Assignment 9: Airport Runway Capacity and Delays

Date Due: November 17, 2021
Instructor: Trani

Problem 1

This problem analyzes the runway capacity for an airport with runway configuration shown in Figure 1. Assume landing aircraft on runway 07 touchdown before the intersection with runway 03 (i.e., no wake vortex effect for departures on runway 03). Use IMC conditions to solve the problem. The airport fleet mix is shown in Table 1. Note that the regional airport uses the new Re-Categorization developed by FAA with 6 groups (see page 43 of the Aircraft Classification handout). Assume the departing aircraft acceleration is 2.0 m/s^2. Consider the interactions between arrivals on runway 07 and departures on runway 03. For this analysis we use the following technical parameters: a) in-trail delivery error of 19 seconds under IMC conditions, b) probability of violation is 5%. Arriving aircraft are "vectored" by ATC to intercept the extended centerline off the runway 07 at a fix located 10 miles from the runway 07 threshold. Tables 2 and 3 show the arrival-arrival and departure-departure separations.

The ATC operations at the airport are such are such that, if an arrival is 2.5 nm from runway 07 threshold, the departure on runway 03 can be cleared for takeoff. The 2.5 nm distance provides a margin of safety for the departure to accelerate on runway 03 and cross the intersection.

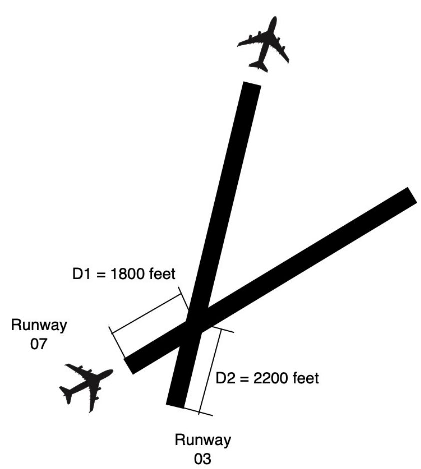


Figure 1. Runway Configuration for Problem 1.

Table 1. Runway Operational Parameters and Fleet Mix for Problem 1. RECAT Phase 1 Groups.

Aircraft RECAT Group	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) from FAF
D	82	50	140
E	18	48	134
Totals	100		

Table 2. Minimum arrival-arrival separations under IMC conditions. Values in are nautical miles. ***Values Shown Do Not Include Buffers.***

Minimum Separation Matrix (nm)			Arrivals-Arrivals	
		Trailing Aircraft (Header Columns)		
Lead (column 1)	E	D	C	B
E	2.5	2.5	2.5	2.5
D	3	2.5	2.5	2.5
C	3	3	3	3
B	5	5	4	3

Table 3. Minimum departure-departure separations under IMC conditions. Values in are seconds. ***Buffers are Included.***

Departure-Departure Separation Matrix (seconds)				
		Trailing Aircraft (Header Columns)		
Lead (column 1)	E	D	C	B
E	70	70	70	70
D	70	70	70	70
C	120	120	120	120
B	120	120	120	120

a) Derive the critical equation to estimate the time gaps needed to account for the dependency between operations on runways 07 and 03.

Assume that ATC controllers release departures on Runway 03, around 10 seconds after an arriving aircraft crosses the intersection between runways 03 and 07.

Also, assume that landing aircraft are on the ground before the intersection. This eliminates the possibility of wake vortex delays for departures since the wakes are normally dissipated once the aircraft is on the ground.

Time for arrivals pass through the intersection
1800 feet=0.296 nm

E: 0.296/134*3600=8.0 seconds
D: 0.296/140*3600=7.6 seconds
C: 0.296/155*3600=6.9 seconds

Time for departures pass through the intersection
2200 feet=670.56 m
T= sqrt (2*670.56/2.0)=26 seconds

Total: 8+10+26=44 seconds

$$\delta = 2.5 \text{ nm} = \delta_{ij} + \frac{B_{ij}}{3600} V_j - \frac{44}{3600}(V_j)$$

b) Estimate the arrival and departure capacities for the airport.

Arrivals only on runway 7 = 36.24 arrivals/hr

Departures only on runway 3 = 51.43 departures/hr

Departures with 100% arrivals=5.20

Technical Parameters (inputs)	Parameter	Values	Units	Notes
Dep-Arrival Separation (nm)	δ	2	nm	arrival-dep
Common Approach Length (nm)	γ	10	nm	common a
Standard deviation of Position Delivery Error (s)	σ	19	seconds	standard d
Probability of Violation	Pv	5	dim	probability
Cumulative Normal at Pv	qv	1.65	dim	cumulative
	ε	10	seconds	clear for ta

	E	D	C		
ROT (s)	48	50	62	49.64	E(ROT)
Percent Mix	18	82	0	100	Total %
Vapproach (k	134	140	155		

Minimum Separation Matrix (nm) — Arrivals-Arrivals

	Trailing E	Trailing D	Trailing C
E	2.5	2.5	2.5
D	3	2.5	2.5
C	3	3	3

Error Free Separation Matrix (seconds)

	Trailing E	Trailing D	Trailing C		Expected Value
E	67.16	64.29	58.06		E(Tij)
D	92.11	64.29	58.06		68.49
C	117.00	102.03	69.68		

Pij Matrix (dim)

	Trailing E	Trailing D	Trailing C		Sum of Pij
E	0.032	0.148	0.000		0.18
D	0.148	0.672	0.000		0.82
C	0.000	0.000	0.000		0.00
					1.00

Buffer Matrix (seconds)

	Trailing E	Trailing D	Trailing C		Expected Value
E	31.35	31.35	31.35		B(Tij)
D	27.90	31.35	31.35		30.84
C	20.43	23.88	31.35		

Augmented Matrix (Tij + Bij) (seconds)

	Trailing E	Trailing D	Trailing C		Expected Value
E	98.51	95.64	89.41		E(Tij) + B(Tij)
D	120.01	95.64	89.41		99.33
C	137.43	125.91	101.03		

Arrivals Only Capacity (per hour): 36.24

Departure-Departure Separation Matrix (seconds)

	Trailing E	Trailing D	Trailing C		Expected Value
E	70	70	70		E(Td)
D	70	70	70		70
C	120	120	120		

Departures Only Capacity (per hour): 51.43

Gap analysis to determine the conditions to release a departure on runway 3 between successive arrivals on runway 7. The analysis shows that only the gap left between RECAT groups D (lead) and E (trail) allows one departure operation (see third matrix below). Since there are 35.24 arrivals gaps, this yields 5.2 departures (the probability of D followed by E is 0.148) between successive arrivals with 100% arrival priority (i.e., no reduction in the number of arrivals to increase departures).

Note that the solution obtained uses a relatively conservative rule of 2.5 nm from the arrival threshold. If the rule is reduced to 2.0 nm, then all cells in the gap analysis matrix will allow a departure between two successive arrivals producing 35.2 departures per hour instead. This shows you how sensitive is the runway capacity to the operational concept adopted by Air Traffic Control.

Time remaining on following aircraft approach segment(Tij+Bij-44 seconds)

n=1	E	D	C
E	54.51	51.64	45.41
D	76.01	51.64	45.41
C	93.43	81.91	57.03

Distance left between following aircraft and intersection point(nm)

n=1	E	D	C
E	2.03	2.01	1.96
D	2.83	2.01	1.96
C	3.48	3.19	2.46

Number of departures per arrival gap

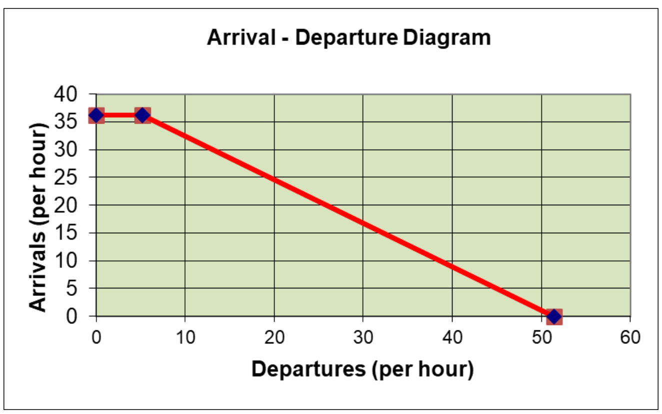
	E	D	C
E	0	0	0
D	1	0	0
C	1	1	0

Number of departures on runway

	E	D	C
E	0.00	0.00	0.00
D	5.20	0.00	0.00
C	0.00	0.00	0.00

Sum of departures	5.20

c) Plot the IMC arrival-departure capacity diagram for this airport.



d) Name two popular aircraft operated in the National Airspace System that belong to RECAT D group.

D	***Boeing 757-200 and -300, Boeing 737-800, Airbus A320, Airbus A321, McDonnell Douglas MD-80, Embraer 190, Bombardier CS-300, Gulfstream 550 and 650***

Problem 2

This problem analyzes the runway capacity for an airport with runway configuration shown in Figure 2. To solve the problem, assume the same technical parameters and aircraft fleet mix used in Problem 1.

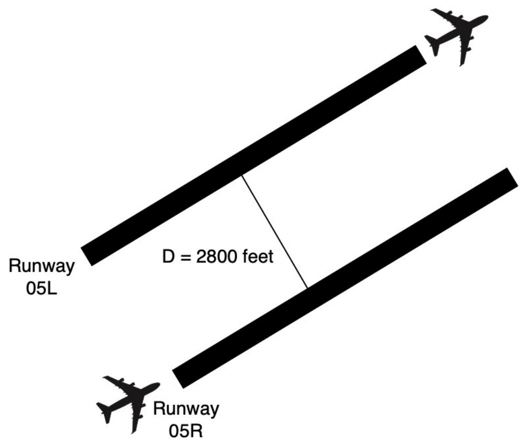


Figure 2. Runway Configuration for Problem 2.

a) Estimate the arrival and departure capacities for the runway configuration shown in Figure 2.

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 to operate simultaneously. This is a segregated operation (one runway for arrivals and its parallel one for departures)

Arrivals = 36.24 arrivals/hr

Departures = 51.43 departures/hr

Technical Parameters (inputs)				Parameter	Values	Units	Notes
Dep-Arrival Separation (nm)				δ	2	nm	arrival-dep
Common Approach Length (nm)				γ	10	nm	common a
Standard deviation of Position Delivery Error (s)				σ	19	seconds	standard de
Probability of Violation				Pv	5	dim	probability
Cumulative Normal at Pv				qv	1.65	dim	cumulative
				ε	10	seconds	clear for ta
	E	D	C				
ROT (s)	48	50	62	49.64	E(ROT)		
Percent Mix	18	82	0	100	Total %		
Vapproach (k	134	140	155				

Minimum Separation Matrix (nm)		Arrivals-Arrivals	
		Trailing	
	E	D	C
E	2.5	2.5	2.5
D	3	2.5	2.5
C	3	3	3

Error Free Separation Matrix (seconds)				
		Trailing		
	E	D	C	Expected Value
E	67.16	64.29	58.06	E(Tij)
D	92.11	64.29	58.06	68.49
C	117.00	102.03	69.68	

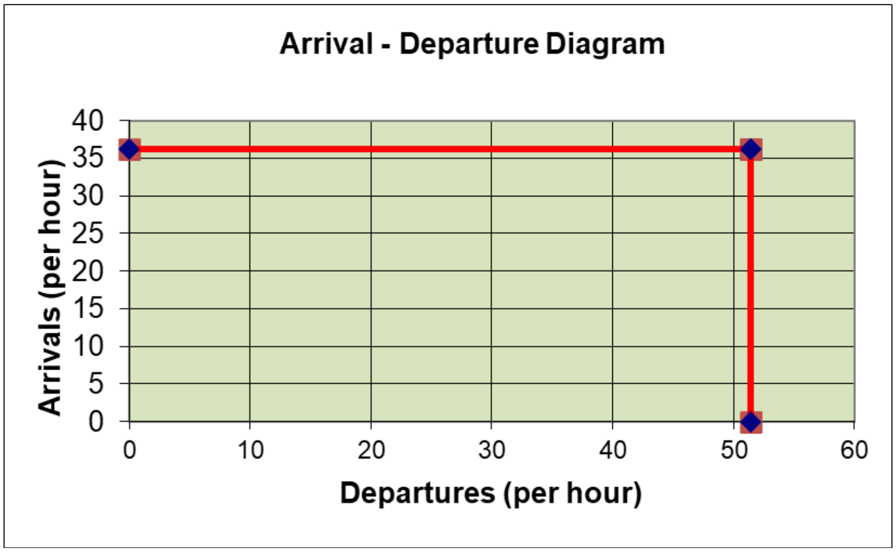
Pij Matrix (dim)				
		Trailing		
	E	D	C	Sum of Pij
E	0.032	0.148	0.000	0.18
D	0.148	0.672	0.000	0.82
C	0.000	0.000	0.000	0.00
				1.00

Buffer Matrix (seconds)				
		Trailing		
	E	D	C	Expected Value
E	31.35	31.35	31.35	B(Tij)
D	27.90	31.35	31.35	30.84
C	20.43	23.88	31.35	

Augmented Matrix (Tij + Bij) (seconds)				
		Trailing		
	E	D	C	Expected Value
E	98.51	95.64	89.41	E(Tij) + B(Tij)
D	120.01	95.64	89.41	99.33
C	137.43	125.91	101.03	
Arrivals Only Capacity (per hour)			36.24	

Departure-Departure Separation Matrix (seconds)				
		Trailing		
	E	D	C	Expected Value
E	70	70	70	E(Td)
D	70	70	70	70
C	120	120	120	
Departures Only Capacity (per hour)			51.43	

b) Plot the IMC arrival-capacity capacity diagram for this airport.



c) Compare the capacity of the two-runway configuration with that obtained in Problem 1.

The segregated operation (one runway for arrivals and its parallel one for departures) achieves a higher overall capacity compared to the crossing runway operation in Problem 1. However, segregated operation requires more land for development. This is a tradeoff.

d) Name an important airport in the United Kingdom that operates two runways in segregated mode.

Heathrow International Airport in London operates in segregated mode most of the time.

Problem 3

This problem analyzes the runway delays for an airport with runway configuration similar to that shown in Figure 2. The fleet mix for this problem is different than Problem 2. Calculation of runway capacity for this airport yields 34 arrivals per hour and 48 departures per hour. Airlines schedule arrivals according to the demand function shown in Figure 3.

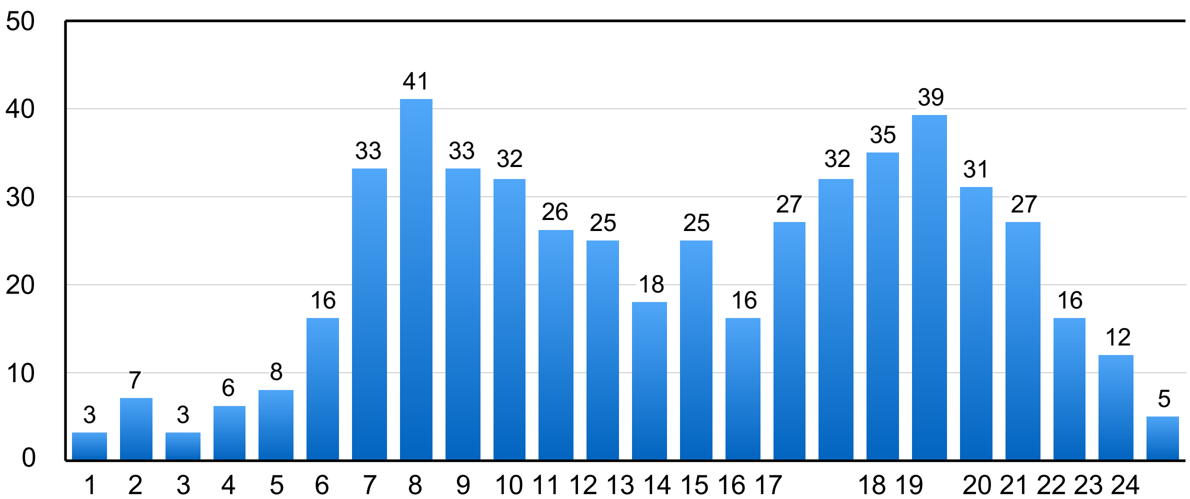
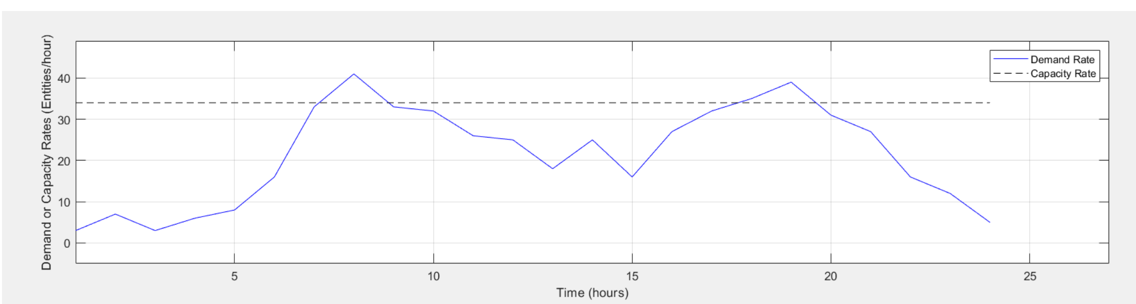


Figure 3. Arrival Demand for Problem 3.

a) Draw the rate diagram (supply and demand) for the arrival runway.



b) Use Deterministic Queueing theory to estimate the total delay (in units aircraft-hours) to arriving aircraft for the configuration shown. You can use the MATLAB code provided in class. Show me the input parameters that you changed to solve the problem.

Total delay (aircraft-hour) = 21.8234

```
time = 1:24;                    % values of time (time vector)
demand = [3 7 3 6 8 16 33 41 33 32 26 25 18 25 16 27 32 35 39 31 27 16 12 5];          % values of demand over time
capacity = 34*ones(1,24);  % values of capacity over time
```

c) Find the maximum queue length and the average queue length for the morning period

Max queue length (aircraft) = 6.09 aircraft

Delay for the morning period=14.10 (aircraft-hour)

Queue Period = 10.94-7.08=3.86 hours

Average queue length=14.10/3.86=3.65 aircraft

d) Find the average delay per aircraft for aircraft that are affected by the limited runway capacity of the airport.

Average delay per aircraft=21.8/234=5.60 minutes per aircraft

Time (hours)	Cumulative Arrivals	Arrivals in Queueing Period
7.08	63.19	129
10.94	192.18	
17.79	359.89	105
20.87	464.77	
	Total Arrivals Queued	234