Assignment 7: Runway Throughput and Capacity

Date Due: November 8, 2021
Instructor: Trani

Problem 1

An internet application to show communities around airports the extend of their operations is shown in Figure 1. The application is called Webtrak (https://webtrak.emsbk.com/lax4). This application shows flight operations to an airport. Study the airport configuration for Los Angeles International airport (https://www.faa.gov/airports/runway_safety/diagrams/). Normally, arrivals are conducted on runways 24R (Northern runway) and runway 25L (Southern runway). Departures on runways 24L and runway 25R.

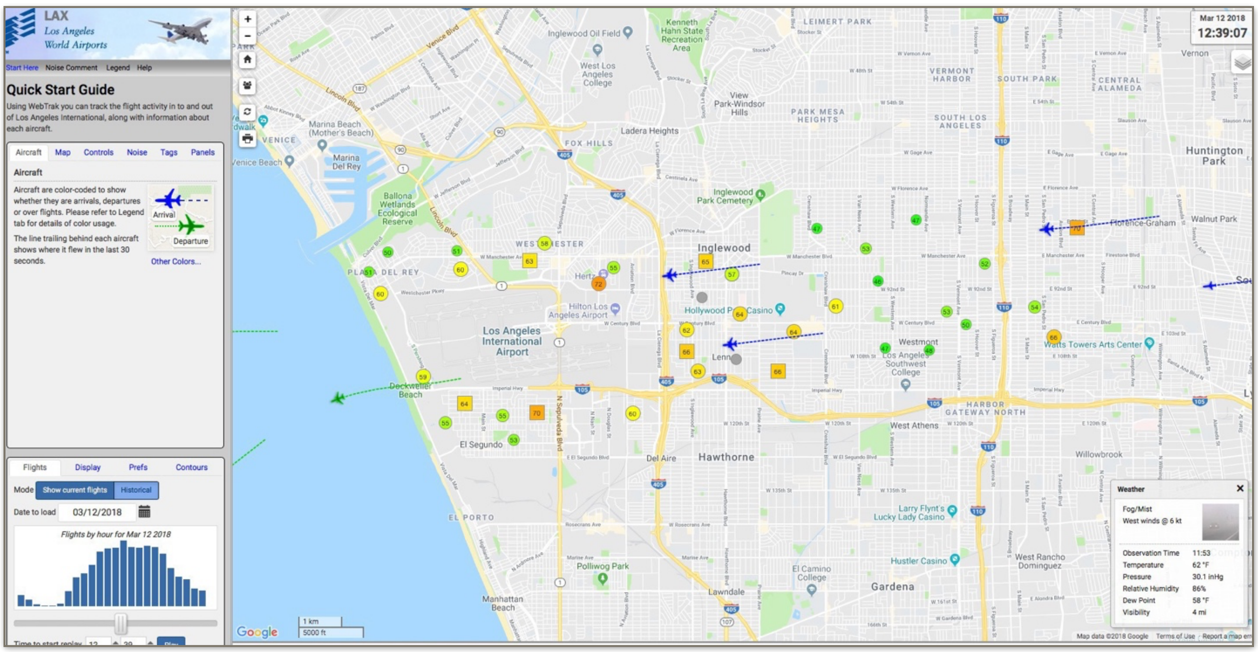

Figure 1. Webtrak system for Los Angeles International Airport. Departures are shown in Green. Arrivals in Blue. Airport Weather Conditions Panel Shown at the Lower Right Viewport. Replay Panel on the Lower Left.

a) Use the replay feature in Webtrak5 to estimate the number of landing operations between 11:00-11:30 hrs (i.e., called runway throughput) at LAX runway 24R airport on September 30, 2021.

The number of landing operations on runway 24R between 11:00-11:30 AM is 13.

b) Use the replay feature in Webtrak5 to estimate the number of departure operations at LAX during the period 11:00-11:30 hrs.

The number of departure operations at LAX during the period 11:00-11:30 AM is 23.

c) Find the runway hourly throughput of the airport in West flow configuration with arrivals on runways 24R, 25L and departures on runways 24L and 25R. Since you collected data for a 30-minute period, assume the period 11:30-12:00 would have similar number of operations.

There are 26 landings/hr on an arrival runway (assuming double the arrivals observed on runway 24R since runway 25L on the South is also used for arrivals). There are 46 departures/hr the airport. The runway hourly throughput is estimated to be (26x2 + 46) 98 operations per hour.

Problem 2

The objective of the problem is to find the capacity of San Diego International Airport. San Diego is a single runway airport. The airport has an airport surveillance radar (ASR) which tracks aircraft up to 50 nautical miles from the airport site. The radar has a scan rate of 4 seconds. Tables 1 through 3 show technical parameters and the typical ATC separations at the airport under Instrument Meteorological Conditions (IMC). Assume the minimum separations under VMC conditions are reduced by 10% from those observed under IMC conditions. Four aircraft groups operate at the airport. 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 located 11 miles from the runway threshold as the aircraft overfly the Sweetwater Reservoir (see Figure 2). Arrivals follow in-trail after crossing the final approach fix. The airport aircraft mix, runway occupancy times and approach speeds are shown in Table 1.

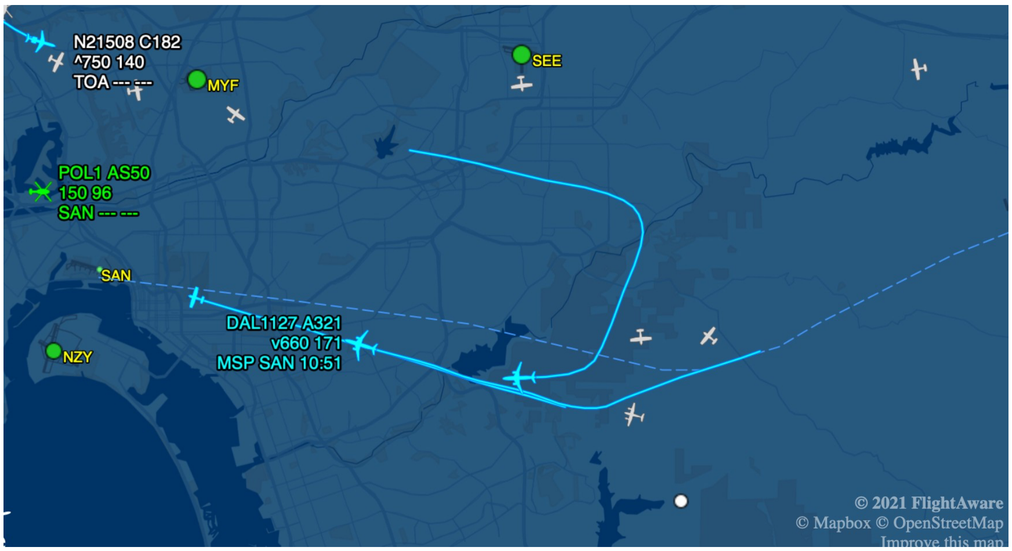

Figure 2. San Diego International Airport Final Approach Segment Configuration. Source: Flightaware.

You are allowed to modify the spreadsheet provided in class to solve the problem. Show me sample calculations for both opening and closing cases so that I know that you can do such calculations by hand.

a) Calculate the arrivals-only saturation capacity under IMC conditions.

The arrivals-only saturation capacity under IMC conditions is 35.74 arrivals/hr.

Technical Parameters (inputs)				Parameter	Values	Units	Notes
Dep-Arrival Separation (nm)				d	2	nm	arrival-departure separation
Common Approach Length (nm)				g	11	nm	common approach length
Standard deviation of Position Delivery Error (s)				s	16	onds	standard deviation of in-trail
Probability of Violation				Pv	5	dim	probability of violation
Cumulative Normal at Pv				qv	1.65	dim	cumulative normal at Pv
				e	10	seconds	clear for takeoff time lag

	E	D	C	B		
ROT (s)	47	51	62	64	51.047	E(ROT)
Percent Mix	18.2	75.3	3.5	3	100	Total %
Vapproach (kı	126	137	147	151		

Minimum Separation Matrix (nm) — Arrivals-Arrivals

Leading	Trailing: 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

Error Free Separation Matrix (seconds)

	Trailing: E	D	C	B	Expected Value
E	71.43	65.69	61.22	59.60	E(Tij)
D	110.95	65.69	61.22	59.60	75.89
C	130.61	98.50	73.47	64.39	
B	194.89	158.19	97.96	71.52	

Pij Matrix (dim)

	Trailing: E	D	C	B	Sum of Pij
E	0.033	0.137	0.006	0.00546	0.18
D	0.137	0.567	0.026	0.02259	0.75
C	0.006	0.026	0.001	0.00105	0.04
B	0.00546	0.02259	0.00105	0.0009	0.03
					1.00

Buffer Matrix (seconds)

	Trailing: E	D	C	B	Expected Value
E	26.40	26.40	26.40	26.40	B(Tij)
D	19.52	26.40	26.40	26.40	24.84
C	14.16	21.04	26.40	28.35	
B	2.75	14.22	26.40	26.40	

Augmented Matrix (Tij + Bij) (seconds)

	Trailing: E	D	C	B	Expected Value
E	97.83	92.09	87.62	86.00	E(Tij) + B(Tij)
D	130.47	92.09	87.62	86.00	100.72
C	144.77	119.53	99.87	92.73	
B	197.64	172.40	124.36	97.92	
Arrivals Only Capacity (per hour)			35.74		

b) Calculate the departures-only saturation capacity under IMC conditions.

The departures-only saturation capacity under IMC conditions is 49.15 departures/hr.

Departure-Departure Separation Matrix (seconds)

	Trailing: E	D	C	B	Expected Value
E	70	70	70	70	E(Td)
D	70	70	70	70	73.25
C	120	120	120	120	
B	120	120	120	120	
Departures Only Capacity (per hour)			49.15		

c) Calculate the arrival-departure saturation capacity diagram (Pareto diagram) under IMC conditions. In your diagram, include at least one point to estimate the departure capacity with 100% arrival priority under mixed runway operations. Show me sample calculations of Tij and Bij so that I can judge your analysis.

Estimation of Critical Departure Gaps (seconds)

Departures	Gap (EDTij)	
1	125.69	seconds
2	198.94	seconds
3	272.19	seconds
4	345.44	seconds
5	418.69	seconds
6	491.94	seconds
7	565.19	seconds
8	638.44	seconds
9	711.69	seconds
10	784.94	seconds
11	858.19	seconds

E(ROT)	64.00	seconds
E(d/Vj)	51.69	seconds
sg*qv or e	10.00	seconds

Departures per Gap

	Trailing			
	E	D	C	B
E	0.00	0.00	0.00	0.00
D	1.00	0.00	0.00	0.00
C	1.00	0.00	0.00	0.00
B	1.00	1.00	0.00	0.00

Departures per hour with 100% Arrival Priority

	Trailing					
	E	D	C	B	Expected Value	
E	0.00	0.00	0.00	0.00	0.00	
D	4.76	0.00	0.00	0.00	4.76	
C	0.22	0.00	0.00	0.00	0.22	
B	0.19	0.78	0.00	0.00	0.97	Total Departures
					5.96	with 100% arrival priority

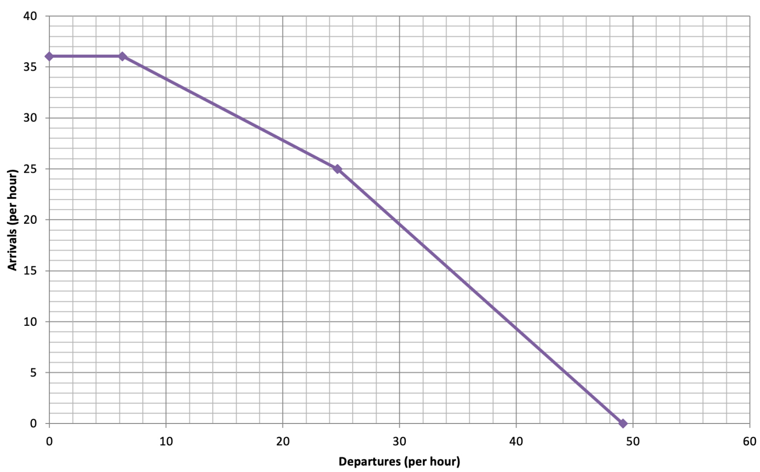

Figure. San Diego Arrival-Departure Hour Capacity Diagram.

d) Repeat part (a) for VMC conditions. Comment on the differences observed. Specifically, comment on the number of departure values obtained with 100% arrivals. Show me sample calculations of Tij and Bij so that I can judge your analysis.

The arrivals-only saturation capacity under VMC conditions is 38.4 arrivals/hr. Compared to 35.7 under IMC condition, the arrivals-only saturation capacity increases a little bit under VMC condition. The number of departure values obtained with 100% arrivals is 1.29.

Technical Parameters (inputs)	Parameter	Values	Units	Notes
Dep-Arrival Separation (nm)	d	2	nm	arrival-departure separatio
Common Approach Length (nm)	g	11	nm	common approach length
Standard deviation of Position Delivery Error (s)	s	16	seconds	standard deviation of in-tra
Probability of Violation	Pv	5	dim	probability of violation
Cumulative Normal at Pv	qv	1.65	dim	cumulative normal at Pv
	e	10	seconds	clear for takeoff time lag

	E	D	C	B		
ROT (s)	47	51	62	64	51.047	E(ROT)
Percent Mix	18.2	75.3	3.5	3	100	Total %
Vapproach (	126	137	147	151		

Minimum Separation Matrix (nm) Arrivals-Arrivals

Leading \ Trailing	E	D	C	B
E	2.25	2.25	2.25	2.25
D	2.7	2.25	2.25	2.25
C	2.7	2.7	2.7	2.7
B	4.5	4.5	3.6	2.7

Error Free Separation Matrix (seconds)

Trailing	E	D	C	B	Expected Value
E	64.29	59.12	55.10	53.64	E(Tij)
D	102.38	59.12	55.10	53.64	68.81
C	122.04	90.61	66.12	57.23	
B	180.61	145.05	88.16	64.37	

Pij Matrix (dim)

Trailing	E	D	C	B	Sum of Pij
E	0.033	0.137	0.006	0.00546	0.18
D	0.137	0.567	0.026	0.02259	0.75
C	0.006	0.026	0.001	0.00105	0.04
B	0.00546	0.02259	0.00105	0.0009	0.03
					1.00

Buffer Matrix (seconds)

Trailing	E	D	C	B	Expected Value
E	26.40	26.40	26.40	26.40	B(Tij)
D	20.21	26.40	26.40	26.40	24.99
C	15.38	21.57	26.40	28.15	
B	5.11	15.44	26.40	26.40	

Augmented Matrix (Tij + Bij) (seconds)

Trailing	E	D	C	B	Expected Value
E	90.69	85.52	81.50	80.04	E(Tij) + B(Tij)
D	122.58	85.52	81.50	80.04	93.81
C	137.42	112.19	92.52	85.39	
B	185.72	160.48	114.56	90.77	
Arrivals Only Capacity (per hour)			38.38		

Departure-Departure Separation Matrix (seconds)

Trailing	E	D	C	B	Expected Value
E	70	70	70	70	E(Td)
D	70	70	70	70	73.25
C	120	120	120	120	
B	120	120	120	120	
Departures Only Capacity (per hour)			49.15		

Estimation of Critical Departure Gaps (seconds)

Departures	Gap (EDTij)				
			E(ROT)	64.00	seconds
			E(d/Vj)	51.69	seconds
1	125.69	seconds	sg*qv or e	10.00	seconds
2	198.94	seconds			
3	272.19	seconds			
4	345.44	seconds			
5	418.69	seconds			
6	491.94	seconds			
7	565.19	seconds			
8	638.44	seconds			
9	711.69	seconds			
10	784.94	seconds			
11	858.19	seconds			

Departures per Gap

Trailing	E	D	C	B
E	0.00	0.00	0.00	0.00
D	0.00	0.00	0.00	0.00
C	1.00	0.00	0.00	0.00
B	1.00	1.00	0.00	0.00

Departures per hour with 100% Arrival Priority

Trailing	E	D	C	B	Expected Value	
E	0.00	0.00	0.00	0.00	0.00	
D	0.00	0.00	0.00	0.00	0.00	
C	0.24	0.00	0.00	0.00	0.24	
B	0.20	0.84	0.00	0.00	1.05	Total Departures
					1.29	with 100% arrival priority

e) Compare the solution obtained in part (c) with the FAA runway capacity diagram (https://www.faa.gov/airports/planning_capacity/profiles/media/SAN-Airport-Capacity-Profile-2014.pdf). Comment on the possible sources of error.

The probability of violation is affected by human factors. The common approach length varies according to the traffic density conditions as well.

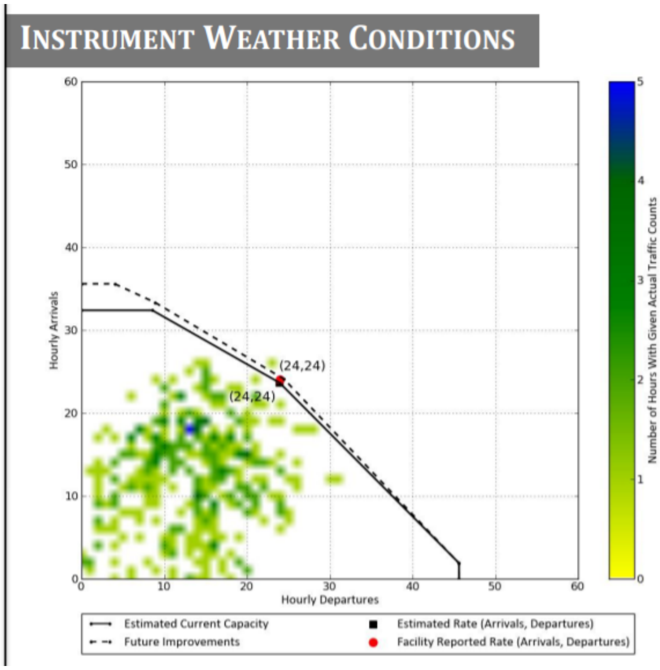

Figure FAA Published SAN Arrival-Departure Capacity Diagram.

The analysis presented using the time-space method is very close to the FAA published diagram. For example, our analysis shows 25 departures and 24 arrivals with 50/50 operational conditions.

Table 1. Runway Occupancy Times and Fleet Mix for San Diego International Airport (Source: FAA/Virginia Tech Landing Database).

Aircraft RECAT Group	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) from FAF
E	18.2	47	126
D	75.3	51	137
C	3.5	62	147
B	3.0	64	151
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

Problem 3 (Bonus Problem 5 Additional Points)

Evaluate the performance of a 3000-meter runway configuration shown in Figure 3. Use the FAA/Virginia Tech Runway Exit Design Model (REDIM) demonstrated in class. The runway has all right-angle exits at locations shown.

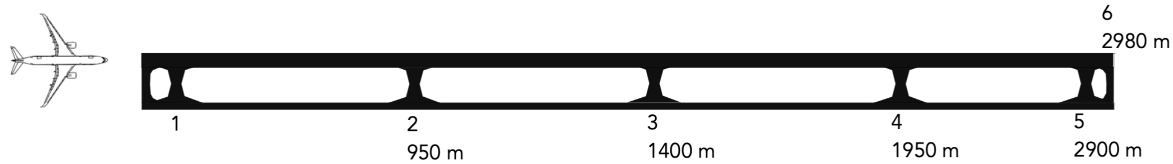

Figure 3. Runway Exit Configuration for Problem 3 (Bonus Problem).

Table 2. Aircraft Mix for Problem 3.

Aircraft	Percent Mix (%)
Pilatus PC-12	5.0
Embraer Phenom 300	3.8
Aerospatiale ATR 42	11.2
Boeing 737-800	25.6
Airbus A320	23.6
Boeing 757-200	12.5
Airbus A321	11.8
Airbus A330	6.5
Totals	100

a) Calculate the runway occupancy times for each aircraft using the REDIM model.

Critical AAC is D group. And Critical ADG is V.

Runway width 150 feet

- Analysis Info
- Selected Aircraft
  - A320 - Airbus A320 - 23.6%
  - A321 - Airbus A321 - 11.8%
  - A332 - Airbus A330-200 - 6.5%
  - AT42 - Aeropatiale ATR-42-200 - 11.2%
  - B738 - Boeing 737-800 - 25.6%
  - B752 - Boeing 757-200 - 12.5%
  - E55P - Embraer 55 Phenom 300 - 3.8%
  - PC12 - Pilatus PC-12 - 5%
- Analysis Constraints
  - Runway Occupancy Type: Fuselage Out
- Environmental Data
  - Airport Elevation: 0 meters
  - Airport Temperature: 30°C
  - Runway Length: 3000 meters
  - Runway Width: 46 meters
  - Wet Conditions: 10%
- Existing Exits
  - E1
    - Status: Open
    - Point Of Curvature Location: 200 meters
    - Type: 90°
  - E2
    - Status: Open
    - Point Of Curvature Location: 950 meters
    - Type: 90°
  - E3
    - Status: Open
    - Point Of Curvature Location: 1400 meters
    - Type: 90°
  - E4
    - Status: Open
    - Point Of Curvature Location: 1950 meters
    - Type: 90°
  - E5
    - Status: Open
    - Point Of Curvature Location: 2900 meters
    - Type: 90°
  - E6
    - Status: Open
    - Point Of Curvature Location: 2980 meters
    - Type: 90°

Aircraft Name	E1	E2	E3	E4	E5	E6
A320				50.7s	82.5s	69.0s
A321				48.5s	81.1s	
A332				55.2s	88.7s	81.1s
AT42		33.0s	45.4s	62.6s	93.9s	
B738				48.5s	78.7s	66.1s
B752			40.1s	56.3s	88.6s	
E55P		34.0s	46.0s	62.5s	93.3s	
PC12		39.4s	55.9s	78.6s	117.0s	115.9s

b) Improve the ROT of the runway by replacing runway exits 3 and 4 with two high-speed exits located at 1300 and 1700 meters.

- Analysis Info
- Selected Aircraft
  - E55P - Embraer 55 Phenom 300 - 3.8%
  - PC12 - Pilatus PC-12 - 5%
  - A320 - Airbus A320 - 23.6%
  - A321 - Airbus A321 - 11.8%
  - AT42 - Aeropatiale ATR-42-200 - 11.2%
  - B738 - Boeing 737-800 - 25.6%
  - B752 - Boeing 757-200 - 12.5%
  - A332 - Airbus A330-200 - 6.5%
- Analysis Constraints
  - Runway Occupancy Type: Fuselage Out
- Environmental Data
  - Airport Elevation: 0 meters
  - Airport Temperature: 30°C
  - Runway Length: 3000 meters
  - Runway Width: 45 meters
  - Wet Conditions: 10%
- Existing Exits
  - E1
    - Status: Open
    - Point Of Curvature Location: 200 meters
    - Type: 90°
  - E2
    - Status: Open
    - Point Of Curvature Location: 950 meters
    - Type: 90°
  - E3
    - Status: Open
    - Point Of Curvature Location: 1300 meters
    - Type: 30° (with 1,400 ft spiral)
  - E4
    - Status: Open
    - Point Of Curvature Location: 1700 meters
    - Type: 30° (with 1,400 ft spiral)
  - E5
    - Status: Open
    - Point Of Curvature Location: 2900 meters
    - Type: 90°
  - E6
    - Status: Open
    - Point Of Curvature Location: 2980 meters
    - Type: 90°

Aircraft Name	E1	E2	E3	E4	E5	E6
A320				41.7s	84.2s	68.7s
A321				40.5s	82.6s	
A332				45.7s	89.5s	69.1s
AT42		32.7s	42.0s	53.2s	96.7s	
B738				39.9s	80.5s	66.4s
B752			36.3s	46.7s	91.2s	
E55P		32.0s	40.3s	50.4s	94.4s	
PC12		39.3s	51.5s	64.3s	119.8s	117.6s

c) With the improvement made, does the runway meet the 50 second ROT criteria to allow reduced in-trail separations?

Aircraft Name	E1	E2	E3	E4	E5	E6	Aircraft Mix
A320				19.8%	80.1%	0.1%	23.6%
A321				9.9%	90.1%		11.8%
A332				3.6%	96.3%	0.1%	6.4%
AT42		1.2%	54.3%	39.2%	5.3%		10.9%
B738				12.9%	86.9%	0.1%	25.8%
B752			1.6%	54.2%	44.2%		12.6%
E55P		1.6%	50.8%	37.1%	10.5%		3.8%
PC12		23.5%	63.9%	9.2%	3.4%	0.1%	5.1%
Exit Mix	0.0%	1.4%	11.3%	22.4%	64.8%	0.1%	

No. The average ROT is about 70 seconds. So, the runway does not meet the 50 second ROT criteria to allow reduced in-trail separations.

Runway Exit Aircraft Assignment							Aircraft Name	Weighted averageAverage ROT	Fleet Mix	Average ROT for the total fleet (s)
				19.80%	80.10%	0.10%	A320	75.7695	23.60%	70.3898733
				9.90%	90.10%		A321	78.4321	11.80%	
				3.60%	96.30%	0.10%	A332	87.9028	6.40%	
		1.20%	54.30%	39.20%	5.30%		AT42	49.1779	10.90%	
				12.90%	86.90%	0.10%	B738	75.1016	25.80%	
			1.60%	54.20%	44.20%		B752	66.2026	12.60%	
		1.60%	50.80%	37.10%	10.50%		E55P	49.5948	3.80%	
		23.50%	63.90%	9.20%	3.40%	0.10%	PC12	52.2504	5.10%	
ROT										
				41.7	84.2	68.7				
				40.5	82.6					
				45.7	89.5	69.1				
		32.7	42	53.2	96.7					
				39.9	80.5	66.4s				
			36.3	46.7	91.2					
		32	40.3	50.4	94.4					
		39.3	51.5	64.3	119.8	117.6				