

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

1 **Abstract**

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

10
11 This paper describes the methods for extraction and analysis of surface track data for Runway
12 Occupancy Time (ROT). Runway occupancy time (ROT) data is essential to effectively
13 monitor current airport operating efficiencies and to plan for the introduction of new aircraft
14 surface movement guidance and control systems. A fast and accurate algorithm to calculate
15 ROT using surface track data is described. The method is generic and can be applied to any
16 runway at any airport. A case study for Dallas Forth Worth (DFW) Airport is provided.

17
18 *Keywords: Runway Occupancy Time, ASDE-x, Radar data, multilateration.*

19
20 **Introduction**

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

27
28 Over the past decade, ASDE-x has been installed at major US airports. The FAA has
29 identified 35 airports (OEP-35) in the United States as candidates for ASDE-x systems and
30 has made 11 installations to date. The use of multiple sensors by the ASDE-x system results
31 in highly accurate and reliable coverage of aircrafts on the airport surface.

32
33 This paper provides a fast, accurate and generic method to measure Runway Occupancy
34 Time (ROT) using the more readily available radar track data information so that it could be
35 used to evaluate benefits achieved by any technological or procedural changes implemented
36 to reduce ROTs. This work can also be directly used to aid ongoing data-fusion efforts at
37 FAA to add runway and ROT fields to ASPM (Aviation System Performance Metrics) using
38 surface track data.

39
40 This report presents the analysis of runway occupancy times (ROT) for aircraft landing at
41 Dallas Fort Worth Airport. ROT data provide metrics on a critical aircraft operating
42 parameter that is a significant driver for overall National Airspace System (NAS) operation.
43 ROT provides a baseline measurement of current operations against which to measure
44 improvements or degradations caused by changing procedures or introducing new
45 technologies. It is obvious that if occupancy times are minimized runway capacity can be
46 increased [3], and that small improvements matter: ‘saving an average of 5 seconds on every
47 aircraft’s runway occupancy time would add another 1-1.5 movements per hour [at London

71 **Method**

72 Algorithms were developed to extract ROT from the 4-D track data and runway geometry.
73 During the 3-day period the data includes over 2000 landing tracks. In addition to ROT, for
74 each landing track the output of the algorithm included the runway used and arrival speed
75 just before touch down.
76

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

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

82

83 (i) Identify Operation

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

88 If ($\text{Velocity}_{\text{trackStart}} > 80 \text{ knots}$)

89 Operation = Arrival

90 Else

91 Operation = Departure

92

93 (ii) Identify Runway Threshold

94 All arrivals fly directly over the runway threshold. For this reason the runway
95 identification algorithm is implemented as follows.

- 96 • For the first 80 HITS of each Arrival track:
 - 97 ○ Find the minimum Euclidean distance in the xy plane (excluding height
98 information) from each of the thresholds (T1 to T14). Let these distances
99 be d_1^{\min} to d_{14}^{\min} .
 - 100 ○ Runway threshold used is the argument of the minimum of these distances,
101 i.e. $\arg \min d_i^{\min}$

102

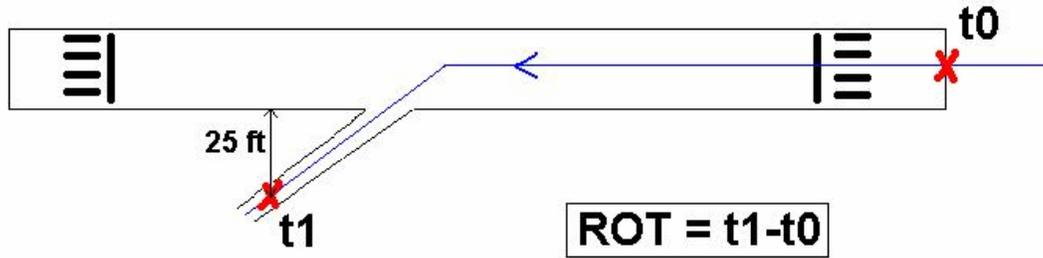
103 (iii) Find Runway Occupancy Time

104 After identification of threshold used, the next step is to find the ROT. ROT is calculated
105 using the traditional ‘point in a polygon’ method. Traditionally ROT of an arriving
106 aircraft is defined as:

107 The time between the instant an aircraft touches down on the runway and the instant it is
108 on a runway exit, with all parts of the aircraft clear of the runway.

109 However, for the purpose of this analysis, we have made some approximations and
110 redefined the ROT as:

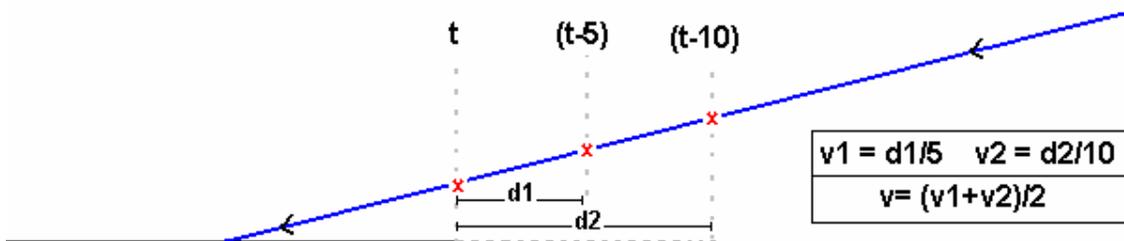
111 The time between the instant an aircraft crosses the imaginary plane of the threshold and
112 the instant it is 25 feet clear of the runway boundary as shown in Figure 2. The 25 feet
113 buffer was chosen to make sure the entire aircraft is clear of the runway before ‘stopping’
114 the ROT clock.



115
116 Figure 2: ROT calculation boundaries.
117

118 Arrival Velocity Calculation

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

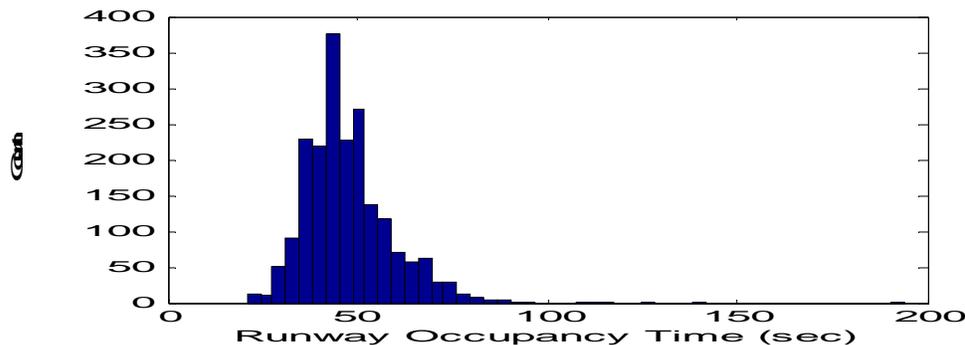


127
128 Figure 3: Arrival(Ground) Velocity calculation
129

130 **Results of Analysis**

131 *All Aircraft*

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



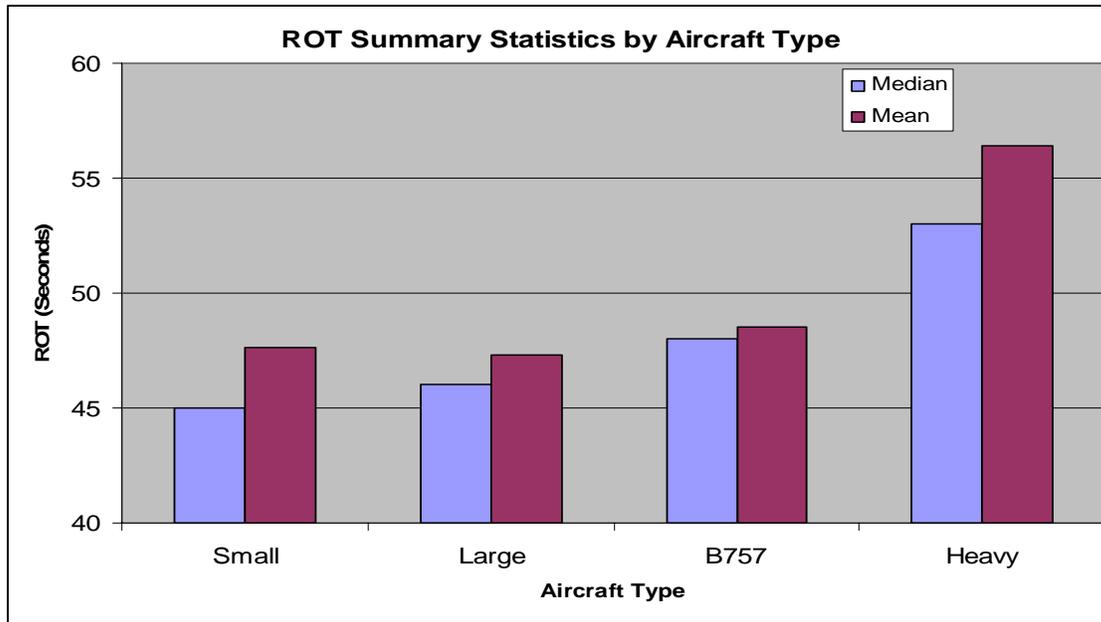
137
138 Figure 4: Distribution of ROT for all aircraft samples(2035)

139 **ROT by Aircraft Category**

140 Table 2 shows the summary statistic for ROT by aircraft category. Figure 5 shows the
 141 increasing (non-decreasing) trend of the median (mean) of ROT as the aircraft size increases.
 142

		Count	Min	Max	Median	Mean	StandardDev
1	Small	104	22	115	45	47.6	15.1
2	Large	1710	21	194	46	47.3	11.6
3	B757	140	24	82	48	48.5	9.5
4	Heavy	81	29	92	53	56.4	15.8

143 Table 2: ROT summary statistics by Aircraft Category
 144



145 Figure 5: ROT mean and median as a function of aircraft size
 146

147
 148 **Aircraft Classification and ROT**

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

Small	B757	Large		Heavy
B190	B752	MD82	B735	B763
SF34	B753	MD83	CRJ7	B772
FA50	B757	B738	MD88	A343
BE58		E170	E135	B744
LJ31		B733	B712	B742
E120		B737	CRJ9	A306
E45X		B734	A318	B762
G2		A320	DC93	L101
C680		A319	DC95	DC87
C25B		E145	MD80	MD11
C56X		B722	E190	MD10
		CRJ2	DC91	B741
		DC94	GLF2	
		A321		

157
158

Table 3: Aircraft Category List

Class[Representative]	Max Landing Weight (tonnes)
Small [E45X]	30
Large [MD80]	58.1
B757 [B757]	95.3
Heavy [B763]	145.2

159 Table 4: Maximum Landing Weight table for each aircraft category
160

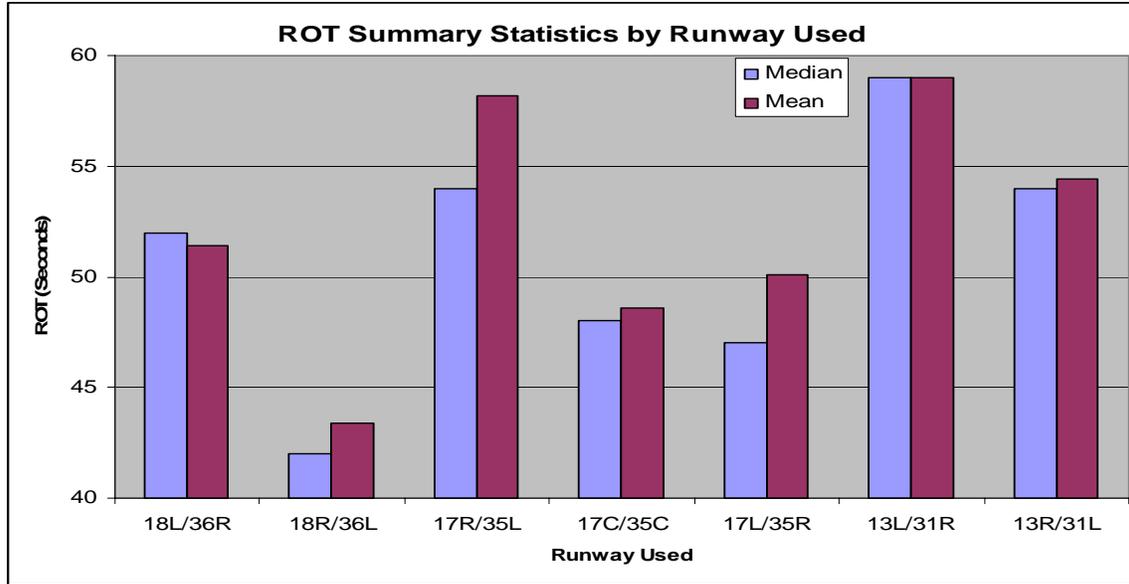
161 ***Runway Used***

162 Table 5 shows the breakup of runway occupancy time by runway used. It must be noted here
163 that the four main runways at DFW, i.e. 18R/36L, 18L/36R, 17R/35L and 17C/35C are all
164 equally long (13400 feet). Runways 18R/36L and 17C/35C are the outer runways and are
165 used for arrivals most of the time. An interesting fact that was uncovered for these runways is
166 that even though both these runways are exactly identical in terms of their length, width and
167 the number and location of rapid exit taxiways, the mean and median ROT for runway
168 18R/36L is significantly lower (> 5 sec) than that of 17C/35C.
169

		Count	Min	Max	Median	Mean	Standard Dev
1	18L/36R	21	30	76	52	51.4	9.5
2	18R/36L	765	22	92	42	43.4	9.1
3	17R/35L	29	40	139	54	58.2	18.3
4	17C/35C	859	28	194	48	48.6	10.7
5	17L/35R	27	32	76	47	50.1	10.2
6	13L/31R	1	59	59	59	59	0
7	13R/31L	333	21	115	54	54.4	16

2035

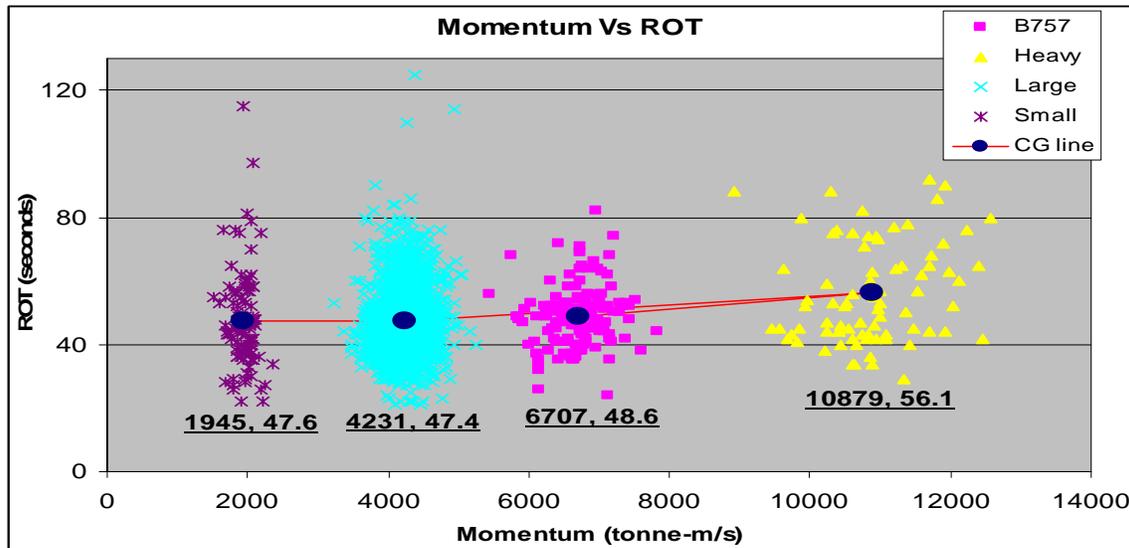
170 Table 5: Runway Occupancy Time break up by Runway used
171



172
173 Figure 6: ROT mean and median as a function of Runway Used
174

175 ***Aircraft Momentum***

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



186
187 Figure 7: ROT as a function of Momentum
188

189

190 **Conclusion**

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

194

195 Analysis of the ROT statistics and DFW identified some interesting properties:

196 (1) The data shows that ROT for small category of aircraft is as high as that of Large
197 category.

198

199 (2) Identical runways exhibit statistically significant ROT. Runways 18R/36L and 17C/35C,
200 even though exactly identical in terms of their length, width and the number and location of
201 rapid exit taxiways, had significantly different ROTs. The mean and median ROT for runway
202 18R/36L is about 5 seconds less than that of 17C/35C.

203

204 **Future Work**

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

209

210 **Acknowledgement**

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

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