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

Sherry, Neyshabouri (2013)
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**

**Defintions**

*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

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**Diagram: Aviation System Performance Metrics (ASPM) Data**

1. **ASPM Data**
   - Airline Flight #
   - Aircraft Tail #
   - Aircraft Type
   - Gate Arrival/Departure Time
   - Wheels-On Time

2. **Data-based Input Models**
   - Aircraft Type (Takeoff Weight)

3. **Kinematics Model**
   - Aircraft Class
   - Initial Speed
   - Target Speed

4. **Atlanta International Surface Network Simulation Model**
   - FAA Separation Standards
   - Flight Inter-Arrival Time Distributions
   - Aircraft Class Probability
   - Airline Gate Assignments
   - Aircraft Movement (Acceleration & Deceleration)

5. **Output**
   - Plot of Surface Count Per Time
   - Max # of Aircraft on Surface
   - Total & Average Taxi-In Time
   - Total & Average Taxi-Out Time

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**10 Department of Systems Engineering and Operations Research**

**A Network Model to Simulate Airport Surface Operations**

**SYST 699 – Spring 2014**
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.

<table>
<thead>
<tr>
<th>Aircraft Class</th>
<th>Aircraft Takeoff Weight (lbs)</th>
<th>MAX Taxi Speed (Knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Weight &lt;= 41,000 lbs</td>
<td>17</td>
</tr>
<tr>
<td>Large</td>
<td>41,000 &lt; Weight &lt;= 255,000 lbs</td>
<td>15</td>
</tr>
<tr>
<td>Heavy</td>
<td>Weight &gt; 255,000 lbs</td>
<td>12</td>
</tr>
</tbody>
</table>
Kinematics: Aircraft Equation of Motion

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

- The Aircraft Class determines the default values for:
  - Maximum Thrust
  - Mass
  - Wing Surface Area
  - Drag Coefficient

- Time, Velocity, and Applied Thrust are dynamic variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Velocity (m/s)</td>
</tr>
<tr>
<td>t</td>
<td>Time (s)</td>
</tr>
<tr>
<td>T</td>
<td>Thrust (N)</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>Angle of Attack (radians)</td>
</tr>
<tr>
<td>( c_D )</td>
<td>Coefficient of Drag</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Air Density (kg/m³)</td>
</tr>
<tr>
<td>A</td>
<td>Wing surface Area (m²)</td>
</tr>
<tr>
<td>m</td>
<td>Mass (kg)</td>
</tr>
<tr>
<td>g</td>
<td>Gravitational Acceleration (m/s²)</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>Flight Path Angle (radians)</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Coefficient of Friction</td>
</tr>
</tbody>
</table>
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**
  
  \[ \text{Airline Prob} = \frac{\text{Count Aircraft (Airline Code)}}{\text{Total Aircraft Modeled}} \]

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

  \[ \text{Aircraft Class Prob} = \frac{\text{Count Aircraft Class Flights}}{\text{Total Aircraft Modeled}} \]

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

  \[ \text{In – Gate Time} = \text{Gate Arrival Time} – \text{Gate Departure Time} \]
Data-based Input Model Output

Inter-arrival time distribution

Distribution Summary
- Distribution: Lognormal
- Expression: \(0.5 + \text{LOGN}(1.69, 1.87)\)
- 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 = 2.88
- Sample Std Dev = 5.66

Histogram Summary
- Histogram Range = 0.8 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:
  
  1. Identify Airport Geometry
  2. Identify Traffic Flows
  3. Create Links & Nodes to Geometry
  4. Create Aircraft, Runway, Taxiway, Ramp, & Gate Objects
  5. Set Rules & Conditions for Various Scenarios
Identification of ATL Simulation Geometry

Nearly half of the airport

Runways (1 Arrival, 1 Departure)  Taxiways  Ramps  Gates
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

Note: color coding simply differentiates two days. Both were blue sky days.
Wireframe Network Model and Objects

Environment: MATLAB

- Aircraft Objects (small, large, heavy)
- Runway Objects
- Taxiway Objects
- Gate Objects
- Ramp Objects
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=glLn8vmIB6s
### Results (Normal Half Day at ATL)- Upper Half

<table>
<thead>
<tr>
<th></th>
<th>* Expected</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Surface Count</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>Taxi in time (minutes)</td>
<td>7.15</td>
<td>6.66</td>
</tr>
<tr>
<td>Taxi out time (minutes)</td>
<td>13.86</td>
<td>14.74</td>
</tr>
</tbody>
</table>

*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
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

<table>
<thead>
<tr>
<th></th>
<th>Simulated</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Surface Count</td>
<td>22</td>
<td>4.76%</td>
</tr>
<tr>
<td>Taxi in time (minutes)</td>
<td>6.95</td>
<td>4.35%</td>
</tr>
<tr>
<td>Taxi out time (minutes)</td>
<td>17.16</td>
<td><strong>16.42%</strong></td>
</tr>
</tbody>
</table>
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


