2015-2016 ACRP University Design Competition

Just in Time

Concept for Improved Airport Operations

Design Challenge

Airport Operation and Maintenance

University

Georgia Institute of Technology

Undergraduate Team Members

Madison Luther

Alexander Naber

Matthew Stout

Eric Koob

John Amin

Faculty Advisor

Dr. John-Paul Clarke

Executive Summary

Just in Time is a concept designed to drastically improve the current state of commercial airport operations, taking into account nearly every party involved in and impacted by commercial airline travel. This concept consists of two main parts: the passenger tracking and notification system (PTNS) and a network of automated electric tugs for aircraft towing. The purpose of the PTNS is to reduce the time that passengers spend at the gate before boarding by ensuring that they have updated flight information. A corresponding cellphone app notifies the passengers when they should head to their gate for boarding. The notification time is based on the passenger's location in the terminal and the flow of the other passengers around the terminal. The PTNS will forecast the security wait time, taking that time into account when notifying passengers who have not gone through security. The purpose of the network of tugs is to automate all aircraft operations on the airport surface to reduce taxi time, minimize fuel spent during taxi, and improve safety on the surface. A scheduling algorithm determines the ideal times for the aircraft to pushback from the jetway. The central management system (CMS) sends the individual tugs their schedules and taxi routes. On the surface, the tugs are tracked and guided by differential GPS receivers and transmitters. Each tug is fitted with an inertial reference unit and lane-following technology to confirm the validity of the GPS data. The tugs' GPS data, alongside ADS-B and ASDE-X data, is sent to ATC on a taxi display system. If conflicts arise among the tugs, they are resolved locally through an algorithm that determines the most time efficient course of action, taking into account priority and weight class of each aircraft involved. Runway incursions will be greatly reduced because the tugs stop before crossing any runway unless ATC confirms that the aircraft is cleared to cross. Both the pilots and ATC will have the ability to stop the tug at any moment to ensure the safety of the aircraft and its passengers.

Table of Contents

List of Tables

List of Figures

1. Problem Statement and Background

Flights often require that the passengers arrive at the gate 15 minutes before the boarding process is forecasted to begin. When the flight becomes delayed, whether the delay is 10 minutes or 1 hour, passengers are often told to come back to the information desk at the gate in a specified amount of time to receive updated information on the delay. The Just-in-Time concept will give the passengers access to up-to-date information on their flight and reduce the number of frustrated uninformed passengers that airline employees encounter. Even with long delays or layovers, passengers often do not utilize the amenities that major airports have to offer due to the fear of missing the flight. The Just-in-Time cell-phone application will give the passengers the freedom to leave the gate without this fear.

At airports with large amounts of commercial airline travel, ground control is often not run as efficiently as possible, causing aircraft to have to wait on the taxiway before receiving their takeoff clearance. The average taxi-out times for some of the largest US airports in 2013 are shown in Table 1 below (‘Taxing Times”). The scheduling algorithm that the Just-in-Time concept employs will reduce these taxi times by minimizing the delays on the airport surface.

Table 1. Average Taxi-out Time for the Largest US Airports in 2013

Airport	Taxi-out Time (minutes)
Hartsfield-Jackson Atlanta International	18.2
Chicago O’Hare International	16.7
Dallas/Fort Worth International	14.5
Los Angeles International	15.4
John F. Kennedy International	25.8

Runway safety is one of the most important items to the Federal Aviation Administration. The safety of the runway is determined by monitoring the frequency, severity, and type of runway incursions (“National Runway Safety Plan”). In 2015, there were a total of 1456 runway incursions in the United States (“Runway Incursion Totals”). Table 2 below breaks down these runway incursions into three types of surface events: operational incidents, pilot deviations, and vehicle/pedestrian deviations. Operational incidents which are “attributed to ATC action or inaction” and pilot deviations which are “actions of a pilot that violates an Federal Aviation Regulation” together make up a large majority of the total runway incursions (“National Runway Safety Plan”). The Just-in-Time concept will greatly reduce the number of runway incursions in these two categories through a network of fully autonomous aircraft tugs.

Table 2. Runway Incursion Totals for Fiscal Year 2015 (“Runway Incursion Totals”)

Region	Operational Incident	Pilot Deviation	Vehicle/Pedestrian Deviation	Total
Alaskan	10	34	13	57
Central	9	18	4	33
Eastern	46	78	21	145
Great Lakes	43	106	43	192
New England	18	22	4	44
Northwest Mountain	35	78	22	125
Southern	62	168	38	268
Southwest	26	121	42	189
Western Pacific	82	256	65	403
Totals	**321**	**881**	**252**	**1456**

2. Literature Review

In the literature review for the Passenger Tracking and Notification System, passenger tracking and flight app examples were found in numerous airports around the world. There are a multitude of apps available today that provide useful information to passengers at an airport. Some apps can track planes and forecast arrival times while others can estimate security wait times and still others can provide information on products and services available in your terminal. Even major airlines like Delta, British Airways, and Southwest have apps, because companies know that it's of the most effective ways to reach its passengers and customers. One major vein of theses flight information apps involves estimating the time it takes to get through security or to the gate. This is where passenger tracking becomes very useful. By looking at the flow of passengers through the airport, multitudes of information can be extracted.

Some major airports have already begun to implement passenger tracking systems. For example, in 2015, new sensors were installed in Brussels Airport to track wireless devices. These sensors collected the MAC addresses of the devices at multiple points to see how long it took a passenger to travel from one point in an airport to another. With this information, the airport would be able to improve resource allocation in order to shorten queues and prevent bottlenecks. The Brussels Airport also used this method in their security checkpoints and baggage reclaim areas.

A very similar method of passenger tracking was also demonstrated in 2012 in Sydney's international airport. Passengers were tracked as they travelled from their gates to immigration. By tracking a device, the researchers were able to come up a travel time for the trip and thus determine a passenger's average walking speed. By tracking many devices over a period of time the researchers were able to produce distributions of walking speeds that described the movement of the crowds.

In the literature review regarding aircraft towing systems, the team quickly found that the mechanical aspects of the tugs that were defined as constraints and goals already existed and in some cases were currently being used. Thus, the team decided to focus on the automation of the network of tugs. Nonetheless, different types of tugs were researched to learn about their successes and shortcomings.

The implementation of the Taxibot into commercial airports is one of the biggest steps towards automating towing operations despite still requiring pilots to control all of taxi operations. Taxibot is used in many airports around Europe and are operated by the pilot with an onboard supervisor in the Taxibot itself. Numerous articles have shown that experts expect each Taxibot to cost approximately one million dollars ("Taxibot Green Taxiing"). While seemingly expensive for a single aircraft tug, the fuel savings from the implementation of these tugs boast to be substantially larger.

Mototok is a company that has designed automated tugs to move aircraft around hangars. Through both the use of careful layout and a line-following system, these tugs are able to tow planes into the hangar and safely position them within not only inches of the walls, but inches of each other as well. This line-following technology and ability for precise movements are key aspects of this tug. While it is unable to go over speeds of a few miles per hour, the important take away is Mototuk's ability to pull large planes along very specific paths in precarious situations (Mototok.com).

3. Problem Solving Approach

The way a solution to a problem is developed is incredibly important in any field, especially engineering. An organized, methodical approach is proven to be the most efficient and effective. This section of the report goes into how the team divided the individual responsibilities and how the standard engineering design process was applied to the Just in Time concept.

3.1 Team Composition

Despite all being Aerospace Engineering majors, each of the team members bring different expertise and interests to the table. Each team member was involved in all of the decisions made on the design. However, for workflow management, a point person for each facet of the concept was set. Figure 1 below shows this breakdown.

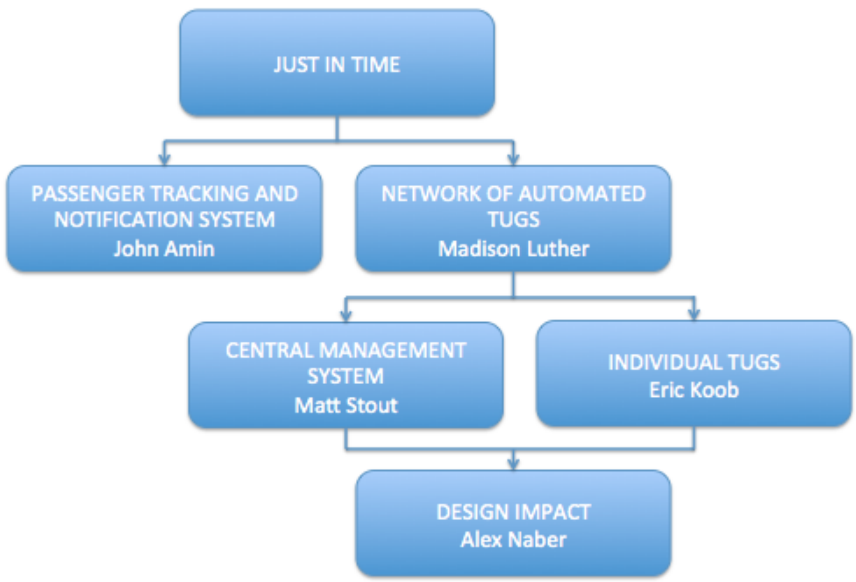

Figure 1. Team Composition Breakdown

John Amin was selected as the lead for the Passenger Tracking and Notification System for his interest in simulation and flow patterns. John hoped to learn a new skill in taking on this responsibility. Madison Luther is a commercial pilot and loves airport planning and management. With the most experience with commercial airports, Madison became the lead for the Network of Automated Tugs. Last spring, Madison interned at Gulfstream Aerospace Corporation in the simulation and software engineering department. This experience made her the lead on the taxi display system as well. Matt Stout is a Georgia Tech Aerospace Systems and Design Lab undergraduate researcher. Matt's exposure to complex algorithms in his research and his interest in automation lead him to be the Central Management System head. Alex Naber was a member of a team of students designing space mission to obtain a volcanic rock sample from the Lunar Aitkens-Basin, where he specializes in risk assessment, CAD production, and fiscal analysis. Alex's previous work in risk assessment and fiscal analysis is the reason he became the Design Impact leader. Eric Koob was a project member on a Person Air Vehicle (PAV) research and design team and was also a part of the Lunar Aitkens-Basin mission design team, where he focused on telecommunication and navigation systems. Eric's experience with communication and navigation lead him to be the head of the Individual Tugs.

3.2 Engineering Design Process

The Just in Time concept was brought to life and developed through the traditional engineering design process, shown in Figure 2 below. The team showed early interest in designing fully autonomous aircraft tugs. From here, the problems that a network of tugs could solve or reduce were defined based on the specified technical design challenges. The team began researching these problems and the current approaches attempting to solve them. The highlights of this research process are explained in the Problem Statement and Background and Literature Review sections.

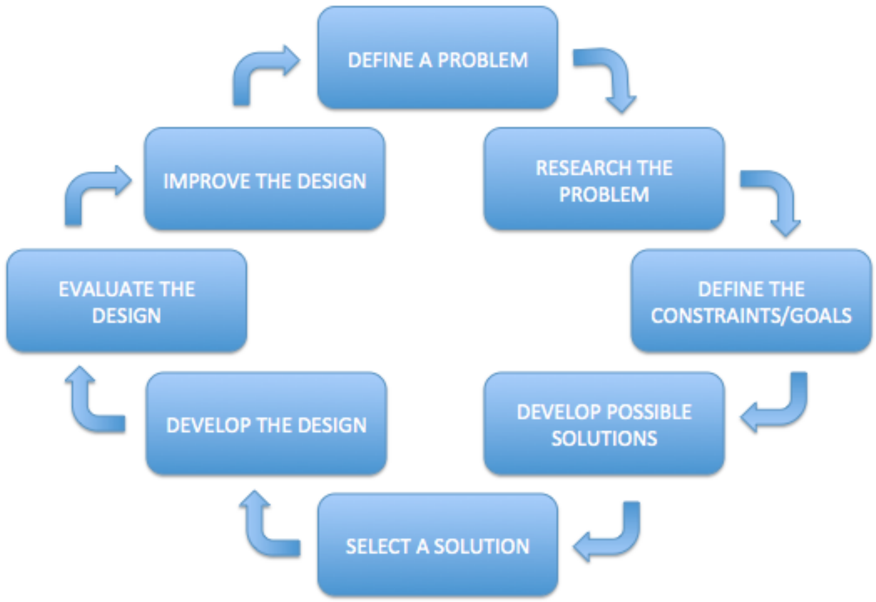

Figure 2. Engineering Design Process

Table 3. Initial Constraints and Goals

System	• will minimize all of the aircraft's taxi time. • will minimize fuel spent during taxi.
Tugs	• will tow the aircraft at the current engines-on taxi speed. • will be completely autonomous, requiring no pilot control.

The solution selected to best solve these problems was a network of automated tugs connected to a central system. The key improvement made to the design was the addition of the Passenger Tracking and Notification System (PTNS). Focusing on the time saved by minimizing taxi time, the team thought to continue the design into the terminal. Thus, the final design saves time for the passengers throughout their entire airport experience.

As shown in Figure 2 above, the engineering design process used was a loop. Throughout the design of the network, problems with the design or forgotten components were noticed. Thus, the loop began again. Most of the new problems discovered and thus new improvements came along during the safety risk analysis. Noteworthy improvements after the design had been finalized include the addition of proximity sensors around the tug to reduce collisions with foreign object debris and the development of a system protocol for emergency landings. Many of the improvements addressed additional needs in airport operations.

4. Safety Risk Assessment

The mission of the FAA is "to provide the safest, most efficient aerospace system in the world" ("Safety"). In any design to be implemented into United States airports, safety must be a priority. As outlined in FAA Advisory Circular 150/5200-37, there are five phases to the safety risk management (SRM) process, shows in Table 4 below ("Advisory Circular").

Table 4. Five Phases of the SRM Process

Phase 1	Describe the system
Phase 2	Identify the hazards
Phase 3	Determine the risk
Phase 4	Assess and analyze the risk
Phase 5	Treat the risk

This safety risk assessment process was completed in detail for the Just-in-Time concept. This section of the report briefly touches on the primary safety issues that were addressed throughout the design process. More specific details on how the risks are mitigated through the design will be provided later in the Design sections.

4.1 Internal Tug Issues

With any mechanical device or system, internal issues are unavoidable. For each individual tug, a multitude of problems can arise ranging from a flat tire to electrically overheating. Using the mechanical design of the Taxibot, to which these basic mechanical problems are assumed to be taken into account, the team added an internal health monitoring system for additional safety. This monitoring system includes temperature and pressure sensors, battery life monitors, etc. If at any point during an assignment a tug is deemed unfit to tow the aircraft, the tug will stop and the nearest unassigned tug will take its place to complete the assignment.

4.2 Loss of Communication

While a complete loss of communication between an individual tug and the CMS is highly unlikely, a protocol was designed for if these possible communication losses occur. If at any point in a tug's assignment the tug loses communication with the CMS, the tug will stop and the pilot will be notified. The tug and CMS will then run an algorithm to determine if it is faster for the pilot to taxi to the runway engines-on or for the nearest unassigned tug to complete the assignment. The most time efficient action will then be commenced.

4.3 Foreign Object Debris Collisions

There are a series of proximity sensors around the tug. The sensors on the front of the tug are connected to the autonomous braking system. Thus, the tug will complete an emergency stop if it is going to collide with something on the ground. If any of the proximity sensors detect an object within a set range of the aircraft, the pilots will be notified on their taxi display system to increase their ground situational awareness. Both pilots have the ability to stop the tug at any point.

4.4 Conflicts Between Tugs

Each individual tug will broadcast its current position, velocity, acceleration, and taxi route to every other tug. This allows the tugs to forecast any possible conflicts or collisions. If a conflict arises, the individual tugs involved will resolve the conflict locally (among themselves). The tugs involved will run the conflict resolution algorithm to determine the appropriate response. Ideally, this would result in one or more tugs making speed changes to avoid the conflict so that no aircraft has to stop on the airport surface.

4.5 Runway Incursion

The CMS assigns each aircraft the taxi routes after the pushback times are determined. If any taxi route involves crossing an active runway, the tug's guidance system assumes that it must stop and hold short of the runway(s). When the tug is approaching the runway, before it must begin slowing down to hold short, ATC has the opportunity to clear the tug to cross on the user interface. The runway crossing clearance box on the user interface will update in real-time the time that the tug would cross the runway using the tug's current position relative to the hold-short line and its current velocity. If ATC denies the request or no answer is inputted, the tug stops.

4.6 Risk Matrix and Assessment

Figure 3 below shows the risk assessment matrix that was completed for the network of automated tugs.

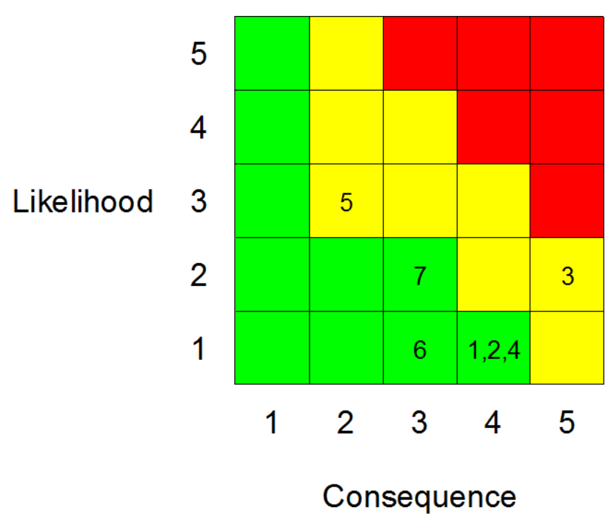

Figure 3. Risk Assessment Matrix

A risk matrix evaluates each risk based on the likelihood of each risk and the severity of the consequences that can result from the risk. The risks that were mentioned in the previous sub-sections of the report were generalized into seven different types of failures and are labeled as such:

1) Communication loss to the central computer
2) Communication loss with other tugs
3) Sensor failure
4) Algorithm error
5) Differential GPS failure
6) Human error
7) Mechanical system failure

The loss of communication to the central computer and other tugs can cause several different problems, including runway incursion, which is why the severity of these problems are both ranked at a four. However, both of these problems are extremely unlikely. Mitigations have also been implemented to prevent many of the problems that could occur from communication loss. An algorithm error also falls under this category because it could cause runway incursion, but it is also extremely unlikely. These risks are relatively not concerning. If a sensor were to fail, some very disastrous things could occur, such as human injury or plane destruction, so it was ranked as a five for severity. This sensor failing is unlikely so it is an overall moderate risk. A differential GPS transmitter or receiver error is completely plausible. It could happen, and it could cause some big problems as far as runway incursion or the plane taxiing off of the taxiways. This issue is mitigated by the fact that four different GPS devices are used in the tug, and it is very unlikely that all four will fail simultaneously. The inertial reference units and lane-following technology are also mitigation factors that make complete location and navigation failure extremely unlikely. Human error is always a concern when it comes to new system; this could cause many problems, but since it can be easily fixed, it has a severity ranking of three. It also unlikely that with proper training someone would make a large mistake. The taxi display system is a mitigation factor for air traffic controller error. A mechanical system failure is slightly more severe than a human error, but it is equally unlikely. The internal health monitoring system is a mitigation factor for failure of any of the mechanical system components.

5. Design

This section of the report goes through each component of the design. This includes the passenger tracking and notification system, network of automated tugs, and taxi display system.

5.1 Passenger Tracking and Notification System (PTNS)

The primary idea behind the Passenger Tracking and Notification System (PTNS) is more accurately determining the time it would take any passenger in an airport of any flight to reach the appropriate gates. This can be done by tracking the flow of passengers through the airport. Airline passengers have the ability to download a free app, which would give them updated information about their flight. By inputting information on their flight (either manually or automatically through ticket purchase and opting into the PTNS), the passenger will receive updates on arrival of the flight: possible gate changes, delays, and other pertinent information. In addition, the system monitors the passenger's whereabouts within the airport and gives them directions to their gate, estimated security wait times, and other useful information about the terminal itself.

5.1.1 Tracking Passenger Locations

To bring the app to life, the passengers currently in the terminal need to be tracked. There are two groups that will be tracked. One group is the passengers of a specific flight. The other group is the remaining people around the airport. These two groups are tracked in separate ways so that the system is robust. For the passengers of the specific flight, the app they have downloaded onto their smartphone will request user permission for “Find Location Access”. This will give the app location information from both the phone network and GPS. As the phone is carried around by the passenger, it will continue to update its location, allowing for precise tracking, resulting in accurate directions and time estimates that can be sent to the passenger.

The other group will be the mass of people, not passengers of the specific flight. This is known as the crowd. These people will be tracked in a way similar to that discussed in the literature review above: by MAC address. As the wireless device looks for the Wi-Fi networks to join, it sends out a request probe to try to establish a connection to a network. This probe contains the device's MAC address, a sequence of characters that uniquely identifies an electronic device. Sensors can detect these probes and store the MAC address of the device trying to connect. As the person with the cellphone walks around the airport, different sensors receive the probe. Multiple sensors in an area receiving a probe with the same MAC address around the same period of time can be used to triangulate a person’s location. By comparing multiple points where a person was triangulated to, the time it took that person to travel from point A to B can be determined. This process can be used to track an individual throughout the airport. If this is applied to all cellular devices in the airport, the general flow of the crowd can be determined.

We can take the data collected from both groups and use it to in a variety of ways. For the traveler, we can plan the most efficient path to a destination, or forecast wait times at security checkpoints or other hold-ups. This information can also be used by the airport so that resources can be reallocated more efficiently to ease congestion and improve the overall passenger experience.

5.1.2 Forecasting Security Wait Time

Passenger tracking allows the system to determine how long it takes a person to get from point A to point B. This method can also be applied to determining security wait times. A rough estimate on how long it takes a person to move through a queue by tracking their cellphones as they pass through the checkpoint can also be determined. The system can also make an estimate on how many people are in a given area waiting in line by looking at all the unique devices sending out probes. This information can be used in combination to determine the average rate at which people pass through a security checkpoint. While this is useful, the system can go beyond this idea and can produce predictions for wait times later on.

In order to make better predictions on future wait times, a model will be developed. A preliminary model using Arena Discrete Event Simulation Software that modeled people passing through check in and then security was created (shown in Figure 4 below). The flow of people entering the airport was assumed to vary with peak arrivals occurring in the morning and early afternoon. The simulation determined how long it would take the passengers to travel from the airport entrance to their terminal based on check-in lines and security wait times. By taking a model and substituting inputs obtained by passenger tracking and crowd flow, a more dynamic model that is able to more accurately predict the amount of time it takes to get through security checkpoints at the present time as well as the future can be developed.

This information can be used by the airport to determine if it should reallocate resources to shorten lines and prevent potential bottlenecks. This information can also be used by the passenger tracking app to determine how long it will take to get from their current position through security to their respective gates.

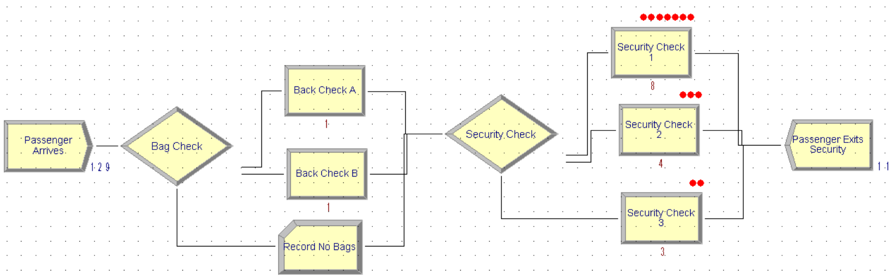

Figure 4. Arena Simulation

5.1.3 Mobile Phone Application

The app will take the passenger tracking information and the subsequent forecasted security wait times to inform the passenger about how crowded the airport is and how much long it will take to get to their gate. It does this by taking the forecasted security and check-in wait times and adding the time it takes to walk to your gate while taking into account your pace and general crowd density, The app could also determine the quickest route and provide directions much like the navigation systems in most cars. The app will also provide information about flight like gate changes, delays or expected boarding times. Once the taxi schedule for the flight is determined and the departure time is determined, passengers using the app will be notified, the app will also give notifications when boarding begins and also warnings as the boarding period ends. This allows passengers to use their time more effectively without having to wait around the gate, listening to announcements. Passengers can do whatever they want in the airport and will be notified when they have to return to the gate just in time for their flight.

5.2 Network of Automated Tugs

The second facet of the Just-in-Time concept is a network of automated electric tugs. Each aircraft will be towed from jetway to runway (and from runway to jetway) by its assigned tug. These tugs will communicate with the central management system (CMS) to receive their pushback schedule. At the specified time, the aircraft will pushback and proceed on its given taxi route to the runway hold short line. The pushback times are designed to minimize the taxi time for each aircraft by reducing the delays on the airport surface. When a tug completes an assignment, it will return to the central charging station until it is assigned to another aircraft. The new aircraft may be assigned by the CMS immediately after an assignment is completed, during the commute to the charging station, or while at the charging station. In the same way that the aircraft are assigned taxi routes to and from the runway, tugs are given routes to follow in between assignments.

5.2.1 Central Management System (CMS)

The CMS assigns each aircraft its pushback time and taxi route. To avoid traffic and congestion, two algorithms will be developed. The first algorithm creates a schedule and taxi routes for the tugs. An algorithm with this level of complexity will have a long computational time, of up to 15 minutes. To remain as accurate as possible, the algorithm will need to be run at least once an hour to account for unforeseen changes in schedule. However even with the first algorithm being run every hour it will not be able to resolve small changes in schedule such as a plane arriving a little early or a little. To solve for this we will need a second algorithm with a small computational time to resolve conflicts where one aircraft or more is off of the first algorithms schedule.

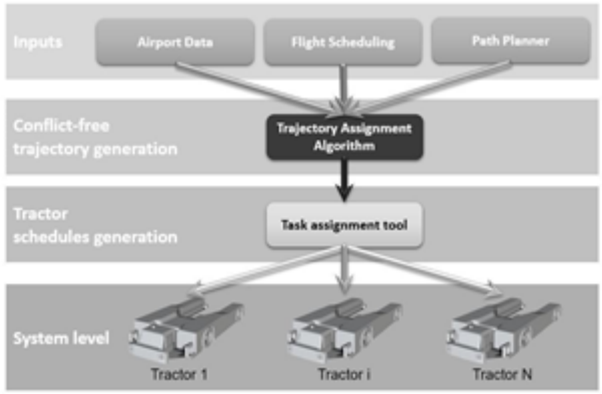

Figure 5. Scheduling Algorithm Breakdown

As shown in Figure 5, there are three inputs to the first algorithm: airport data, flight scheduling, and a path planner. Airport data includes information such as number of tugs, features of tugs, and waypoints to be used in the path planning. The flight schedule includes time related information for every aircraft. The path planner finds every possible path for an aircraft to take form its current position to ending position. It finds all possible routes because the shortest route might not be the fastest route.

The algorithm is a particle swarm based algorithm. In this particle swarm, each particle represents a solution to the algorithm. Each particle contains 3n elements. N is the number of tugs in the system. The first 3rd of the particle contains routing information for tugs to pick up planes. The 2nd 3rd of the particles contains information relating to the tug moving a plane. The last 3rd contains information for the tug dropping off the plane and moving to a charging location. To find the particle solution that is the best you need a way to compare different particles. Particle swarm algorithms do this using a value called the fitness value.

$$F = \frac{1}{K1 * Cost + K2 * Penalty}$$

The fitness value is calculated if the equation above. A higher fitness value means a particle is better. The cost represents the cost of energy consumption of the tug. A penalty is applied every time there is a chance of a plane collision. This is represented by a safe space around a tug. To find the solution without any penalties K_1 was left at 1 and K_2 was made 1 million. These K values force the best solution to have 0 penalties.

In each iteration several dozen particles are created. The algorithm remembers the best overall particle and the best particle of the iteration. Using these two particles the algorithm performs additional iterations to try and find other particles with lower fitness values. At the end of the iterations the best particles information is interpreted and distributed to each tug.

5.2.2 Individual Tugs

Basing the mechanical design of the tugs on the Taxibot, to which basic mechanical problems are assumed to be taken into account, the team added an internal health monitoring system for additional safety. This monitoring system includes pressure sensors to assess the conditions of the tires and temperature sensors to ensure that the tug's electrical components are not overheating. Each tug will also have a battery life monitor to ensure that the tug has enough charge complete its assignment and return to the central charging station. The last component of the internal health monitoring system is a traction monitoring system to ensure safety of the aircraft in inclement weather. Each of the sensors/monitors will have thresholds that can be set. The protocol for the tugs when reaching a threshold(s) can also be set. For example, if the tug is triggering a failsafe threshold before takeoff or will reach that point during the mission, then it will remove itself from its plane pulling duties in order to return to the charging station for charging or maintenance. The next available tug will be summoned to the gate in order to take over responsibilities. If at any point during an assignment a tug is deemed unfit to continue towing the aircraft, the tug will stop and the nearest unassigned tug will take its place and complete the assignment. If the original tug is not able to return to the central charging station for the required maintenance on its own, the internal health monitoring system will notify airport personnel to immediately remove the tug from the airport surface.

Each individual tug will broadcast its current position, velocity, acceleration, and taxi route to every other tug. This allows the tugs to forecast any possible conflicts or collisions. If a conflict arises, the individual tugs involved will resolve the conflict locally among themselves. The tugs involved will run the conflict resolution algorithm (a high speed computational algorithm) to determine the appropriate response. Ideally, this would result in one or more tugs making speed changes to avoid the conflict so that no aircraft has to stop on the airport surface. The conflict resolution algorithm takes into account the original schedule set by the CMS and the weight class of each aircraft involved to determine the response that will save the most time for all of the involved aircrafts collectively. Priority will always be given to the plane furthest behind in scheduling. That means that if both planes are late, the latter plane will get priority. It also means that if both planes are early the plane closest to the original algorithms expected time will get priority.

In terms of FOD removal from the airport surface and its relations to the tugs, the tugs can help contribute to keeping the taxiways clear. The tugs will have a series of proximity sensors. While on the airport surface, if any of the sensors detects foreign object debris they can provide the location of the incident to airport personnel automatically. This method will decrease the time of detection of these objects which will in turn decrease response time in clearing the taxiways of these objects. While this is not the intended purpose of the proximity sensors, it is an added benefit of this system. Figure 6 below shows the positions of the five LIDAR pucks on the tugs. Each puck is capable of 360 degree detection with a range of 100 m. The figure below shows an Airbus A380 with the pucks operating at an approximate range of 80 m. Four pucks are placed on the four corners of the tug, using 270 degrees of detection. The last puck is placed on the front of the tug in the center, with 180 degrees of detection. As shown in Figure 6, a complete circle around the aircraft can be created with the LIDARs, where every area around the tug is scanned by at least two pucks.

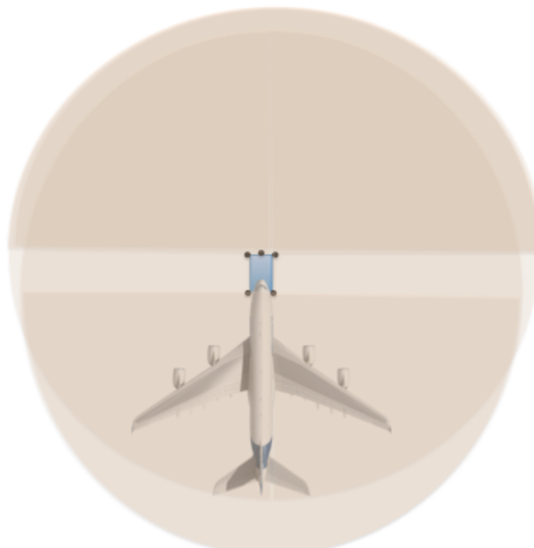

Figure 6. Proximity Sensors on Each Tug

Table 5. Individual Tug Technology Requirements Cost Breakdown

	Individual Cost	**Quantity (per tug)**	**Total Cost (per tug)**
Lane Keeping Assist System with Autonomous Emergency Braking	$5,000	1	$5,000
Traction Monitoring System	$800	1	$800
Tire Pressure Sensors	$300	1	$300
Temperature Sensors	$30	4	$120
Battery Life Monitor	$100	1	$100
Differential GPS Transmitter/Receiver	$100	4	$400

LIDAR Puck	$10,000	5	$50,000
Inertial Reference Units	$10,000	1	$10,000
Guidance and Conflict Resolution Software	$10,000	1	$10,000
Video Cameras	$1,000	4	$4,000
			$80,720

5.2.3 Taxi Display System

The taxi display system was developed as a stand-alone system to minimize the issues in integration with current ATC systems and the aircraft cockpits. For ATC, the application would be on a monitor. For pilots, the application would be on a tablet. While most commercial airline pilots use iPads or similar devices in the cockpit, the tablets are included in the upfront costs of the design. While the automation of the tugs decreases the workload for the both ATC and pilots on the ground, the taxi display system improves current ground operations beyond that. The users are notified when something important is about to happen. The taxi display system for the pilot's is designed to increase situational awareness during taxi. The layouts were developed with this in mind. The pilots always know what is coming next so they can focus their attention outside of the cockpit to increase airport surface safety.

5.2.3.1 Air Traffic Control Views

Figure 7 below shows the ATC views during an aircraft's taxi time. When the controller hovers over an aircraft, its pushback time and taxi route will appear if they have been assigned by the CMS. If the aircraft's taxi route involves crossing a runway(s), the taxi route will appear in red. Once the aircraft crosses the runway(s), the taxi route will turn from red to blue.

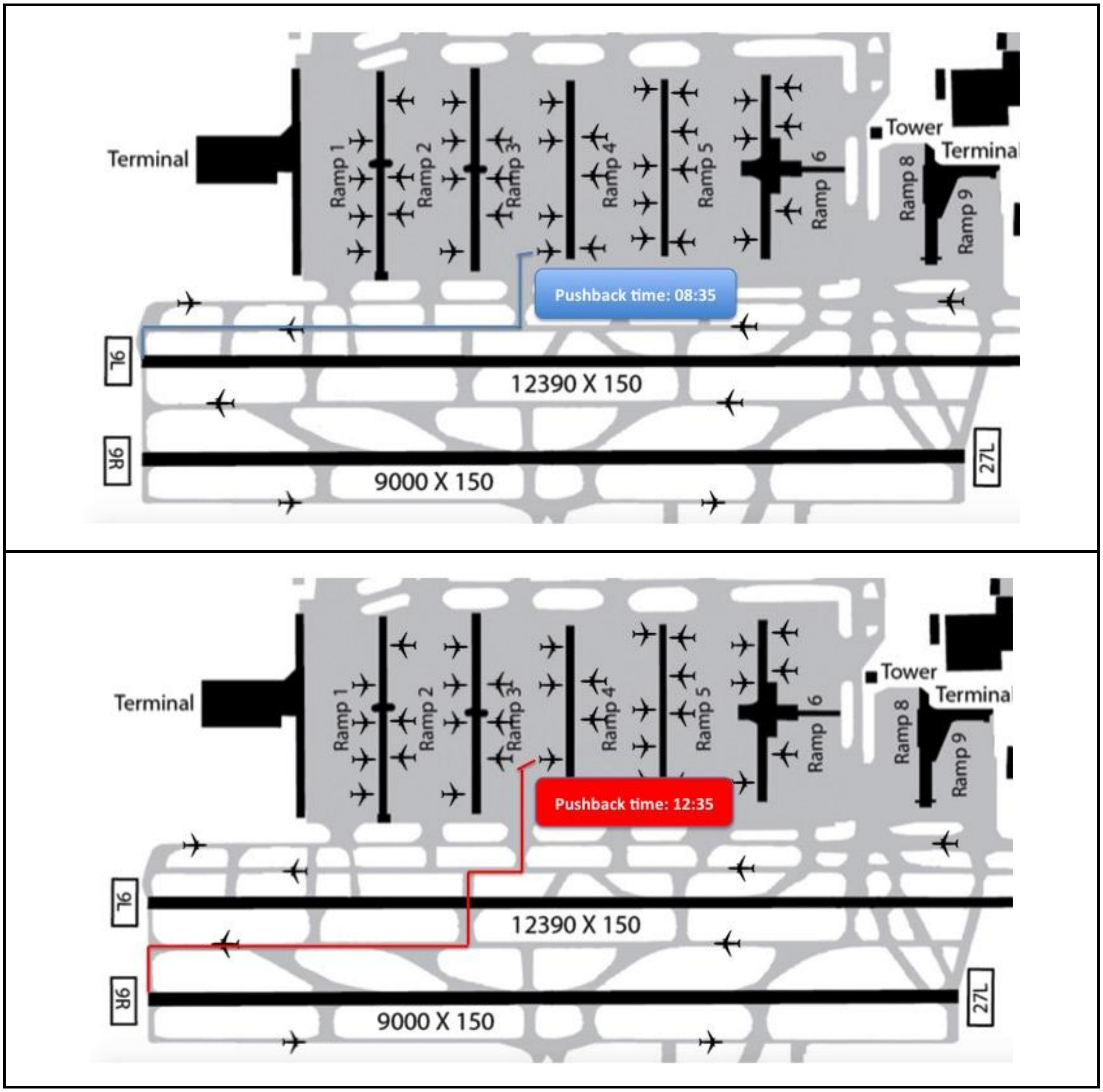

Figure 7. ATC Taxi Views

Figure 8 below shows the ATC runway crossing views. If any taxi route involves crossing an active runway, the tug's navigation system assumes that it must stop and hold short of those runway(s). When the tug is approaching the runway, before it must begin slowing down to hold short, air traffic control has the opportunity to clear the tug to cross the runway on the taxi display system. The runway clearance box (shown in Figure 8 below) on the user interface will update (in real-time) the time that the tug would cross the runway, using the tug's current position relative to the hold-short line and its current velocity. Runway clearances require two confirmation commands from the controller for safety. If ATC denies the runway clearance or no answer is inputted, the tug stops at the hold-short line. While the clearance box is available for ATC, the pilots will also be prompted on their taxi system display that the aircraft is approaching a runway and will also be given the real-time crossing estimate (shown in Figure 8 below).

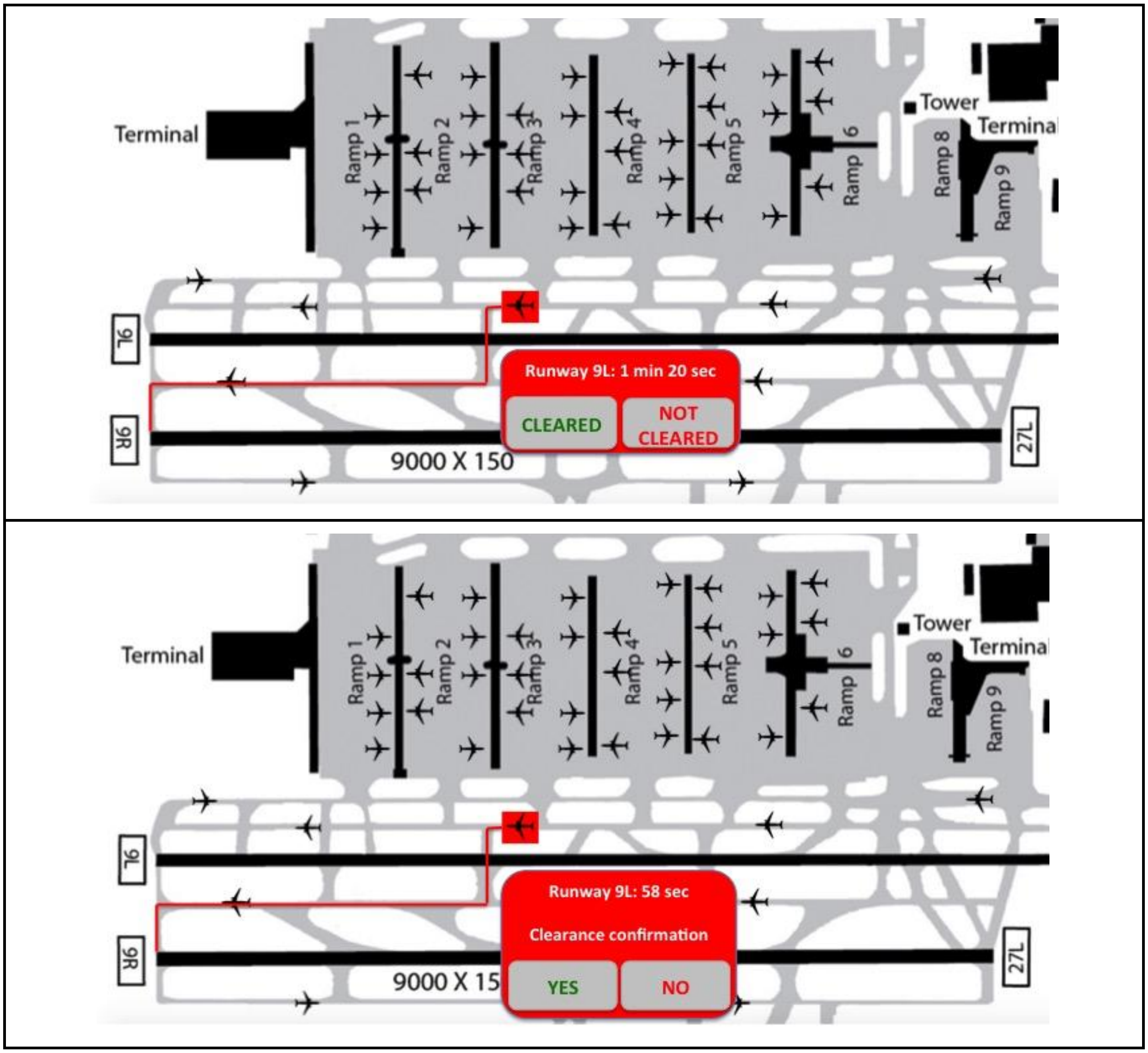

Figure 8. ATC Runway Crossing Clearance Views

Figure 9 below shows the ATC takeoff clearance views. In the same way that runway crossing clearances were given, taxi clearances are given by ATC. Two commands (clicks in different locations) are also required for takeoff clearances. For takeoff, the time estimate includes the tug slowing down to stop at the hold short line and the time for the tug to detach from the aircraft.

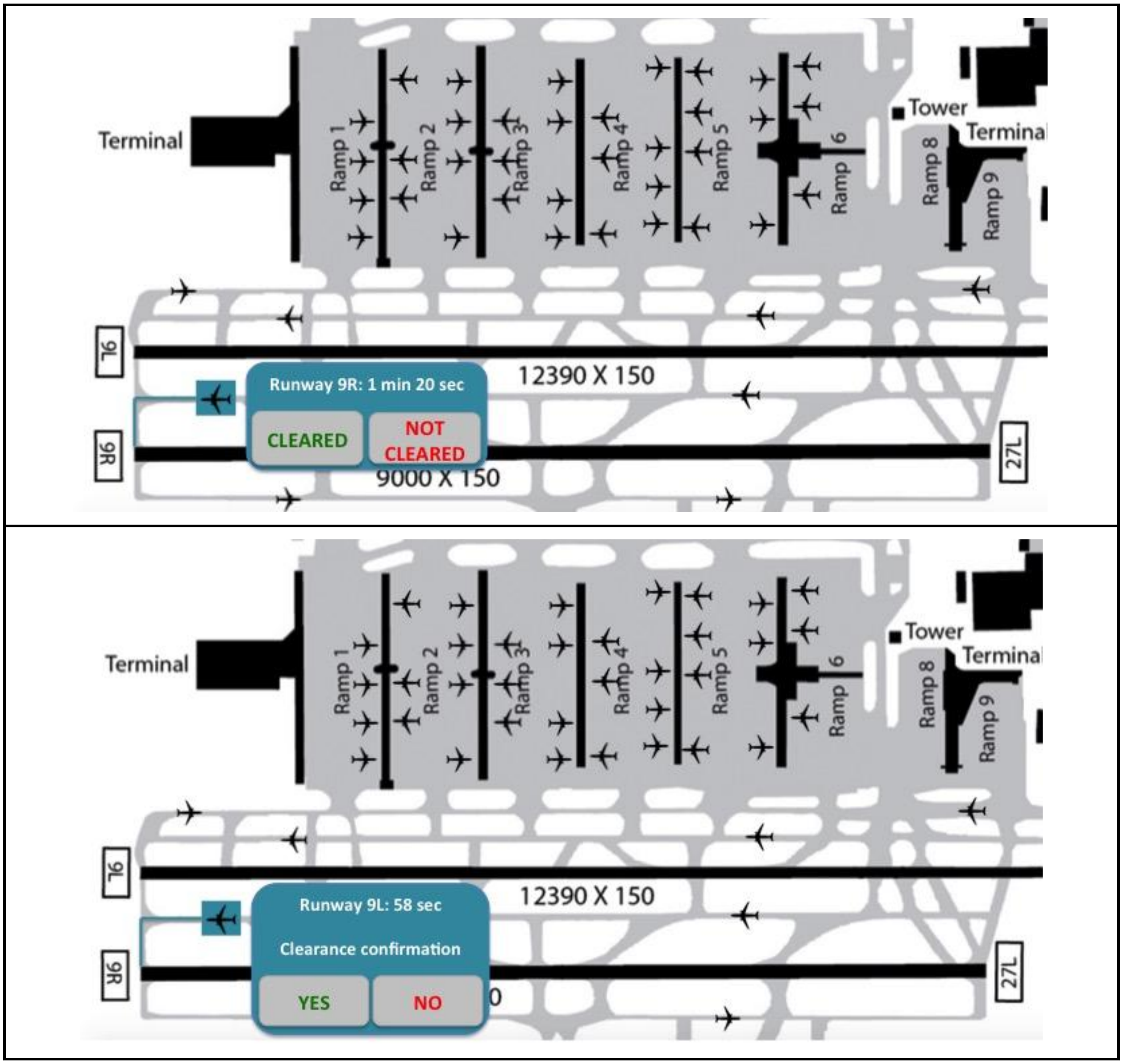

Figure 9. ATC Takeoff Clearance Views

5.2.3.2 Pilot Views

Figure 10 below shows the pilot's views when taxiing. Just like the ATC views, a taxi route that does not cross a runway is shown in blue. At the bottom of the screen, the taxiways are listed how they would be given in clearance delivery. As turns are made, the taxi route updates. The time until the engines need to be started is also provided at the bottom of the screen. When it is time, the box will turn red and the pilots will be notified.

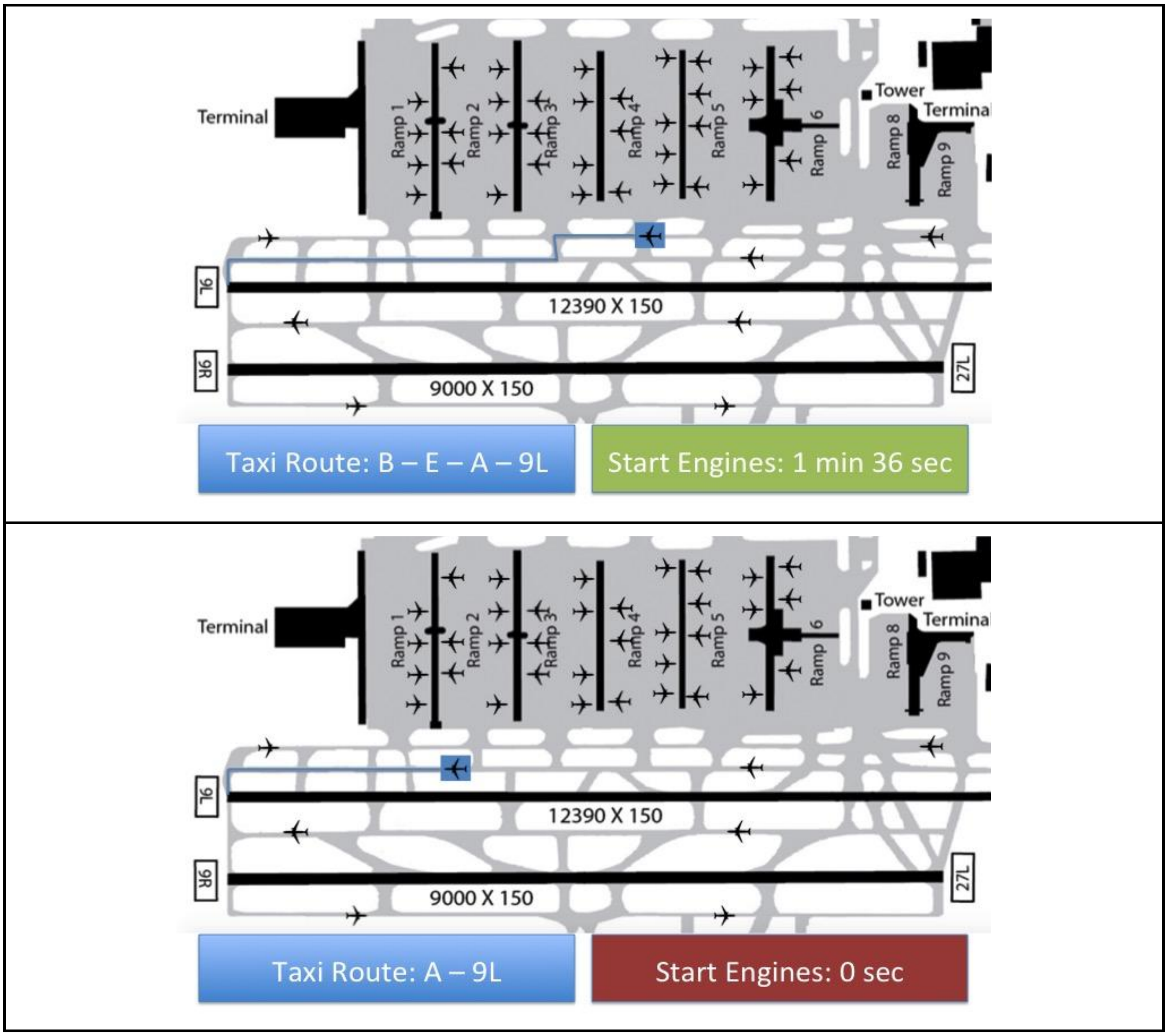

Figure 10. Pilot Taxi Views

Figure 11 below shows the pilot's view when the tug has stopped due to something on the airport surface being detected by the LIDAR system. The right side of the screen will show the live camera feed from the tug where the object was detected. The pop-up box allows the pilot to notify the airport personnel immediately to remove the object.

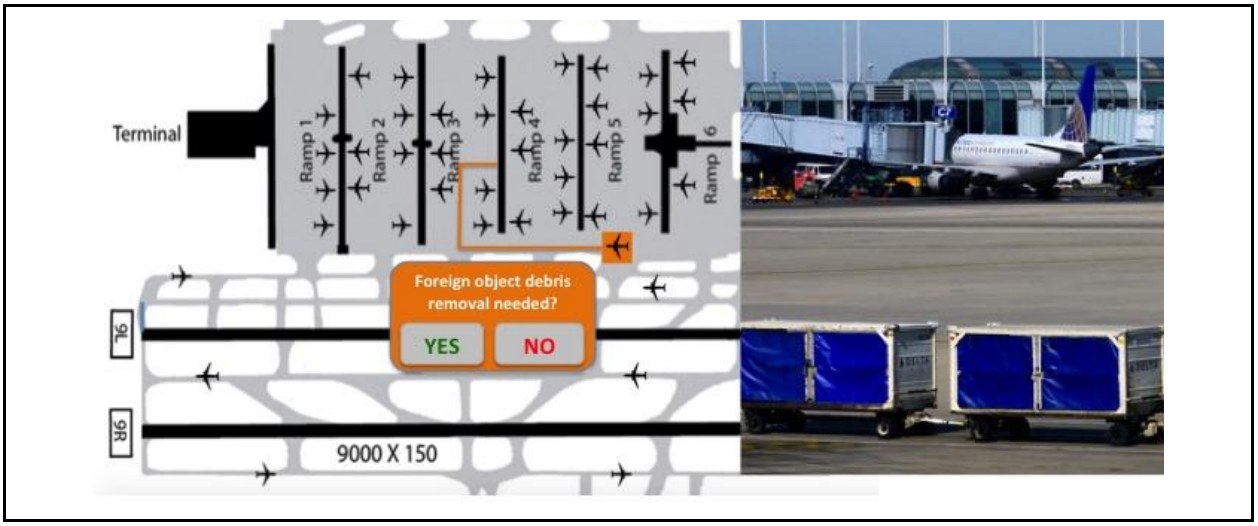

Figure 11. Pilot Foreign Object Debris Removal View

Figure 12 below shows the pilot's view after the aircraft received its clearance to cross the active runway 9L. The pop-up box shows the time until the aircraft will cross the hold-short line and ATC's response (either CLEARED or NOT CLEARED). Both pilots have access to an emergency stop switch if at any point they believe it is unsafe to cross the runway.

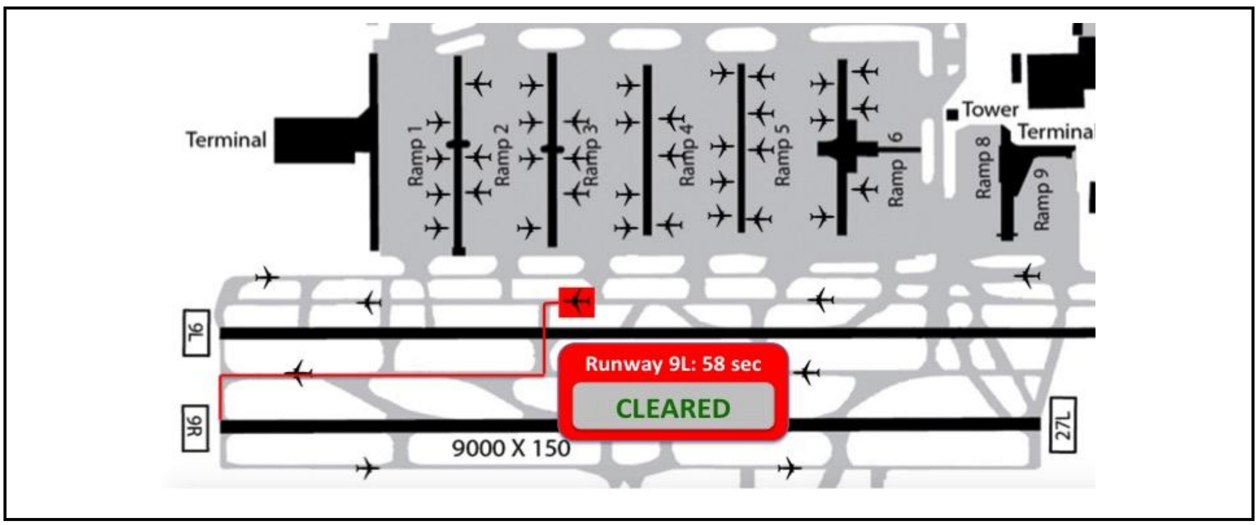

Figure 12. Pilot Runway Crossing Clearance View

6. Industry Interactions

Early in the design process, the team worked with an industry expert (Yoon Jung - NASA Ames) and an airport operator (Chris Oswald - ACI-NA Safety and Technical Operations). The team also seeked out feedback from Georgia Tech professors in similar fields. In early communications, while the team was still forming the higher-level conceptual design, Oswald strongly recommended "conducting a high level safety risk assessment as part of the evaluation of autonomous tugs that includes consideration of runway and taxiway collisions, loss of control, and pedestrian/ground service equipment collisions …" throughout the design process. Thus, the team made it a priority to complete a safety risk assessment every time a decision was made on the design. His comments also narrowed the team's focus to solve the major problems at hand, instead of seek out little problems that could also be addressed but may diminish the effect the primary problem.

The team also worked very closely to Giuseppe Sirigu, a graduate student visiting Georgia Tech for the past couple semesters. For his PHD project, Sirigu is working on an algorithm to determine the ideal pushback time for aircraft in a busy setting. His previous work on algorithms and expertise on the matter was invaluable. He had also presented the concept of fully automating aircraft taxi numerous time where he was drilled with questions. The audience's questions gave us issues that needed to be resolved for public support of the concept.

Regarding the PTNS phone app, Oswald mentioned that one of the keys to providing an effective solution is "getting authoritative data across diverse stakeholders - TSA, airlines, terminal operator, airport operator, and FAA." While researched extensively, the team was not able to address this concern. This remaining step is addressed in the Implementation sub-section.

In completing the cost-benefit analysis, the team received assistance from Clayton Tino (Virtustream) to learn the process of estimating the costs associated with the taxi display system. Sarah Thomas (Walt Disney World) assisted in estimating the number of man hours needed to develop the taxi display system applications for ATC and the pilots. Both also provided feedback on how to estimate software and computer maintenance costs.

Regarding the presentation of the design, Jung recommended writing out the step-by-step process of a tug completing a towing assignment. Jung also hoped to see more discussion on how "airport infrastructure modification will be needed in order to accommodate autonomous electric tugs (e.g., charging stations, extra taxiways, etc.)." Both of these comments changed the team's overall approach on how to best present the concept. While both Jung and Oswald were impressed by the benefits of the Just-in-Time concept, they wanted to know more about the details of the design and how safety was being considered. This shifted the focus of this report to be about the design itself.

7. Design Impact

The benefits of implementing the Just in Time design into the United States airport system have a wide range, from monetary savings for airline companies to reduced NOx emissions for communities around the country. This section of the report breaks down the numerous advantages into categories based on who will benefit from this design implementation. Each type of benefit will then be delved into specifically for the Hartsfield-Jackson Atlanta International Airport, showing how the benefits can be scaled up to the United States' commercial airports.

7.1 Improved Passenger Experience

With an easy-to-use mobile phone app providing the most up-to-date information regarding each flight, passengers minimize the time spent waiting at the gate before boarding. As layovers are lengthened due to airlines spreading out flights to use the planes and ground crews more efficiently, passengers will be able to maximize their time enjoying the newest airport amenities without risk of missing their connecting flight. In addition, restaurants and shops throughout the airport terminals will have more passengers passing by, bringing a better chance for increased business.

7.2 Fuel Savings for Airlines

One of the major benefits to this design is the immense amount of money being saved yearly due to fuel burned during taxi. A case study showing the taxiing fuel cost for Hartsfield-Jackson Atlanta International Airport is performed below. The millions of dollars saved by airlines in fuel provides a large incentive for the airlines to support the incorporation of this design into commercial airports.

7.3 Environmental Benefits

Mono-nitrogen oxides (NOx) are very dangerous to human life and to the environment. Aircrafts emit NOx while their engines are running, which causes a major safety problem on and around the airport surface. NOx can damage easily damage soft tissue, such as lung tissue, and cause premature death. NOx also inhibits organic production of ozone. By introducing the network of electric tugs, jet engines will not run for most of taxiing which will drastically reduce these emissions.

Both aircraft and airport noise are complex issues that the FAA is continuing to study. Common measures used to combat this noise include "development and adoption of quieter aircraft, soundproofing and buyouts of buildings near airports, operational flight control measures, and land use planning strategies" ("Aircraft Noise Issues"). With engines-off taxiing, there is noise reduction on the airport surface. With the active FAA program The Continuous Lower Energy, Emissions, and Noise (CLEEN), the Just-in-Time concept would further support these improvements. The noise reduction on the airport surface is also beneficial to the airport personnel that work around these high decibels of noise every day.

7.4 Increased Safety on Airport Surface

Situational awareness is one of the primary components of aeronautical decision making, a systematic approach to determining the best course of action for any circumstance. A key to situational awareness for the pilot is his or her ability to perceive the current and potential hazards. Stress and work overload are two primary obstacles to situational awareness for pilots. With a greatly reduced workload for the pilots on the ground due to the automated taxiing, the pilots are better suited to identify these hazards, such as collisions with foreign object debris and runway incursion.

While the pilots are no longer required to control the aircraft during taxi, their situational awareness on the ground is also substantially improved by the Just-in-Time concept. The taxi display system is based on notifying the pilot when a situation that could involve risk is about to occur. The Pilot's Aeronautical Handbook states that "pilot familiarity with all equipment is critical in optimizing both safety and efficiency." This is why the taxi display system added to the cockpit features a simple user interface that is conducive to efficient resource management.

In addition to the pilots improved situational awareness on the ground, the automated tugs are equipped with five proximity sensors to identify potential collisions on the airport surface. The automation of the tugs also reduces the risk of runway incursion. The tugs will not cross any runway unless ATC gives the clearance on the taxi display system. With improved situational awareness, the pilots are now more capable of identifying a potential runway incursion. Both the pilots and ATC will have the ability to stop the tug if there is a risk of FOD collisions or runway incursion.

7.5 Hartsfield-Jackson Atlanta International Airport Case Study

Since Hartsfield-Jackson Atlanta International (ATL) is one of the largest international air travel hubs and is so familiar, it was used to gain some discrete information. The FAA database on airplanes and their taxi times at ATL in the year of 2014 and the FAA's list of each registered N-Number were used to identify each aircraft's engines within Atlanta's airport. Using the ICAO emissions database, the idle fuel burn rate for each aircraft was used to determine how much fuel was used during taxi times. Using the price of fuel in Atlanta, the approximate financial savings based on fuel were calculated. The same ICAO database provides the NOX emissions of each of the engines, so the environmental benefits can also be analyzed.

7.5.1 Cost Benefit Analysis

After the initial fuel savings analysis was done, a basic equation was formulated to determine the general fuel savings for an airport based on the number of planes and the average taxi time. This coefficient, which has a 13 percent error, was used to estimate three extra airports, which include LAX, DFW, and JFK. The results of these calculations are shown below in Figure 13 below.

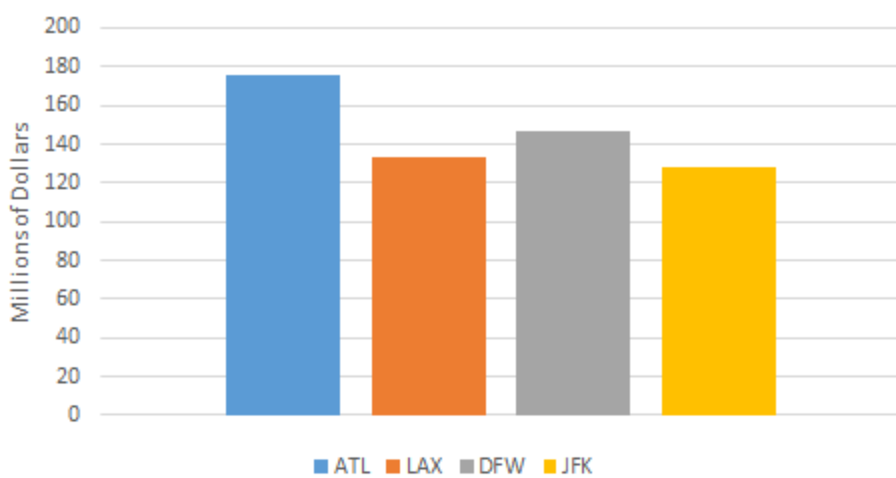

Figure 13. Fuel Savings Per Year at Various Airports

To determine the number of tugs needed for ATL, the number of flights for the year of 2014 (369,789) was transformed to the average number of flights per minute (0.704). With an average taxi-time of 24.5 minutes, the minimum number of tugs required so that every aircraft ready to pushback at its given time has an assigned tug was found to be 17.2. This number of tugs was approximately doubled to be sure that enough tugs are always available. Times that these additional tugs may be needed include peak traffic times and when numerous tugs are charging or are down for maintenance. Thus, in the up-front costs for ATL, thirty-five tugs were factored in.

The total non-recurring implementation cost for the Just-in-Time design comes out to be $106,100,000. Table 6 below shows the breakdown of the non-recurring costs of each of the systems.

Table 6. Implementation Costs for Hartsfield-Jackson Atlanta International Airport

	Individual Cost	**Quantity**	**Total Cost**
Autonomous Electric Tugs	$2,000,000	35	$70,000,000
Central Management System	$10,000,000	1	$10,000,000
Charging Stations	$10,000	10	$100,000
ATC Software and Displays	$15,000,000	1	$15,000,000
Airport Application, Software, and Displays	$10,000,000	1	$10,000,000
Airport Personnel Training	$1,000,000	1	$1,000,000
			$106,100,000

The calculate the price of power needed for the tugs, the number of tugs (35) was used with the average amount of power that is used by the battery, which was calculated to be about 89 watts per tug. Using Atlanta's power price of 11 cents per kilowatt-hour and an estimated two hours of charging per day for each tug, the price of the power per year was calculated to be about

$121,500. As with the fuel savings, the recurring costs of power for each tug were calculated for the four previous airports. The total yearly recurring cost for the Just-in-Time concept is estimated to be $430,000. Table 7 below shows this cost breakdown. These values were determined through dialog with experts in the industry. This granted an idea of how much each type of recurring cost would be.

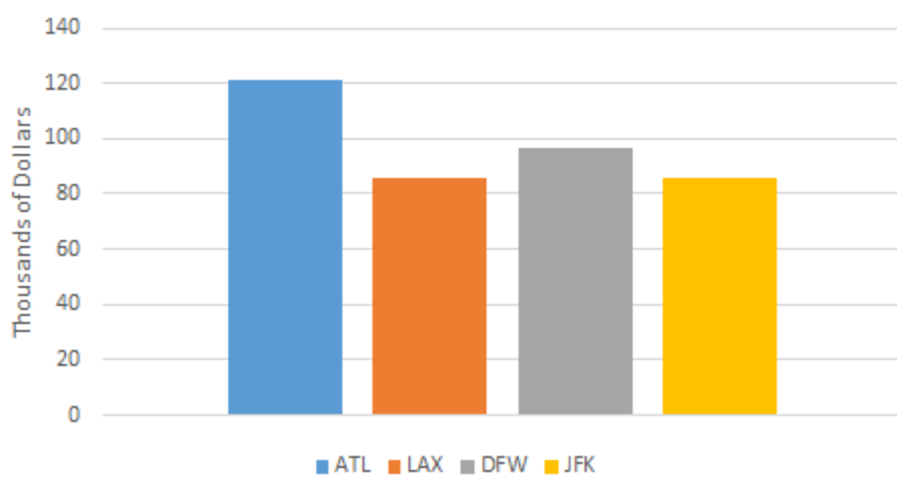

Figure 14. Price of the Power for the Tugs Based on Airport

Table 7. Yearly Costs for Hartsfield-Jackson Atlanta International Airport

	Total Cost (per year)
Network of Tugs - Maintenance	$200,000
CMS - Maintenance	$10,000
Tugs and CMS - Electricity	$200,000
ATC Software - Maintenance	$10,000
Airport Software - Maintenance	$10,000

Toxic emissions on the tarmac is a very large problem for all airports. By introducing this tug system, emissions on the runway are greatly reduced. The current system of taxiing has engines emitting NOx throughout the whole process along with during takeoff and landing, but with this automated tug system, NOx emissions are only happening during takeoff and landing.

For Hartsfield-Jackson Atlanta International Airport alone, NOx emissions will be reduced by 451 tons.

8. Implementation

This section of the report goes into what would need to be done for the concept to be implemented into a large commercial airport. For the PTNS, the app needs to be developed from scratch. Using the successes of other flight information apps, the views for the passengers would be determined. The primary issue with implementation of this facet of the concept is getting the involved parties like the FAA, TSA, airlines, etc. to work together to allow this amount of data transfer to occur.

By taking the Taxibot design as a starting point, the team would need to design a prototype tug that will fulfill all of the mission needs. This prototype would combine the function of the currently used Taxibots and add all the additional instruments that this mission would require, primarily increasing safety. The prototype would need to be tested to ensure safety, functionality, and durability. This step would be the most expensive and taxing part of the overall implementation process.

The taxi display system app would need to be developed from scratch. Because the data the system processes is already being used in similar applications, the primary development would be fine tuning the displays to be most effective for the air traffic controllers and the pilots. Collecting data on which views are preferred by controllers and pilots is the best way to determine the best course of action.

Due to the newness of the concept and the general public's wariness of fully automated systems, the network of tugs would need to be tested in full scale. This would take both time and money to complete. If any issues arise, more time and money are required to solve the issues. Regarding the operation of the individual tugs themselves, testing of the calibration of the differential GPS receivers/transmitters and IRUs regarding the aircraft staying on the centerline of the taxiway during turns is also a must.

Appendix A

Madison Luther
mluther3@gatech.edu

Matthew Stout
mstout3@gatech.edu

Eric Koob
erickoob@gatech.edu

Alexander Naber
amnaber5@gatech.edu

John Amin
jamin6@gatech.edu

John-Paul Clarke
johnpaul@gatech.edu

Appendix B

As a premier technological university, Georgia Tech has more than 100 centers focused on interdisciplinary research that consistently contribute vital research and innovation to American government, industry, and business. There is no doubt that Georgia Tech stands out as a distinctively different kind of university, one that is eagerly encouraging and developing the revolutionary technologies of the 21st century. Equipped with the extremely rich resources of an outstanding student body and faculty; strong partnerships with business, industry, and government, Georgia Tech is designing a future of global preeminence, leadership, and service. The School of Aerospace Engineering at the Georgia Institute of Technology is one of the oldest educational programs of its kind in the country. The Institute had been asked to instruct United States Army personnel in aviation subjects as early as 1917. A stand-alone department was formed in 1930 after receiving the seventh grant from the Daniel Guggenheim fund. At that point, the school was know as the Daniel Guggenheim School of Aeronautics, its name was officially changed to the School of Aerospace Engineering on July 1, 1962.

Degree programs in aerospace engineering are offered at bachelors, masters, and doctoral levels. The undergraduate Bachelor of Science in Aerospace Engineering degree is accredited by ABET. These undergraduates gain a fundamental understanding of aerodynamics, structures, vehicle dynamics and control, propulsion, and interdisciplinary design and are well prepared for careers in aerospace and related engineering fields. They are well-trained to function as professionals who can formulate, analyze and solve problems that may include economic, social and environmental constraints. And, finally, they are prepared to communicate well, function well in the global environment and in teams, and contribute substantially by doing research, developing, and implementing future systems and applications.

Appendix C

Virtustream

Virtustream is a cloud computing management software provider. Their service model used is “infrastrure as a service.” Virtustream was founded in 2009 and its headquarters are located in Bethesda, Maryland.

The Walt Disney Company

The Walt Disney Company, commonly referred to as Disney, is arguably the most well known media and entertainment company in the world. The Walt Disney Company’s reach includes media networks, parks and resorts, studio entertainment, products, and interactive media.

NASA Ames

The Ames Research Center (ARC), commonly known as NASA Ames, is one of the major NASA research centers. NASA Ames is located in California’s Silicon Valley. Currently, the Aviation Systems Division is conducting research and development in air traffic management and high-fidelity flight simulation.

ACI-NA

The Airports Council International – North America, abbreviated as ACI-NA, represents local, regional, and state governing bodies that own and operate commercial airports in the United States and Canada. The mission of ACI-NA is “to advocate policies and provide services that strengthen the ability of commercial airports to serve their passengers, customers, and communities.”

Appendix E

Madison Luther

The ACRP University Design Competition definitely provided a meaningful learning experience for me. I obtained my private pilot's license in high school and since then, I have been fascinated by commercial aviation and airports. While I love what I'm learning in the aerospace engineering curriculum at Georgia Tech, there are not classes available regarding airport operations or planning. This competition gave me that learning environment that I have been looking for. In addition, I learned far more about aircraft themselves than I expected, including how towing affects aircraft, engine warm up, and pilot-cockpit interactions on the ground.

The biggest challenges that our team faced were all based around all being new to the material. While I know the ins and outs of airport surface management, it took the others a little while to nail down the nomenclature, processes, and regulations. With this newness factor, extensive research had to be done before design decisions were made. This made time an issue. I wish we would have learned about the competition in the fall semester so we would have had more time to further our design. Nonetheless, we overcame this by making strict deadlines for big decisions, so that all of the research was done in time.

The team was formed around the common interest in improving the efficiency of commercial airports. Because of this, we jumped a few steps in the engineering design process. Nonetheless, the cyclical design process was still used. We first set requirements and goals for the design. When nailing down the specifics to address those requirements and goals, we noted any possible issues (especially regarding safety) and additional features we wanted to add. This process continued countless times.

The industry interactions were my favorite part of this design competition. While most of their feedback pertained to the high-level concepts, their expertise on the subject matter was evident. After we nailed down our basic concept, I felt very confident in my knowledge of the current inefficiencies of airports and how our design would improve these issues. It was very eye-opening when we first contacted the industry experts had immediate questions and concerns about things that we had not considered. Their comments were definitely useful, especially regarding safety concerns that arose due to our design.

One of the most evident things I learned from this competition was the complexity of airport management. I learned about countless facets, like foreign object debris removal, that I completely forgot were involved in airport management. I also learned about safety risk assessments in general. I had read countless articles and papers on the importance of airport safety and how the FAA works to promote safety. However, I had never heard of the five phases of SRM or completed a safety risk matrix. I know this skill will be helpful down the road, whether it is in my summer internship or my senior design course in the fall.

Matthew Stout

The Airport Cooperative Research Program University Design Competition provided me a a meaningful learning experience by forcing me to learn about more types of algorithms used in the aerospace industry. I am currently involved in a Bachelors/Masters program with Georgia Tech research in the systems of systems field. However, I have not gotten to take a class in that area yet. In my research, I have only been exposed to one type of algorithm. ACRP gave me more experience coming into contact with another type of algorithm. The way the university design competition was set up, I was able to pursue my interests under advisement while working on a team to meet our goals.

The biggest challenge the team encountered was communication within the team. There were several misunderstandings on what we were suppose to do at certain times. At other time there were misunderstanding on when stuff was do. This caused us to lose some productivity but then our group started using an app called GroupMe. The app helped us with our communication and made the team more successful at completing stuff by our self assigned due dates.

I joined the team a little late, so I was not involved in developing the hypothesis. However, I know that our concept was started and based around the idea of automated tugs improving safety on the airport surface and saving fuel by taxiing engines off. Several Georgia Tech teams started working in a close setting. Groups were formed by interest to begin with. These similar interests quickly lead to hypotheses.

The participation with industry experts certainly affected our team. While industry is currently not using algorithms to control and route tugs, their expertise on the system as a whole was very helpful. Giuseppe Sirigu's work on an algorithm to route tug for his PHD project was one of the most influential to me. His insight into the project, on both an algorithm and systems design level, was very helpful and meaningful.

I learned a great deal about system of systems routing algorithms. I believe this knowledge will mostly help me further my education as I am just a 2nd year student. However it will also help me in the workforce. Coming into the project I thought there was only one way of doing rerouting algorithms, the way my research group was doing one. However this project helped me understand that there are multiple ways of solving one problem.

Eric Koob

The ACRP did indeed provide a meaningful learning experience for me. As an Aerospace Engineering student focused on the space industry, this project provided an interesting perspective on the airline and fixed wing craft industry. It was nice to use the skills that I've been developing throughout my schooling in a new and refreshing environment.

Perhaps the biggest challenge of this competition was learning a whole new set of information. Much of the material was new to me, and presented some significant challenges. I addressed this by researching the stuff I did not know in order to successfully complete my responsibilities.

We developed our hypothesis by trying to think of ways to make the airport experience better from an engineering perspective. With this as a starting point, we tried to tackle glaring issues by coming up with solutions in order to make airports more efficient.

The participation of industry certainly provided a unique perspective. For problems that we weren't sure how to solve, it was nice to get the industry perspective on how to solve them. Conversely, it was also helpful to get their perspective on when there were methods or ideas that the group had that we were told to be unfeasible or ill-advised by members of the industry. All in all it helped serve to give a greater understanding of the situation.

I definitely learned a lot about what goes on in terms of planning at airports. The design of airports and how they are managed was never something I had previously thought of before. Perhaps the most interesting thing was how much there can be done to help improve airport management. It helped me adjust my problem solving approach to entirely new and unfamiliar scenarios which I would say is a highly valuable skill to have before entering the workforce.

Alex Naber

The ACRP University Design Competition did provide a meaningful learning experience. This competition helped me understand different things. One of these things is complex group work, which I will explain further below. I also learned how complex an airport is, which I will also explain later.

A big challenge that the group faced was scheduling inconvenience. There was only one hour a week where we could meet and work as a group. One way we overcame this problem was by using various forms of social networking to make group decisions. We also used our hour together to make the large decisions and divvy up work.

The way we developed our hypothesis was through the use of our advisor, Dr. Clarke. We offered him several ideas and he helped us narrow down our ideas to the "Just in Time" system. We then used the standard engineering design process that is taught in our intro to aerospace engineering course.

The participation of the two industry experts was useful because they helped us realize the feasibility of our project. Other industry professionals also helped us estimate the costs of many of the more ambiguous systems that we struggled to find on our own.

This competition helped me further understand the complexity of the airport as a working machine. There are many moving parts to the airport surface, and each part is strictly regulated. When devising ways to improve airports, each of these regulations must be accounted for, which makes the process ever growing in difficulty. Through this competition, I gained the skills of understanding and analyzing the different systems within an airport. This can be helpful in entering the workforce because an airport is a difficult system to learn, and I have a head start in completely understanding it.

John Amin

The ACRP University Design Competition provided meaningful learning experience and a unique opportunity for me to look into airport design. Although I am studying Aerospace

Engineering, I was fairly unfamiliar with how airports work and all the details that were involved in scheduling departures, or taxing protocol. This gave me a chance to expand my understanding into operations of airports as well.

The challenge was with understanding the new material. I was somewhat unfamiliar with how cell phones were tracked. In order to solve this, I had to do a lot of research into how it worked, when it was effective and where this was being used, etc. In addition I also talked to advisors that had more experience in the subject.

We began by looking at the problem and how we could improve efficiency in an airport. After extensive research into the specific examples, we finally came to deciding in what ways we could improve efficiency. This came down to the use of automated tugs and a personalized app.

Participation of industry helped. People who knew more about the processes going on at airports could provide additional insight into the way things worked in airports. They could also give us ideas on additional ways we could improve the experiences of travelers in airports.

Working on this project taught me a lot. I learned about technology used to track phones and how that could be applied to various applications. I also learned about modelling software and gained some experience with using Arena and other software. I also learned a lot about the processes that occur in airports and how some aspects could be improved. This information could be useful when I enter the workforce, providing me with additional understanding that would give me an edge over the competition.

John-Paul Clarke

1. The primary value of the education experience for the students was learning about "real-world

constraints."

2. Yes.

3. The challenges that the students faced included managing significant quantities of data, estimating benefits with incomplete information, estimating the cost of equipment/hardware and software.

4. Yes. It gives a great opportunity for students who do not want to build an air vehicle but are more interested in aviation systems.

5. Add some "inside the terminal" challenges as well as additional algorithm challenges.

Appendix F

"Advisory Circular." *faa.gov*. Federal Aviation Administration, 28 Feb. 2007. Web. 25 Apr. 2016.<http://www.faa.gov/documentlibrary/media/advisory_circular/150-5200-37/150_5200_37.pdf>.

"Aircraft Noise Issues." *faa.gov*. Federal Aviation Administration, n.d. Web. 25 Apr. 2016. <https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/airport_aircraft_noise_issues/>.

Barker, Ronald. "Chicago O'hare International Airport (ORD) Photo." *Airport-Data.com*. Airport-Data.com, 10 Mar. 2014. Web. 25 Apr. 2016.

"FAA Foreign Object Debris Program." *faa.gov*. Federal Aviation Administration, n.d. Web. 25 Apr. 2016. <http://www.faa.gov/airports/airport_safety/fod/>.

"Innovative TaxiBot Now Used in Real Flight Operations." *Lufthansa Group*. N.p., 20 Jan. 2015. Web. 25 Apr. 2016. <https://www.lufthansagroup.com/en/press/news-releases/singleview/archive/2015/february/20/article/3439.html>.

"Mototok.com." *Mototok.com*. Mototok International, n.d. Web. 25 Apr. 2016. <http://www.mototok.com/>.

"National Runway Safety Plan 2015-2017." *faa.gov*. Federal Aviation Administration, n.d. Web. 25 2016. <http://www.faa.gov/airports/runway_safety/publications/media/2015_ATO_Safety_National_Runway_Safety_Plan.pdf>

"Runway Incursion Totals for FY 2015." *faa.gov*. Federal Aviation Administration, n.d. Web. 25 Apr. 2016. <http://www.faa.gov/airports/runway_safety/statistics/regional/?fy=2015>.

"Safety: The Foundation of Everything We Do." *faa.gov*. Federal Aviation Administration, n.d. Web. 25 Apr. 2016. <https://www.faa.gov/about/safety_efficiency/>.

"TaxiBot Green Taxiing Vehicle Receives European Approval for Boeing 737 Commercial Operations." *Green Air Online*. Ed. Christopher Surgenor. GreenAir Communications, 12 Oct. 2014. Web. 25 Apr. 2016. <http://www.greenaironline.com/news.php?viewStory=2004>.

"TaxiBot - International." *TaxiBot - International*. N.p., n.d. Web. 25 Apr. 2016. <http://www.taxibot-international.com/>

"Taxing Times." *AirInsight*. AirInsight, 27 Jan. 2014. Web. 25 Apr. 2016. <http://airinsight.com/2014/01/28/taxing-times/>

"TNA Presents the Next Generation of Towbarless Electric Aircraft Tugs with Cabin and Unique Nose Gear Coupling Technology Helping Ground Crews Maneuver Efficiently." *PRWeb*. Vocus PRW Holdings. 19 Oct. 2015. Web. 25 Apr. 2016. <http://www.prweb.com/releases/2015/11/prweb13090954.htm>