A Network Model to Simulate Airport Surface Operations

Project Proposal

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Table of Contents

Table of Figures

I. Introduction

Improvements to the efficiency of the United States (U.S.) air transportation system are constantly challenged by the increasing demand for air travel. One of the main constraints for efficiency is airport capacity. Insufficient capacity results in delays for airborne and airport surface traffic. Recent advancements in technologies such as Traffic Flow Management (TFM) [1] have in some instances improved the timeliness of arrivals. However, in certain circumstances this prioritization of inbound aircraft may come at the expense of delayed departures and leading to airport surface congestion.

Airport surface congestion (or gridlock) occurs when the count of aircraft on the surface exceeds the capacity of the airport. Or more specifically, the traffic flow needed exceeds the maximum flow enabled by taxiways, ramps, gates, and departure holds due to standard avoidance of wake vortices during takeoff. Surface gridlock significantly increases airline operating costs in the form of greater taxi times and fuel burn.

Recent studies such as [1] have renewed interest in surface management techniques that aim to keep airports operating within capacity limits, particularly in times of high demand. A "two-sigma" day arises when the surface count of aircraft is greater than two standard deviations beyond the mean. Airport surface counts in excess of two-sigma occur approximately 18 times each year at major U.S. airports. Causes include issues with departure navigation systems, wind shifts that trigger a runway configuration change, other system failures, and staff shortages. For instances, with a known cause often the only mitigation is resolution of that causal agent. A "blue sky day" is an exceptional case with no known cause, severely limiting mitigations. One unusual characteristic of blue sky days is that approximately 60% of arriving aircraft are early.

Surface congestion management techniques are strongly dependent on airport geometry and operating procedures. Hartsfield-Jackson Atlanta International Airport (ATL) is currently the busiest airport in the world with almost 2,500 aircraft arrivals and departures daily carrying over 250,000 passengers. It has five major runways, two terminals with 7 concourses, and approximately 207 gates [2]. It is one of the most congested airports in the U.S. and has multiple documented cases of blue sky days [1].

II. Problem, Need & Scope

Frequent congestion at major U.S. airports results in Inefficiencies on the airport surface, which leads to increased aircraft taxi time and consequently fuel burn. Hartsfield-Jackson Atlanta International Airport (ATL) suffers from surface congestion and has many documented cases of blue sky days with little to no mitigation strategies.

There is a need to design an integrated airport surface simulator that can re-create airport surface events to assist in identifying mitigations for extreme surface congestion at ATL.

The scope of the project is limited to the design of a model that re-creates events on the surface of ATL airport, and provides results that demonstrates a realistic representation of the airport surface operations.

III. Requirements

The following high-level requirements were determined by the Airport Surface Group (ASG) through research and stakeholder interviews.

1. Project Requirements

1.1. The ASG shall develop an airport surface simulator of Hartsfield–Jackson Atlanta International Airport (ATL).

1.2. The ASG shall analyze data for blue sky days at ATL.

1.3. The ASG shall have biweekly meetings with the sponsor to provide status updates.

1.4. The ASG shall provide status briefings to the course instructor.

1.5. The ASG shall provide a final report of this study to the course instructor.

1.6. The ASG shall present the results of this study to the GMU SEOR faculty on May 9, 2014.

1.7. The ASG shall produce a website containing all final deliverables.

2. System Requirements

2.1. The system shall model aircraft kinematics on the airport surface.

2.2. The system shall model the surface configuration of ATL.

2.3. The system shall model surface traffic flows.

    2.3.1. The system shall model arrivals.

    2.3.2. The system shall model departures.

    2.3.3. The system shall model taxiway movement.

    2.3.4. The system shall model ramp movement.

    2.3.5. The system model gate movement.

        2.3.5.1.   The system shall model gate entry

2.3.5.2.   The system shall model gate occupation.

2.3.5.3.   The system shall model gate exit.

2.4. The system shall input Aviation System Performance Metrics (ASPM) data.

2.5. The system shall output the number of arrivals in a user specified time frame.

2.6. The system shall output the number of departures in a user specified time frame.

2.7. The system shall output the number of aircraft on the surface in a user specified time frame.

2.8. The system shall output aircraft taxi times in a user specified time frame.

2.9. The system shall provide a Graphical User Interface (GUI) depicting the traffic flow on the airport surface.

2.10. The system shall identify scenario surface counts in excess of user defined thresholds.

2.11. The system shall allow user control of time-based components.

2.12. The system shall be capable of identifying surface gridlock causes.

IV. Hartsfield- Jackson Atlanta International Airport (ATL)

It is one of the busiest airports in the world and suffers from surface congestion. Figure 1[4] shows the airport configuration with five parallel runways and 2 terminals (7 concourses) located in the center of airport. The innermost runways (8R/26L, 9L/27R) are generally used for departures, and the outer runways (26R/8L, 27L/9R, 28/10) for arrivals.
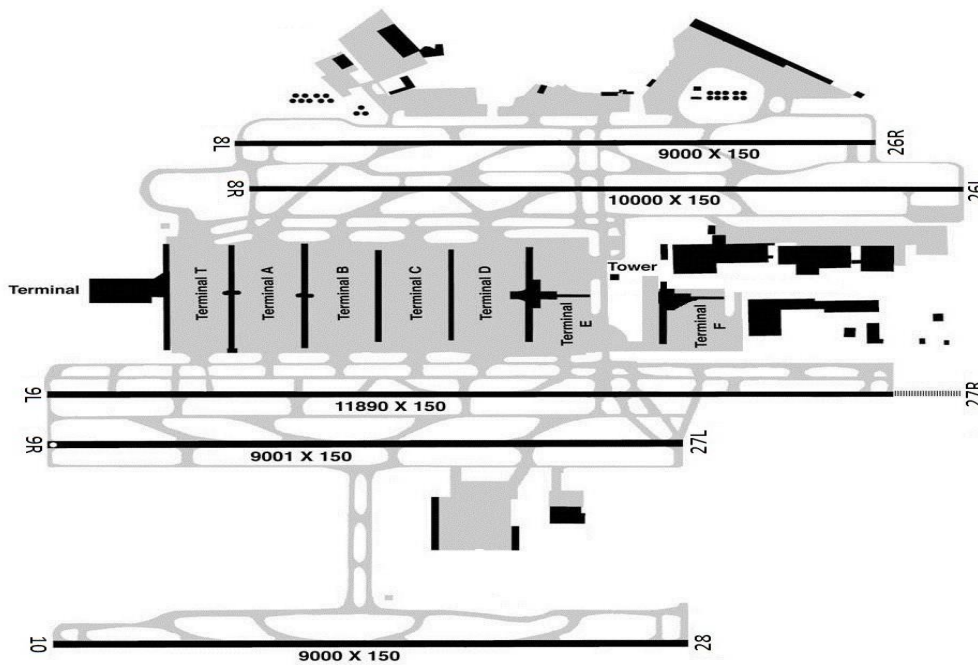

Figure 1: ATL Airport Configuration [4]

V. Technical Approach

The proposed methodology for ATL's surface simulator is shown in Figure 2.The simulation inputs, outputs, and controls are mapped out. As displayed in the diagram, there are two main models currently being developed, which are the Kinematics Model and the Atlanta Airport Surface Network Model.
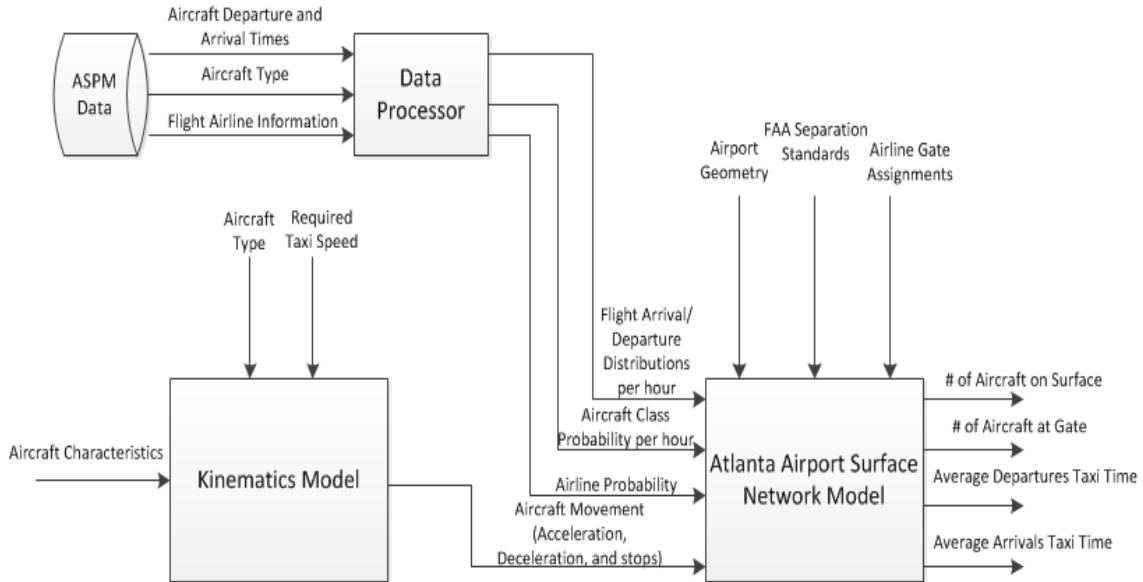

Figure 2: Method of Analysis

1. Aircraft Kinematics Model

As shown in Figure 2, an aircraft kinematics model is needed to accurately simulate aircraft movement between the nodes of the airport surface network. The model takes the aircraft characteristics as an input, and is controlled by the aircraft type and the required taxi speed on the surface. The model is modified to account for aircraft in three different classes (small, large, and heavy), which is performed to reproduce realistic variance in surface kinematics and group aircraft with similar performance (e.g., acceleration). Aircraft characteristics (e.g., thrust, mass, wing surface area) for a regional jet (RJ), Boeing 737, and Boeing 747 are incorporated to represent small, large, and heavy classes respectively. Additionally, a more advanced control algorithm will be implemented to easily accommodate acceleration between two speeds (e.g., between turn speed and maximum taxi speed).

A widely used aircraft equation of motion [3] below has been adapted for the purpose of the model.

$$ma = F_{net} = T cos\alpha - D - W sin\gamma$$

where:

$m = $ *aircraft mass (kg)*

a = acceleration (m/s^2)

F_{net} = net force in the longitudinal (along track) direction (N)

T = thrust (N)

α = angle of attack (radians)

D = drag (N)

W = aircraft weight (N)

γ = flight path angle (radians)

Per [3] expansion of the drag and weight components yield the following:

$$ma = T\cos\alpha - (1/2)c_D\rho v^2 A - mg\sin\gamma$$

where:

c_D = aircraft specific coefficient of drag (unitless)

ρ = air density (kg/m^3)

v = horizontal velocity (m/s)

A = wing surface area (m^2)

g = gravitational acceleration $(9.81\ m/s^2)$

An additional force for rolling resistance was added to more accurately represent movement on the surface:

$$ma = T\cos\alpha - (1/2)c_D\rho v^2 A - mg\sin\gamma - \mu(W\text{-}L)$$

where:

μ = coefficient of cumulative friction (unitless)

L = lift (N)

As lift is negligible while aircraft are taxiing the equation above transforms into:

$$ma = T\cos\alpha - (1/2)c_D\rho v^2 A - mg\sin\gamma - \mu mg$$

Solving for longitudinal acceleration yields:

$$a = [T\cos\alpha - (1/2)c_D\rho v^2 A]/m - g\sin\gamma - \mu g$$

In difference equation form acceleration may be represented as follows:

$$a = (v_n - v_{n-1})/(t_n - t_{n-1})$$

where:

t = time (s)

n = current value

$n - 1$ = previous value

Incorporating this representation of acceleration and solving for current velocity yields a difference equation for aircraft motion on the surface for use in a discrete time simulation:

$$v_n = v_{n-1} + (t_n - t_{n-1})[(Tcos\alpha - (1/2)c_D\rho \, v_{n-1}^2 A)/m - gsin\gamma - \mu g]$$

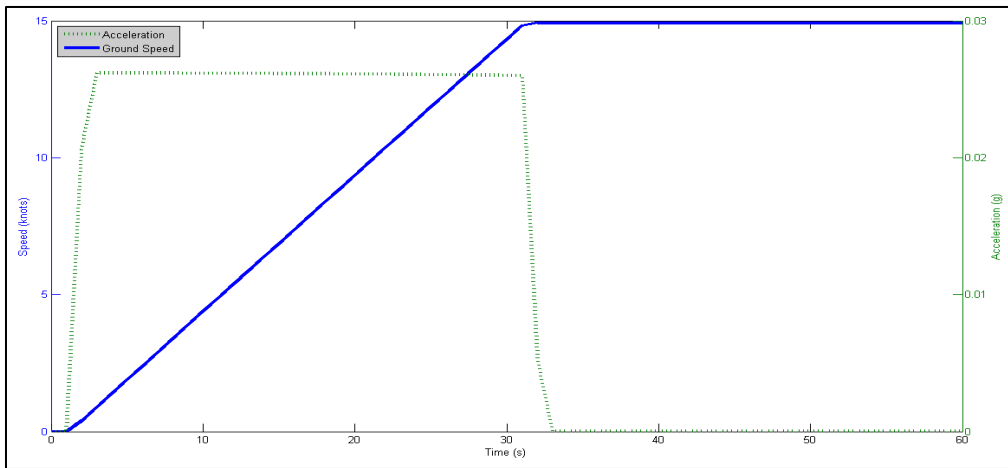Figure 3 contains sample output for a Boeing 737-900ER accelerating from a complete stop to a 15 knot taxi speed.

Figure 3: Kinematics Model Output for a Boeing 737-900ER

2. Atlanta Airport Surface Network Model

As shown in Figure 2, the network model takes inputs from the kinematics model and the data processor. It is controlled by the airport geometry, FAA separation standards to maintain safety, and airline gate assignments. The outputs of the model include the count of the aircraft on the surface, or at the gate. It also outputs the average arrival and departure taxi times.

The data processor utilizes the Aviation System Performance Metrics (ASPM) data, which contains aircraft arrival and departure times, aircraft type, and airline information. Using the ASPM data, the data processor generates distributions for arriving and departing aircraft every hour (inter-arrival and inter-departure times respectively). It also determines a probability for each aircraft class and for the airline arrivals and departures. Airline information will be used determine terminal/gate assignments such that aircraft for different airlines are not directed to airline-specific gate clusters (or ramp areas).

The network model will program aircraft objects to initialize at arrival runway end nodes navigating through the ramps, taxiways, reaching the gates, and finally deactivate at the nodes located at the beginning of departure runways. The model will be include all the components (e.g., motion, collision avoidance logic, priority logic) necessary to provide a realistic representation of the airport surface operations at ATL.

Preliminary work suggests that a graphical user interface is needed to enable faster validation of functionality (e.g., in comparison to analysis of numeric output alone) and provide a visualization component for the end user.

The tool will include a component that enables the end user to modify relevant parameters (e.g., input data, changes to hypothetical scenarios, timing information) and provide feedback regarding the impact of these changes (e.g., change in surface counts, taxi times).

The verification of the network model parameters is performed using the Airport Surface Detection Equipment, Model-X (ASDE-X), which incorporates real-time tracking of aircraft on the surface to detect potential conflicts and monitor conformance. However, the data generated by it can be used for surface operations analysis. The parameters in ASDE-X include each aircraft's position, and velocity, which are utilized to identify the path any aircraft used to reach its assigned gate or departure runway. It is also used to identify the locations where aircraft remained motionless during extreme congestion.

On the other hand, verification of the network model outputs is to be done utilizing the ASPM Data reports that provide the average taxi-in and taxi-out times for any given day.

VI. Expected Results

The expected results of this study are to provide a realistic method of simulating airport surface operations in Atlanta-Jackson Hartsfield International Airport to assist our stakeholder in identifying mitigation strategies to the problem.

VII. Project Plan

1. Work Breakdown Structure

A Work Breakdown Structure (WBS), depicted in Figure 4, was developed to assist in planning, evaluating, and managing project tasks. The WBS has been decomposed into five components: project management, deliverables, frond end analysis, back end analysis and development, and solution. Project management consists of planning, team meetings, Earned Value Management (EVM), and sponsor evaluations. The purpose of these tasks is to ensure the project team remains focused on sponsor needs, within budget, and on time. Deliverables include status briefings, written reports a project website, and peer evaluations. The front end analysis consists of research, problem definition, scope determination, and requirements formulation. It also includes data analysis, which is critical for the back end analysis and development that encompasses the design, coding, and testing of the software. The solution includes analysis of results and group recommendations for the problem.
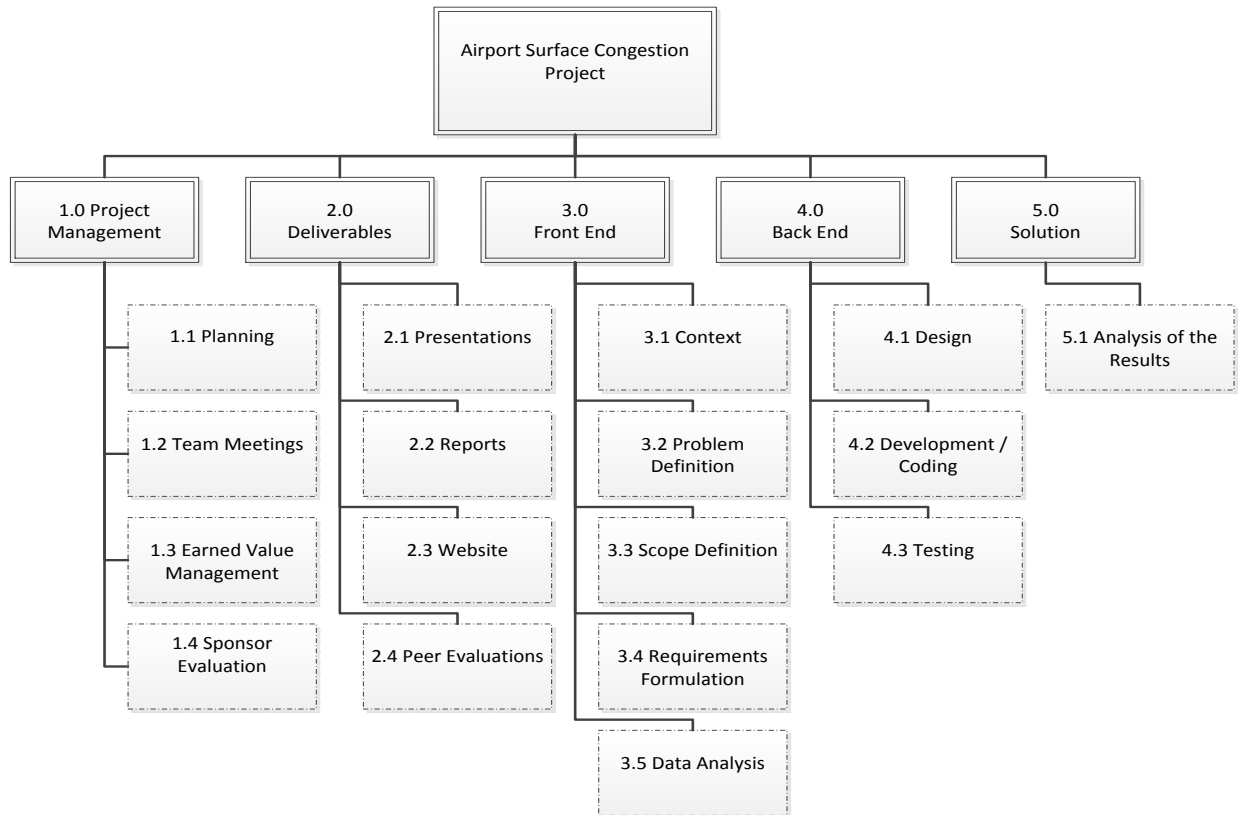

Figure 4: Project Work Breakdown Structure

2. Schedule

The project schedule was implemented as a Gantt chart as shown in Figure 5. The schedule was set to 16 weeks. The duration of each task in the WBS was estimated. The project progress will be tracked throughout the semester using EVM
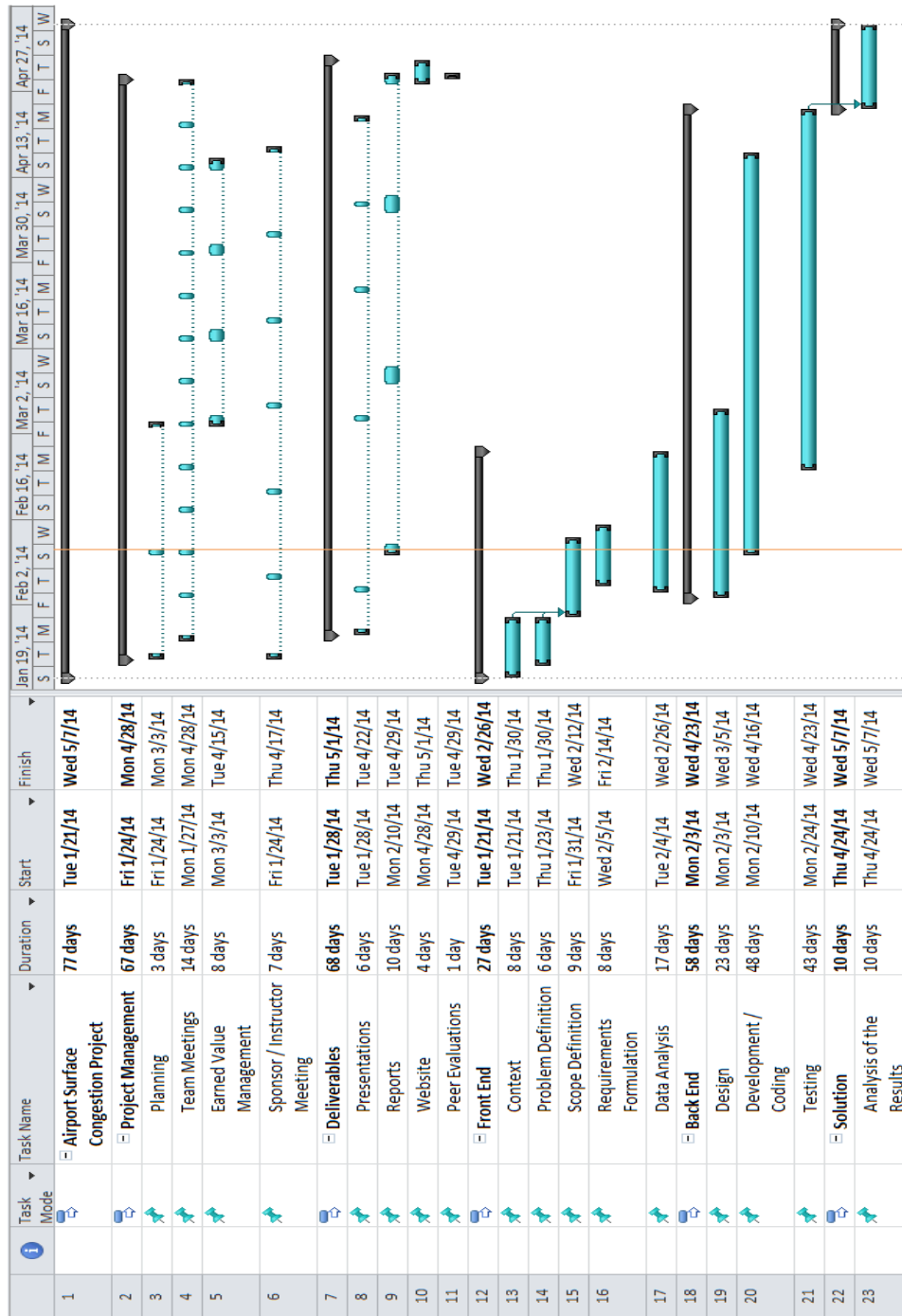

Figure 5: Schedule & Gantt Chart

11

3. Risks & Mitigations

There are also some risks involved in the project. The table below describes each risk as well as the severity and mitigation strategy for that risk.

Table 1: Risks & Mitigations

ID	Risk	Severity	Mitigation
1	Failure to complete the entire Atlanta Airport model due to time constraints.	High	Based on a meeting with an SME, the airport has two control towers each controlling half of the airport. Once the medium complexity network (top half of the airport) is finished, it is safe to assume that the portion of the model will still provide reliable results.
2	Failure to integrate the kinematics and network model	Medium	Use constant speeds for each aircraft class
3	Failure to verify and analyze the models.	Medium	Allocate time for testing and analysis in order to show the capability and results of the work accomplished.
4	Having incompatible code that makes the models difficult to integrate.	Small	Attempt to implement all of the models and code in a single language (Matlab) for easier integration.

VIII. References

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

[2] AirNav, LLC, 2013, KATL - Hartsfield - Jackson Atlanta International Airport, available: http://www.airnav.com/airport/KATL

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

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