ANTS – Automated NextGen Taxi System

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Executive Summary

This design packet addresses the Airport Management and Planning Challenge of the FAA Design Competition for Universities in the 2009-2010 academic year. Through our extensive research, examination of similar design literature, and communications with many distinguished industry experts, we have developed a full proof automated aircraft towing system called Automated NextGen Taxi System (ANTS). ANTS is designed to fill a gap between the conventional, engine-propelled taxiing and a more fuel and operations efficient taxiing system. ANTS incorporates a system of automated tractors, termed Towing Support Vehicles (TSV), a precise GPS navigation system (LAAS), and a monitoring data management system that allows for safe and efficient airport ground operations synced to future NextGen technologies. The ANTS design's benefits are demonstrated through several cost and safety risk assessments, models, and diagrams. Our ANTS design delivers a significant impact to the industry in the following categories: monetary savings to airlines and airports, environmental/carbon footprint, and noise pollution.

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Problem Statement and Background

The airline industry has many factors to manage when operating in a high-risk, and extremely competitive market. One of the more critical factors is fuel costs, which constitute anywhere from 10% to 15% of total operating costs by convention (ATA, 2008). However, in the last quarter of 2009, domestic airlines spent an average 23.7% of their operating expenses on jet fuel (BTS, 2009). In addition, volatility of the fuel market exacerbates most departments' prediction capabilities. A quick analysis of spot prices of crude oil from 2000 to 2010 shows an average of $3.82 per barrel monthly fluctuation. Such a low margin appears to be frivolous to mention, but this monthly vicissitude multiplied by millions (airline) or billions (nationwide) of gallons creates a serious dent in a budget. Larger monthly differences in price per barrel in the past decade were $12.82 in May of 2008 and $27.50 in October of 2008 (USEIA, 2010). As an example, a $21 change in average price of oil resulted in a $1.5 billion difference in a fuel bill for American Airlines (Bansal, 2006). These stark variances demonstrate fuel price volatility, proving the difficulties in hedging appropriately to save capital. Overall, this has caused much anxiety amongst airlines trying to budget their costs each year and climb out of debt. To solve the problem of rising fuel costs, companies have even implemented procedures to tow aircraft from the gate to runway. This is especially important because of the current economic crisis which has caused many airlines to file for bankruptcy.

The rudiments of fuel conservation can be found during the 1973 oil crisis, which precipitated a need for an efficiency plan for operations. As a result, airport managers and the airlines, as recommended by the FAA, implemented gate-hold procedures in order to combat the mounting fuel expense figures. Under this program, aircraft are to hold at the gate if a delay for take-off exceeds 5 minutes (*Aviation Week & Space Technology*, 1977). While this saved fuel costs caused by delays and engine idling on taxiways, there was still a need for fuel conservation. In an experimental effort in the early 80's, Air France designed a 35 mph tow tractor that would tug airplanes to runways to combat excessive fuel burn. Even the FAA and Seattle-Tacoma International Airport wrestled the idea but had concerns of low taxiing speeds causing costly delays (Mouat, 1981). However, over the next decade, oil prices dropped, putting such innovative concepts on hold. Nonetheless, not many airline fuel management departments predicted the price escalation that occurred in recent years, such as oil surpassing $120 per barrel (USEIA, 2010). Consequently, airlines began executing towing procedures for especially high fuel-burning aircraft in various taxi operations. For example, American Airlines purchased high-speed tugs with minimal fuel consumption, to transfer empty airplanes to maintenance facilities (Hilkevitch, 2008). Virgin Atlantic also suggested, in 2006, the idea of towing all of its airplanes to a designated holding area to reduce fleet fuel burn and decrease contribution to global CO_2 emissions (Johnson, 2006). In conjunction with the late 2000s recession, oil prices stabilized, but airlines had other concerns to manage, such as their survival through challenging economic times. This again put fuel conservation on the backburner, perhaps until prices were expected to rise in the near future. Nonetheless, given this background of information, a problem continues to exist that is in need of addressing. The current airport operations fail to effectively recognize and alleviate existing congestion issues, which ultimately results in a considerable amount of financial loss for airline operators due to excess fuel burn and increased engine wear.

Even with gate-to-runway towing systems, there are several challenges inherent in design and implementation. An initial problem system engineers found back in the 80s, which is still applicable today, is efficiency and speed of towing tractors. Aircraft sequencing proves to be very difficult, when managing more than 75 airplanes an hour at a typical busy airfield (FAA, ASPM, 2010). In addition, conventional tow tractors haul at a very minimal speed, provoking further counterproductive delays, costing airlines more money. Other considerations include stress on the landing gear, during prolonged periods of taxiing (Correspondent, 2008). If such a system were automated, there would need to be safety countermeasures implemented such as pilot control and ATC oversight. Pilot checklists would have to be modified to allow for taxi towing and delayed engine startup. Lastly, acquiescence with NextGen and airport authorities would be needed to ensure proper incorporation of future ground operation programs with a gate-to-runway taxiing system.

Literature Review

When researching designs relevant to aircraft towing systems comparable to our initial concept, we found three similar models. These three systems are automated to some degree, but shortcomings in their designs were believed to exist that could be addressed by our eventual innovations on an automated aircraft towing system. The three patent holders identified were Airborne Holding, an individual named Edward Leblanc, and Ricardo Engineering.

In 2001, Airborne Holding developed an aircraft towing system concept labeled airport ground navigation system. This design’s model used aircraft tugs to transport aircraft around the airport. In the patent, designers illustrated the benefits of using these tugs, such as fuel costs and engine wear reduction. Although this design was beneficial, it did not provide specifications of the tug nor did it present estimated costs of the tug. Also, the patent was very vague in how the system would operate and be implemented at airports and with aircraft. Overall, the Airborne Holding design illustrates key design principles, but did not articulate a particular management system, perhaps a paramount factor for successful implementation (Dow, 1998).

The next aircraft towing system was designed in 2003 by Edward Leblanc of Ontario, Canada. Leblanc also patented the design and developed several detailed diagrams and models. The patent discussed the benefits of the design, which included fuel savings, reduction of environmental pollution, and decrease of engine maintenance, without mentioning specific monetary savings. The basics of this design were the automation and control of the aircraft towing vehicle through a remote, located within the aircraft itself, with another mode of control still possible through LORAN or GPS. However, the towing vehicle must be attached and detached from the aircraft manually, and the towing vehicle utilizes a towing bar to couple to the aircraft, which increases time spent on connecting the towing vehicle to the aircraft. Also, this aircraft towing system would solely be used to taxi aircraft from gate to runway and not during the post-landing phase. As in the previously discussed aircraft towing system by Airborne Holding, there is no description of the specifications of the design of the aircraft towing vehicle or the rest of the system (Leblanc, 2003).

The third design partially embodied within our design was by Ricardo Engineering. Their design, called Taxibot, uses a pilot-controlled towing vehicle to tug the aircraft to its destination. It is powered by twin, 500 horsepower V8 diesel engines which have the capability to tow both wide and narrow bodied commercial aircraft. It attaches to the aircraft by using arms that surround and grasp the nosewheel. The Taxibot requires no modifications to aircraft, taxiways, or runways, therefore making it very versatile in the aviation industry. The other benefits of the Ricardo Taxibot, that are standard to most aircraft towing systems, are the curtailment of fuel costs to aircraft, CO_2 emissions and noise pollution.

In Ricardo's Taxibot design there were definitive benefits, but also technical and automation areas in question, impacting Taxibot's feasibility. First, the Taxibot is only automated in the engagement of the towing arms to the aircraft. It requires an operator to drive and position the Taxibot, having only plans to possibly develop an automated driving system (Ricardo, 2009). Another disadvantage of the Taxibot is that if it were to be implemented at airports, it would be necessary to modify the airport's infrastructure. This could delay and add significant costs to the implementation of the Taxibot. Lastly, by using diesel engines to power Taxibots, contribution to aviation's carbon footprint still occurs.

After our design team reviewed these patents and models, we collaborated to form a practical system that could be used at any airport and on nearly any aircraft. From Leblanc's design, we found that there were certain aspects that could be used and improved upon. These entailed the automation of the towing vehicles through some type of positioning system, like Local Area Augmentation System (LAAS), benefits of taxiing aircraft, and using towing vehicles for both takeoffs and landings. After researching Ricardo's Taxibot design, we concluded that a number of elements from their system could be enhanced. Taxibot's use of twin diesel engines influenced our towing vehicle's design to be powered by batteries, therefore increasing the reduction of the environmental footprint of aircraft. Taxibot's use of arms to clamp onto the nosewheel for towing was similar to our initial design concept. Finally, Taxibot and Leblanc's designs both use some type of personnel to either operate the towing vehicle or manually attach/detach the tug from the aircraft. Using workers to drive or attach the towing vehicle is believed to increase costs of using an aircraft towing system and increase the amount of injury potential to ground crew (Dell, 1994). This notion encouraged our team to incorporate less manual labor into our design. Eventually, these designs led to our concept of a fully automated towing vehicle synced with emerging NextGen and ATC technologies and networks, assisted by an innovative data management system. In conclusion, evaluation of the similarities and differences of each of the aircraft towing systems helped shape our eventual design, Automated NextGen Taxi System (ANTS).

Problem Solving Approach

After review of the competition topics, our approach began with listing known challenges to airports, airlines, and aviation as a global system. After due diligence and narrowing down a few candidates, we decided it would be beneficial to examine the FAA's Next Generation Air Transportation System (NextGen) as it related to fuel/energy savings and airport ground operations congestion. A gap analysis of airport congestion/operations programs was performed, and it was concluded that airport ground operations efficiency would be our design challenge to further the cause of NextGen in the National Airspace System (NAS). Below, Figure 1 includes a sample of evaluated NextGen programs related to ground operations, concluding with our prospective ANTS program.

Figure 1

Problem	Solution	NextGen Program
Forecasted air traffic growth will create great inefficiencies, delays at current capacity; need for improvement of situational awareness and greater oversight of operations	Implement a better surveillance system that allows aircraft to share real-time flight data	ADS-B, ASDE-X, SWIM
Voice communication adds to radio and traffic congestion	Implement comprehensive data messaging interface between aircraft and ground stations (i.e. ATC)	Data Comm

Forecasted air traffic growth will create great inefficiencies, delays at current capacity	Directly transmit textual and graphical clearances, taxi and take-off instructions, weather and wake turbulence data to the flight deck; automation of efficient aircraft sequencing	Enhanced Departure Flow Operations, Improved Management of Arrival/Surface/Departure Flow Operations
Fuel price volatility, environmental and noise concerns, and runway incursions pose obstacles to airport and airline operations	Implement an automated towing system using various NextGen technologies such as SWIM, ADS-B, ASDE-X, etc.	Automated NextGen Taxi System (ANTS)

(FAA, 2009); (FAA, NAS EA, 2010)

After narrowing the design topic, we searched for the latest technology relevant to an automated taxi system. The drafted design was further shaped from previously mentioned patents in mind. However, overall integration and feasibility proved to be difficult in detecting. As a result, we contacted knowledgeable professionals in mechanical engineering, airport operations, and global aviation systems. Target design solutions were realized after identifying problems and shortcomings, progressing the engineering process and the ANTS design.

Safety Risk Assessment

To conduct a thorough risk and safety assessment of a system, the envisioned start to finish process of the ANTS operation was mapped and refined as outlined in Figure 6. Risks are identified and tagged with a severity and probability, using a reformatted FAA risk grid, illustrated in Figure 2. Risks were discussed for mitigation techniques or countermeasures necessary to reduce the possibility and gravity of a potential hazard (FAA, AC 150/5200-37, 2007). Risk was quantitatively defined in order to have the awareness of relativity when comparing hazards.

A risk matrix indicating the overall risk associated with a certain severity and a specific probability is outlined in Figure 2. These categories, found in AC 150/5200-37, are each given a number (1 through 5) that corresponds to its magnitude; for example, the highest severity level, catastrophic, is rated as a 5. Severity and probability are matched up according to a particular hazard, and the sum is a quantity (1 through 10) that represents its respective risk (FAA, SMS Manual, 2008).

Figure 2

Severity → Probability ↓	No or Little Safety Effect (1)	Minor (2)	Major (3)	Hazardous (4)	Catastrophic (5)
Frequent (5)	6	7	8	9	10
Probable (4)	5	6	7	8	9
Remote (3)	4	5	6	7	8
Extremely Remote (2)	3	4	5	6	7
Extremely Improbable (1)	2	3	4	5	6

(FAA, SMS Manual, 2008)

The next step was to identify potential threats to ANTS and analyze their causes in order to form countermeasures against a particular risk. Several hazards may inherently be recognized in the system, but proactive mitigation systems and safeguards have been put in place to minimize severity and abate probability. Such defenses include secondary backup systems in proximity sensors and navigation integrity. In addition, the human element is included in the supervision of taxi automation, with the ability to stop and terminate any TSV motion. Such human operators include pilots, who have the authority to stop or disengage the TSV; execution of this control is done through the FMS or issued cockpit remote device. ATC has the ability to cease operations in the event of an emergency or imminent runway incursion, should primary and secondary systems fail. As a final deterrent to hazards, initial training of ANTS educate airport personnel standard operating procedures and continual techniques on how to mitigate risk. Another consideration to note is the ironies that occur in engineering automation. Automated tasks, such as FMS, autopilot, or even ANTS, are highly complex and require little operator-machine interaction, thus making monitoring of a system more difficult and less engaging. This poses serious risks when an unexpected, very infrequent emergency occurs and an operator, who has become deskilled through continuous and monotonous monitoring, fails to respond appropriately to the situation (Reason, 1997). In order to combat any loss of skills and better prepare personnel operating ANTS, recurrent operational training would provide an invaluable, additional defense to risks.

Figure 3 below exemplifies the preliminary hazard analysis, classifying the foremost hazards and defenses of ANTS. The table illustrates the possible hazard and risk, ranked by Figure 2's risk matrix, and the causes of a particular hazard. The hazards are then classified into categories of error, indicating which area of operation the root cause originated. Lastly, mitigation of risk occurs through various countermeasures applied to a particular hazard.

Figure 3

Hazard	Risk	Causes	Category	Countermeasure
Loss of GPS Signal	6: major severity, remote May misdirect aircraft for a few seconds, exposing vulnerability to other objects in its path.	Signal obstruction through interference via buildings, aircraft, vehicles, or equipment	Equipment	1. In the event of GPS RAIMs failure, system will employ ground radar as secondary navigation ; ANTS will fully cease operations. 2. ATC may notice GPS RAIMs failure and execute the termination to cease operations. 3. Pilots have the ability to stop motion of their respective TSVs.
Unexpected loss of power for TSV	4: minor severity, extremely remote May pose obstruction to taxing vehicles and aircraft.	Battery depletes faster with age; poor system management	Equipment, Human Element	1. Once a TSV reaches 15% level of its battery life (6 hours), it will return for charging 2. System monitoring will track TSVs with poor battery stamina and mark them for replacement 3. In the case of battery failure, the TSV would be manually recollected
Data management system (main server) failure, lock	4: minor severity, extremely remote May misdirect aircraft for a few seconds, exposing vulnerability to other objects in its path.	External power surge, overheating, natural disaster, etc.	Equipment, External Services, Operating Environment	1. ANTS will automatically cease operations; pilots would have to manually disengage (with remote or FMS) and wait for recollection of TSVs 2. If ATC notices imminent server failure, they may order ANTS to cease operations and subsequent manual disengagement and recollection

Alignment failure (TSV to aircraft)	5: minor severity, remote May take time to align in poor weather conditions. May cause very minimal damage (due to scraping) to landing gear.	Thick fog, heavy rain or snow	Operating Environment	1. Secondary sensors provide backup to primary proximity sensors 2. ATC in coordination with pilots may cancel alignment operation and order a TSV to return to the station. 3. Ground inspection of landing gear will be required in cases of misalignment.
Nonparticipating ANTS aircraft or vehicle	6: hazardous severity, extremely remote A nonparticipating ANTS aircraft or vehicle is not coordinated in the navigation system; therefore, a collision may be possible.	Airlines may refuse to participate; aircraft incompatible with ANTS; ground vehicles operating on tarmac; poor monitoring by ATC or pilot	External Services, Equipment, Human Element	1. A separate, independent set of radar sensors act as a secondary system to sense any proximate objects 2. Pilots have the authority to stop motion of respective TSV by remote or FMS 3. ATC have the authority to cease operations of ANTS or specific TSV if they predict collision

Design

Many elements of current aircraft taxi methods could be improved to better accommodate the volatility of oil prices and the new capacity demands of NextGen. Automated NextGen Taxi System (ANTS) is designed to fill a gap between current pilot-based, engine propelled taxi and fully automatic taxi system.

Our vision for ANTS is to create an autonomous towing system for airports to maximize efficiency of operations with coordination of air traffic controllers and aircraft while maintaining safety. Safety and efficiency are the key words that connect ANTS' aims with the FAA's vision. NextGen not only allows for efficiency by improving communication between aircraft and navigation systems, but its strategy also fulfills strict safety requirements of controlled surface movement.

ANTS is composed of two designs: the ANTS data management system (DMS) and the robotic tractors, or Towing Support Vehicles (TSVs). DMS controls the TSVs by using NextGen communication methods and system management. In addition, DMS also combines all the information to create the best taxiway routes for each TSV. The TSVs are designed to autonomously attach and detach to aircraft, delivering aircraft to requested areas, without compromising safety.

Design Specifications

The TSV is an automated towing tractor that attaches/detaches to aircraft and navigates autonomously, aided by DMS. It has the ability to avoid sudden obstructions or vehicles on the tarmac or taxiway. The TSV utilizes a towbarless design to couple to aircraft for quicker attachment time, which facilitates automation.

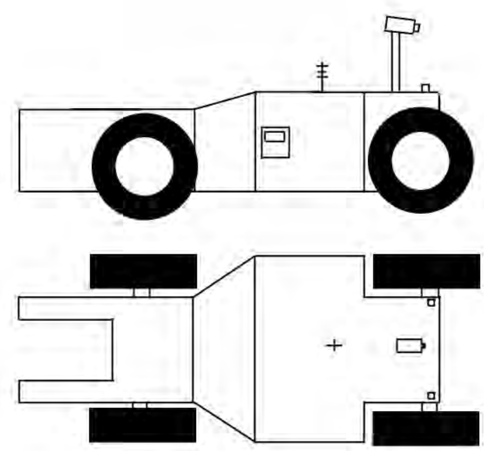


Figure 4: Concept art of a TSV

<u>TSV Specifications</u>

1. *Two Electric Motors (100 volts D.C.)*

   Two rechargeable batteries (50 volt/1000 amperes)

   Utilizing two electric motors, powered by two industrial batteries (in series), fulfills energy and torque requirements for aircraft towing.

2. *GPS transponder (Local Area Augmentation System)*

   The Local Area Augmentation System (LAAS) is used for positioning of TSVs. Accurate positioning is critical for safety and efficient operations; LAAS fulfills this requirement with precision and reliability, having an allowance of less than one meter. LAAS aids in cost minimization since it is a GPS system already in place (FAA, LAAS Quick Facts, 2009).

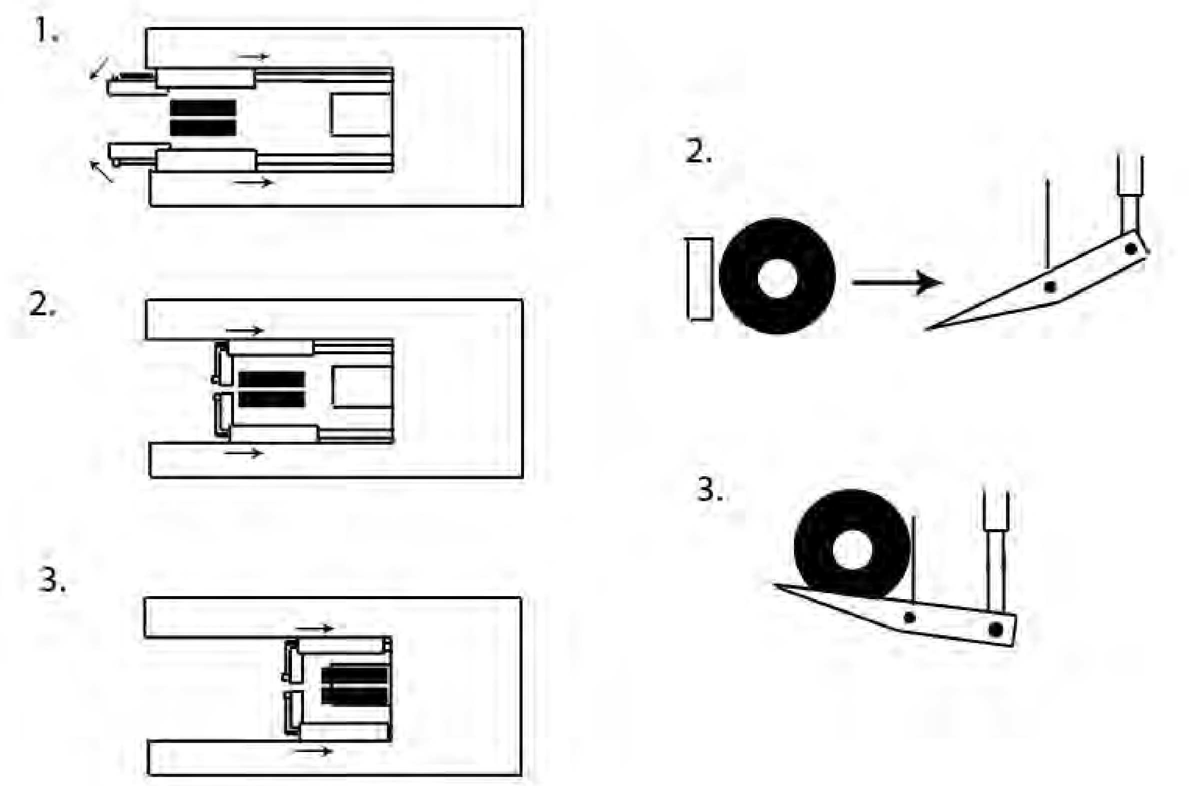
3. *Eight Microwave radar sensors: range- 160m, width- 4m*

   Radar sensors are used for two purposes: obstacle avoidance and nose gear alignment. There are two sets of four radar sensors, acting independently as primary and secondary systems. Each set includes two rear sensors for landing gear alignment and two front sensors for obstacle avoidance (Smartmicro, 2008).

4. *Night vision camera*

   A high-resolution, pivoted camera is attached to provide better situational awareness and other potential auxiliary uses. Additionally, the night vision mode allows for operations in dark settings.

Figure 5



5. Towbarless Design

Current pushback tractors employ the conventional towbar design, which requires ground crews to manually attach and detach the towbar to an aircraft. This requires ground personnel to adjust towbar height, connect towbar to the nosewheel, and lock connecting pin in place, possibly consuming valuable departure minutes. In contrast, the towbarless design can significantly save time and resources, allowing for attachment and detachment within minutes. This expedited process allows for automatic attachment when the aircraft nose gear and tractor are accurately aligned. Figure 5, above, illustrates the towbarless attachment process. Prior to attachment, a TSV is aligned by automation, using its microwave radar sensors as shown in Figure 7 on page 24. Initially, the TSV actuates its grappling arms to an open position in order to clasp the nosewheel. The TSV then closes its grappling arms and pulls aircraft toward a platform wedge as shown in the second step of Figure 5. Finally, when the front wheels are completely on the platform, the grappling arms and platform locks the front gear firmly in preparation for towing (Hammonds, 2007).

Data Management System (DMS)

ANTS data management system (DMS) is a system of servers that combines all the information to control TSVs efficiently and safely. DMS would prospectively be integrated with the FAA's SWIM (System Wide Information Management) technology to ensure the interoperability among different systems and industry standards. In its entirety, DMS requires a main central server and a computer interface for ATC, incorporating NEXCOM technology and Controller Pilot Data Link Communications (CPDLC).

<u>DMS capabilities:</u>

1. *Integrating different data for decision making*

   ANTS combines flight plans, aircraft specifications, weather and runway/taxiway information to accurately calculate decisions in traffic routing. DMS has the ability to configure the best runway to use, accompanied by the most efficient route. To do this, aircraft profiles are analyzed, which include wing span, turning radius, weight, and other dimensions, which DMS takes into account before assigning taxi routing. Furthermore, DMS also considers real-time weather information and runway/taxiway NOTAMS or fixed obstructions, using updated airport taxiway layouts.

2. *Sending the information to ATC, pilot and TSVs via CPDLC and DataComm*

   DMS acts as an information exchange between ATC, pilots, and TSVs, disseminating taxiing instructions, clearances, and runway routing. Under approval of ATC, DMS sends all runway/taxiway information and clearance via CPDLC.

3. *Managing movement of each TSV*

   DMS oversees the locations of each TSV and regulates safe distances between aircraft.

4. *Creating immediate emergency ground traffic control procedures*

   DMS modifies the traffic flow depending on the emergency scenario. Imminent runway incursions or traffic hazards are identified and mitigated through dynamic rerouting.

Departure Procedure

One of the most challenging obstacles for ANTS is fitting DMS and TSVs into current air traffic control and pilot procedures, such as checklists. Figure 6 shows the departure procedure using ANTS DMS and TSVs to tow aircraft from gate to runway.

1. *Preflight*

   When the IFR flight plan is submitted, DMS checks aircraft type and appropriate gate assignment. DMS then searches for the best runway for the aircraft by gathering weather information and taking into account the aircraft's minimum take-off distance. After deciding the best runway, DMS calculates the most appropriate taxiway for the aircraft by searching taxiway profiles and the traffic load of each taxiway in use.

2. *Pushback*

   While the aircraft is preparing for departure at the gate, the ground crew orders TSV attachment to the aircraft. The ground crew then supervises this process, checking for GPS or alignment errors. With ATC approval, the TSV starts auto pushback once the pilot advises ATC orally or through CPDLC. The entire pushback process is overseen by the ground crew and wing walkers.

3. *Taxi Request*

   When the pilot requests for pushback, ATC provides clearance data and taxi routing information, with the assistance of DMS. Upon clearance acceptance, ATC approves of the taxi through DMS. DMS then gives taxiing information to the TSV, and the towing process is initiated.

4. *Taxiing*

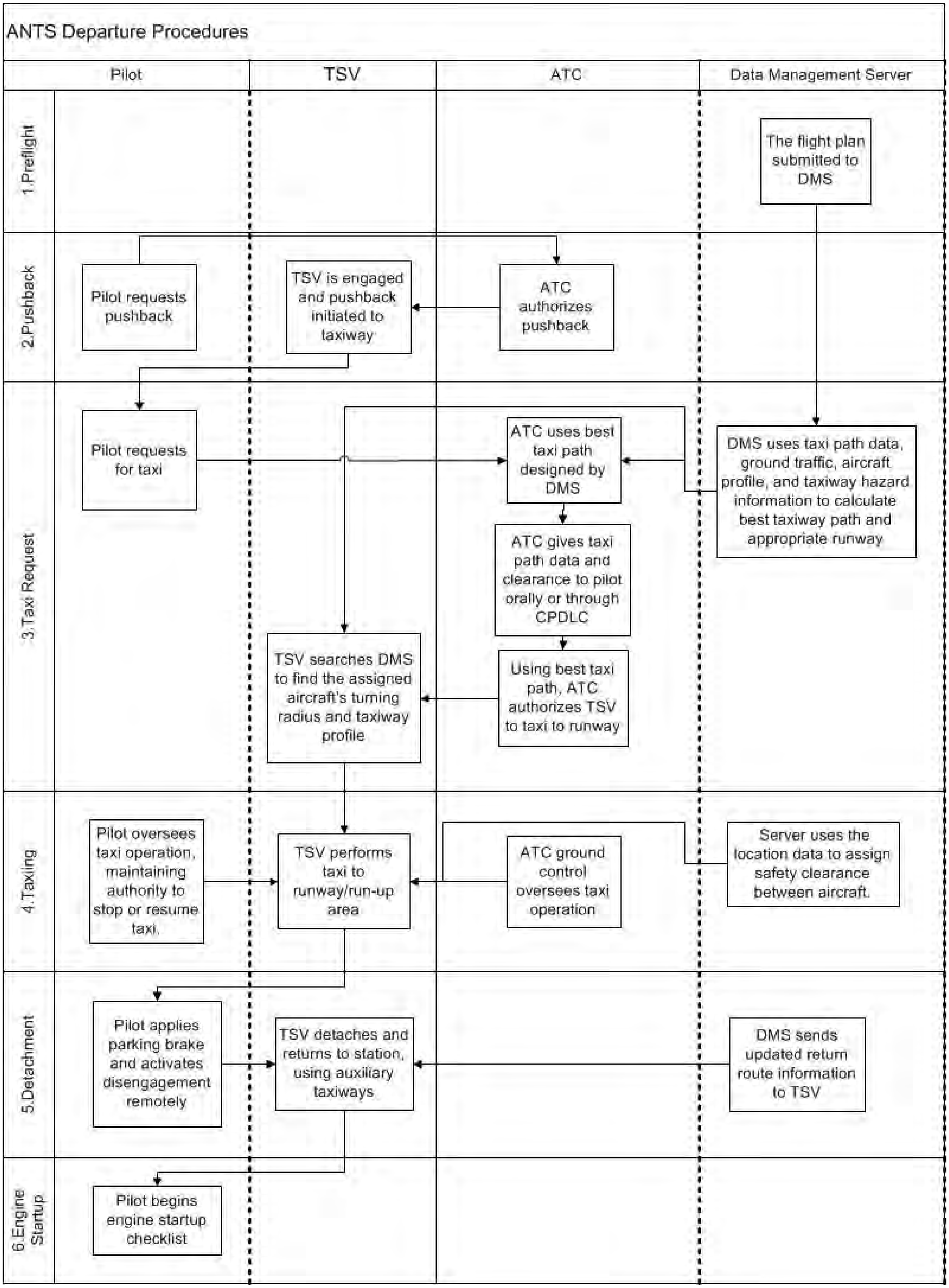
   While TSV is taxiing to the engine run-up area, the flight crew, ATC and DMS oversee the operation:

   - When there is an unexpected emergency, the pilot can stop the TSV by using an emergency stop button on flight management system (FMS) that is linked to DMS via NEXCOM and CPDLC. Alternatively, aircraft without an FMS are issued remotes for this oversight process. If a pilot utilizes the stop button, DMS warns ATC and ceases the traffic of the TSVs that follow.
   - If ATC detects a possible runway or taxiway incursion, they can stop the entire taxiing system or specific operating area. ATC can also adjust distances between aircraft through DMS, allowing for amendable safety margins.
   - DMS constantly gets location feedback from each TSV. If there is an error between GPS data and ground radar data of a TSV, DMS stops the particular TSV and notifies ATC. When there is a traffic conflict, DMS also has the ability to modify the acceleration or velocity of TSVs.

5. Detachment

When a TSV reaches the engine run-up area, the pilot applies the parking brake and requests for engine start to ATC and TSV detachment. Subsequently, the TSV disengages and returns to the base station. After checking that the TSV is within a safe distance, the pilot begins the engine start-up checklist.

Figure 6

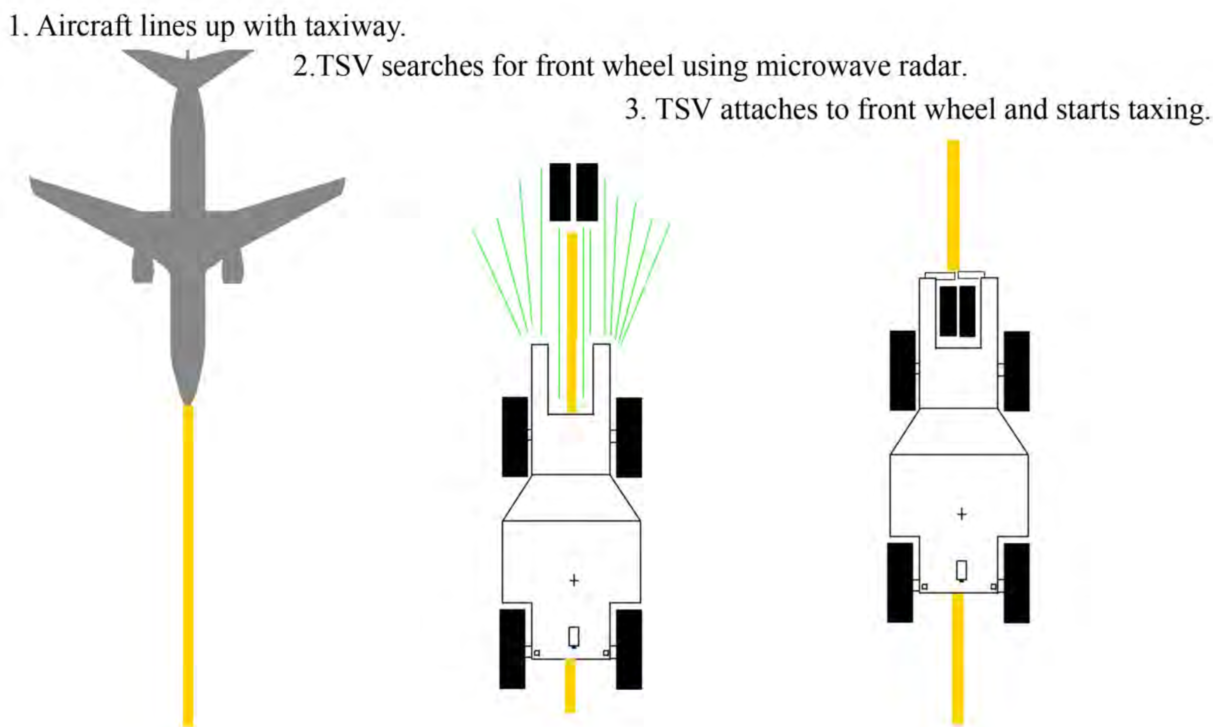

ANTS Departure Procedures
Pilot
TSV
ATC
Data Management Server
1.Preflight
2.Pushback
3.Taxi Request
4.Taxiing
5.Detachment
6.Engine Startup
The flight plan submitted to DMS
Pilot requests pushback
TSV is engaged and pushback initiated to taxiway
ATC authorizes pushback
Pilot requests for taxi
ATC uses best taxi path designed by DMS
DMS uses taxi path data, ground traffic, aircraft profile, and taxiway hazard information to calculate best taxiway path and appropriate runway
ATC gives taxi path data and clearance to pilot orally or through CPDLC
TSV searches DMS to find the assigned aircraft's turning radius and taxiway profile
Using best taxi path, ATC authorizes TSV to taxi to runway
Pilot oversees taxi operation, maintaining authority to stop or resume taxi.
TSV performs taxi to runway/run-up area
ATC ground control oversees taxi operation
Server uses the location data to assign safety clearance between aircraft.
Pilot applies parking brake and activates disengagement remotely
TSV detaches and returns to station, using auxiliary taxiways
DMS sends updated return route information to TSV
Pilot begins engine startup checklist

Arrival Procedure

The ANTS arrival procedure, illustrated in Figure 8, is similar to the departure process map with the exception of the following:

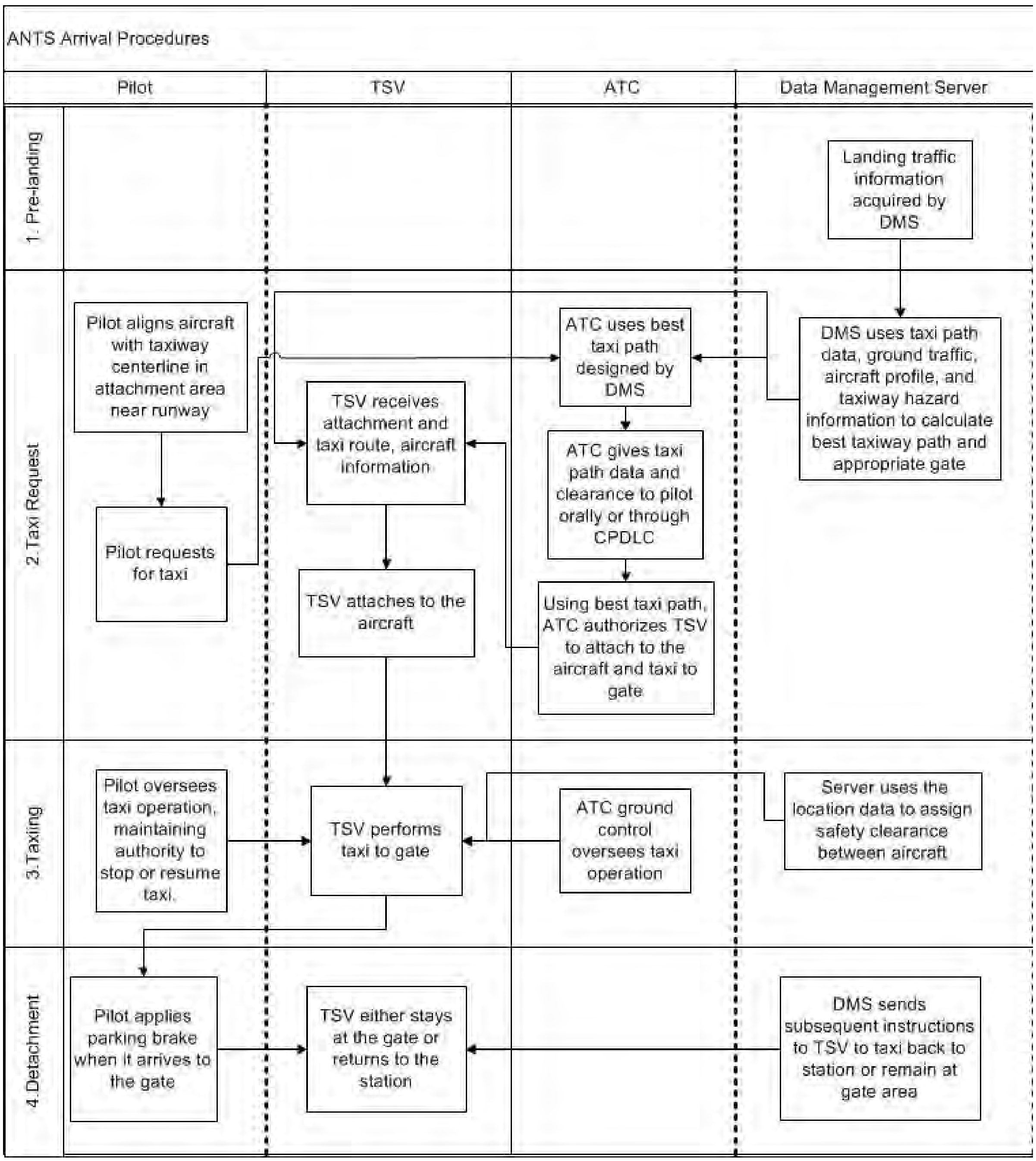
- After landing the pilot should align to the designated taxiway centerline nearest to the runway, before requesting for taxi. When ATC clears the aircraft to taxi, the nearest TSV on standby is aligned and attached to the aircraft with guidance of the microwave proximity radar (refer to Figure 7 below). For details on towbarless attachment, check figure 5 on page 18.

Figure 7



- When the aircraft arrives at the gate, DMS decides the subsequent instructions to send to the TSV- whether it is an order back to the base station or to remain in the gate area. To make the decision, DMS takes into account: battery life, flight schedules, and peak demands for the TSV.

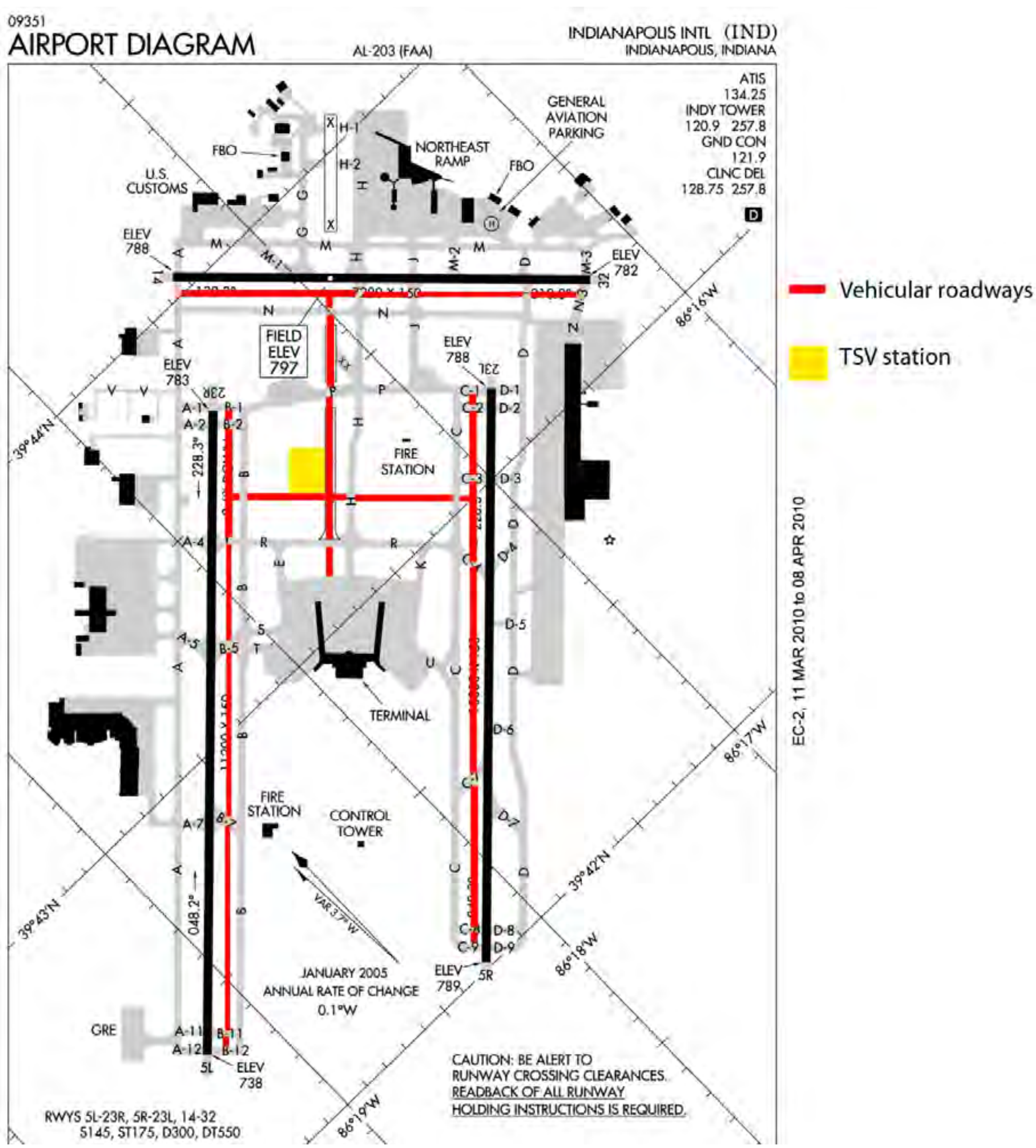
Figure 8



Airport Configuration

In order to apply ANTS to an airport, additional roadways and a hangar station are required. The base station is utilized for charging, maintenance, and housing of TSVs. Furthermore, in order to minimize any conflict with air traffic and ground vehicles, TSVs are given access to supplementary airport pathways, labeled *vehicular roadways*. Figure 9 depicts the base station and the vehicular roadways exemplified at Indianapolis International Airport.

Figure 9



Industry Interaction

After we designed our Automated NextGen Taxiing System (ANTS) we consulted multiple engineering professors, an aviation expert, and one airport operator. First, to combat our overall problems of interacting with the airport's environment and uses of our design, we contacted Professor Stewart Schreckengast, a professor of aviation technology at Purdue University and former ICAO airport consultant. Next, we asked engineering professors for advice on the technical aspect of ANTS. These professors were Dr. K.M. Li and Dr. George Chiu, both associate professors of mechanical engineering at Purdue University. Our additional contact was an airport operator by the name of Betty Stansbury, A.A.E. and current airport director/manager of Purdue University Airport. All of these contacts provided vital input and feedback to our ANTS project and design, and without them, the project would have not succeeded.

When we met with Professor Schreckengast, he supplied us with useful feedback and criticism that greatly influenced our project. Our original concept for ANTS was to utilize ground radar, which is located at many large, busy airports such as O'Hare International Airport, to coordinate and track the towing support vehicles (TSV) as it drives around the aerodrome. He informed us that ground radar had too great of a margin of error (100-200 feet) to be used to coordinate the TSVs precise maneuvers near aircraft. He instead suggested we use the Local Area Augmentation System (LAAS), which has a margin of error of about 2-3 inches. This is a much smaller margin compared to ground radar, so it was clear that we had to change our positioning system for TSVs.

In order for the TSVs to reach aircraft safely and efficiently, we decided to build to additional roadways used solely by ground vehicles and TSVs. These new vehicular roadways would be adjacent to current runways and taxiways and would be narrow enough so only these TSVs could drive on them, since the utilization of current taxiways and runways would become a hazard to aircraft. Professor Schreckengast thought that these additional roadways should be expanded so other airport vehicles, like fire trucks and snowplows, could use them for additional uses such as runway inspections or wildlife scatter. An additional point he brought up was to differentiate these additional roadways by placing distinct marks on them such as large red and yellow lines. This would prevent pilots from mistaking it as a taxiway or runway used for the landing, takeoff, and taxiing of aircraft.

As for the airlines appeal to this new system, Professor Schreckengast commented that airlines would approve of ANTS because of the many benefits, but there were some indifferences that he thought the airlines might have. His suggestions were the fact that airlines and the pilots would want an override system to be in place, in case the TSV goes astray or malfunctions. This override system would allow pilots and air traffic controllers to take over control of the TSV.

His last suggestion to our ANTS design was the implementation of the system. He advised us to use an example airline that has a fleet of identical aircraft, and an airport, that is in the top 50 busiest airports with good climate. Having an airport with good weather would ease the process of implementing ANTS because there would be no risk of weather delays, such as snow, to the preliminary implementation. As for the airlines, a common fleet would be easier to analyze and calculate savings costs of switching to ANTS.

Our next contact was Dr. Li, who in the past worked with Purdue University Airport to help reduce and prevent airport noise. He advised us on the design of the motors of TSVs along with the noise reduction part of our design. He recommended that we use a track system that would be directly on top of the runways and taxiways. The TSV would be hooked up to and would then tug the aircraft. This would eliminate the need for a GPS or positioning system, but after our design team contemplated Dr. Li's idea, we concluded to not use this track system because a track system directly on top of the runways and taxiways would be hazardous to other aircraft. When we discussed the noise abatement part of our design, he approved of the entire noise reduction plan. He said that the noise reducing attributes of the ANTS design would be a major selling point to airports because of the recent government pressure to reduce noise.

The other mechanical engineering professor, that we consulted, was Dr. George Chiu. His research activities that pertained to our ANTS design were signal processing, mechatronics, and dynamic systems and control. His first suggestion to our ANTS design was to use TSVs only for taxiing the aircraft from the gate to runway. His reasoning was that most of time an aircraft spends on the ground is during its taxiing from the gate to runway and not after it lands. Our ANTS design team concluded that when we initially implement our system, we will only use it for takeoffs which will reduce the complexity of the initial implementation of ANTS. As for the specifications of the TSVs, he recommended that we use the specifications of previous research done on towing robots in past. His other advice on ANTS was to integrate the controls with the flight management system (FMS) and the Controller Pilot Data Link Communication (CPDLC). This would provide additional oversight and control in the case of pilots noticing a problem or verge of a collision/incursion; they would be able to cease TSV operations and prevent an accident. His last suggestion was to use radar as a proximity sensor and use LAAS for positioning and locating the TSVs. He concluded that, overall, the ANTS design is realistic and its attractive benefits could be immediately seen at many airports.

Our last contact was Betty Stansbury, A.A.E. and airport director of Purdue University Airport. When we presented our ANTS design, her first thoughts were how the TSVs were going to communicate with ATC, aircraft, and other TSVs. We solved this issue by having ATC communicate with pilots and TSVs via DMS and DataComm.

Project Impact

ANTS offers several benefits to the industry. One of the principal reasons for its existence is to replace the conventions of engine-powered taxiing; therefore, it is paramount to calculate potential fuel savings without the current taxi status quo. Using blunt figures and limiting use to a popular narrow body aircraft model, it is possible to estimate the total fuel usage during pre-takeoff and post-landing taxis. Using the Boeing 737-800 as an example, the fuel consumption of one of the most popular Boeing 737 models, 800 series, comes out to be 334 pounds of jet fuel per minute with both engines at idle (Boeing, 2000). Utilizing this figure from the 800 series allows for a mathematical buffer since, undoubtedly this is the most efficient of the Boeing 737 models. Taking this burn rate in combination with the average total taxi time of 23.6 minutes, we can calculate an estimated amount of fuel usage between the gate and runway (Goldberg & Chesser, 2008). That equates to 1534 pounds of fuel consumed for every flight an airline operates. Using the most recent mean Jet A price in North America of 701.9 US cents per metric ton, a total of $488 is spent during taxi operations on an average flight (ATA, 2010). Taking the country's third busiest airport by air traffic movements, Dallas/Fort Worth International Airport and its annual take off and landing operations, a sum of 328,155 flights per year can be computed. Multiplying this number with average taxiing costs, a preliminary estimate of $160,139,640 is figured to be a potential saving (ACI, 2010). Applying this concept across the nation with 9,552,929 flights in 2009, total costs of airline taxiing equates to nearly

$4.7 billion (BTS, 2010). These mammoth numbers show a picture of significant impact possible through innovation in routine taxi operations.

Airport Example

To illustrate the overall saving potential for a domestic airport with frequent daily commercial air traffic, Phoenix Sky Harbor International Airport (PHX) was chosen, due to its runway layout and traffic statistics. In Figure 10 a case study can be seen, outlining forecasted infrastructure expenditures, TSV unit cost, and overhead implementation expenses. In order to approximate an overall cost of design, production, and implementation of ANTS, rounded costs of the industry's status quo are used. PHX averaged 1235 flights per day in the year 2009, with 18 hours of bulk flight operations from 6AM to midnight (FAA, ASPM, 2010). This equates to

Figure 10

Towing Support Vehicle (TSV)		**Price per Unit**	**No. of Units**	**Subtotal**
bas(FAA, ASPM, 2010); (FL DoT, 2010)				
mic				
night vision camera		$250	1	$250
radio transmitter		$125	2	$250
internal computer		$2,000	1	$2,000
GPS transponder		$2,000	2	$4,000
miscellaneous costs	(25% of subtotal)	$19,530	1	$19,530
				$53,708
			Total	$268,538

AIRPORT Implementation (PHX)		**Price per Unit**	**No. of Units**	**Subtotal**
Towing Support Vehicle		$268,538	76	$20,408,850
mainframe servers		$50,000	4	$200,000
hangar/base station	(per sq ft)	$100	20000	$2,000,000
maintenance		$1,200	76	$91,200
training costs	(pilots, ATC)	$400,000	1	$400,000
pilot remote		$100	500	$50,000
vehicular roadways	(per mile)	$175,462	8	$1,403,695
			Total	$24,553,745

roughly 69 flights per hour, presupposing minimal night operations. Assuming 30 minutes of total taxiing and towing per flight using ANTS, such traffic data indicates a need of about 35 TSVs per hour. However, since battery life is limited to 6 hours, two rotating shifts would be required to compensate for recharging periods. In addition, a 10% quantity buffer is added to account for downtime, maintenance, or incidents for any TSVs. This brings the suggested needed amount to approximately 76 TSVs for this particular airport. Other costs to be noted include maintenance costs estimated for one year, initial training for pilots, ATC, and airport personnel, and the recommended annual recurrent training. Further infrastructure costs include mainframe servers for the DMS, auxiliary taxiways for ANTS routing, and the multi-level station base for hangaring TSVs. As a result, the preliminary cost estimate for ANTS implementation amounts to about $25 million at PHX. However, in a very short period of time, the return on investment proves its merit by repaying initial costs after only a couple of months, taking into account fuel expenses during taxi and assuming every aircraft uses the system. After the first two months, fuel savings were calculated to an average of $18 million a month on more than 38,000 flights (ACI, 2010). Therefore, implementing ANTS to PHX gives the airport a great cost advantage, saving nearly $200 million for its air operators in the first year of operation.

Airline Example

ANTS operations have the potential for also providing enormous savings for airlines, as outlined previously. Using Southwest Airlines as an airline case study, a cost-benefit analysis can be conjured to demonstrate reasons for ANTS adoption. Southwest proves to be an appropriate illustration due to its fleet commonality of B737-700s and history of good fuel management techniques. Taking the idle fuel consumption for a more efficient model (B737-800) in the very first example, a calculation of daily operation savings can be made. Southwest, operating about 3,200 flights a day, has the option of reducing its fuel budget by about $1.5 million a day. Annually, this results in overall savings of $570 million a year, not including the reduced maintenance costs since there is more wear on the engine during traditional taxiing operations. Realistically, ANTS implementation would only occur airport by airport; thus, if Las Vegas McCarran International Airport was used initially, operating 220 Southwest flights daily, the airline would have annual gross savings of about $39 million (Southwest, 2010). While a significant fiscal amount can be saved, adoption of ANTS for airlines has one potential drawback: the initial capital required to support implementation at airport hubs.

Environmental Impact

ANTS also has other positive elements that may make it attractive to airport operators. One chief aspect is the impact on carbon emissions and overall reduction of environmental impact. As previously mentioned, ANTS dramatically cuts CO_2 emissions by reducing engine idling, reducing aviation's current 2% contribution to global emissions (Milmo, 2008). One study suggested that emissions could be cut by 50%, or 150 million tons of CO_2 annually by towing a particular airline's fleet to runways (Johnson, 2006). Other recent research claims that even if fuel-powered towing systems were in place, emissions would be reduced from 18 billion tons to 2 million tons per year (Suslik, 2009). Additionally, carbon credits could potentially be used, since ANTS operations would reduce ground-level emissions in an already highly-concentrated pollutant zone. Essentially, a towing system not only provides a reduction of aviation's carbon footprint, but it boosts an operator's public image, moving toward a *greener* perspective of social responsibility.

Noise Impact and Other Uses

ANTS has further potential in the measurement of decibels; in that, it facilitates airport noise abatement initiatives. Rather than running the engines at idle during taxi, multiplied by the number of aircraft in ground transit at any moment, a towing system would allow for only APU operation, which is considerably quieter. While the bulk of engine noise is heard during take-off and landing, the high decibel taxiing operations could be dramatically reduced or omitted to provide at least, an incremental noise reduction.

The implementation of ANTS could also provide crossover use for other daily airport tasks. The attached camera could be used for foreign object debris/damage (FOD) detection at night, runway and taxiway inspection, significantly reducing the occurrences of foreign object damages. This supplementary camera can simply be incorporated into any FOD prevention program at an airport. Currently, Boeing estimates that $4 billion in FOD damage occur every year (Batchel, 1999). Other studies indicate $1-2 billion in direct damage and as much as $12 billion in subsequent, indirect costs (FAA, AC 150/5220, 2009). Supplementary items could include additional radar sensors or electro-optical sensors to aid in further FOD detection. The vehicular roadways provide additional waypoints for fire trucks during emergencies, facilitating any rescue efforts. Such roadways can also be employed for traditional airport inspection runs by ground vehicles. Lastly, using these additional roadways through use of cameras could facilitate wildlife prevention efforts. Devices could be attached to TSVs to purge the runway environment of any hazardous fauna. Furthermore, in colder climates, TSVs with attached plows could aid in snow removal.

Summary

An outline of the general cost advantages of ANTS was examined, illustrating the large potential savings if implemented nationwide. Economic potential was also analyzed for a few of the busiest domestic airports. Further evaluation was emphasized using Phoenix Sky Harbor International Airport, as a model due to its traffic capacity and climate. Taking a typical high-volume aerodrome, an estimated of $25 million was proposed as preliminary start-up cost, paying for itself in fuel savings after two months. However, a more realistic implementation would involve a gradual introduction of the system, starting with support of a particular terminal or gate area and an airline with an identical fleet, such as Southwest. This airline was selected for its aircraft uniformity and reputation for adopting innovative strategies for minimizing fuel expenses. Concept or beta testing with an air carrier such as from Southwest, or comparable airline, and a sizeable airport could accelerate an implementation process. Financial support, mostly from the participating airline, consenting airport, and other public agencies would be required for the initial investment. Although the airlines would collect the majority of the monetary gains, the involved airports would also benefit from the aforementioned immeasurable advantages like the reduction in local carbon emission, lessening of noise pollution, and additional resource equipment for daily airport operations (i.e. inspection, snowplowing). Furthermore, ANTS promotes safety by relieving ground navigation for pilots, abating the probability of runway incursions with additional oversight by ATS and Data Management Server (DMS). Taken as a whole, ANTS has a great potential for airlines, airports, and other aviation operations through reduced impact of fuel usage environmentally and fiscally, while enabling safe ground handling/movement operations.

Appendix A

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Appendix B

Purdue University is a coeducational, state-assisted system in Indiana. Founded in 1869 and named after benefactor John Purdue, Purdue is one of the nation's leading research institutions with a reputation for excellent and affordable education. Purdue University is accredited by the Higher Learning Commission of the North Central Association of Colleges and Schools. The West Lafayette campus offers more than 200 majors for undergraduates, over 70 master’s and doctoral programs, and professional degrees in pharmacy and veterinary medicine.

Purdue University’s College of Technology is one of the largest and most renowned technology schools in the nation with more than 34,000 living alumni. More than 5,500 Purdue students are currently pursuing their education in the College of Technology. The College of Technology consists of eight academic departments, and resides in ten Indiana communities in addition to the West Lafayette campus. The Aviation Technology department is one of the eight departments within the College of Technology. Three undergraduate programs are offered within the department: Aeronautical Engineering Technology, Aviation Management, and Professional Flight. Graduate studies in Aviation Technology are also offered. In addition, the department pursues signature research areas that embrace tenets of the emerging Next Generation Air Transportation System, which include Hangar of the Future aircraft maintenance technology innovation, National Test Facility for Fuels and Propulsion, and Safety Management Systems.

Appendix C

Our non-university partner was Betty Stansbury, airport director of Purdue University Airport. While she is affiliated with Purdue, she is a member of the American Association of Airport Executives and provided a vital airport director's perspective on our design.

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Appendix E

For Student Team:

1. Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?

As we collaborated and developed a design solution to a problem, we gained valuable experience in not only the aviation industry but also experience with teamwork, organization, and communication. As we balanced chaotic college lives and differing ideas, we learned to collaborate and organize as one to manage conflict and accomplish a goal. We were able to improve our communication skills technically and graphically because of the long length of the design package. We designed multiple diagrams and models along with writing from a technical perspective on the description of our design.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

Throughout the duration of project, we encountered many problems which complicated and lengthened our design schedule. Our major problems were time management, the fact that we commenced the project late, and overall design challenges. The first two problems were solved by meeting multiple times each week to combat our issues of meeting together and starting in January on our design. The design challenges we encountered throughout our design process were both internal and external. Internally, we could not decide what problem to address and how, and then externally, we faced the problem of finding useful industry contacts. This problem was solved through the use of our resourceful faculty advisor, Professor Tim Ropp. He helped us in exactly defining the problem and pointing in the correct direction to find industry experts. We also researched alike designs, which helped narrow what problem to address.

3. Describe the process you or your team used for developing your hypothesis.

After defining our problem through research, we first performed a gap analysis on the topic. We found the status quo of our problem, and then looked at where current approaches should be. This perfect gap was assessed on what needs to be implemented to bring the problem to the correct level. This was done through not only looking at comparable designs, but also contacting industry experts and working through the engineering process.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Attending a prominent, large university allowed us to be exposed to many innovative industry leaders and experts. Our industry contacts gave us direction towards our ultimate design and without them we would have not succeeded as well as we did. By having not only aviation experts but engineers, we were able to gain not just an aviation view on the design but also a technical perspective on it.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

We learned many valuable skills that can easily be applied to our future aviation careers. First, we learned how to effectively coordinate a team to accomplish a common goal. We achieved this through collaboration, diligence, and managing our time efficiently. We also gained extensive knowledge on taxiing and towing at airports along with current and future grounds systems through the design process. Lastly, we were able to acquire a basic understanding of engineering mechanics because of our towing vehicle design. All of these skills and knowledge we acquired through this experience will undoubtedly be applied to our future careers in aviation.

For Faculty Members:

l. Describe the value of the educational experience for your student(s) participating in this Competition submission.

I believe the most immediate value of this project realized by the student team was the amount of follow up and tenacity required for a design project of this type; especially for a project so heavily based upon innovation. Although the team is comprised of aviation students relatively familiar with the industry from an entry level perspective, they quickly found that skills in project planning and re-planning, due diligence reviews and both verbal and graphical communication are sometimes more important than core technical skills. It has been an awakening experience for them to see the extensive collaborative effort required across many industries to achieve even small breakthroughs in technology-based systems. This became especially evident as they evaluated their initial design assumptions against a system comprised of highly regulated, hazardous or risk-sensitive technologies like air transportation.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

The student team's experience was very appropriate for the type of research encouraged within the aviation department's research initiatives and as pursued within the Hangar of the Future

Research Laboratory which is largely NextGen centric. Students from freshmen through graduate are introduced to elements of research and problem solving, especially in upper level courses within the Aviation Technology program. This was an excellent opportunity for them to connect to a real world problem, transfer and practice their emerging research skills.

3. What challenges did the students face and overcome?

The first challenge was the students' ability to come to consensus on the problem to address, narrow down and lay it out visually and descriptively enough to relay a intended solution path clearly to others. They were forced to transform their ideas from merely a mental model based on discussion and general intuition, to more concrete visual design. In doing so, they discovered there were assumptions they were making (or duplication of an existing design) requiring them to seek out expertise to validate their assumptions and re-design certain concepts. This in turn resulted in retracting or altering originally assumed solution paths. Second, as undergraduates they did not always have the savvy of gaining access to higher level industry contacts for expertise and guidance in a timely fashion (i.e., airport directors, former ICAO members), then explaining their project succinctly.

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

This was my first experience in the FAA competition and the team was a volunteer group of undergraduate students from various disciplines. As an educator I have learned a lot myself and gained insight into how I can use this much more effectively within my courses. Learning from the challenges to the team and myself this round, I have ideas for improvements and use in the future as part of my structured classroom approach.

5. Are there changes to the Competition that you would suggest for future years?

The competition is an excellent platform for students new to research and development to explore the realities of doing so in a controlled and structured manner, while connecting to an agency with real global influence. The field of topics is somewhat restrictive; students found it difficult to come up with an idea that had not already been pursued or produced. However, this did lead to good discussion on innovation, building upon previous ideas, the importance of patent/copyright law and searches and the like. Our largest concern is that which has been shared by previous submission teams: that the team's idea presented is not already in existence somewhere which was not discovered in the literature and technology reviews.

Appendix F

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