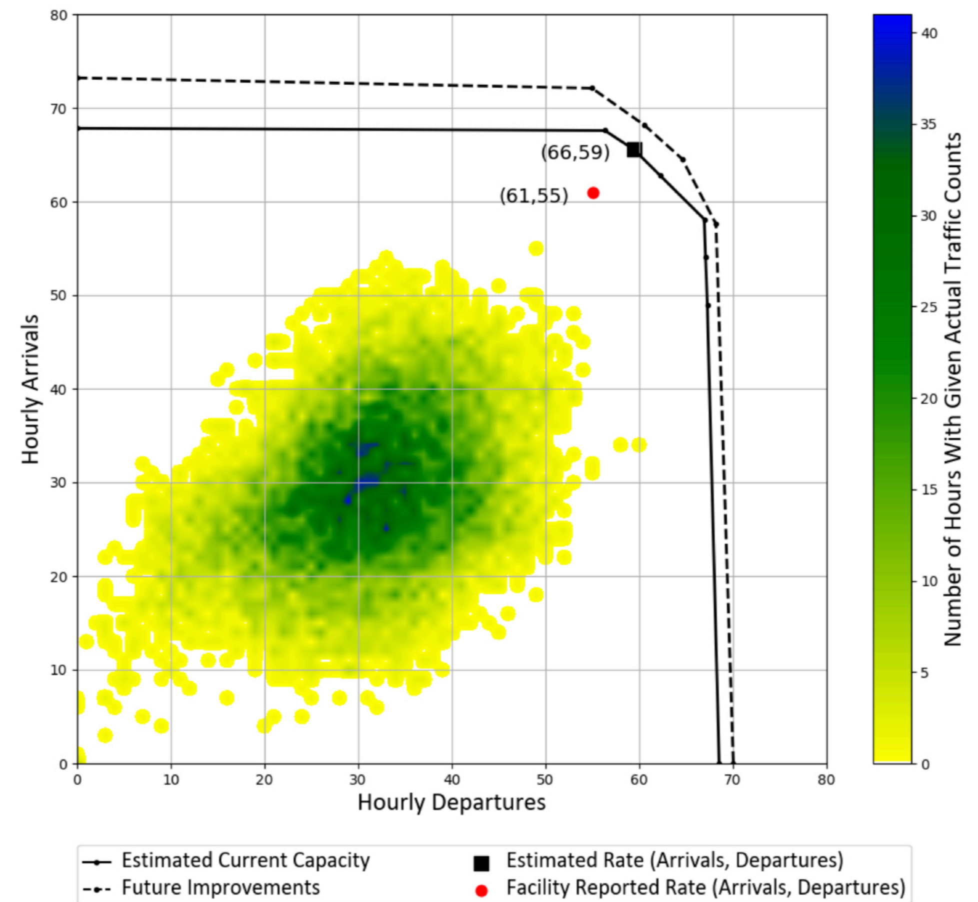
Aircraft Class	% Mix
Small	15.2
Large	70
B757	10.3
Heavy	4.5

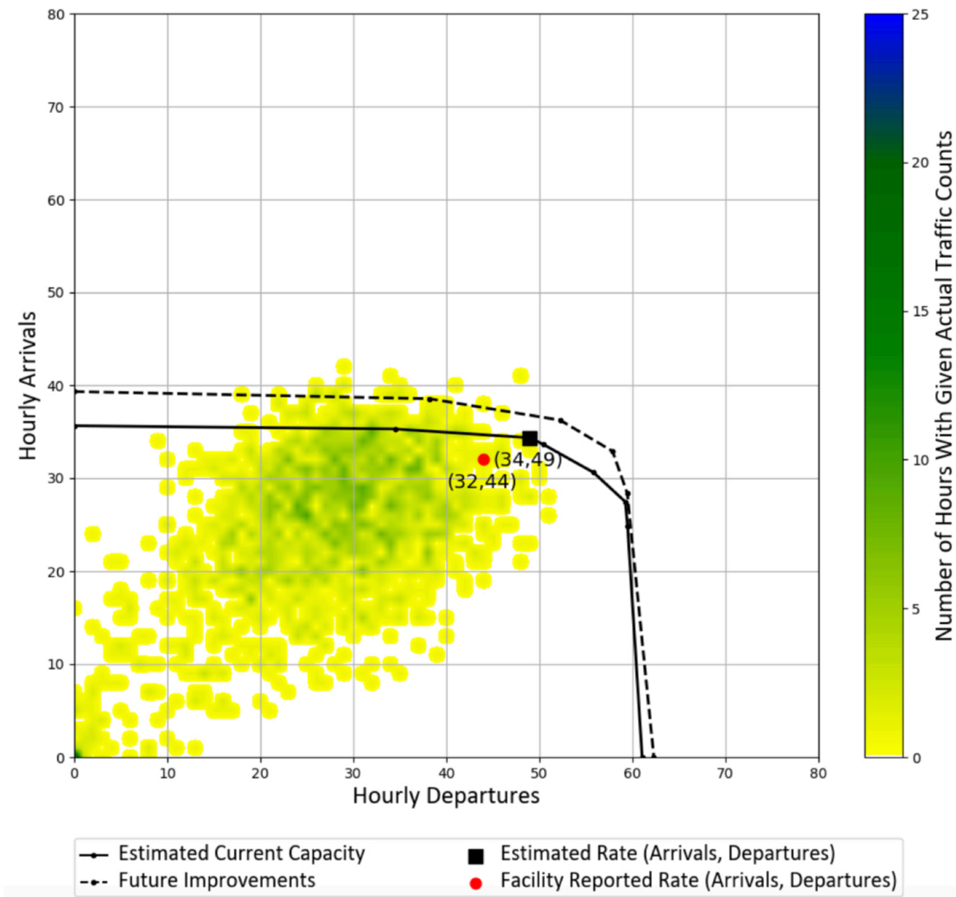
Condition	Hourly Capacity
VFR	123-131
Marginal VFR	112-117
IFR	90-93

Airport # 2: Boston Logan: North Flow

Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
Current Operations	04L,04R	04L,04R,09	116	125
Future Improvements	04L,04R	04L,04R,09	N/A	129

Type Operations	Arrival Runways	Departure Runways	Hourly Rate	
			ATC Facility-Reported	Model-Estimated
Current Operations	04R	04L,04R,09	76	83
Future Improvements	04R	04L,04R,09	N/A	88





https://www.faa.gov/airports/planning_capacity/profiles/media/BOS-Airport-Capacity-Profile-2019.pdf

Airport # 3 Ronald Reagan National Airport (DCA)

Primary runway is 19
Runway 15 is limited to regional jets and turboprops

Aircraft Class	% Mix
Small	2.0
Large	96.3
B757	1.7
Heavy	0.0

VFR Conditions

Condition	Hourly Capacity
VFR	72-87
Marginal VFR	60-84
IFR	48-70

Airport # 3 Ronald Reagan National Airport (DCA)

Primary runway is 01
Runway 33 is limited to regional jets and turboprops
Runway 04 for GA aircraft

Aircraft Class	% Mix
Small	2.0
Large	96.3
B757	1.7
Heavy	0.0

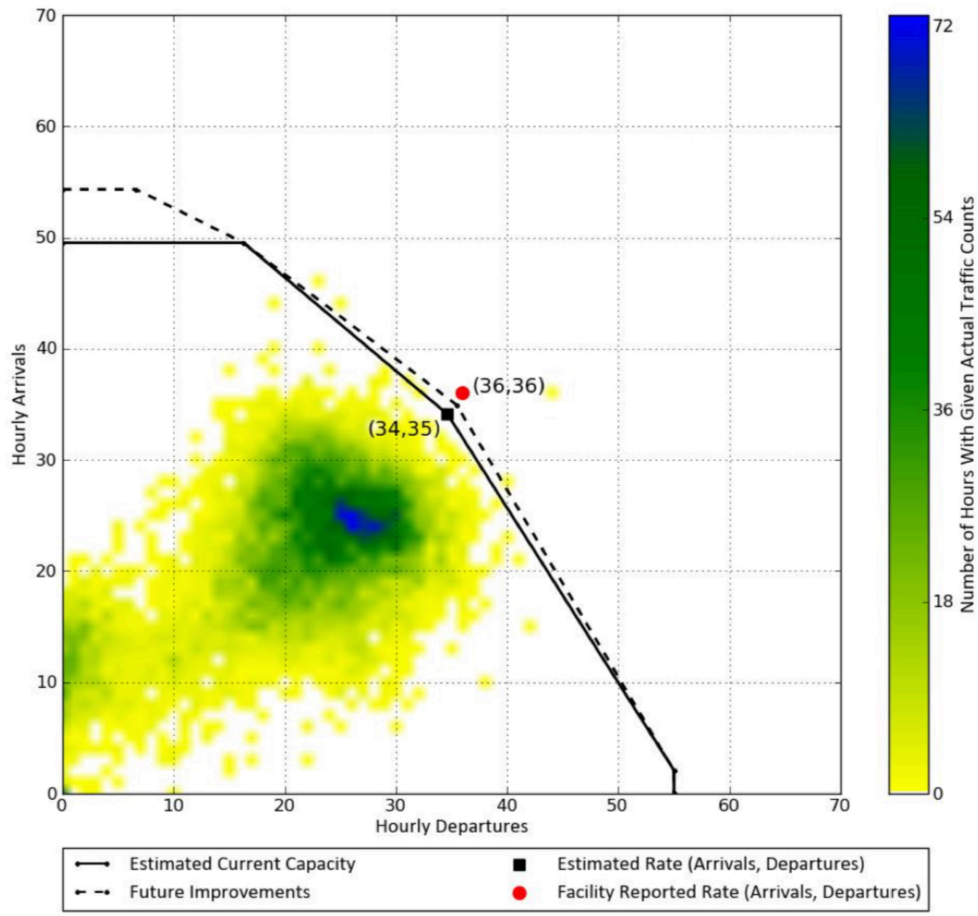
IFR Conditions

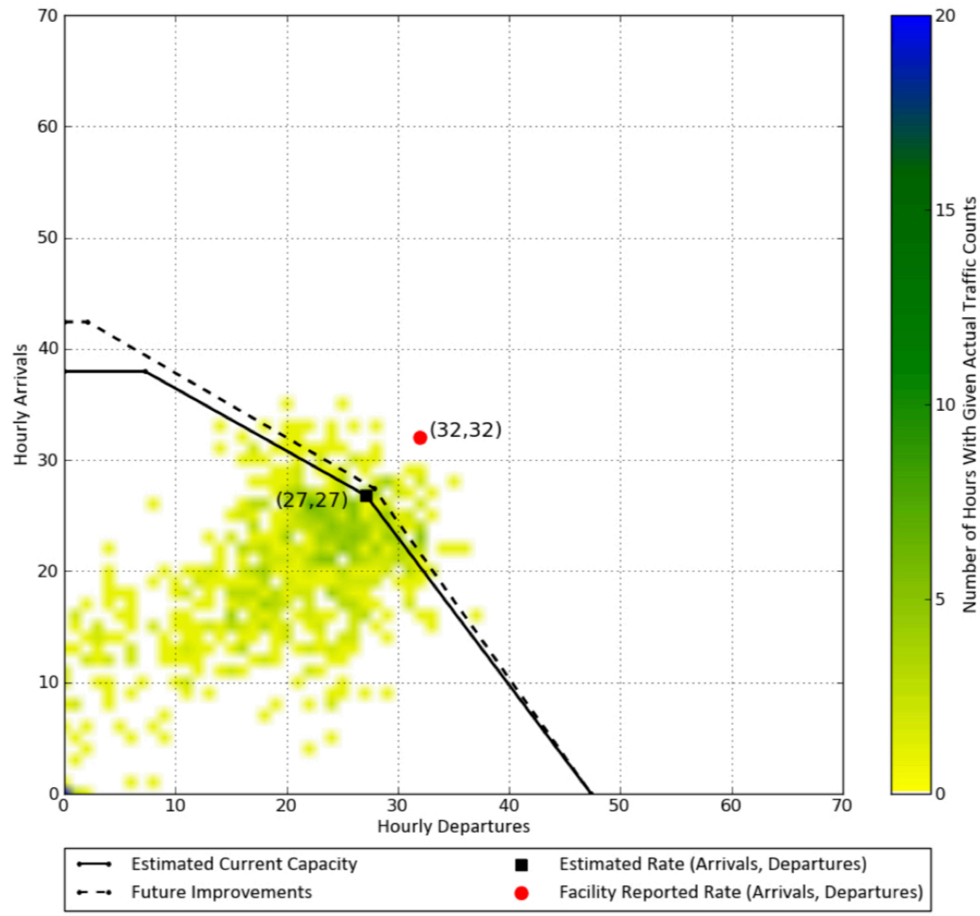
Condition	Hourly Capacity
VFR	72-87
Marginal VFR	60-84
IFR	48-70

Airport # 3: DCA North Flow

DCA Scenario	Arrival Runways	Departure Runways	Procedures	Hourly Rate	
				ATC Facility Reported	Model-Estimated
Current Operations	1, 33	1, 33	Visual Approaches with Circle-to-Land Approaches to Runway 33, Visual Separation	72	69
Future Improvements Improved Runway Delivery Accuracy	1, 33	1, 33		N/A	70

DCA Scenario	Arrival Runways	Departure Runways	Procedures	Hourly Rate	
				ATC Facility Reported	Model-Estimated
Current Operations	1	1	Instrument Approach, Radar Separation	64	54
Future Improvements Improved Runway Delivery Accuracy	1	1		N/A	55

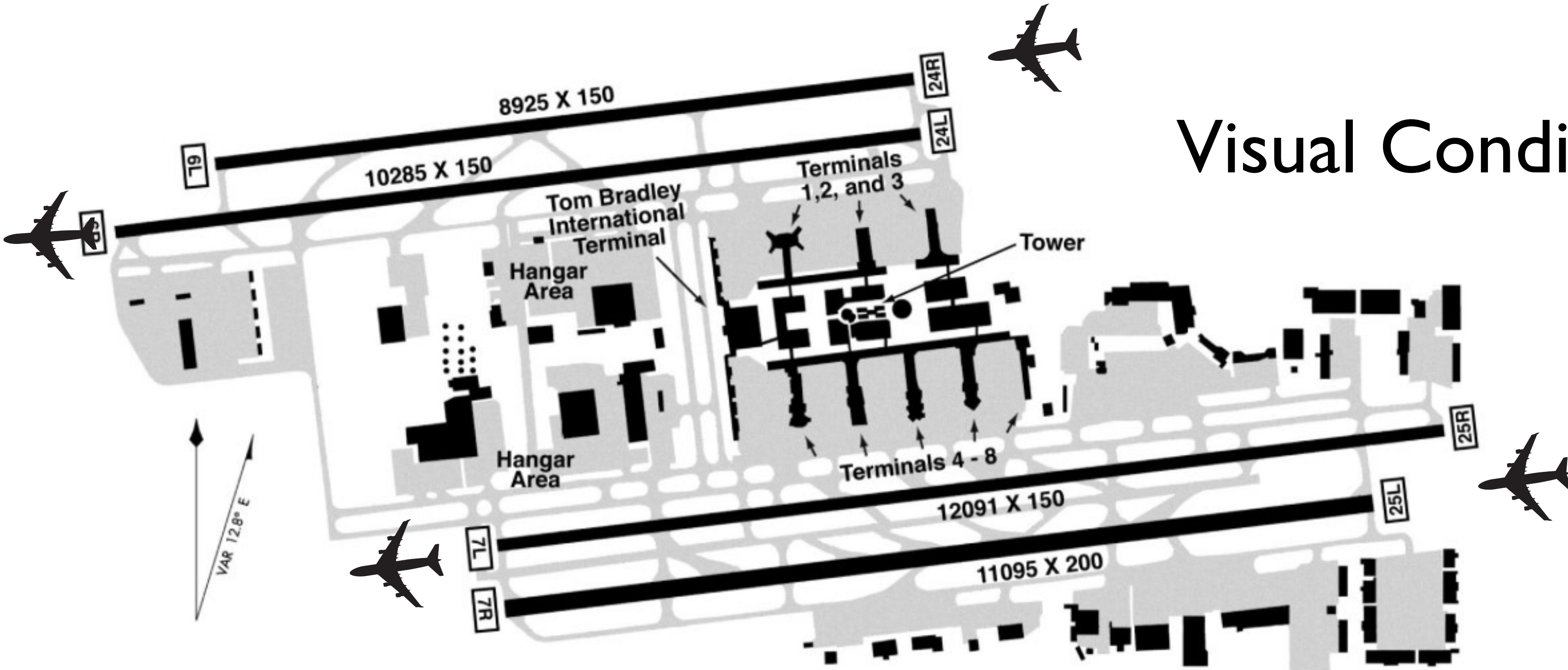




https://www.faa.gov/airports/planning_capacity/profiles/media/DCA-Airport-Capacity-Profile-2014.pdf

Los Angeles International Airport

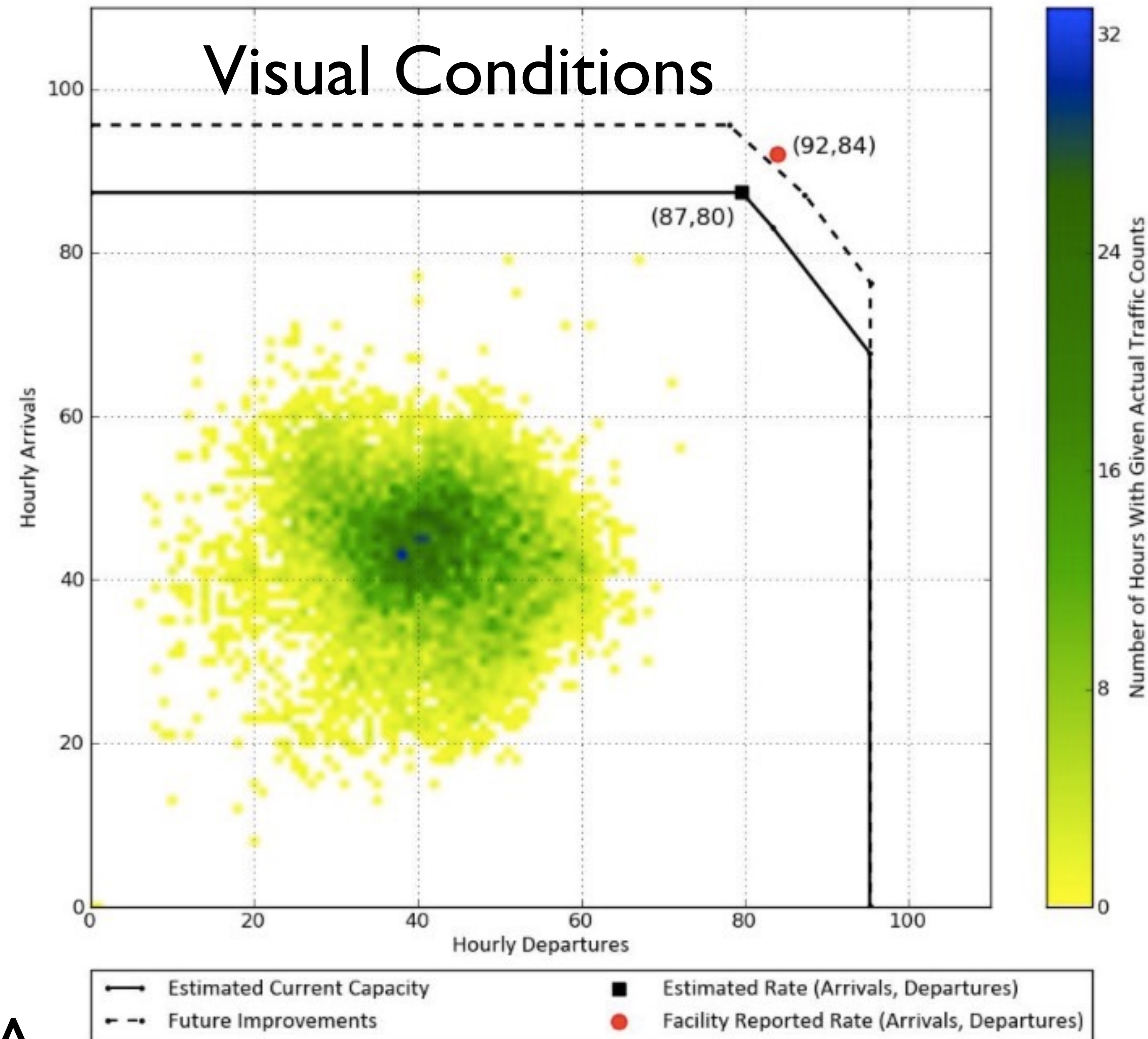
Visual Conditions



LAX Scenario	Arrival Runways	Departure Runways	Procedures	Hourly Rate	
				ATC Facility Reported	Model-Estimated
Current Operations	24R, 24L, 25R, 25L	24R, 24L, 25R, 25L	Visual Approaches, Visual Separation	176	167
Future Improvements Improved Runway Delivery Accuracy	24R, 24L, 25R, 25L	24R, 24L, 25R, 25L		N/A	174

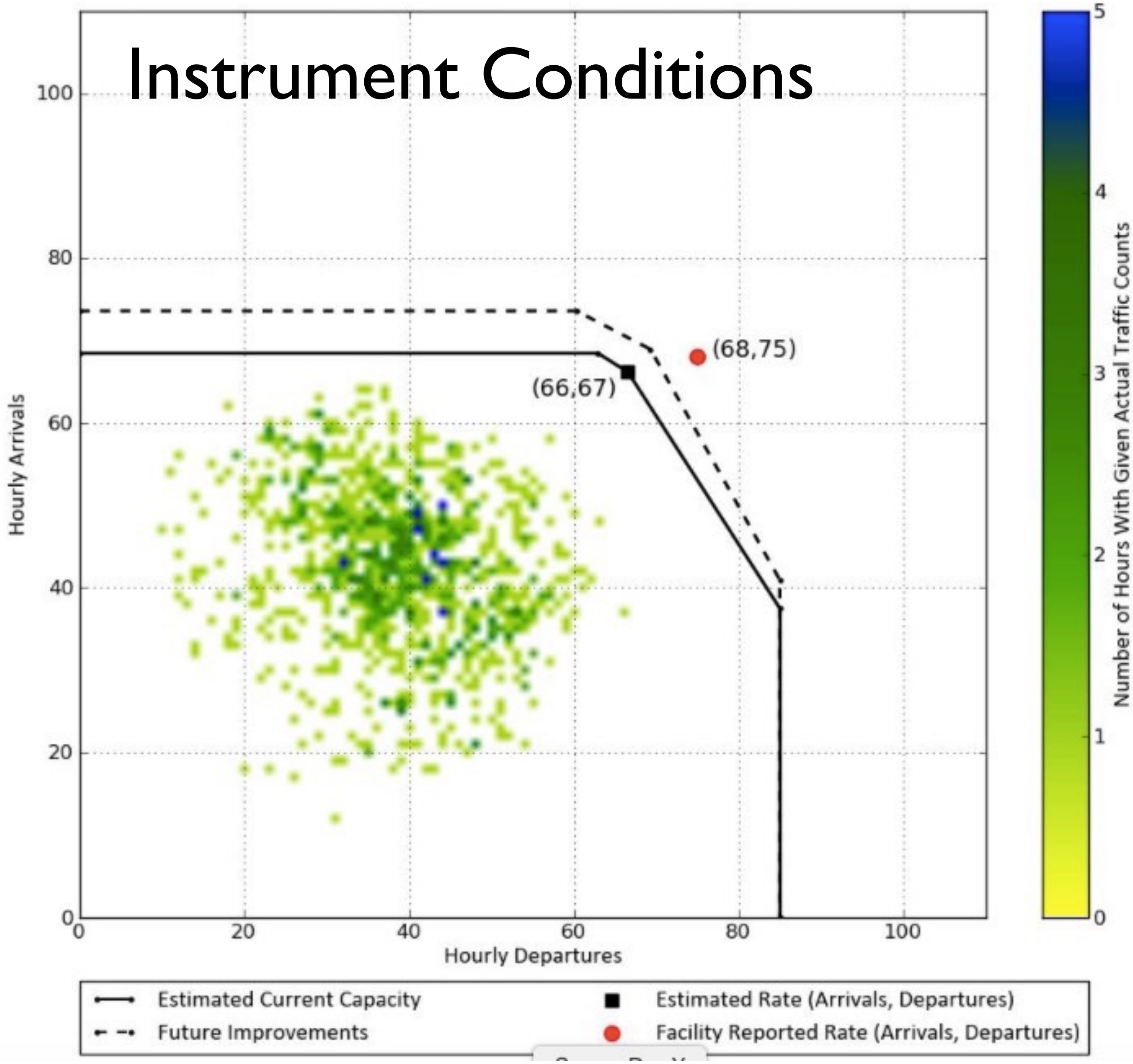
source: FAA

Los Angeles International Airport



source: FAA

Los Angeles International Airport



source: FAA