A Network Model to Simulate Airport Surface Operations

Adel Elessawy, Robert Eftekari, Yuri Zhylenko

Sponsor: Center for Air Transportation Systems Research (CATSR)

Dr. Lance Sherry

CATSR

GEORGE MASON UNIVERSITY

Objective

- Provide CATSR with a method to:
  - Re-create and analyze previous congestion events on the airport surface
  - Showcase impacts of surface operation changes on surface counts and taxi times

Agenda

- ***Context***
- Problem & Need
- Method of Analysis
- Results & Recommendations

Bottlenecks

- Evolution in Air Traffic Control (ATC) and Traffic Flow Management (TFM) shifted “bottlenecks” from the air to the ground

"Sherry, Neyshabouri (2013), Analysis of Airport Surface Congestion. Internal CATSR Report"

Airport Surface Operations

- Aircraft in movement areas in-between the runways & the gates (e.g. taxiways & ramps)
  - Arriving aircraft taxiing in to gates (Not at the gate)
  - Departing aircraft taxiing out of gates to the runway (Not on the runway)

What is Surface Congestion?

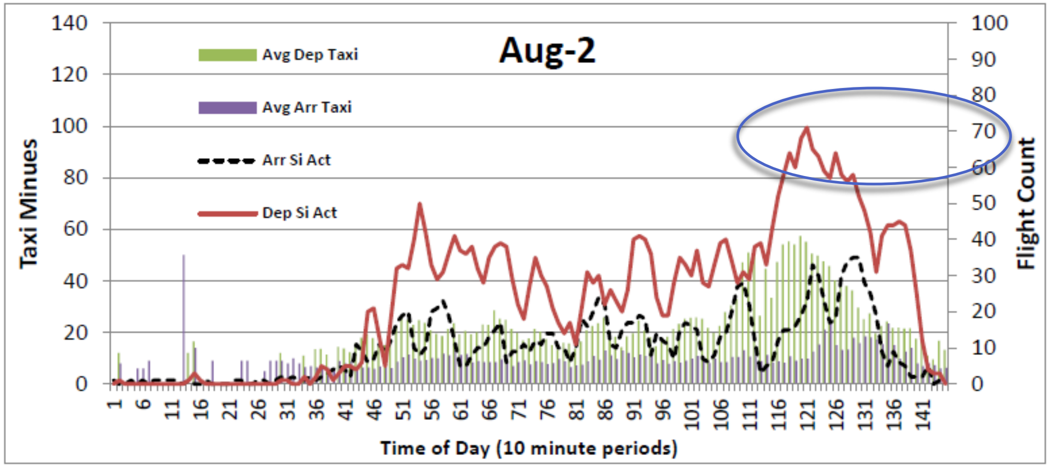
- Surface Congestion & Gridlocks: number of aircraft on the surface exceeds maximum capacity of the airport

Surface Congestion → ↑Taxi Time → ↑Fuel Burn→↑Airline Operational Cost

- "2+ Sigma" Days
  - Surface count of aircraft is greater than two standard deviations beyond the mean value
  - Happens ~ 18 times each year at major U.S. airports, causing delays, increasing airlines' taxi times and operating costs
  - Causes:
    - Issues with navigation (NAV) systems used for departures
    - Wind shifts that trigger a runway configuration change (arrival runway ↔departure runway)
    - "Blue Sky" Days

Blue Sky Day?

- A 2+ sigma day with:
  - No departure NAV issues
  - No significant winds or weather
  - No system failures
  - No staff shortages

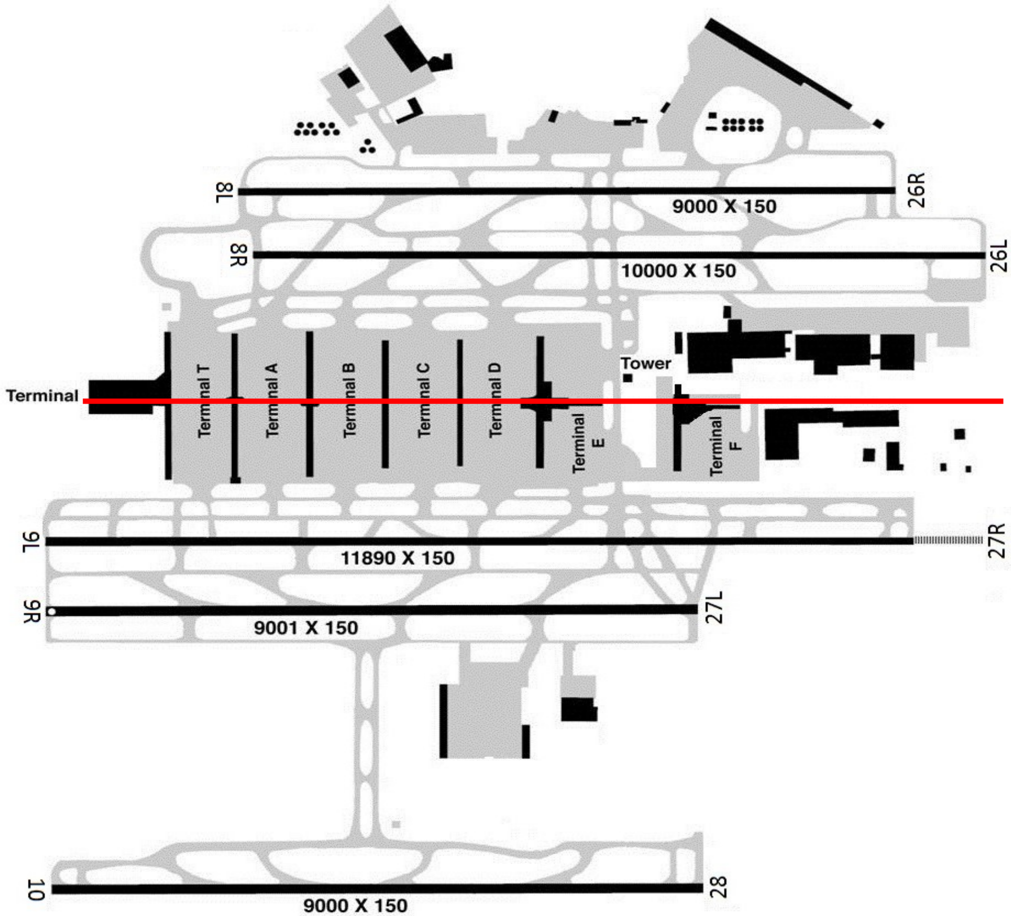


Sherry, Neyshabouri (2013)

- One unusual pattern: 60% of arriving flights are early

Hartsfield–Jackson Atlanta (ATL) Airport

- Busiest Airport in the World
  - Almost 2,500 aircraft arrivals and departures daily
  - Averages more than 250,000 passengers a day
- 5 Major Runways
  - Departures: Inner Runways (8R/26L, 9L/27R)
  - Arrivals: Outer Runways (26R/8L, 27L/9R, & 28/10) 7 Terminals
- 7 Terminals with 207 Gates



Problem & Need

- Hartsfield-Jackson Atlanta Airport (ATL) suffers from surface congestion especially on 2+ sigma days, which increases aircraft taxi times and airline operating costs
- There is a need for an Integrated Airport Network Simulation Model that can:
  - Re-create and analyze congestion events on the airport surface
  - Assist in better understanding of 2+ sigma days
  - Showcase impacts of surface operation changes on surface counts and taxi times

Approach

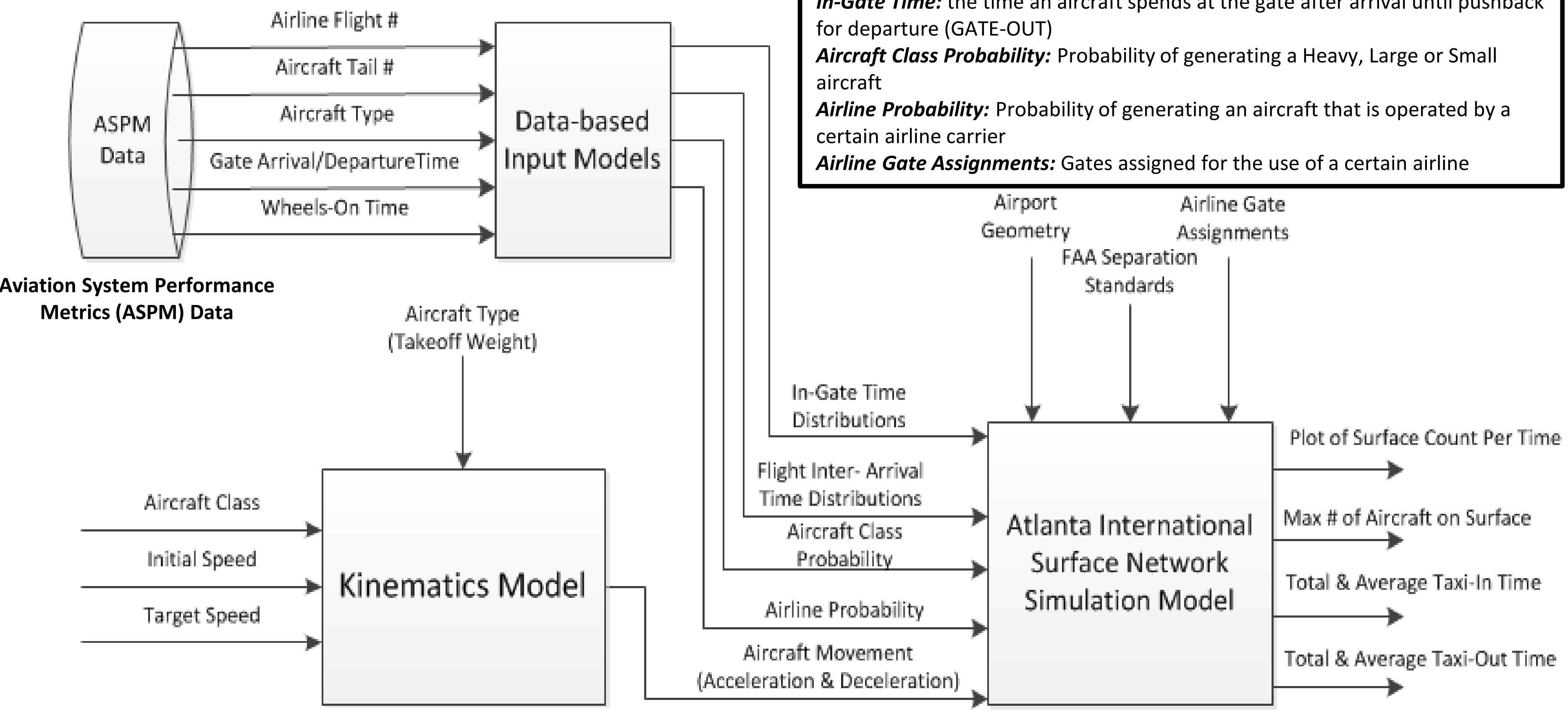
Definitions

In-Gate Time: the time an aircraft spends at the gate after arrival until pushback for departure (GATE-OUT)

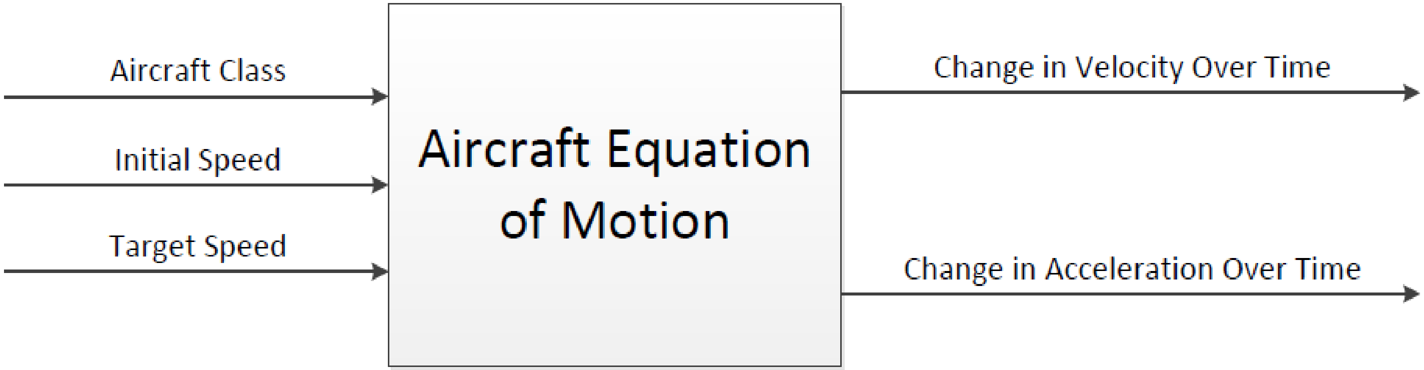
Aircraft Class Probability: Probability of generating a Heavy, Large or Small aircraft

Airline Probability: Probability of generating an aircraft that is operated by a certain airline carrier

Airline Gate Assignments: Gates assigned for the use of a certain airline



Kinematics Model



- Developed to accurately simulate aircraft movement on the surface
- The initial & target speeds are specified based on the **separation distance/time with the leading aircraft, BUT** max speed is based on the class

Aircraft Class	Aircraft Takeoff Weight (lbs)	MAX Taxi Speed (Knots)
Small	Weight <= 41,000 lbs	17
Large	41,000 < Weight <= 255,000 lbs	15
Heavy	Weight > 255,000 lbs	12

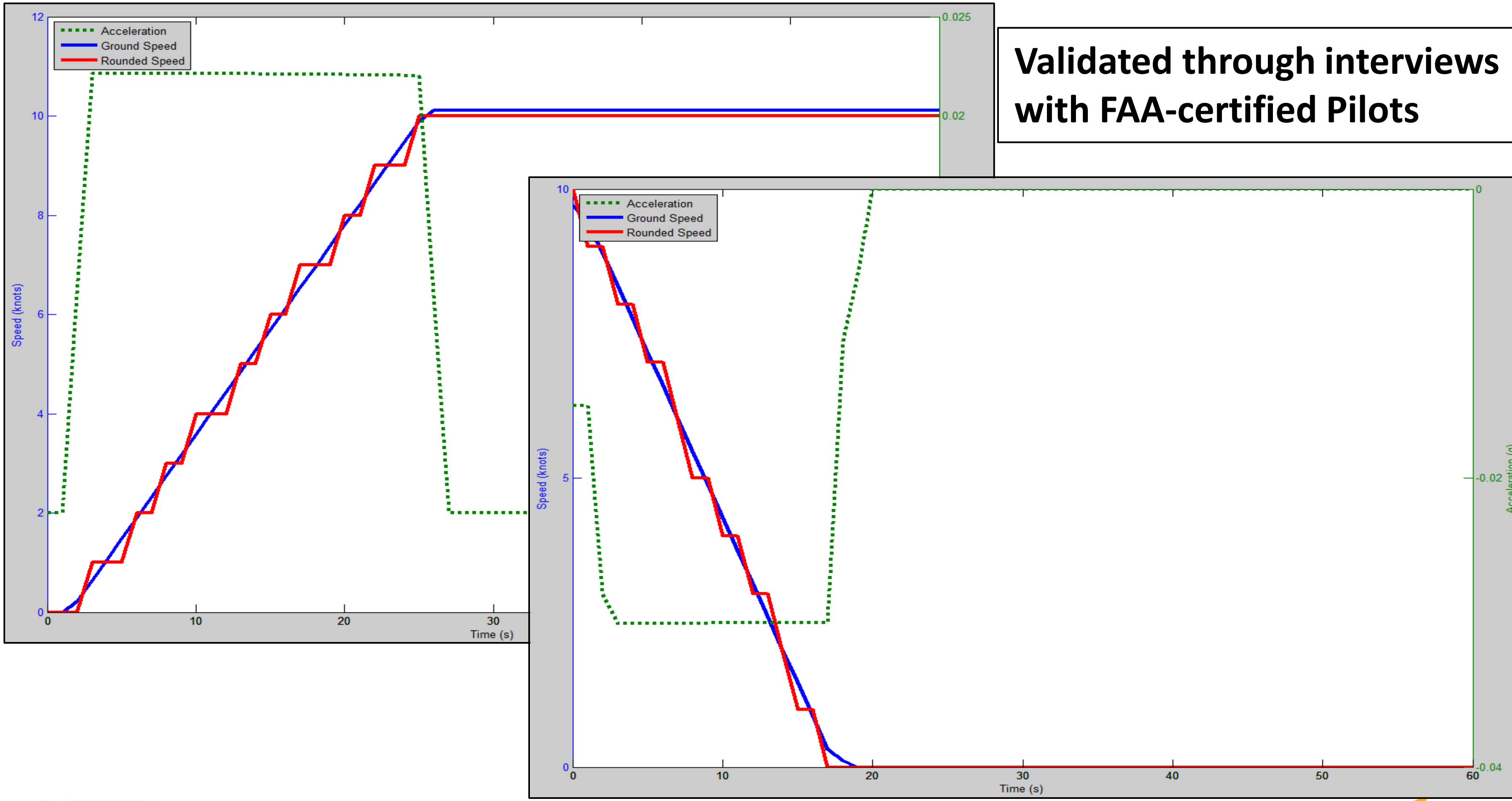
Kinematics: Aircraft Equation of Motion

$$V_n = V_{n-1} + (t_n - t_{n-1})[(T\cos(\alpha) - (1/2)c_D \rho V_{n-1}^2 A)/m - g\sin(\gamma) - \mu g]$$

- The Aircraft Class determines the default values for:
  - Maximum Thrust
  - Mass
  - Wing Surface Area
  - Drag Coefficient
- Time, Velocity, and Applied Thrust are dynamic variables

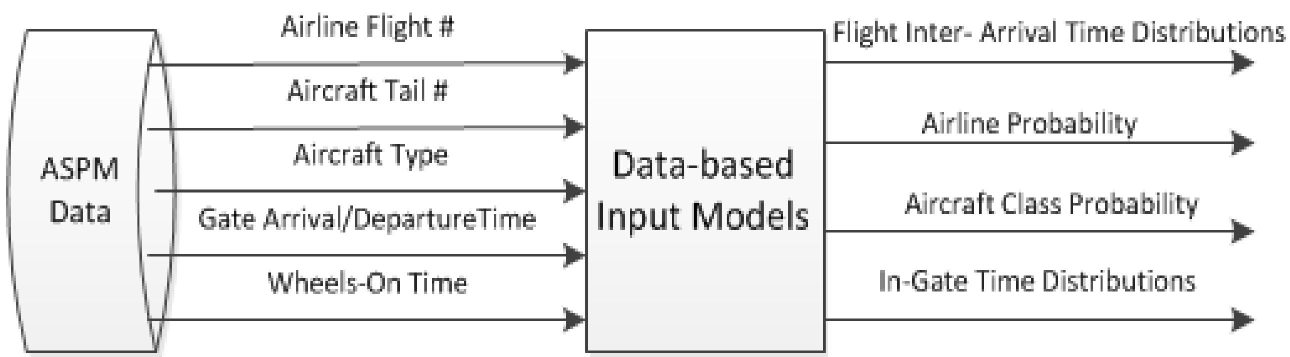
Variable	Definition
V	Velocity (m/s)
t	Time (s)
T	Thrust (N)
α	Angle of Attack (radians)
c_D	Coefficient of Drag
ρ	Air Density (kg/m^3)
A	Wing surface Area (m^2)
m	Mass (kg)
g	Gravitational Acceleration (m/s^2)
γ	Flight Path Angle (radians)
μ	Coefficient of Friction

Kinematics Output Sample



Validated through interviews with FAA-certified Pilots

Data-based Input Models



- **Aviation System Performance Metrics (ASPM) Data** contains detailed flight information (Arrival & Departure Airports, Airline Flight & Tail Number, Aircraft Type, Scheduled/Actual Wheel On & Off Times, and Scheduled/Actual Gate Arrival & Departure Times)
- ASPM of ATL 2012 was used for analysis and modeling

Data-based Input Model Process

- **Inter-Arrival Time Distribution**
  - Filter the flights in ASPM: include **ONLY** aircraft departing & arriving on the modeled runways using FlightStats
  - Sort the flights based on wheels-on time
- **Airline Probability**

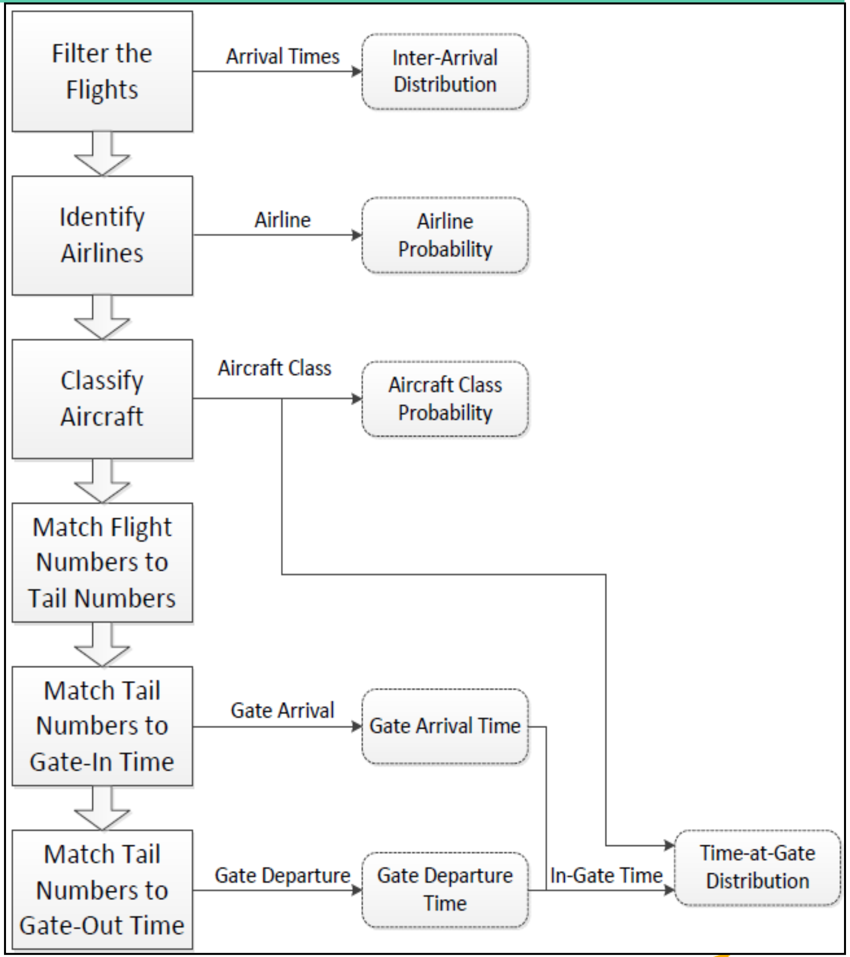
$$Airline\ Prob = \frac{Count\ Aircraft\ (Airline\ Code)}{Total\ Aircraft\ Modeled}$$

- **Aircraft Class Probability**
  - Classify flights using aircraft type (take-off weight)

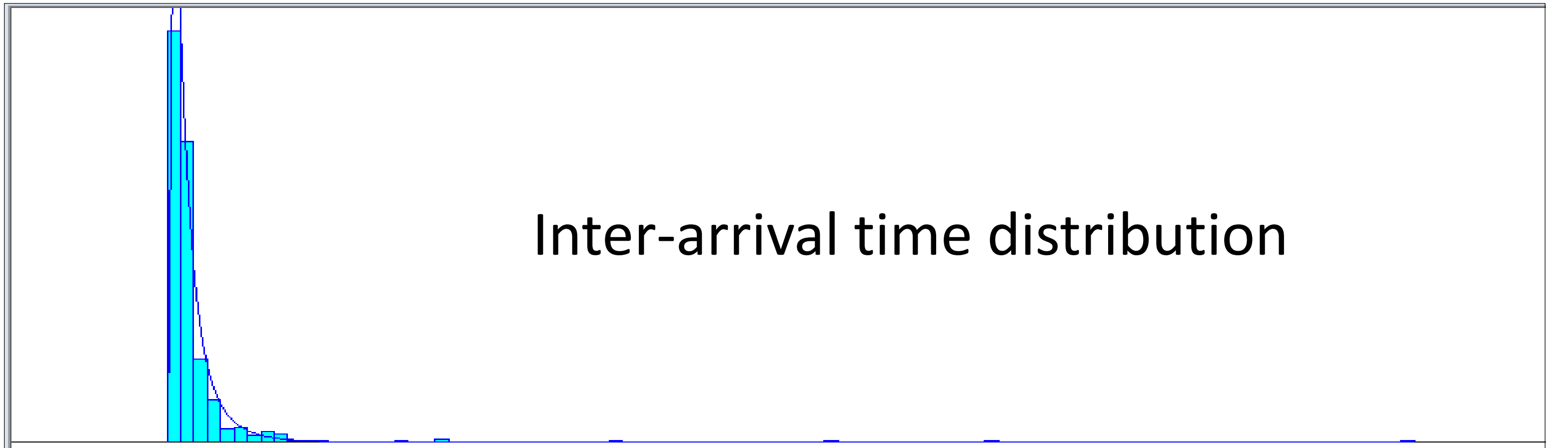
$$Aircraft\ Class\ Prob = \frac{Count\ Aircraft\ Class\ Flights}{Total\ Aircraft\ Modeled}$$

- **In-Gate Time (Gate-Out) Distribution**
  - Match the tail numbers of aircraft to arriving & departing flights to find gate-in and out times

$$In - Gate\ Time = Gate\ Arrival\ Time - Gate\ Departure\ Time$$



Data-based Input Model Output

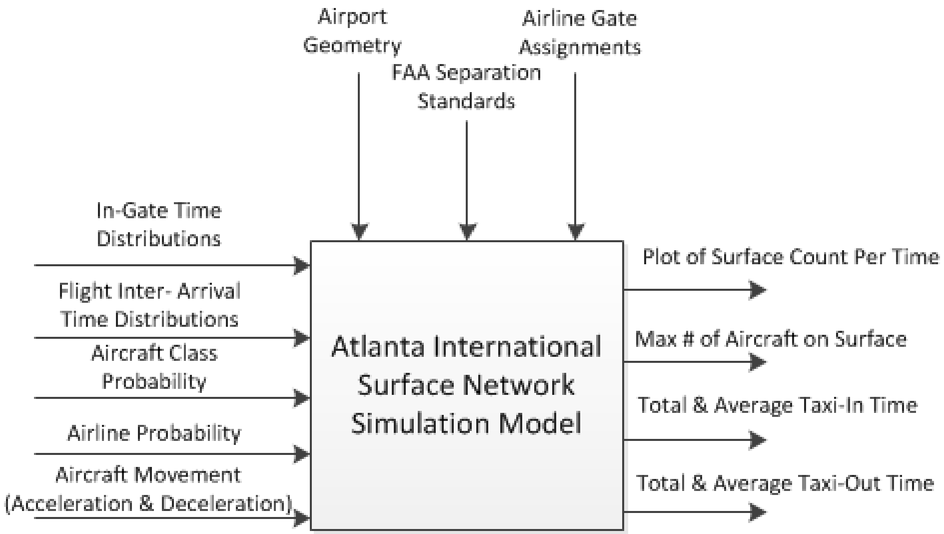


Inter-arrival time distribution

```
        Distribution Summary

Distribution:   Lognormal
Expression:     0.5 + LOGN(1.69, 1.87)
Square Error:   0.003074

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 4
  Test Statistic        = 23.2
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points   = 544
Min Data Value          = 1
Max Data Value          = 93
Sample Mean             = 2.58
Sample Std Dev          = 5.66

        Histogram Summary

Histogram Range         = 0.5 to 93.5
Number of Intervals     = 93
```

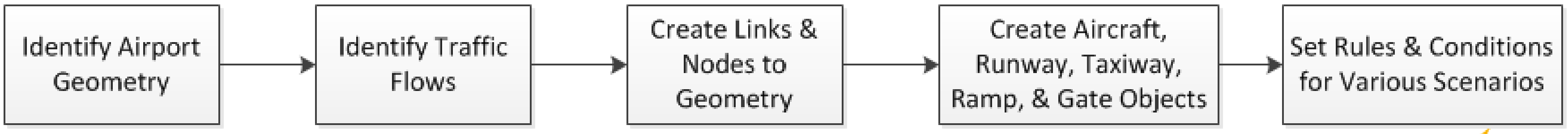
Atlanta Surface Network Simulation Model

- Discrete-event model designed in **MATLAB** that allows the user to simulate airport surface operations at Hartsfield-Jackson Atlanta Airport

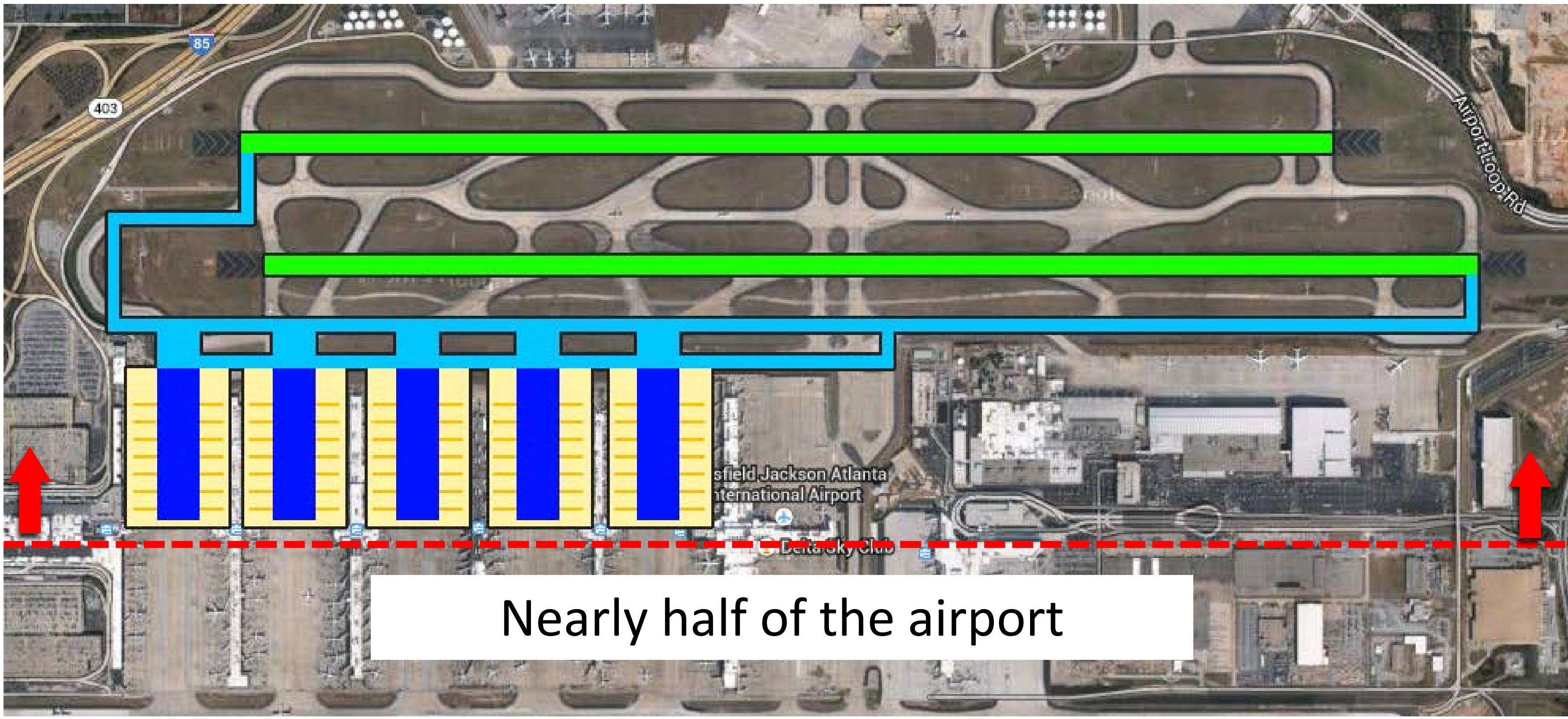


- The inputs are all user-configurable

- The design process:

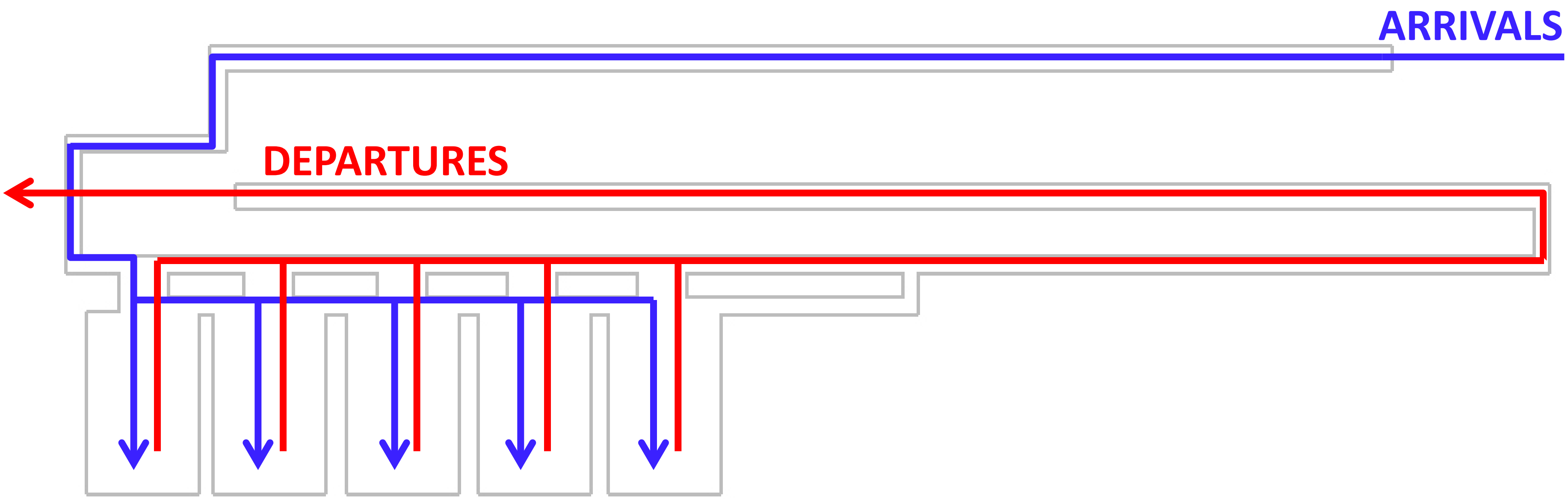


Identification of ATL Simulation Geometry



Runways (1 Arrival, 1 Departure) — Taxiways — Ramps — Gates

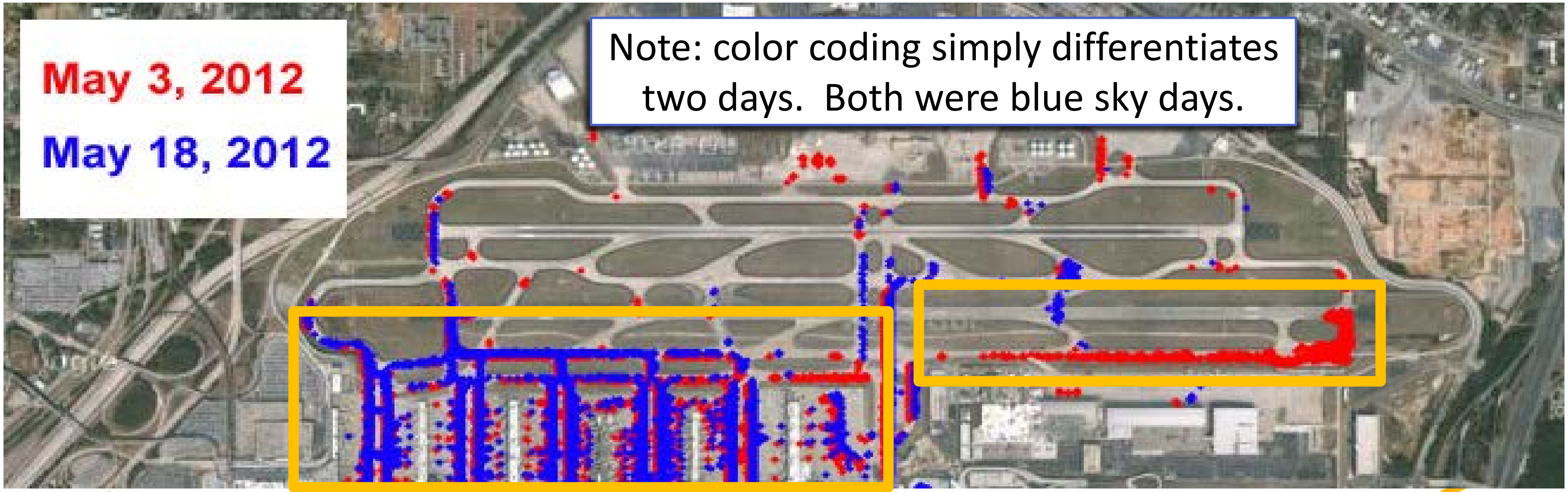
Identification of Traffic Flows



Subject matter experts (SMEs) were consulted to clarify and validate simulation geometry and traffic flows

Data Analysis – Airport Surface Detection Equipment, Model X (ASDE-X)

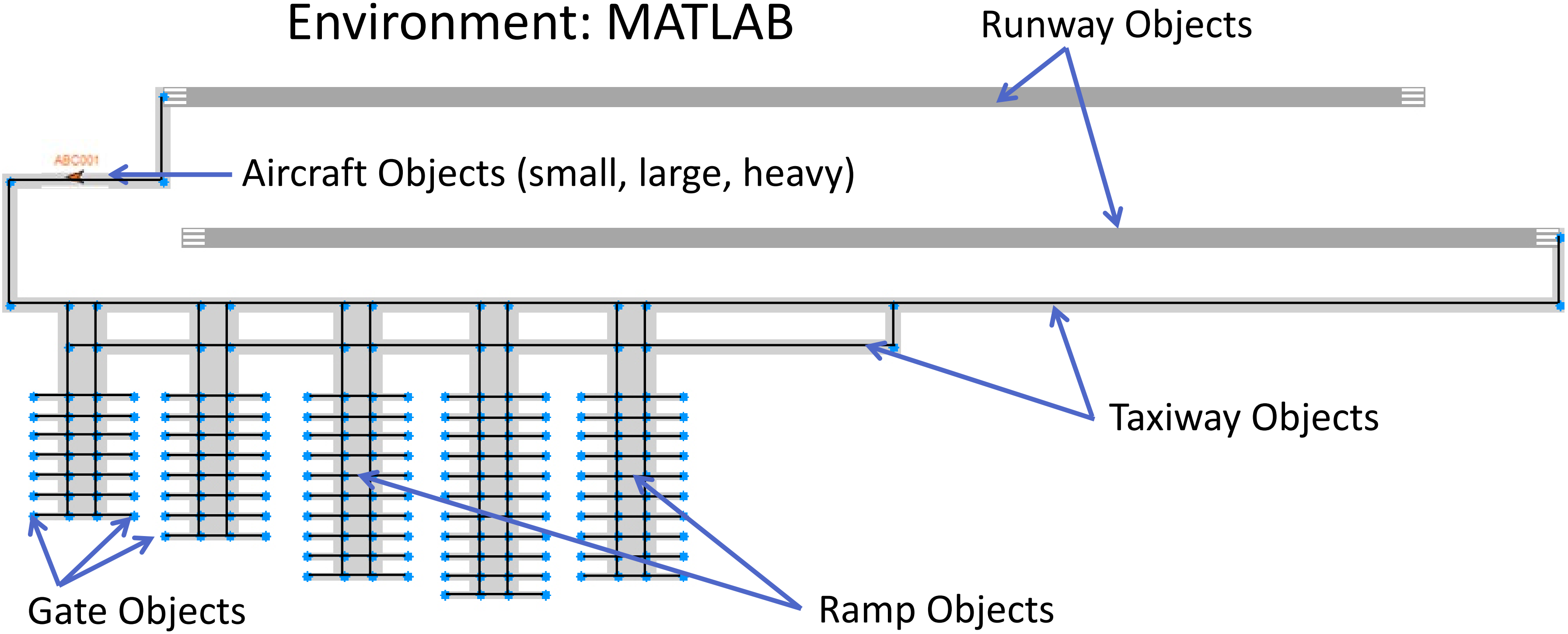
- Stationary Aircraft (Ground Speed = 0); time period throughout the day (morning, afternoon, evening)
- **Observations:** Majority of congestion on two taxiways & the ramps near the gates - No significant causes except aircraft arriving ahead of schedule; ***arrival*** and ***departure*** delays
- Only used to reaffirm validation of identified geometry; it does contain blue sky day congestion



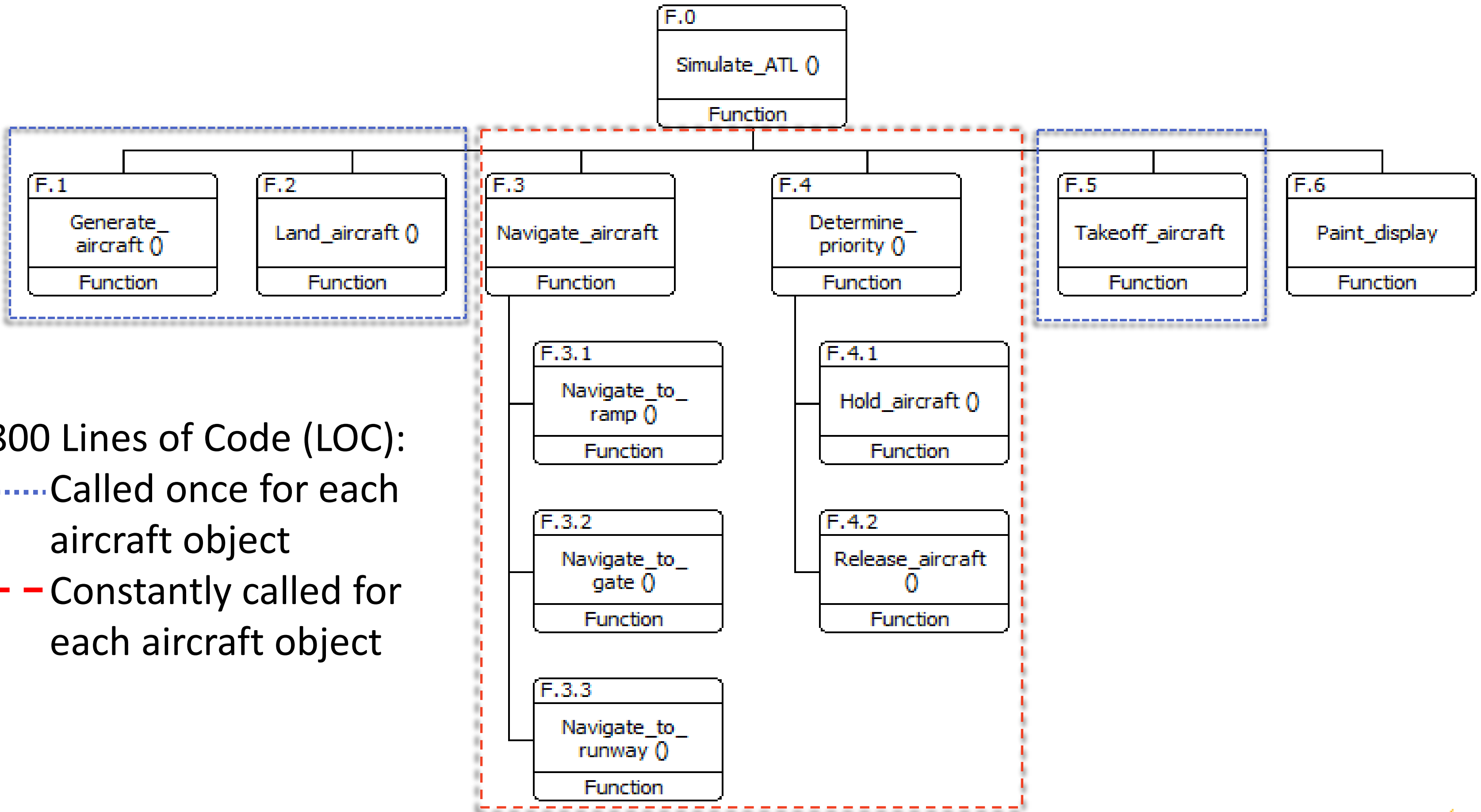
Data provided by CATSR courtesy of SAAB Sensis

Wireframe Network Model and Objects

Environment: MATLAB



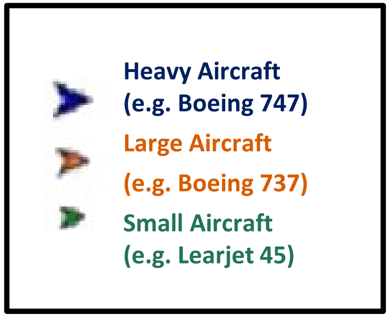
Functional Architecture



1800 Lines of Code (LOC):

- ········ Called once for each aircraft object
- – – – Constantly called for each aircraft object

Video – Simulation



https://www.youtube.com/watch?v=glLn8vmlB6s

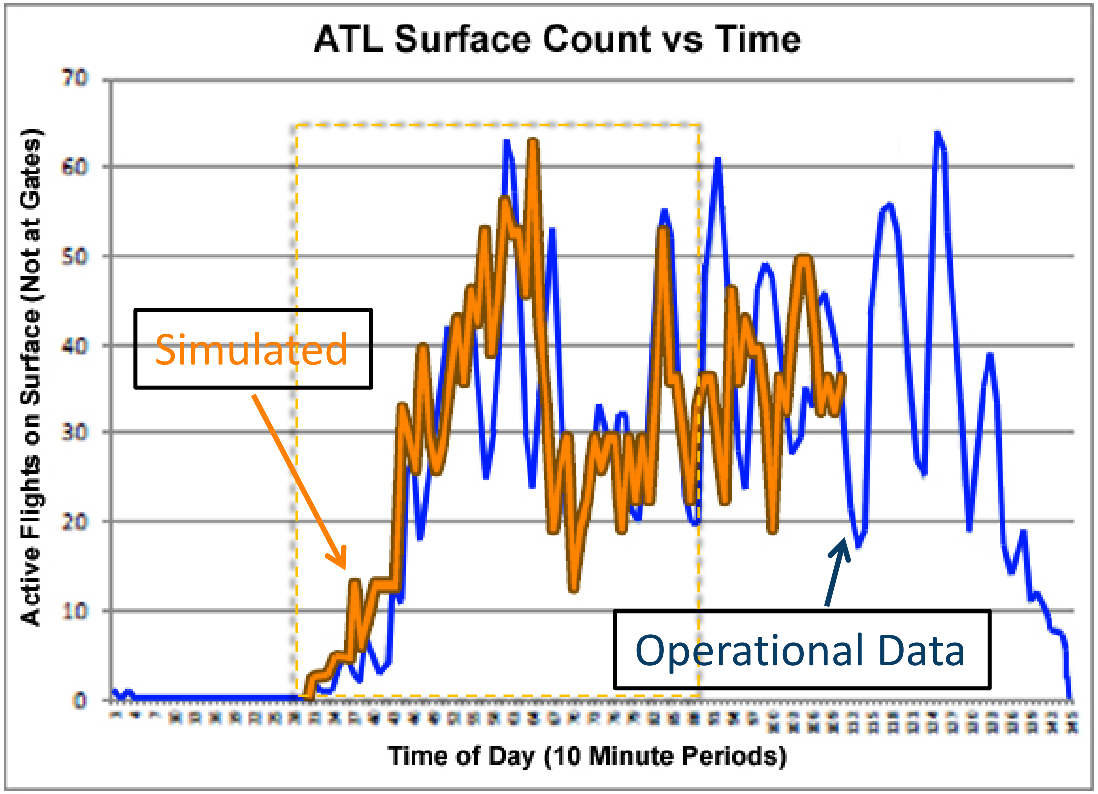
Results (Normal Half Day at ATL)- Upper Half

	*Expected	Simulated
Maximum Surface Count	22	21
Taxi in time (minutes)	7.15	6.66
Taxi out time (minutes)	13.86	14.74

* expected maximum surface count is an actual observed value (67, morning period) scaled down by a factor of 3. This was determined through analysis of surface counts in the upper and lower halves of ATL. The lower half accounts for roughly 2/3 of the total taxiway count because of a much greater distance between the Southern most arrival runway and terminals.

Results (Normal Day at ATL) – Whole Airport

- Frequency analysis of surface count versus time:



- Simulation output time aligned with observed operational data; *Sherry, Neyshabouri (2013)*
- Simulation output amplitude scaled to match observed value (for entire airport)
- Simulated 8 hour period (dashed box) is remarkably close to the observations

Results (Attempted Blue Sky Day) – Upper Half

- Half of a blue sky simulated and analyzed *relative* to a normal half day
  - Limited by simulation capabilities (discussed subsequently)
- Inter-arrival times reduced by 10 seconds to produce banks of early arrivals

	Simulated	Change (%)
Maximum Surface Count	22	4.76%
Taxi in time (minutes)	6.95	4.35%
Taxi out time (minutes)	17.16	**16.42%**

Sensitivity Analysis

- Results are **very** sensitive to these parameters:
  - Inter-arrival times
  - Inter-departure time
    - As expected, greater inter-departure time has a direct impact on departure queue length and wait time
  - Aircraft taxi speeds
    - Empirically determined through iterative modification of published values for small, large, and heavy aircraft; Ravizza et al. (2012)

Conclusions and Recommendations

- The simulation of ATL, configured for a normal day, can accurately represent nominal surface operations
  - The product (MATLAB M file) has been delivered to the project sponsor
  - The simulation is:
    - Scalable for additional objects (e.g., taxiways, runways, runway exits, ramps, gates, etc.)
    - Adaptable for other airport geometries (no limitation to ATL)
- limited analysis of blue sky days indicates that early arrivals may be the cause of surface congestion and departure delays
- The team recommends further analysis for blue sky days

Known Issues (Limitations) and Future Work

- **Issues & Future Work for the Model:**
  - Determine priority function (aircraft holds and releases) is limited to minor congestion scenarios because of time constraints
  - An observed phenomenon – aircraft temporarily parking behind occupied gates when all gates are full – was not fully implemented, also because of time constraints
  - These issues form the rationale for the limited analysis of blue sky day congestion; congestion level could only be marginally increased
- **Future Work for Surface Congestion Management**
  - Include mitigation strategies e.g. Departure Queue Management

Questions?

References

[1] Sherry, L., S. Neyshabouri, 2013, Analysis of Airport Surface Operations: a Case Study of Atlanta Hartsfield Airport, Fairfax, VA, George Mason University.

[2] Federal Aviation Administration, 2014, Aviation System Performance Metrics Database, available: http://aspm.faa.gov/main/aspm.asp

[3] Stroiney, S., B. Levy, 2011, Departure Queue Management Benefits Across Many Airports, Proceedings of the 2011 Integrated Communications Navigation and Surveillance (ICNS) Conference, Herndon, VA, IEEE.

[4] AirNav LLC, 2014, KATL - Hartsfield - Jackson Atlanta International Airport, available: http://www.airnav.com/airport/KATL

[5] Federal Aviation Administration, 2013, Airport Diagram: Hartsfield - Jackson Atlanta International, Washington, DC, U.S. Department of Transportation.

[6] Sherry, L., 2011, Aircraft Performance, Fairfax, VA, George Mason University.

[7] RTCA Special Committee 186, 2014, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, DO-317B, Washington, D.C., RTCA Inc.

[8] Ravizza, S., et al., 2012, The Trade-off Between Taxi Time and Fuel Consumption in Airport Ground Movement, Conference on Advanced Systems for Public Transport (CASPT12), Santiago, Chile.