Example of Capacity and Delay Calculations

Problem 1

An airport has a single 9,000 feet runway oriented East-West as shown in Figure 1. 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 18 seconds (because there is a radar at the site), 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 1) located 9 miles from the runway threshold.

The airport has an aircraft fleet mix made up of 20% small, 70% large and 10% heavy wake class aircraft. Observed runway occupancy times in the field are: 42, 50, and 60 seconds for small, large and heavy, respectively. The average approach speeds obtained from the FAA AC 5300-13 Appendix 13 for these three groups are 120, 135 and 155 knots, respectively.

a) Calculate the arrival-departure saturation capacity diagram (Pareto diagram) under IMC conditions (show all your work). Include one point to estimate the departure capacity with 100% arrival priority under mixed runway operations.

b) Repeat part (a) for VMC conditions.

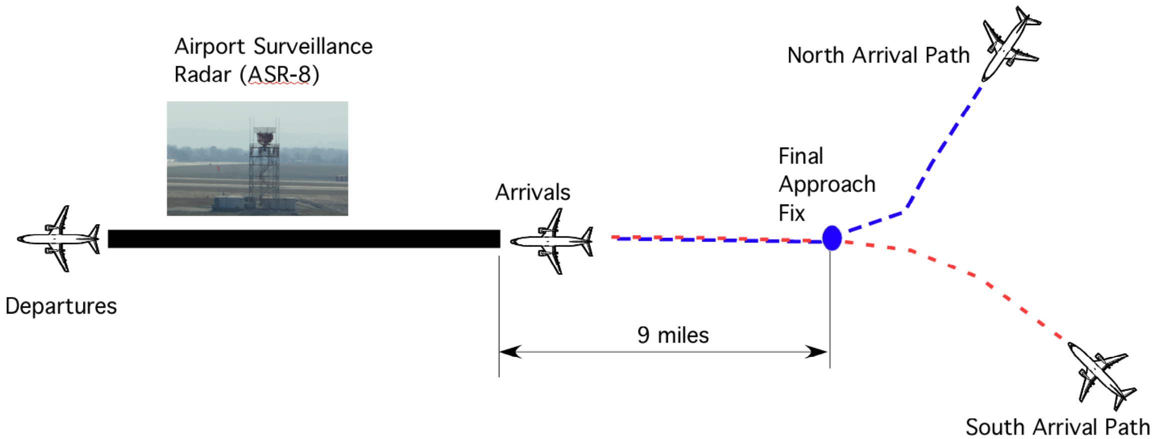

Figure 1. Airport Arrival and Departure Operational Procedures for Problem 1.

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 seconds.

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

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 VMC conditions. Values in are seconds.

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

Solution

The IMC Pareto Diagram shown in Figure 2 has been obtained using the Excel Spreadsheet distributed in class.

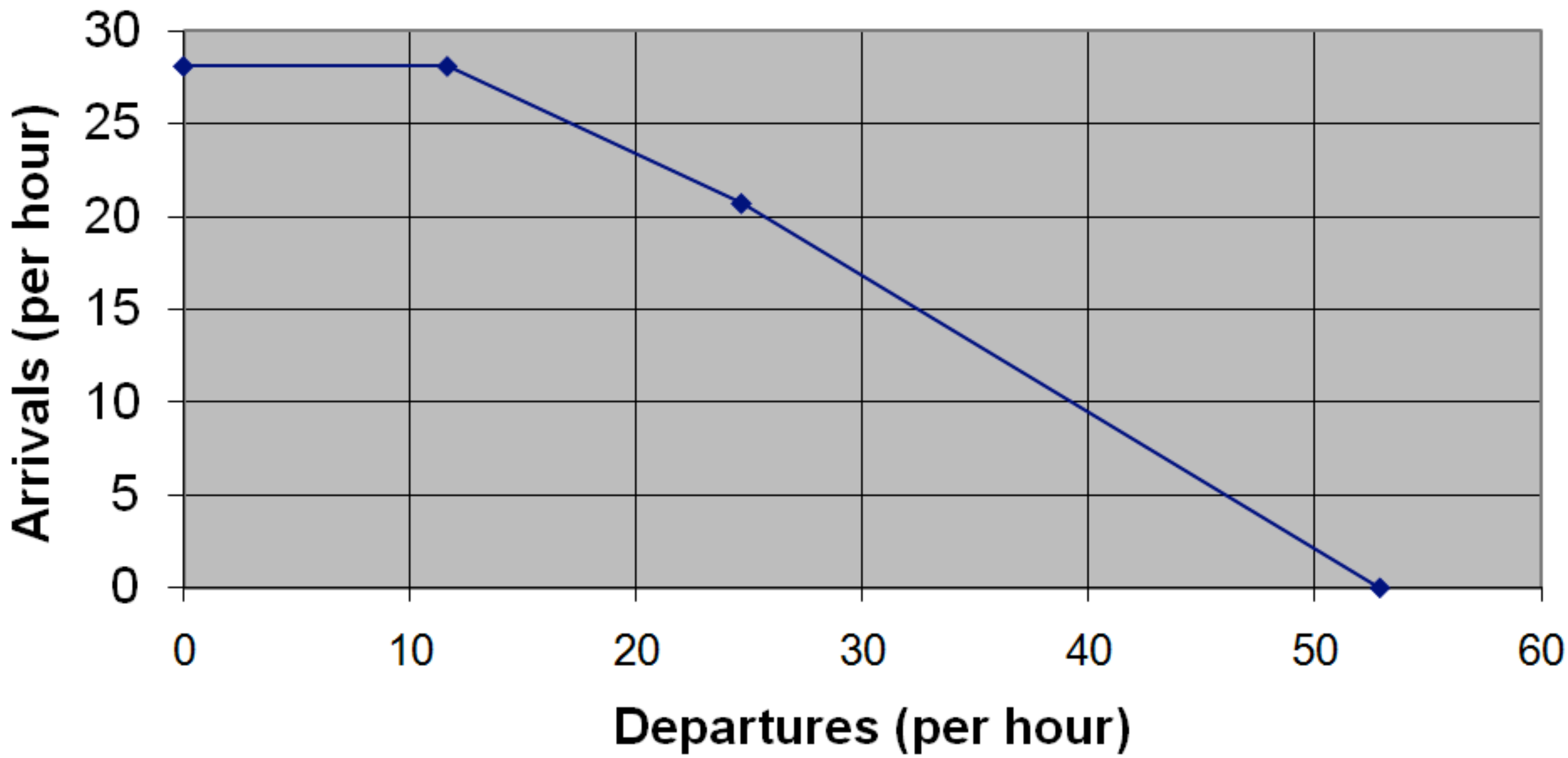

Figure 2. IMC Pareto Diagram.

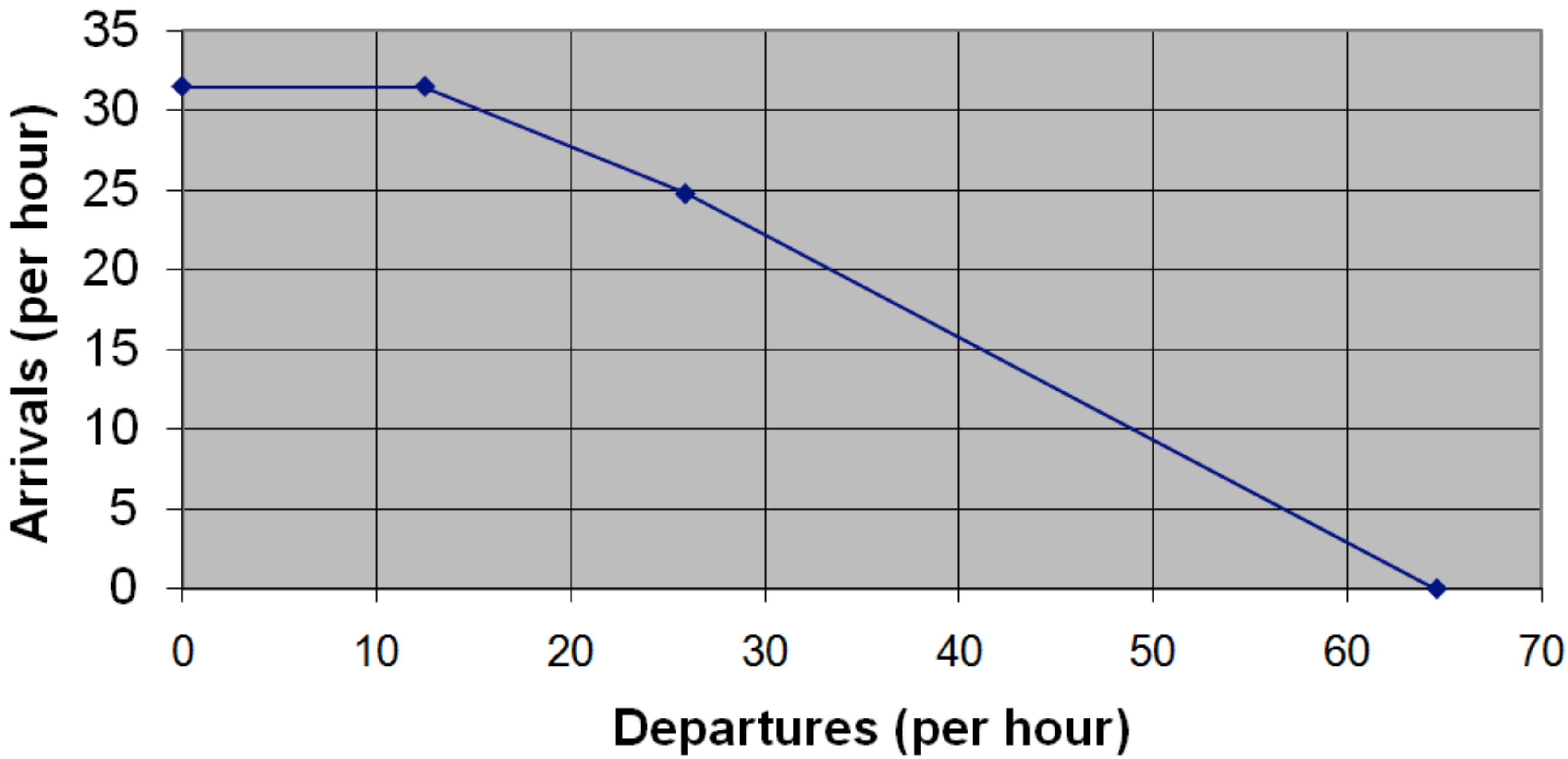

Figure 3. VMC Pareto Diagram.

Problem 2

During a typical day, the airport described in Problem 1 has a demand function shown in Table 5. The table shows arrivals and departures scheduled by airlines operating at the airport.

Table 5. Demand Function for the Airport in Problem 1.

Time (hrs)	Departures per Hour	Arrivals per Hour
0	1	2
1	2	3
2	1	2
3	2	2
4	4	6
5	6	7
6	15	20
7	22	32
8	38	37
9	41	20
10	35	20
11	19	15

Time (hrs)	Departures per Hour	Arrivals per Hour
12	23	25
13	24	34
14	37	30
15	41	32
16	26	25
17	20	25
18	17	12
19	14	14
20	9	11
21	6	7
22	5	6
23	2	3

a) Use a deterministic queueing model to find the average arrival delay per flight if the arrivals are given priority over the departures. Use the demand function in Table 5. Plot the arrival demand vs. the arrival saturation capacity used in the analysis.

Use the Pareto diagram for IMC conditions to find the saturation capacity of the airport under the given conditions. For 100% arrival priority, we find that arrival saturation capacity is 28.11 per hour. Use this value as a constant vector in the deterministic queueing model demonstrated in class. Figures 4 and 5 shows the results of this analysis.

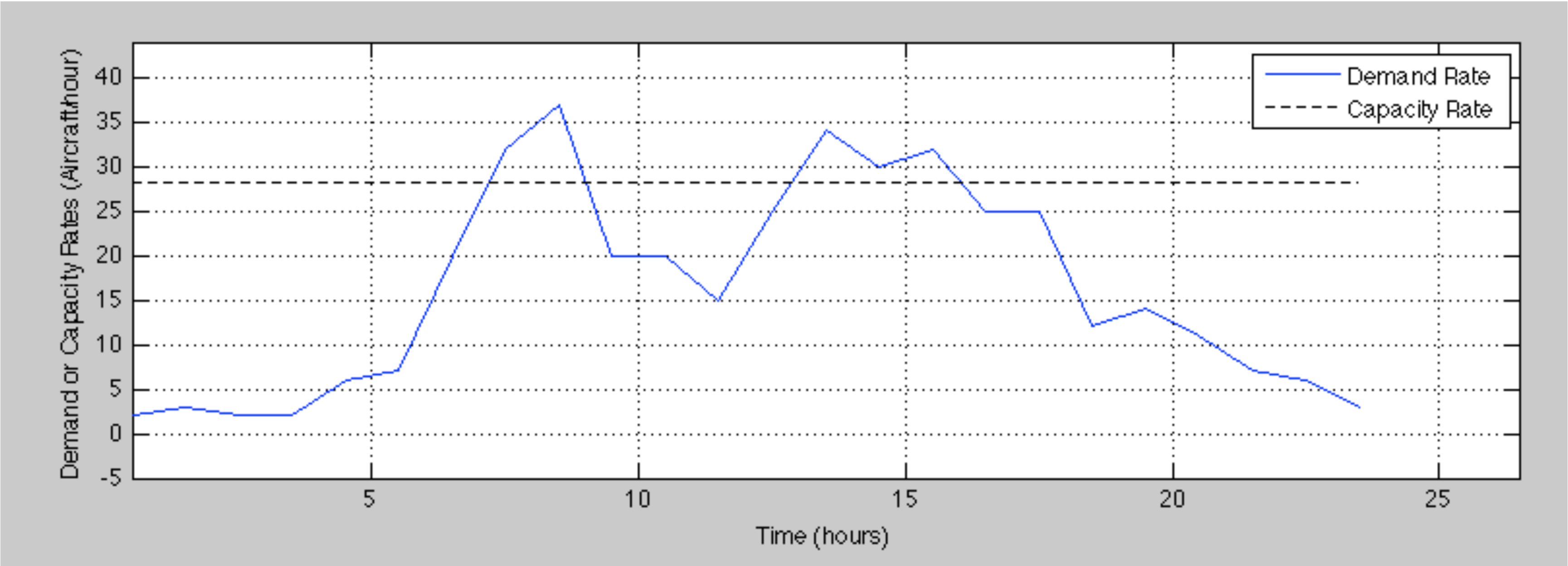

Figure 4. Arrival Rate vs. Arrival Capacity.

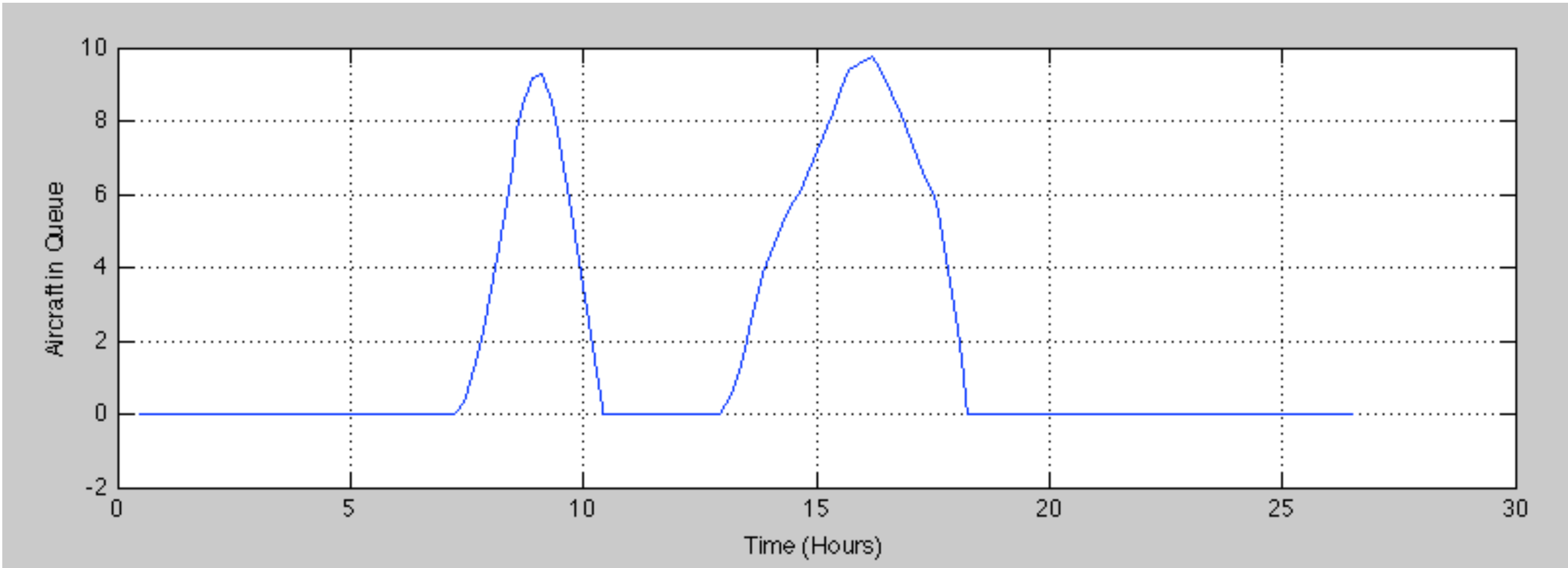

Figure 5. Queueing Diagram for Arrivals under IMC Conditions.

The average delay can be interpreted as:

1)Average delay per flight considering all arrival flights of the day

The total delay for the system is 46.97 aircraft-hours. Since there are 390 arrivals during the day, this would produce an average delay per flight of 7.22 minutes.

2)Average delay per flight considering only flights delayed

The total delay for the system is 46.97 aircraft-hours. This requires an estimation of the number of flights delayed according to the deterministic queueing model. Note from Figure 5 that the queues manifest at periods during the day: 1) 7.2 to 10.4 hours and 2) 12.8 to 18.8 hours. The number of aircraft arriving during that period are calculated from the original arrival demand function.

For period 1 the number of aircraft is estimated to be 93 (139-46) aircraft (using interpolation from the arrival function). For period 2, the number of aircraft delayed are estimated to be 151. This implies a total of 244 aircraft delayed while the queues developed at the airport. This translates into 11.55 minutes of delay per aircraft.

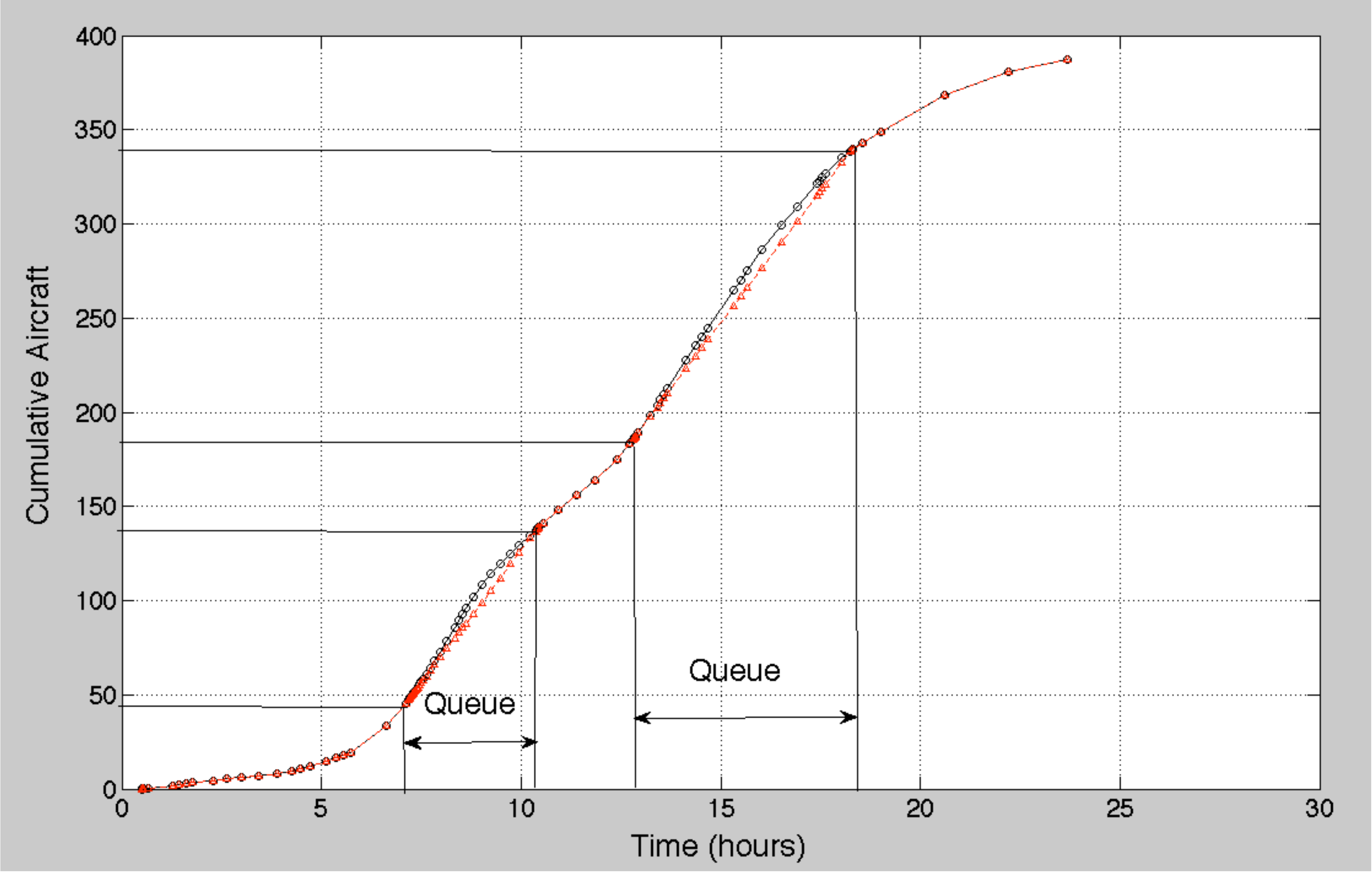

Figure 6. Cumulative Arrivals and Served Arrivals at The Airport.

b) For hour 9:00 AM explain how would the air traffic controllers operate the facility? State the point in the Pareto diagram (arrival-departure diagram) where controllers are likely to operate. Estimate the average headway between successive arrivals to minimize total aircraft delay.

c) Explain how would you change the operations of the airport to improve the delay values obtained in parts (a) and (b). How does the Pareto diagram help explain these operational changes?

A rational improvement is to adjust the arrival separation sequence to match arrival and departure saturation capacities to the demand function provided in Table 1. For example, during hour 9:00 AM the number of arrivals demanded is 20 per hour and the number of departures demanded is 41 per hour. To operate the airport efficiently, ATC could set the separation between successive arrivals so that the arrival capacity could be matched with 20 arrivals per hour demanded. This is illustrated in Figure 7 at the point labeled with a blue star. The Star Indicates that during that period arrivals could be spaced more than the minimum separation criteria allowing more departures to take place per hour. The Average Headway under 20 Arrivals/hr would be 3 Minutes (one arrival every three minutes). The number of departures per hour at that operating point will be around 25 per hour resulting in a total of 45 operations per hour. While 25 departures per hour is below the demanded 41 per hour, the arrivals will experience little or no delay. Departures will experience delays but recall, arrivals are given priority.

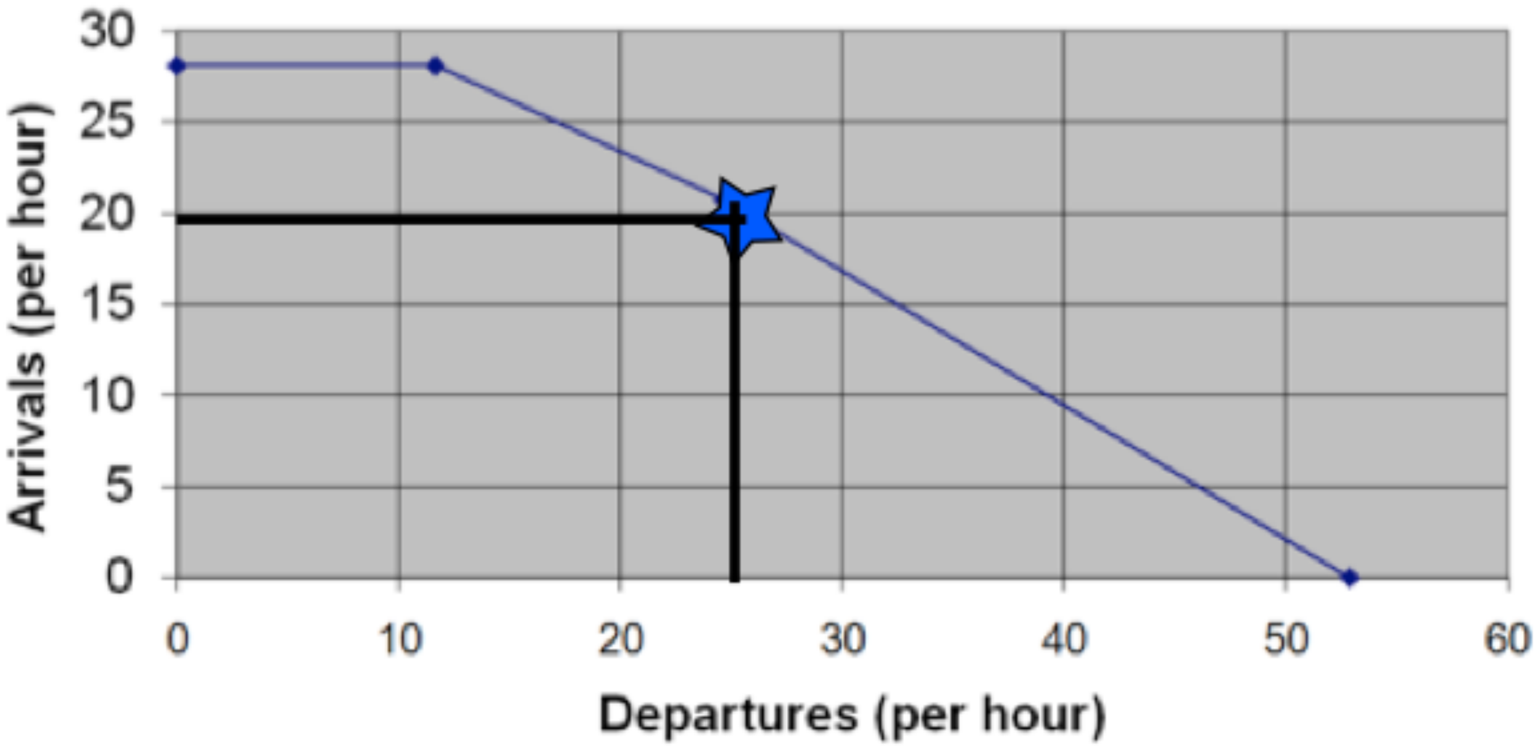

Figure 7. Matching Arrival Capacity for 9:00-10:00 AM period.