Runway Occupancy Time Extraction and Analysis Using Surface Track Data

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Date: July 31, 2009
Total Words: 2248 text + (7 figure + 5 table)*250 = 5248 words
Abstract

Accurate and timely performance information is critical for the design of airport infrastructure and its operations. Performance data for airborne operations has been well developed over the last three decades based on the availability of radar track data. For example, the Aviation System Performance Metrics (ASPM) database is replete with data to analyze Air Traffic Control performance. Airport surface performance data has been a metaphorical “black hole.” The recent installation and availability of surface track data (e.g., ASDE-X) provides the basis for derivation of critical airport surface operational data such as gate assignments, runway assignments, taxi-routes, ramp trajectories and taxiway queuing.

This paper describes the methods for extraction and analysis of surface track data for Runway Occupancy Time (ROT). Runway occupancy time (ROT) data is essential to effectively monitor current airport operating efficiencies and to plan for the introduction of new aircraft surface movement guidance and control systems. A fast and accurate algorithm to calculate ROT using surface track data is described. The method is generic and can be applied to any runway at any airport. A case study for Dallas Fort Worth (DFW) Airport is provided.

Keywords: Runway Occupancy Time, ASDE-x, Radar data, multilateration.

Introduction

The benefits of any technological or procedural changes implemented to reduce runway occupancy time can be evaluated only if there are quick and efficient ways to measure this reduction in ROT. In the past researchers have used dedicated hardware infrastructure like NASA DROMS (Dynamic Runway Occupancy Measurement System) [1]. Although this way of measurement was fairly accurate (to the order of 1 second), it required a specialized hardware which may not be readily available at all airports.

Over the past decade, ASDE-x has been installed at major US airports. The FAA has identified 35 airports (OEP-35) in the United States as candidates for ASDE-x systems and has made 11 installations to date. The use of multiple sensors by the ASDE-x system results in highly accurate and reliable coverage of aircrafts on the airport surface.

This paper provides a fast, accurate and generic method to measure Runway Occupancy Time (ROT) using the more readily available radar track data information so that it could be used to evaluate benefits achieved by any technological or procedural changes implemented to reduce ROTs. This work can also be directly used to aid ongoing data-fusion efforts at FAA to add runway and ROT fields to ASPM (Aviation System Performance Metrics) using surface track data.

This report presents the analysis of runway occupancy times (ROT) for aircraft landing at Dallas Fort Worth Airport. ROT data provide metrics on a critical aircraft operating parameter that is a significant driver for overall National Airspace System (NAS) operation. ROT provides a baseline measurement of current operations against which to measure improvements or degradations caused by changing procedures or introducing new technologies. It is obvious that if occupancy times are minimized runway capacity can be increased [3], and that small improvements matter: ‘saving an average of 5 seconds on every aircraft’s runway occupancy time would add another 1-1.5 movements per hour [at London
Heathrow’ [7] [2]. As demand has increased, so the pressure to minimize runway occupancy times has intensified, and considerable improvements have been made [2].

This paper is organized as follows: Section 2 provides an overview of the data required, Section 3 describes the algorithm used to extract and derive the data, Section 4 describes the results of a case-study for DFW, Section 5 provides conclusions and future work.

**Data Overview**

ASDE-x surface data for three days, during the period 7/1/07 to 7/3/07, was obtained from NASA/FAA Texas Research Station (NTX). This data included aircraft surface movements on all the runways of Dallas Fort Worth Airport (Figure 1). The fields in ASDE-x data relevant to this analysis were latitude, longitude, altitude, time, aircraft ID and aircraft type. Using the temporal and spatial location of aircraft, the time spent on the runway was derived using the algorithm described in the method segment.

![Figure 1: DFW airport layout](image)

Data included aircraft landing on all seven runways on the airport (13R/31L, 18R/36L, 18L/36R, 17R/35L, 17C/35C, 35R/17L and 13L/31R). The number of samples for each runway is shown in Table 1.

<table>
<thead>
<tr>
<th>Count</th>
<th>Runway</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18L/36R</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>18R/36L</td>
<td>765</td>
</tr>
<tr>
<td>3</td>
<td>17R/35L</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>17C/35C</td>
<td>859</td>
</tr>
<tr>
<td>5</td>
<td>17L/35R</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>13L/31R</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>13R/31L</td>
<td>333</td>
</tr>
</tbody>
</table>

Table 1: Number of Arrivals for each Runway
Method
Algorithms were developed to extract ROT from the 4-D track data and runway geometry. During the 3-day period the data includes over 2000 landing tracks. In addition to ROT, for each landing track the output of the algorithm included the runway used and arrival speed just before touch down.

Deducing ROT from radar track data is a 3 step process as described below:

(i) Identify Operation, i.e. Arrival or Departure. Discard all departure tracks as our analysis only focuses on arrivals.
(ii) Identify Runway Threshold Used, i.e. 36L, 35C etc
(iii) Using the ‘threshold’ information, find ROT.

(i) Identify Operation
On a time sorted list of track hits, arrivals have high velocity in the first few hits when compared to departures (which are in the terminal area). 80 knots was used as the cut-off velocity to differentiate arrivals from departures using an if-else condition as shown below:

If (Velocity_{trackStart} > 80 \text{ knots})
  Operation = Arrival
Else
  Operation = Departure

(ii) Identify Runway Threshold
All arrivals fly directly over the runway threshold. For this reason the runway identification algorithm is implemented as follows.

- For the first 80 HITS of each Arrival track:
  o Find the minimum Euclidean distance in the xy plane (excluding height information) from each of the thresholds (T1 to T14). Let these distances be \(d_{1\text{min}}\) to \(d_{14\text{min}}\).
  o Runway threshold used is the argument of the minimum of these distances, i.e. \(\text{arg min } d_{i\text{min}}\)

(iii) Find Runway Occupancy Time
After identification of threshold used, the next step is to find the ROT. ROT is calculated using the traditional ‘point in a polygon’ method. Traditionally ROT of an arriving aircraft is defined as:
The time between the instant an aircraft touches down on the runway and the instant it is on a runway exit, with all parts of the aircraft clear of the runway.

However, for the purpose of this analysis, we have made some approximations and redefined the ROT as:
The time between the instant an aircraft crosses the imaginary plane of the threshold and the instant it is 25 feet clear of the runway boundary as shown in Figure 2. The 25 feet buffer was chosen to make sure the entire aircraft is clear of the runway before ‘stopping’ the ROT clock.
Arrival Velocity Calculation

The arrival velocity is calculated at 5 and 10 seconds from the runway threshold crossing point. Velocity is calculated as the ratio of distance from threshold at these time instants and the time taken to traverse these distances, i.e. 5 and 10 respectively. Figure 3 shows an explanation of this method used. It must be noted here that the velocity calculated is ground velocity. Also, the calculated velocity is the horizontal component of velocity (parallel to the airport surface). However, since the glideslope is typically about 3 degrees, the horizontal component of velocity is almost equal to the actual velocity along the flight trajectory. (cos 3 = 0.9986).

Results of Analysis

All Aircraft

The data probability density function (PDF) for arrival ROTs was analyzed and compared to known distribution PDFs. For all 2035 data points, the best fit according to Arena was an Erlang distribution with parameters 20.5 + Erlang(4.51,6). However, if we removed the outliers, the data fit reasonably well with a normal distribution with the following parameters: Normal(mean = 47.5, sigma = 11), with p-value < 0.005 for Chi Square test of the normal fit.
**ROT by Aircraft Category**

Table 2 shows the summary statistic for ROT by aircraft category. Figure 5 shows the increasing (non-decreasing) trend of the median (mean) of ROT as the aircraft size increases.

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
<th>Mean</th>
<th>StandardDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>104</td>
<td>22</td>
<td>115</td>
<td>45</td>
<td>47.6</td>
<td>15.1</td>
</tr>
<tr>
<td>Large</td>
<td>1710</td>
<td>21</td>
<td>194</td>
<td>46</td>
<td>47.3</td>
<td>11.6</td>
</tr>
<tr>
<td>B757</td>
<td>140</td>
<td>24</td>
<td>82</td>
<td>48</td>
<td>48.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Heavy</td>
<td>81</td>
<td>29</td>
<td>92</td>
<td>53</td>
<td>56.4</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Table 2: ROT summary statistics by Aircraft Category

![ROT Summary Statistics by Aircraft Type](image)

Figure 5: ROT mean and median as a function of aircraft size

**Aircraft Classification and ROT**

The FAA weight classification into Small, Large, B757 and Heavy is based on the physical weight of the aircraft among other things like wing-span, landing speed etc. We use the weight of an aircraft with highest frequency for a given class to act as a representative of the aircraft weight for a given class. For example: MD81 which has a maximum landing weight of 58.1 tonnes is picked to represent the ‘Large’ class. The product of this weight and the ground speed calculated using the method described earlier gives a fair approximation of the momentum of an aircraft at landing. Figure 4 shows the momentum of different aircraft category.
Table 3: Aircraft Category List

<table>
<thead>
<tr>
<th>Class [Representative]</th>
<th>Max Landing Weight (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small [E45X]</td>
<td>30</td>
</tr>
<tr>
<td>Large [MD80]</td>
<td>58.1</td>
</tr>
<tr>
<td>B757 [B757]</td>
<td>95.3</td>
</tr>
<tr>
<td>Heavy [B763]</td>
<td>145.2</td>
</tr>
</tbody>
</table>

Table 4: Maximum Landing Weight table for each aircraft category

<table>
<thead>
<tr>
<th>Runway Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>18L/36R</td>
</tr>
<tr>
<td>18R/36L</td>
</tr>
<tr>
<td>17R/35L</td>
</tr>
<tr>
<td>17C/35C</td>
</tr>
<tr>
<td>17L/35R</td>
</tr>
<tr>
<td>13L/31R</td>
</tr>
<tr>
<td>13R/31L</td>
</tr>
</tbody>
</table>

Table 5: Runway Occupancy Time break up by Runway used
Figure 6: ROT mean and median as a function of Runway Used

### Aircraft Momentum

The Runway Occupancy Time of an aircraft is a function of its weight and velocity, besides other factors like exit type and location, aircraft braking thrust etc. According to simple laws of physics, the higher the momentum, the more force/time it takes to decelerate the aircraft to the point where it can get off the runway. Figure 7 shows ROT as a function of aircraft momentum. Each data point is color coded by aircraft category. From the plot shown, it can be observed that different aircraft categories have distinct ranges of momentum. Also, within a given category, aircrafts show a wide range of variation in their ROTs. Average ROT for Small is almost equal to the ROT for Large category of aircraft. However, ROT increases as we move from Large to B757 to Heavy Category.

Figure 7: ROT as a function of Momentum
Conclusion

The algorithm described in the paper gives accurate and quick results. The running time for
the algorithm (including preprocessing) for 3 days of track data (~2000 arrival tracks) is less
than 3 minutes on an Intel XEON 2.4 GHz CPU with 3.62 GB RAM.

Analysis of the ROT statistics and DFW identified some interesting properties:
(1) The data shows that ROT for small category of aircraft is as high as that of Large
category.

(2) Identical runways exhibit statistically significant ROT. Runways 18R/36L and 17C/35C,
even though exactly identical in terms of their length, width and the number and location of
rapid exit taxiways, had significantly different ROTs. The mean and median ROT for runway
18R/36L is about 5 seconds less than that of 17C/35C.

Future Work

Use weather data to get wind speeds to be able to calculate air-speed for momentum
calculation. Repeat the analysis for a longer time interval and possibly cover different
seasons to capture the effect of wind/rain on the runway occupancy time. Investigate the
cause of difference in ROT of identical runways, namely 18R/36L and 17C/35C.

Acknowledgement

The authors gratefully acknowledge the support of Tony Diana and Akira Kondo of FAA.
Special thanks go to Shawn Engelland of NTX for their inputs and comment with the track
data. Terrence Thompson, Babak Khorrami and Carolyn Cross (Metron Aviation), John
Shortle, George Donohue, Rajesh Ganesan, Jianfeng Wang, Guillermo Calderon-Meza,
Akshay Belle, Yimin Zhang, and David Jacob for technical assistance.
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