Taxi-out Time Prediction for Departures at Charlotte Airport Using Machine Learning Techniques

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Outline

- Introduction: Aircraft taxi time prediction
- Charlotte Douglas International Airport (CLT)
- Taxi-out time data analysis
- Taxi time prediction using machine learning techniques
- Prediction performance evaluation
- Ongoing work for ATD-2
  - Linear regression model with live data at CLT

Motivation

- Taxi-out time for departing aircraft
  - Ground movement time from pushback to takeoff
  - Depend on taxi route and surface congestion
- Aircraft taxi time prediction
  - Increase takeoff time predictability
  - Improve efficiency in airport surface operations
  - Help controllers find better takeoff sequences to maximize runway throughput
- However, accurate prediction is difficult.
  - Uncertainties in airport operations
  - Operational complexity

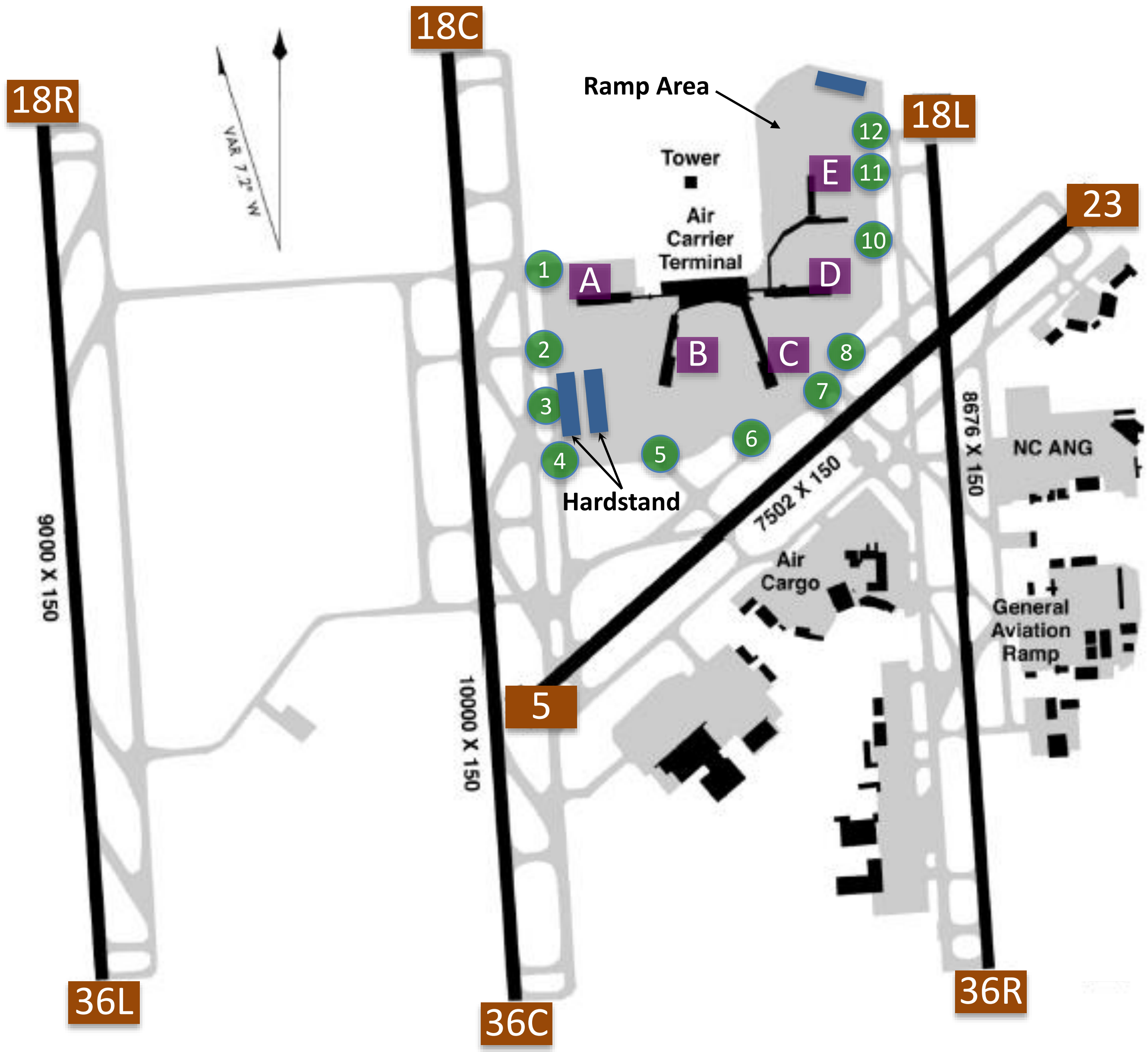
Previous Research

- Queuing models for taxi-out time estimation
- Machine learning based approaches
  - Linear regression models, Neural network model, Reinforcement learning algorithms, etc.
  - Independently applied to limited data at several airports
- Taxi time prediction using machine learning methods and fast-time simulation (Lee, 2015)
  - Used human-in-the-loop simulation data for CLT
  - Possibly over-trained with limited datasets

Objectives

- Analyze actual taxi time data at Charlotte airport (CLT)
  - Identify unique operational characteristics of CLT
  - Determine key factors affecting taxi times
- Develop precise taxi time prediction modules
  - Based on taxi-out time data analysis
  - Using machine learning techniques
- Evaluate taxi time prediction performance
  - Using actual surface surveillance data at CLT
  - Comparison of prediction methods
- Apply the taxi time prediction module to live data and incorporate it with a tactical scheduler for ATD-2 project

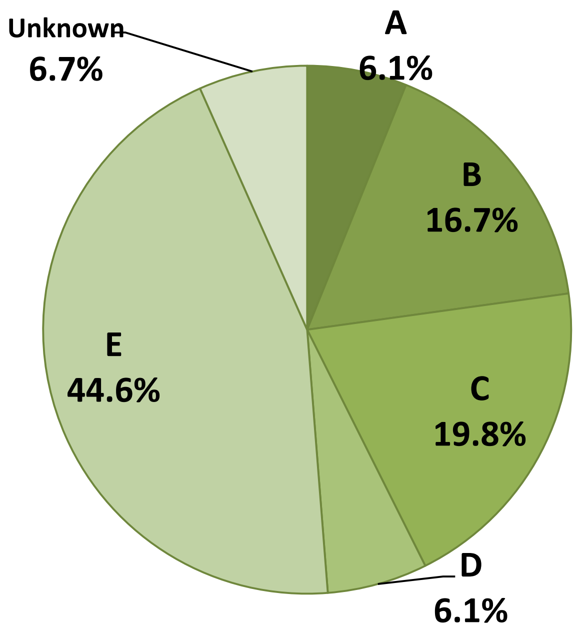
Charlotte International Airport (CLT)



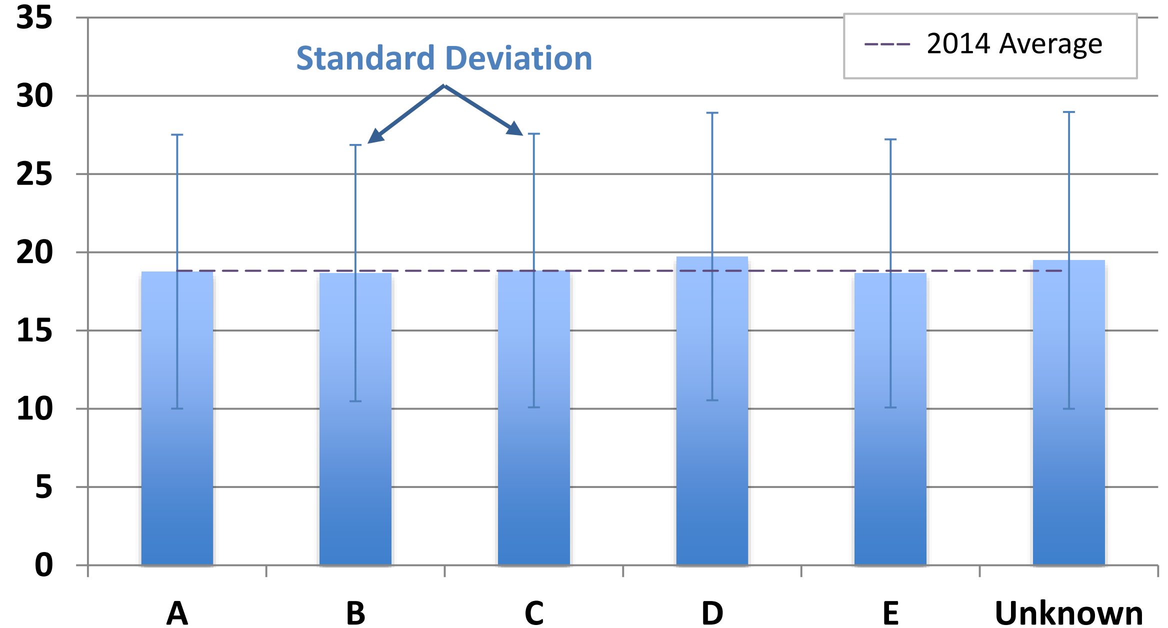
Taxi-Out Time Data Analysis

- Taxi-out time data
  - Used actual flight data at CLT in 2014
  - Analyzed 246,083 departures after data filtering
- Taxi-out times categorized by
  - Terminal concourse
  - Spot
  - Runway
  - Departure fix
  - Aircraft weight class
  - Month

Taxi Time by Terminal



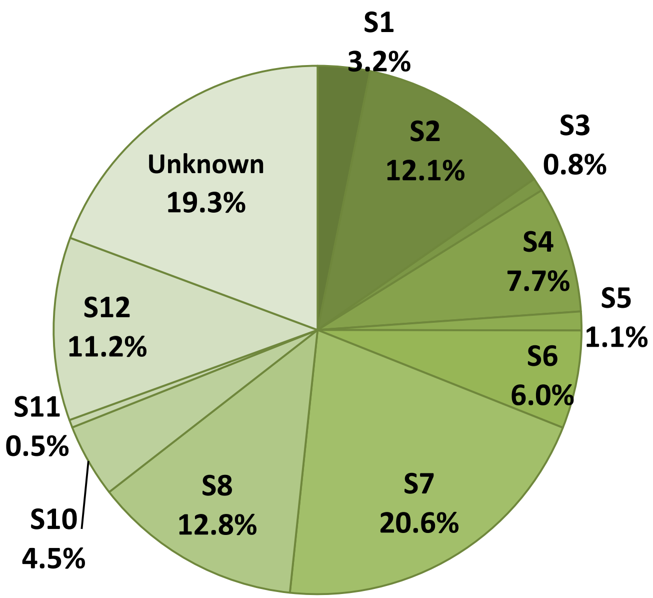
Departure distribution
by terminal concourse



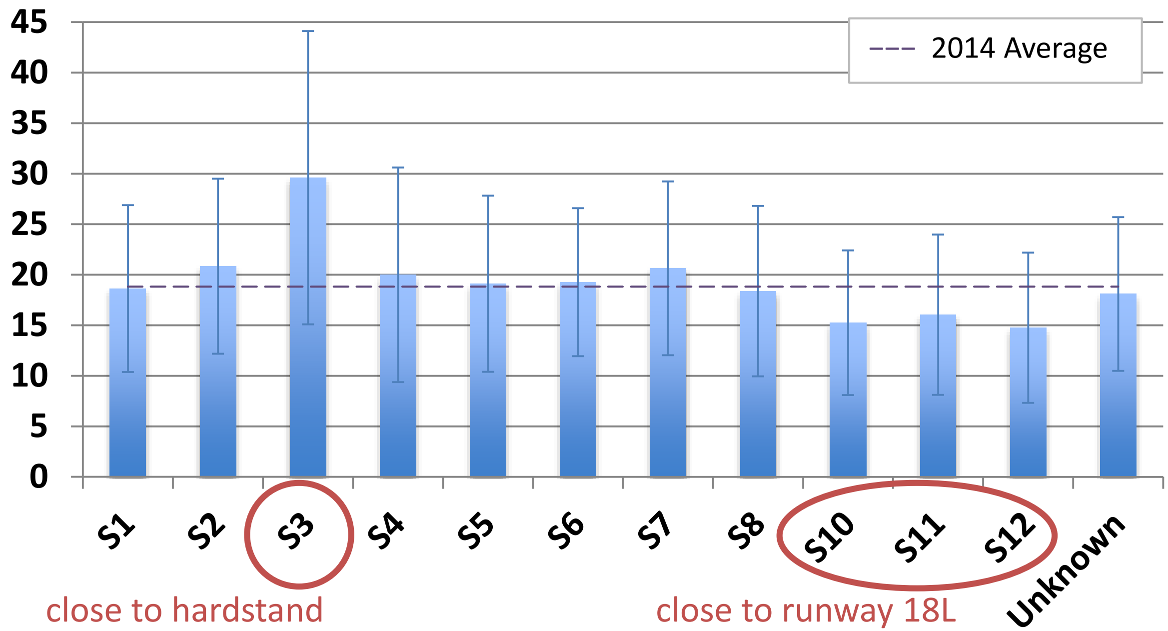
Average taxi-out time (in minutes)
by terminal concourse

Average taxi time seems insensitive to terminal concourse, except for concourse D used by international flights.

Taxi Time by Spot



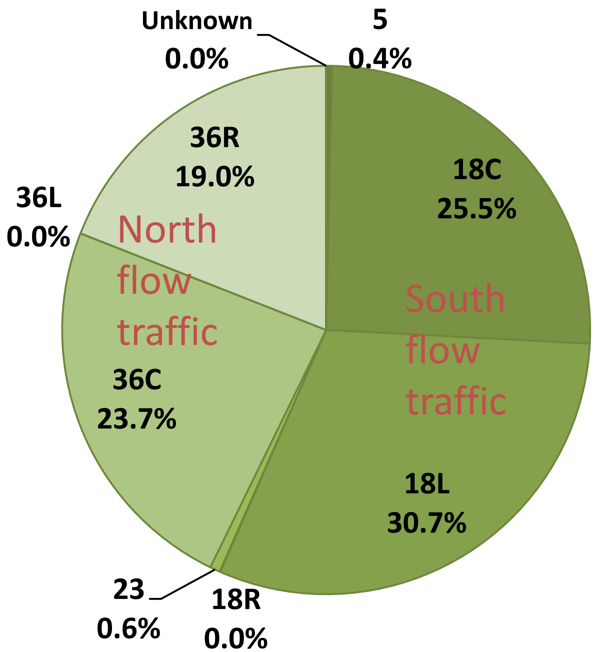
Departure distribution
by spot



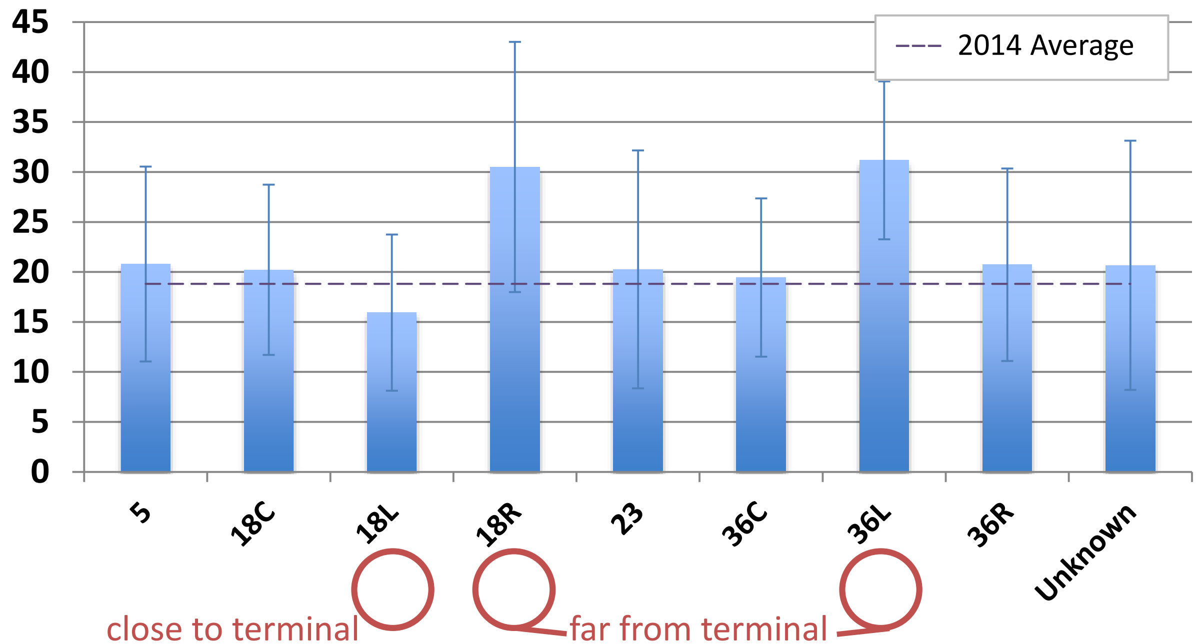
Average taxi-out time (in minutes)
by spot

Spots S10, S11 and S12 are assigned to flights from concourse D/E to runway 18L, leading to short taxi time.

Taxi Time by Runway



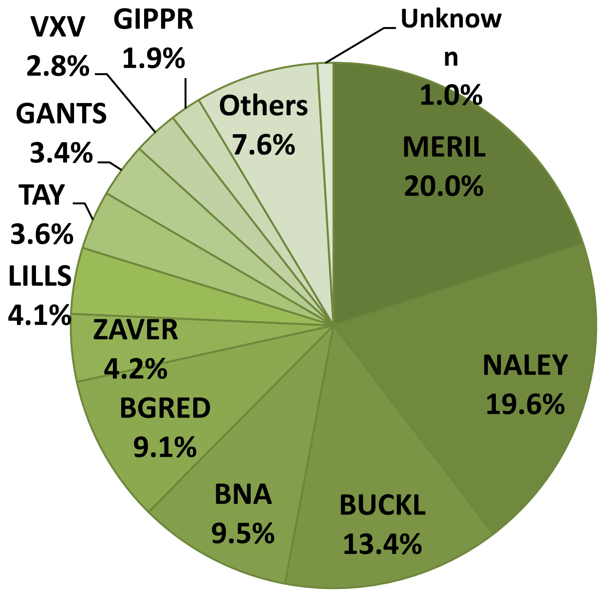
Departure distribution by runway



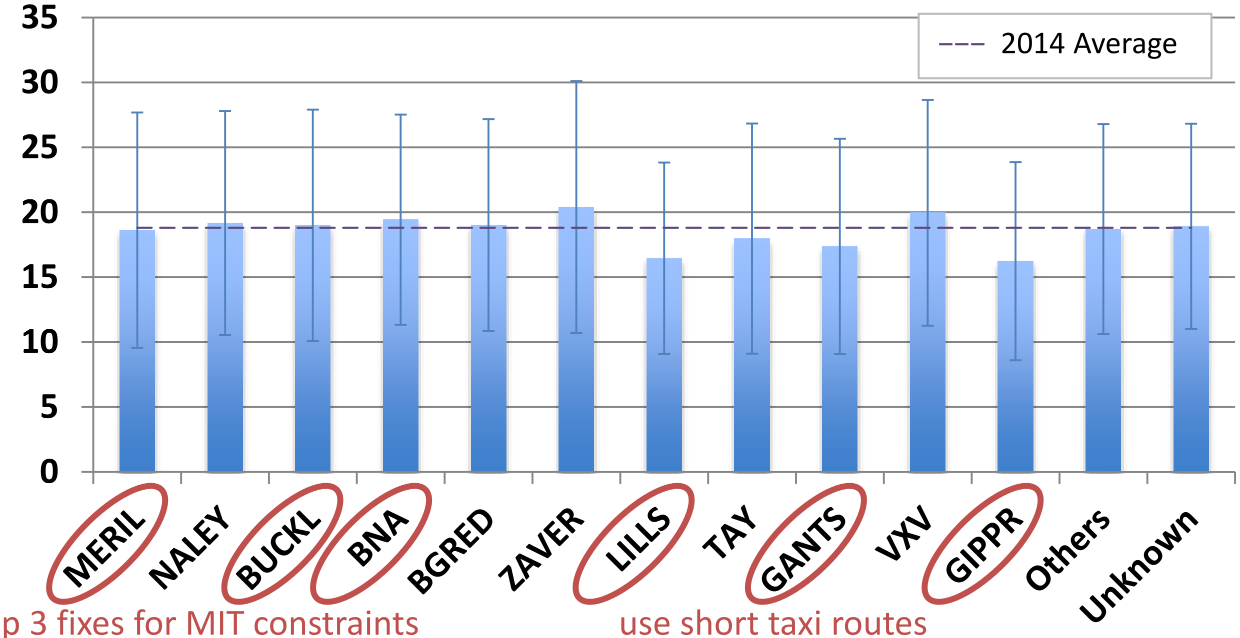
Average taxi-out time (in minutes) by runway

Taxi distance from terminal to runway affects taxi-out time directly.

Taxi Time by Departure Fix



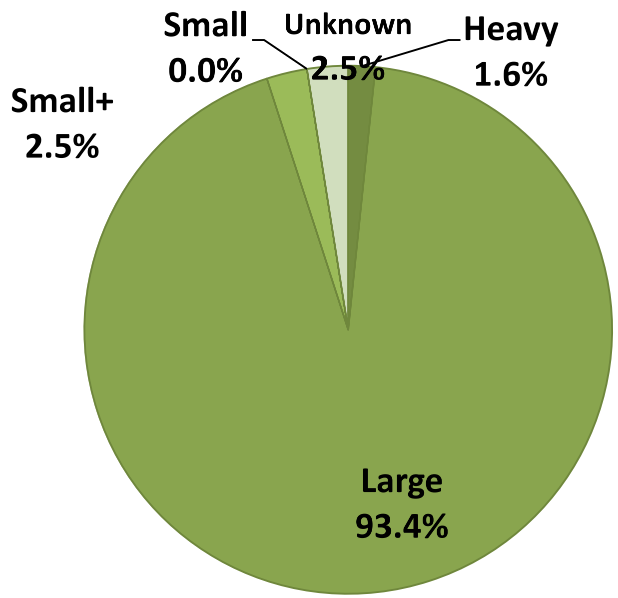
Departure distribution
by departure fix



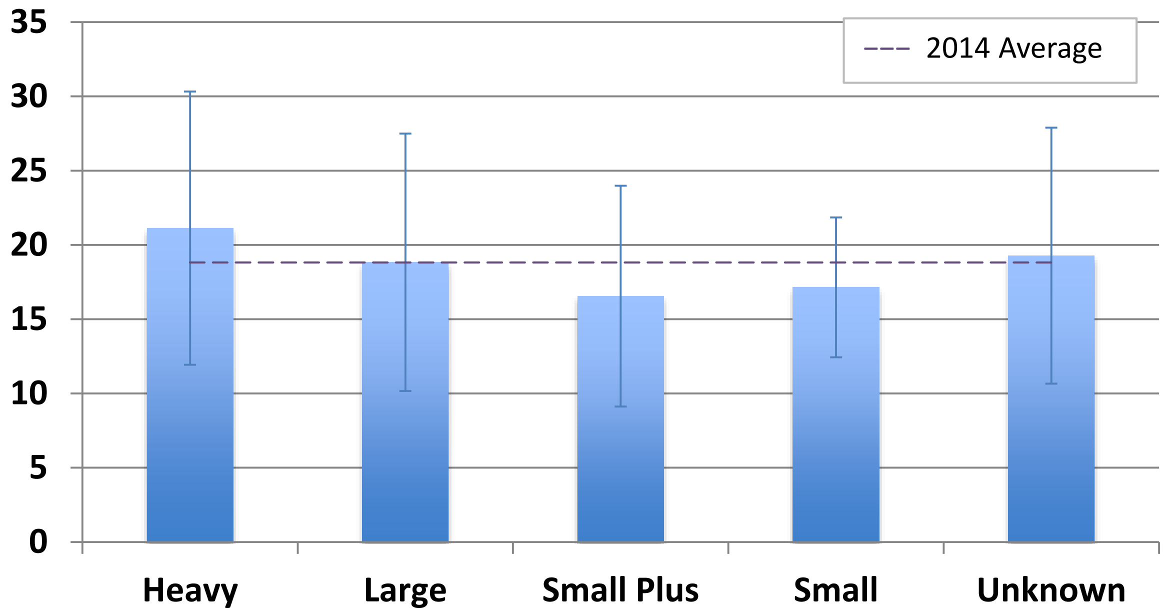
Average taxi-out time (in minutes)
by departure fix

Taxi times of top 3 fixes for miles-in-trail (MIT) constrained departures are similar to the whole year average.

Taxi Time by Weight Class



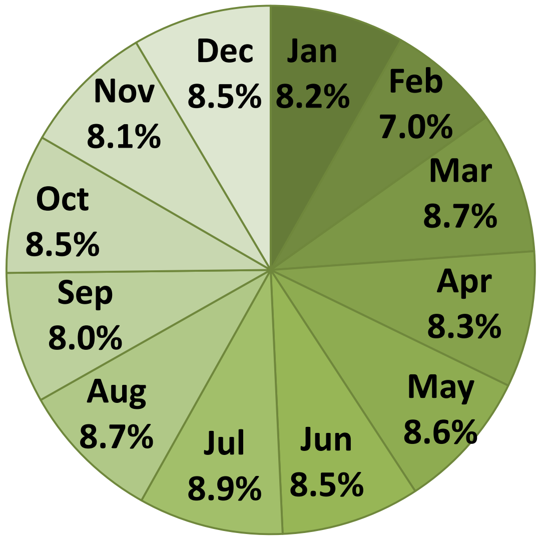
Departure distribution
by weight class



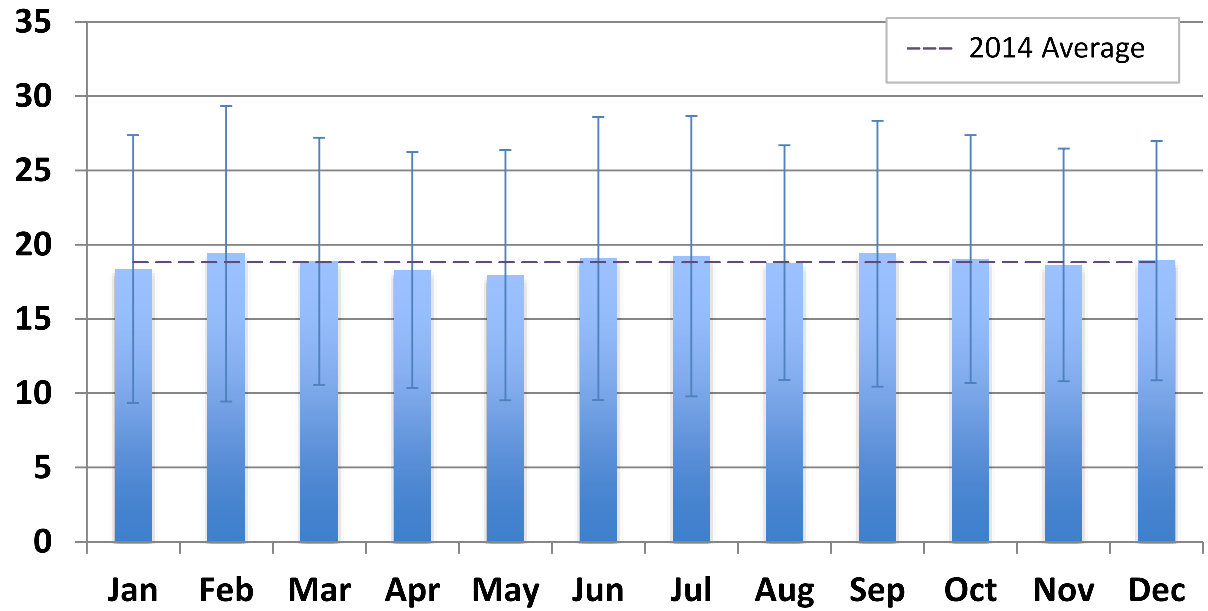
Average taxi-out time (in minutes)
by weight class

Heavy aircraft have relatively longer taxi times, whereas small aircraft have shorter taxi times.

Taxi Time by Month



Departure distribution by month

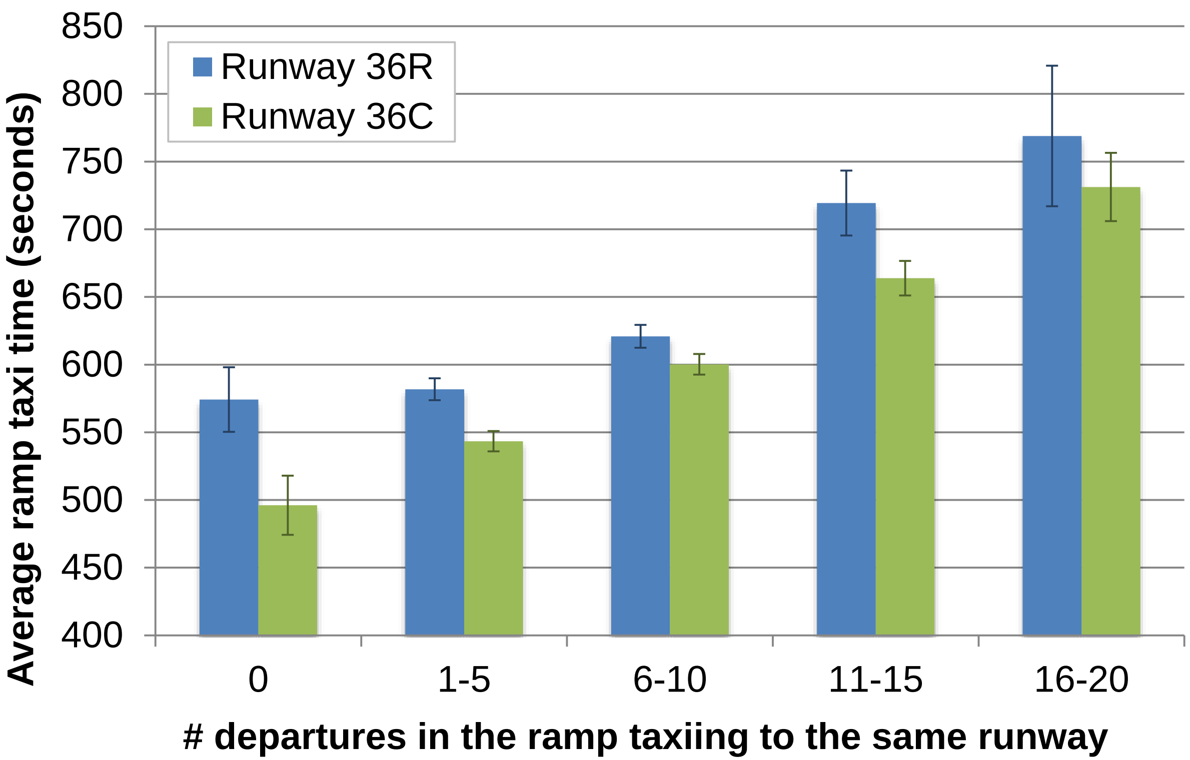


Average taxi-out time (in minutes) by month

Average taxi times are insensitive to month, meaning no seasonal effect on taxi-out time.

Taxi Time by Congestion Level

- Separate data analysis using live data on 9/16-23/2016
- Average ramp taxi time as a function of congestion level in ramp area



Taxi Time Prediction Methods

- Machine learning techniques tested
  - Linear Regression (LR)
  - Support Vector Machines (SVM)
  - *k*-Nearest Neighbors (*k*NN)
  - Random Forest (RF)
  - Neural Networks (NN)
- Dead Reckoning (DR) method
  - Baseline for comparison
  - Based on unimpeded taxi times, defined as 10^{th} percentile of taxi times having the same gate, spot, and runway

Features

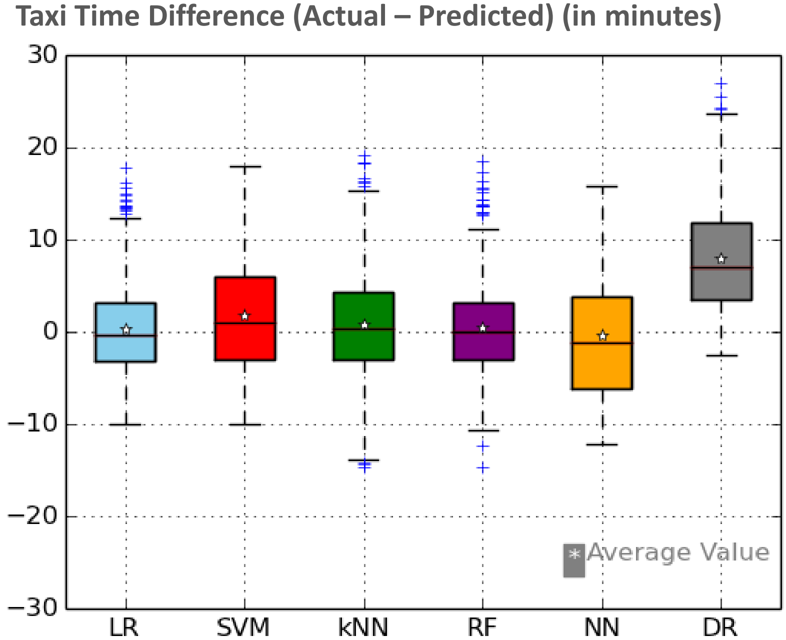
- Terminal concourse and Gate
- Spot
- Runway
- Departure fix
- Weight class and Aircraft model
- Taxi distance
- Unimpeded taxi time
- Scheduled pushback time of day
- Number of departures and arrivals on the surface

Training and Test Datasets

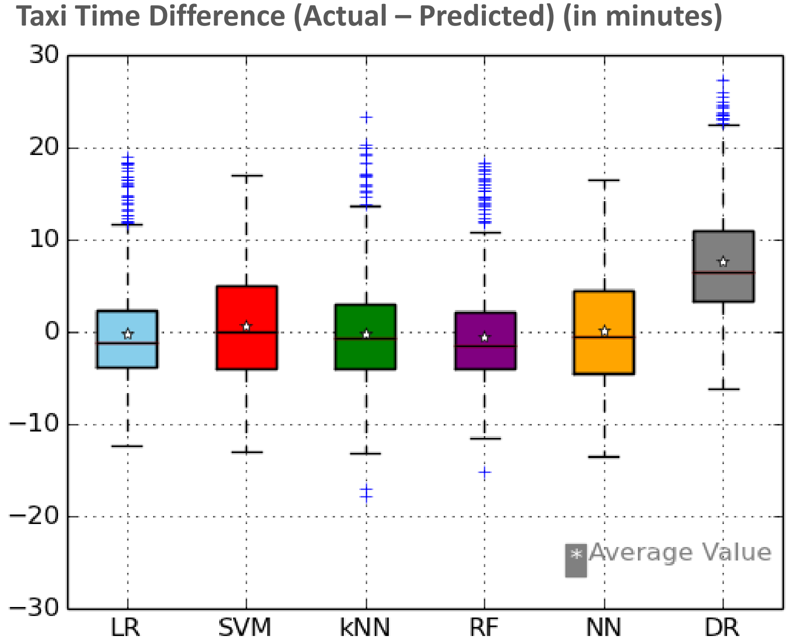
- Two runway configurations: south flow and north flow
- Two weather conditions: good weather and heavy rain

Traffic flow	Weather	Dataset	Dates	Data size	Avg. Taxi time (min)	Std. Dev. (min)
South flow traffic	Good weather	Training	6/1, 6/2, 6/4, 6/7, 6/15	3,361	17.11	6.65
		Test	8/15	689	17.78	6.59
	Rain	Training	6/11, 6/12, 6/25, 7/9, 8/11	3,280	17.98	6.99
		Test	8/12	644	17.68	6.51
North flow traffic	Good weather	Training	6/6, 6/20, 8/25	2,134	19.32	6.13
		Test	8/26	684	19.36	6.09
	Rain	Training	7/21, 8/1, 8/23	1,944	18.83	6.25
		Test	8/24	621	19.31	6.32

Prediction Results – South Flow



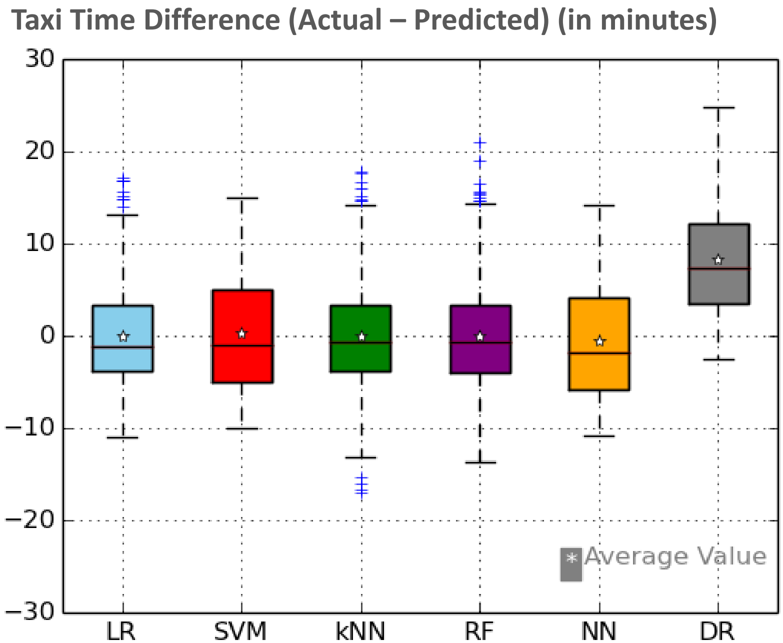
South-flow traffic, good weather



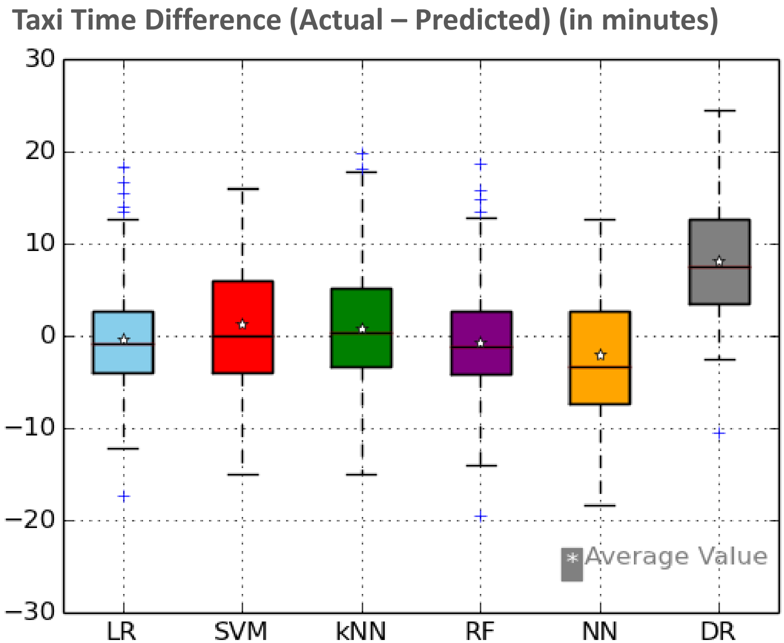
South-flow traffic, heavy rain

Machine learning algorithms show better performance than Dead Reckoning (DR) method. Linear Regression (LR) and Random Forest (RF) are the best.

Prediction Results – North Flow



North-flow traffic, good weather



North-flow traffic, heavy rain

Linear Regression (LR) and Random Forest (RF) are still the best prediction methods for both traffic flow.

Conclusions

- Analyzed the whole year taxi time data at CLT
  - Found several factors affecting taxi-out time
  - No seasonal effect on taxi time
- Applied various machine learning techniques to actual flight data at CLT for taxi-out time prediction
  - Machine learning methods were better than Dead Reckoning method based on unimpeded taxi time.
  - Linear Regression and Random Forest methods showed the best prediction performance.
  - Considered various operational factors, but still needs to be improved.

Ongoing Work for ATD-2

- Apply a linear regression model to live data
  - Focus on ramp taxi time prediction
- Update taxi speed decision trees used in Tactical Scheduler
  - Current taxi speed decision trees based on historical flight data and taxi route data
    - Two decision trees for estimating taxi-out times of departures and taxi-in times of arrivals
    - Taxi speed values both in AMA and Ramp in knots
    - Branches by runway, spot, ramp area, and weight class
  - Need to account for congestion on the surface
    - Count the number of aircraft moving on the surface when a departure is ready to push back

Linear Regression Model

- Formula

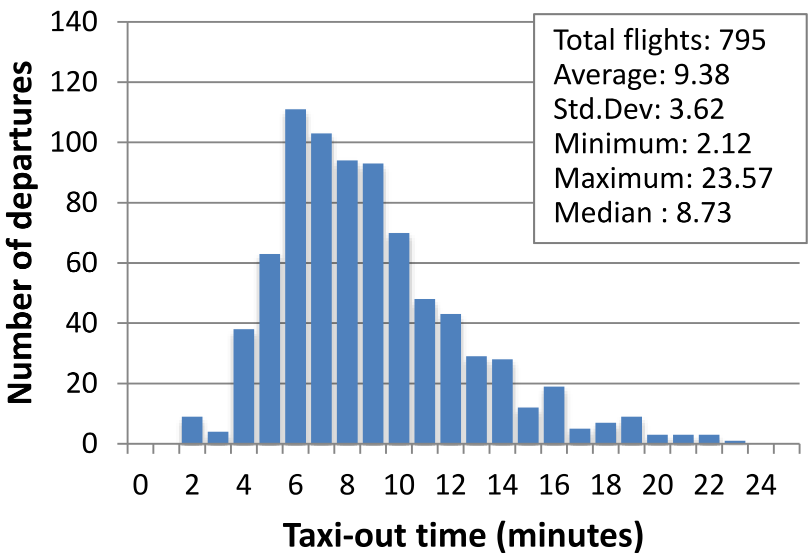
$$y^f = Const + \sum_{i=1}^{n} Coeff_i \times x_i^f$$

  - x^f: variables for flight f
  - y^f: predicted ramp taxi time of flight f
  - Constant and Coefficients determined by training dataset
- Variables
  - Ramp taxi distance (from gate to spot)
  - Binary variables
    - Ramp area, spot, runway, weight class, and EDCT
  - Scheduled off-block time
  - Congestion factors
    - Number of departures in ramp area (by runway and ramp area)
    - Number of arrivals in ramp area (by ramp area)
  - Departures in the previous 15 minutes
    - Number of flights going to the same runway, and their mean taxi time
    - Number of flights going to the same fix, and their mean taxi time

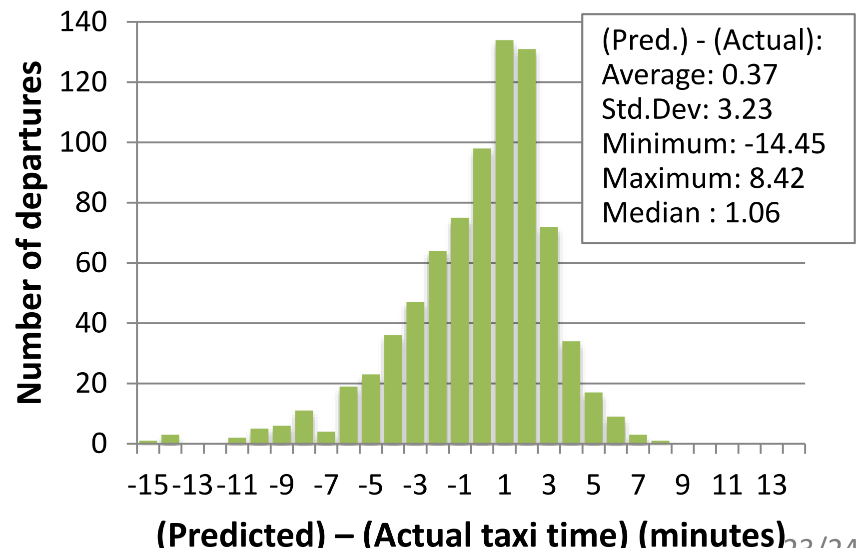
Linear Regression Result

- Live data from CLT
  - North-flow traffic both in training dataset (9/16-22/2016) and test dataset (9/23/2016)
- Prediction accuracy
  - Departures within ±5-min error window: 714 (89.8%)
  - Departures within ±3-min error window: 549 (69.1%)

Actual Taxi Time Distribution



Taxi Time Difference Distribution



Linear Regression Example

- AAL1832 from CLT to SAT (A319)
  - Taxi route: B8 → S13 → 36C
    - Default ramp distance from gate to spot: 370.5m
  - Number of departures taxiing on surface: 6
    - Two aircraft from each Concourse B, C, and E to runway 36C
- Linear Regression model

Variable	Ramp Distance	B_EAST	Spot 13	Runway 36C	Weight Class D	Dep# B to 36C	Dep# C to 36C	Dep# E to 36C
Coefficient	0.2735	166.2	28.6	189.6	74.2	9.9	-1.3	4.6

$$TaxiT_{LR} = 0.2735*370.5 + 166.2 + 28.6 + 189.6 + 74.2 + 9.9*2 + (-1.3)*2 + 4.6*2 = 586.3 \text{ seconds}$$

  - Actual ramp taxi time: 573 seconds (Difference: 13.3 seconds)
  - Predicted taxi speed in ramp area: 370.5/(586.3 – 260) = 2.2 knots