CEE 5614: Analysis of Air Transportation Systems Fall 2013

Assignment 7: ETOPS Operations and Runway Capacity

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Problem 1

A new generation large twin engine aircraft with performance similar to the Boeing Dreamliner (http://128.173.204.63/courses/cee5614/cee5614_pub/boeing787_class.m) flies the route Lagos (LOS), Nigeria to Houston (IAH), Texas. The route requires ETOPS certification because most of the flight crosses the Atlantic Ocean (see Figure 1). Assume the aircraft is flying at Mach 0.82 and 37,000 feet with a mass of 175,000 kg when one of the engines is shut down in flight due to a malfunction. At the time of the engine failure, the aircraft is located 760 nm from Miami, Florida and 715 nm form Bermuda. Assume no wind and ISA conditions.

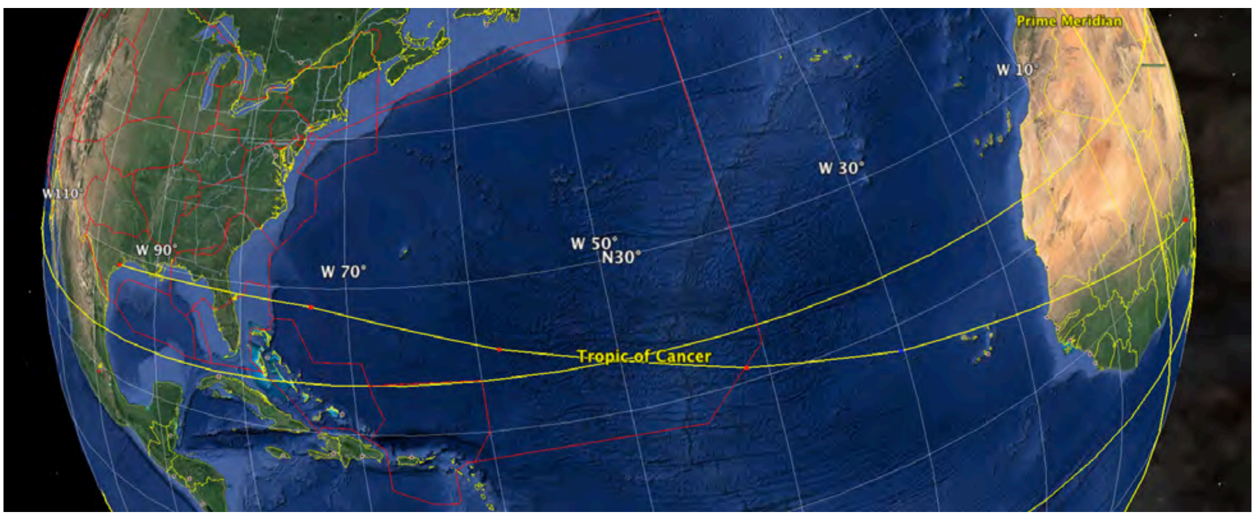

Figure 1. Lagos (LOS), Nigeria to Houston (IAH), Texas Flight Plan. Source Map: Google Earth.

a) Estimate the best Mach number and cruise altitude to continue to any one of the alternate airports. Justify your selection based on the single engine capability of the aircraft and also considering the flight to the closest alternate. In your solution consider that the aircraft requires some excess thrust for maneuvering under single engine conditions.

Using the drag and thrust characteristics for the aircraft, we generated two plots shown in Figures 2 and 3. Figure 2 shows the drag/thrust characteristics at 27,000 feet and Figure 3 at 25,000 feet. Both plots shows that the region between Mach 0.65 and 0.67 is feasible as one-engine detour Mach number. The 25,000 feet plot shows more room for maneuvering at Mach 0.66. I used Mach 0.66 as the detour speed at 25,000 feet. This provides a true airspeed of 204.2 m/s (300 knots indicated airspeed).

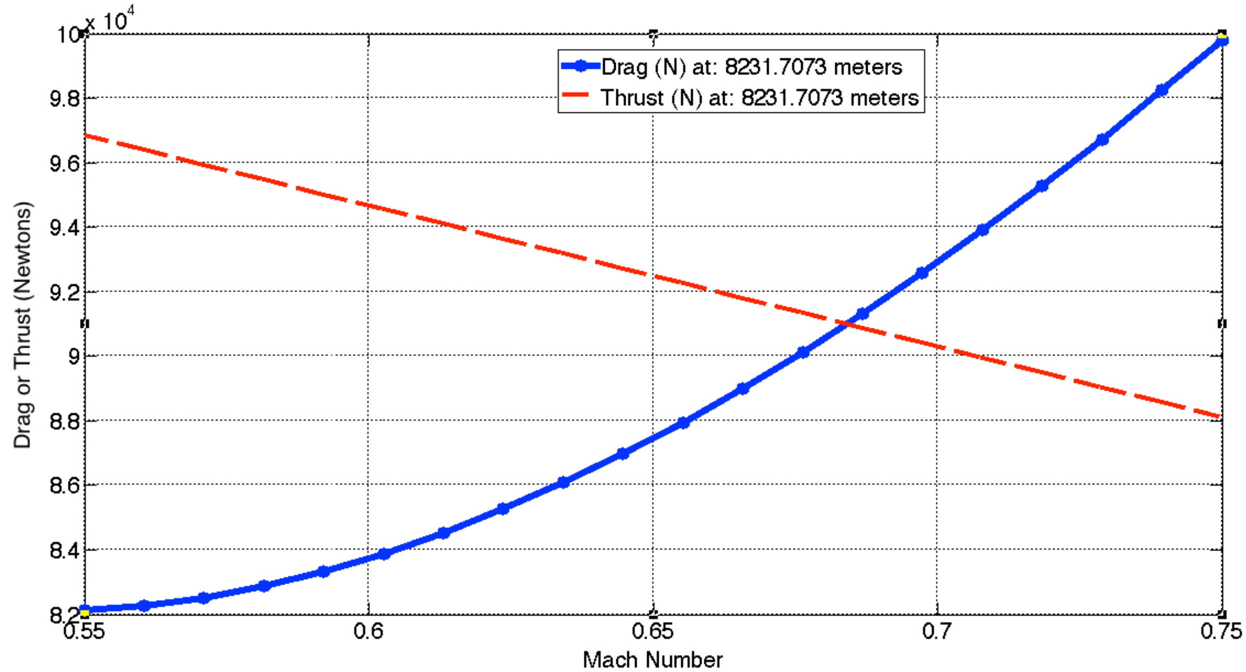

Figure 2. Drag and Thrust for Aircraft at 27,000 feet.

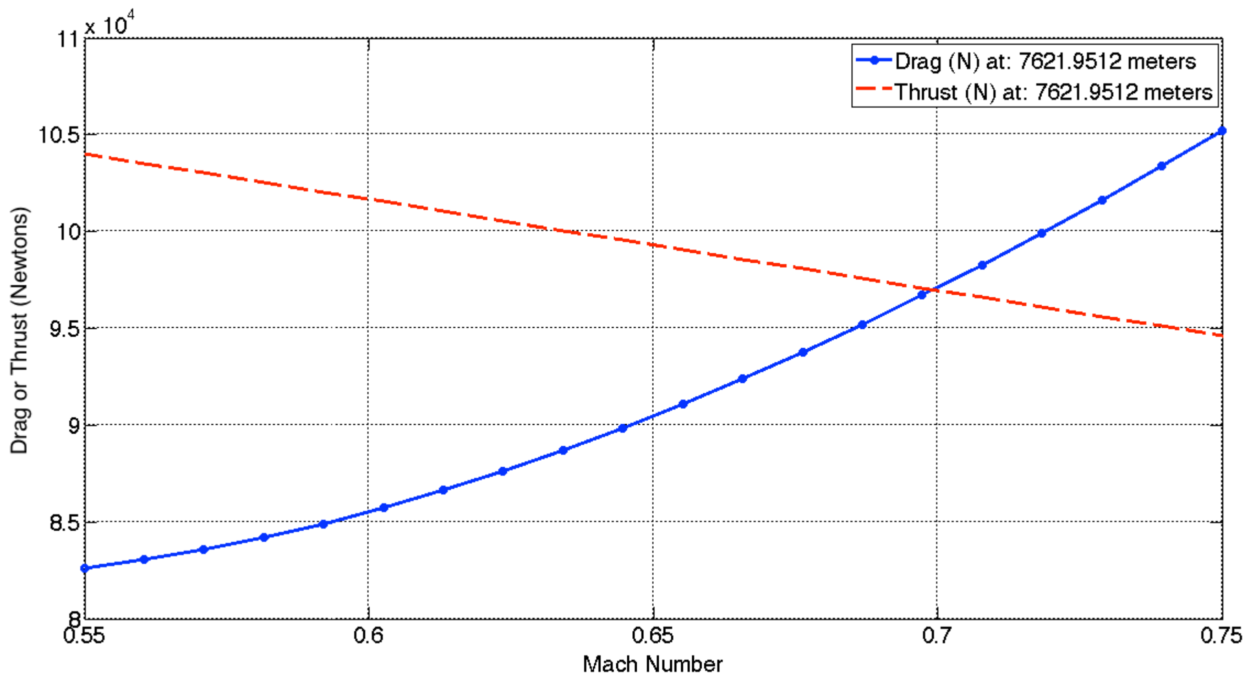

Figure 3. Drag and Thrust for Aircraft at 25,000 feet.

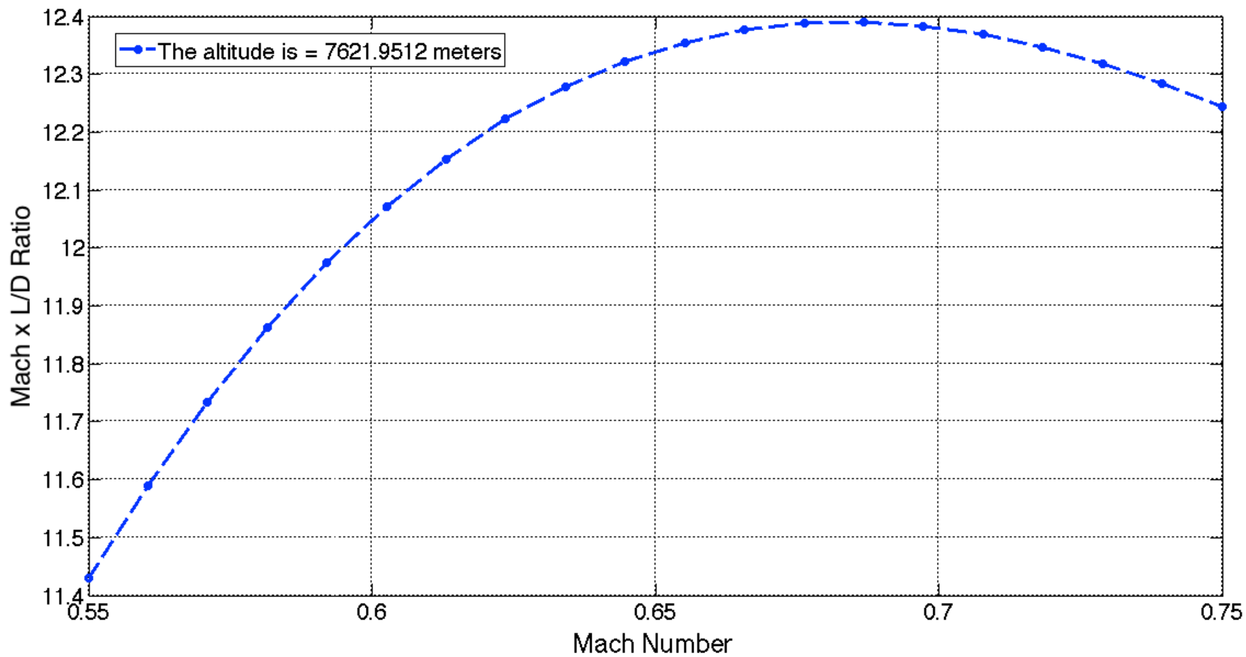

*Figure 4. M * L/D Characteristics for the Aircraft at 25,000 feet.*

b) Find the fuel consumed if the pilot decides to go to land in Miami.

c) If the aircraft suffers a pressurization failure instead, explain how would you do the analysis in part

This would require a descent to 10,000 feet. Note that the drag lower altitudes would be greater and thus involve a higher fuel consumption. For example, at 10,000 feet flying at 250 knots indicated would result in a total drag of 84,441 Newtons. Compare that with a drag of 98,538 N flying at 300 knots indicated.

Problem 2

You are expected to perform a simple capacity analysis for the Mexico City International Airport (ICAO code MMMX) considering both theoretical and real operational limitations. The MMMX airport layout is shown in Figure 2 in the Google satellite picture. The airport has two parallel runways spaced 1,000 feet between runway centerlines. Typically, runway 05R is used for arrival and 05L for departures. The airport is surrounded by terrain and requires that all arrivals be channeled through a single Final Approach Fix (SMO VOR) as shown in Figure 3. The navigation chart showing the ILS approach to Mexico City Runway 5R is shown in Figure 4.

The MMMX airport has a standard airport surveillance radar (ASR) which tracks aircraft up to 60 miles form the airport site. The radar has a scan rate of 4.5 seconds. Table 1 shows the approximate fleet mix operating at the airport. For this analysis we use the following technical parameters: a) in-trail delivery error of 18 seconds (position delivery error at SMO VOR) under both VMC and IMC conditions, b) departure-arrival separation for IMC conditions is 3.0 nautical miles (when mixed operations are conducted on the same runway), c) probability of violation is 5%. Arriving aircraft are “vectored” by ATC to the final approach fix located 15.7 miles from the runway threshold (see Figure 3). Arrivals follow in-trail after crossing the final approach fix (SMO VOR). The airport aircraft mix, runway occupancy times and approach speeds are shown in Table 1. The typical IMC separation values applied by ATC are shown in Table 2 and Figure 5.

Figure 2. Mexico City International Airport Layout. Source: Google Earth 2013. Runways 5R and 5L are separated 1,000 feet. Runway 5R is used for arrivals and 5L for departures.

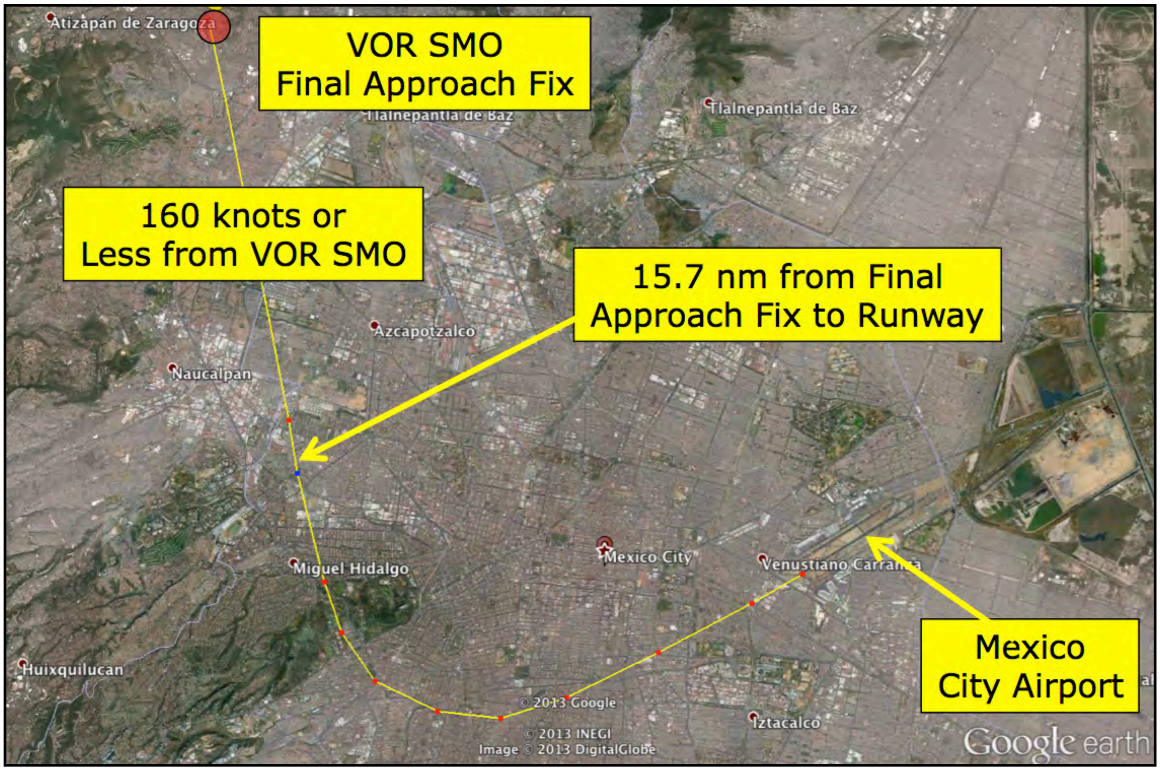

Figure 3. Google Earth View of Approaches to Runway 5R at Mexico City International Airport. Source: Google Earth 2013. Note: all aircraft arriving to runway 5R intercept the San Mateo VOR (NAVAID used as final approach fix).

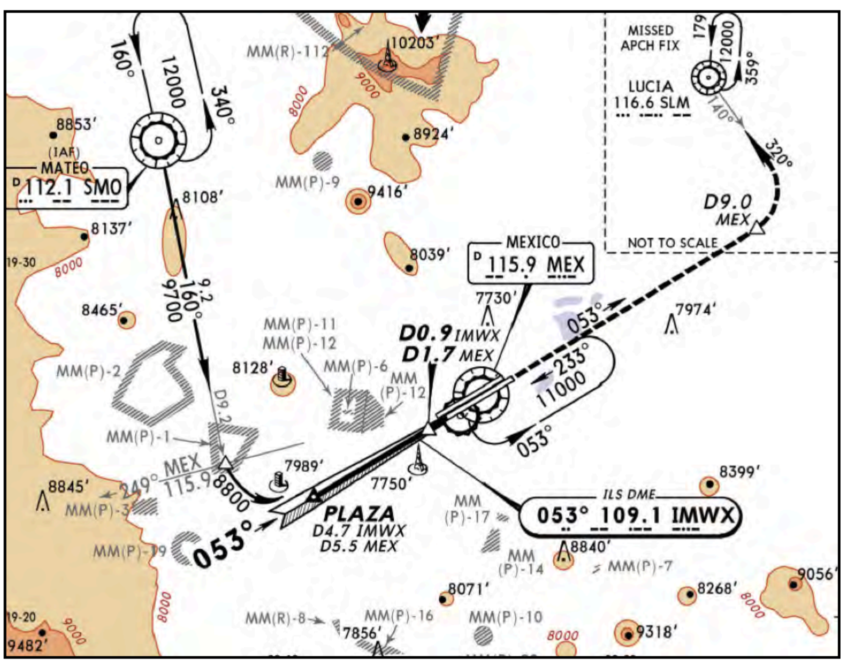

Figure 4. Instrument Landing System Approach Procedure Runway 5R at Mexico City International Airport. Source: Jeppesen 2013.

Table 1. Runway Operational Parameters and Fleet Mix for Problem 1.

Aircraft	Percent Mix (%)	Runway Occupancy Time (s)	Typical Approach Speed (knots) from FAF
Small	5	45	125
Large	70	57	145
Heavy	20	65	152
SuperHeavy	2	85	150

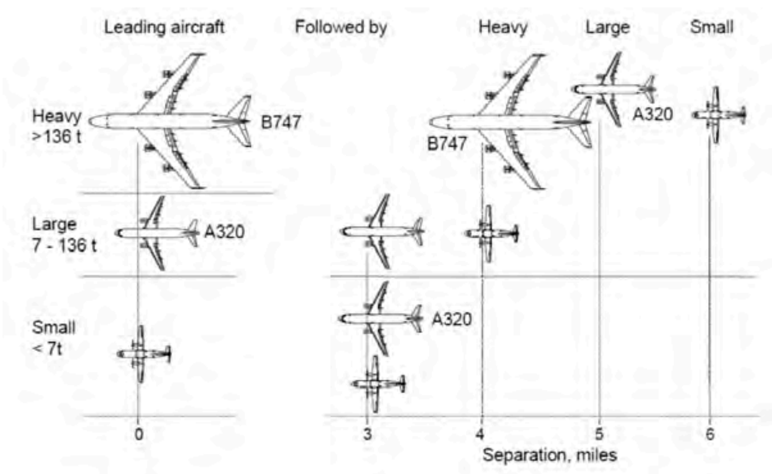

Figure 5. ICAO Recommended IMC Separations. Source: Lang et al., 2010. Arrival-Arrival Separations for all Groups Behind a Super-heavy add 2 nm over the Heavy Category.

Table 2. Minimum Departure-Departure Separations under IMC conditions. Values in are seconds.

Departure-Departure Separation Matrix (seconds)					
	Trailing Aircraft (Header Columns)				
Lead (column 1)	Small	Large	B757	Heavy	Superheavy
Small	60	60	60	60	60
Large	90	60	60	60	60
B757	120	120	60	60	60
Heavy	120	120	120	120	90
Superheavy	150	120	120	120	120

Estimation of Runway Capacity Operations

a) Find the IMC arrival saturation capacity of the runway configuration shown in Figure 2 when only runway 05R is used for arrivals.

The arrivals only capacity is 34 per hour. The final calculations are shown below.

Buffer Matrix (Bij)							
	Trailing Aircraft (Header Columns)						
Lead (column 1)	Small	Large	B757	Heavy	Superheavy		Expected Value
Small	33.00	33.00	33.00	33.00	33.00		B(Tij)
Large	21.08	33.00	33.00	33.00	33.00		28.50
B757	12.54	28.43	33.00	33.00	33.00		
Heavy	4.20	28.86	34.26	33.00	33.00		
Superheavy	0.00	27.21	34.89	33.00	33.00		
Augmented Matrix (Tij + Bij)							
	Trailing Aircraft (Header Columns)						
Lead (column 1)	Small	Large	B757	Heavy	Superheavy		Expected Value
Small	93.00	93.00	93.00	93.00	93.00		E(Tij) + B(Tij)
Large	111.08	93.00	93.00	93.00	93.00		107.26
B757	132.54	148.43	93.00	93.00	93.00		
Heavy	124.20	148.86	154.26	153.00	123.00		
Superheavy	150.00	147.21	154.89	153.00	153.00		
Arrivals Only Capacity (per hour)			34.00				

The departures only capacity is estimated to be 47 per hour if no arrival occur. The calculations are shown below.

Departure-Departure Separation Matrix (seconds)							
	Trailing Aircraft (Header Columns)						
Lead (column 1)	Small	Large	B757	Heavy	Superheavy		Expected Value
Small	60	60	60	60	60		E(Td)
Large	80	60	60	60	60		
B757	120	120	120	90	90		76.9
Heavy	120	120	120	120	120		
Superheavy	180	150	120	120	120		
Departures Only Capacity (per hour)			46.81				

b) Find the IMC saturation departure capacity with 100% arrival priority of the airport if we assume departures operations are dependent of the arrivals calculated in part (a) with only runway 05L used to handle departures. The operational concept used by ATC at MMMX airport is shown in Figure 6 and can be described as follows: The primary arrival runway is runway 05R. Runway 05L is used to handle departures. ATC controllers provide arrival with priority and reserve the short final approach zone (~1.4 nm) so that no departure can be released if the arriving aircraft is inside that zone. This situation is to avoid a possible go-around of an arriving aircraft while at the same time processing a departure on 05L. In such situation, the two aircraft will be flying too close due to the runway separation. Assume the arriving aircraft fly at the average approach speeds provided in Table 1.

Method 1: Consider blocked time for departures.

The expected value of times spent by arrivals in the reserved zone is estimated to be 49.6 seconds per arrival. This implies that in one hours, runway 05L will be blocked 1,863 seconds of the hour. If we one assumes that the runway is available (3600-1863 s) of time per hour (1917 seconds). This implies that under ideal conditions, runway 05L could process close to 25 departures per hour when 100% arrivals take place on runway 05R.

c) Plot the Pareto diagram (arrivals/departures diagram) for using the solutions (a) and (b).

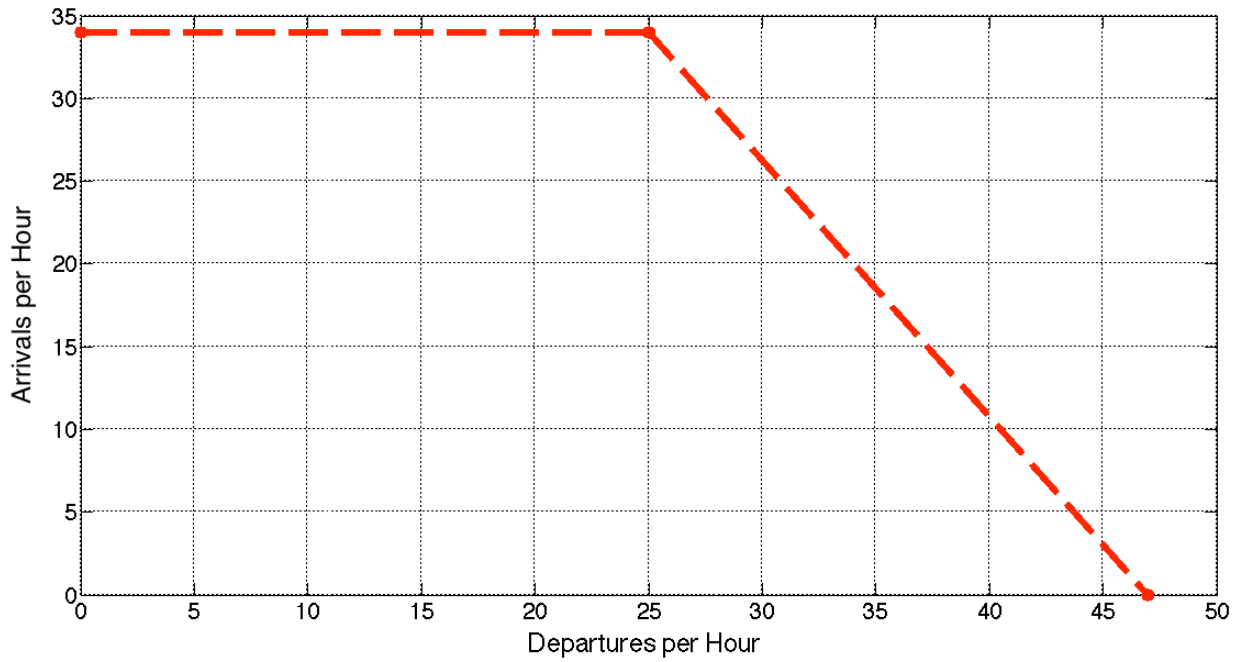

Figure 6. Pareto Diagram of the Airport.