Title of Design:

iTUG: The Next Generation of Ground Support Vehicles

Design Challenge addressed:

Challenge II: Runway Safety/ Runway Incursions/ Runway Excursions

University name:

Purdue University

Team Member(s) names:

Tyler Futch (Graduate)

Zachary Tolley (Graduate)

Bradly Grube (Undergraduate)

Jim Martin (Graduate)

Number of Undergraduates: 1

Number of Graduates: 3

Advisor(s) name: Dr. Mary E. Johnson

PURDUE UNIVERSITY

COLLEGE OF TECHNOLOGY

Executive Summary

Title: iTUG: The Next Generation of Ground Support Vehicles

Team: A team of three graduate students and one undergraduate student from the Department of Aviation Technology, School of Technology

University: Purdue University

The global transportation industry is deeply involved in the development of economically and ecological sustainable technologies in the face of rising energy costs and the looming specter of emissions regulations. The airline industry being particularly energy intensive and dependent on hydrocarbons is leading this charge, and in the last 10 years has seen the introduction of significant operational and technical advances such as single engine taxi, composite fuselage airliners, alternative jet fuels, and geared turbo-fans. The ground support equipment (GSE) used to handle the under-wing functions of airline operation have not seen any significant investment or change over the last 30 years. The iTUG (Informative Terrain & User Guidance) system is meant to bridge this technical gap by applying technologies extant in other industries such as visual communications, vehicle tracking, and collision avoidance systems coupled with a new generation of engines to address the problems that ground service personnel have to endure. The updated communications service, vehicle tracking, and the options of engines will dramatically lower emissions by reducing fuel usage. Additionally, costs will be reduced through avoiding accidents caused by GSE collisions with aircraft, personnel, and runway incursions with the use of the iTUG's integrated collision avoidance system. Ramp delays will be minimized, thus decreasing the on ground APU run time and taxi time, and delivery time of cargo and bags to the aircraft will also be minimized. These changes will have positive dividends in terms of operational costs and would also help the airlines reduce fuel usage and carbon emission to reach the 2% global annual fuel efficiency improvement goal by 2018.

Table of Contents

Table of Figures and Tables

Problem Statement

The state of the art in ground support equipment (GSE) has remained essentially static for the last 30 years. GSE represents a significant portion of an airline's operating cost. The type GSE that will be addressed in this design will the most commonly used push-pull tractors such as baggage and cargo tugs, and pushback tractors. Furthermore, accidents involving these types of vehicles cause over 30% of US airlines maintenance related cancelations. Implementing technologies that could dramatically reduce the risk of aircraft damage from GSE, while minimizing operating costs, would potentially represent a substantial cost and emissions savings for the air transport industry. This is especially attractive when considering the benefits against the required investment when compared to the costs of finding operational and safety improvements on the aircraft side. The cost differential between GSE performance improvements and aircraft performance improvements is an order or orders of magnitude.

Scope and Background

During the last three decades state of the art in other analogous industries has advanced significantly. Of particular note is the advent of autonomous vehicles in both manufacturing settings and the more recent development of autonomous cars, both of which have been enabled by the development of low cost sensors for real time 3D point mapping. Likewise, the technology for wireless data networks has advanced significantly with wireless access points and touch enabled devices having become commodity components within many vehicle systems. By incorporating these components into workhorse GSE vehicles such as tugs, dramatic improvements can be made at relatively low costs.

Summary of Literature Review

Over the last 10 years we have seen a revolution in sensor and navigation technology that has brought the prospect of autonomous cars from the realm of science fiction to now a legal reality in three states with California, Nevada, and Florida all passing legislation legalizing the operation of autonomous vehicles (Weaver, 2013). The advances in the field of fully autonomous vehicles provide an opportunity for other applications such as enabling GSE to be able to automatically detect and avoid possible collisions with the aircraft they are servicing. This would be a significant benefit to the airlines, both operationally and economically. As noted by the SAE report on Aircraft Damage caused by GSE, tow and pushback tractors themselves (Figure 1) account for a significant percent of aircraft damage (SAE, 2009). Available estimates are that between 0.6% and 2.9% of operating income from airlines are lost to ground delays every year. Additionally, civil aviation statistics show that about 40% of non-aeronautical accidents on the ground are from GSE and aircraft (Huawei Technologies, 2013). These incidents and errors cause flight delays, passenger dissatisfaction, and are the source of costly waste and damage. Control and communication between ground personnel can eliminate many of these delays and accidents. Real time business data shows that this system gets 5-10% labor cost savings and an average of 2 minutes (or 20%) increase in available loading time at turnaround (Huawei Technologies, 2013).

Figure 1: Collision between GSE and aircraft

The initial ground work for the advent of autonomous vehicles was laid by DARPAs Grand and urban Challenges which invited university and industry teams to develop and compete with a vehicle that could autonomously navigate an off road course, and then an on road course with unplanned hazards and normal traffic. The first year the Grand Challenge was run not a single team finished, by the next year however five vehicles successfully completed the course.

Figure 2: LIDAR scanning representation

One of the enabling technologies that allowed for these independent teams to build autonomous vehicles was scanning LIDAR. LIDAR (Figure 2) works by using a rapidly spinning and oscillating laser that reflects light off every object in a 360 degree circle around itself out to a distance where beam attenuation makes detecting the reflection impossible (Buehler, et al, 2009). These reflections are then observed by a CDC and used to generate a 3 dimensional point map of the space around the vehicle that the vehicles computer can use to navigate.

However, there are two downsides to LIDAR- based approaches. The first is latency. Like radar the data produced by the LIDAR is only accurate for the moment that the beam is passing over it. In order to reduce the latency of the model being used for navigation, the rate at which the laser spins and oscillates must be extremely fast. This adds mechanical complexity to LIDAR systems and reduces reliability. The second drawback of LIDAR is cost. Today a

LIDAR system suitable for use in a collision avoidance costs approximately $75,000 making it cost prohibitive for developing a collision avoidance system for use in airport tow tractors (Velodyne, 2014).

Thankfully in recent years another 3D mapping technology has entered the market place at a much lower price-point and higher reliability owing to a being entirely solid-state design. This technology is a stereoscopic infrared camera set that can produce high fidelity 3D images,

Figure 4: Xbox Kinect sensor

Figure 3: Kinect depth sensor

developed by Microsoft and marketed as the Kinect One game device (Figure 3). With an open software development kit (henceforth referred to as a SDK) the Kinect has proven to be a valuable option for robotics researchers and has been demonstrated to provide real-time 3D mapping data (Figure 4) to a wide variety of platforms from quad-copters to a variety of tracked and wheeled ground vehicles (Chu, 2013). Kinect sensors offer a high fidelity 3D sensor at a low price, each under $250, or under $1000 for a set of 4 to provide 360 degree coverage. The low price point is critical to enabling a practical collision avoidance system for GSE.

To contrast with the relatively low price of sensors to avoid aircraft collision is the relatively high costs of aircraft damage, both in repairing the aircraft and accommodating disrupted passengers, but also accommodating operationally the lack of aircraft availability in the carrier's schedule. Delays have been estimated to cost US carriers $57 a minute, the cost of a cancelation is often in excess of $150,000 just in lost revenue and passenger accommodations (M2P Consulting, 2006).

As with other sensor technologies GPS has seen dramatic improvements in price and performance over the last two decades with widespread implementation in nearly every sector of the transportation industry. Today GPS receivers are commodity components and with the deregulated civil signal can have a positional accuracy of greater than, plus or a minus, one foot depending on the number of satellites over the local horizon and costing under $40 for a receiver chip (adafruit.com, 2013). Coupled with the automatic collision avoidance system this allows the tug to also eliminate a serious safety risk, the risk of inadvertent incursion into an aircraft movement area such as a runway or taxi way. While this is a relatively rare occurrence, so much so that the only statistics available are for aircraft movement area incursions not GSE (FAA, 2012), it is of sufficient concern that some airports have begun investigating using GPS to prevent GSE incursions (Foster, 2011).

Problem Solving Approach

The initial formation of our design team members stemmed from an aviation sustainability graduate class at Purdue University taught by Dr. Mary Johnson. In this class we discuss topics of different methods, innovations, and actions that are meant to meet the needs of current industry problems, while maintaining viability for future generations. One of the requirements for the class is to choose a project that we would work on throughout the semester. From there, Dr. Johnson let us divide into our own groups so that each individual team could choose a project separately. Our team decided to enter into the FAA Design Competition because we felt it would both teach us something valuable, and give us an opportunity to make an impact. Our team consists of four members, which includes Tyler Futch, Zach Tolley, Brad Grube, and Jim Martin.

We began discussing some current problems going on in the aviation industry with Dr. Johnson and some fellow classmates. After learning about the current state of fleets of tow tractors, better known as Tugs, that are used on airports all over the United States, we decided to tackle the top three issues most associated with these vehicles. With the span of technology that exists today, we can imagine the possible applications that would greatly benefit the airports, airlines, and ground personnel.

First, we learned that airports across the nation are still using tow tractors that were made using designs that have not improved much in 30 years. At the time these tractors were made, emissions from ground support equipment was not as big of an issue as it is today. On top of that, these vehicles are frequently left running to increase the speed of the worker and to keep the engine warm in cold weather conditions. Our team decided that the tow tractors of the future would need to be powered by a more environmentally clean source of energy like compressed natural gas or electricity to decrease the amounts of greenhouse gasses being released into the environment of the ground support crew and the atmosphere.

The second issue that we address in this design is the lack of communication between tow tractors and other ground support personnel and leads. It has been observed at Chicago O'Hare Airport that the tow tractors and their operators lack the means of communicating or relaying important information such as gate changes, special requests, or an airport emergency except by means of two-way radio or their own personal cellphone. We believe that the technology to improve this issue has been developed in the past decade or so.

The last issue our team addresses is the problem of accidents involving collisions of ground support vehicles with pedestrians, aircraft (Figure 5), or other support vehicles, that are usually the result of human error. Currently the automotive industry is using collision avoidance systems on their vehicles to reduce accidents involving distracted driving or emergency stopping. We believe that this technology would be beneficial to reduce unwanted incursions. In aviation, billions of dollars per year are spent on things like aircraft repair and insurance settlements because of the result of accidents involving ground support vehicles. If collision avoidance technology could prevent just one unwanted incursion, it would have the potential to save the airline enough money to immediately pay for itself.

Figure 5: Collision between GSE and aircraft

With these three important issues regarding tow tractors in the aviation community, our team understood that we would both make an impact and increase our knowledge of these issues by designing a new and improved tow tractor of the future. We then began to distribute our work load among the team members with the most applicable knowledge. Tyler Futch was appointed the team leader and has been in charge of project management, editing, and has assembled the process design. Since Zach Tolley is more familiar with performing various analyses, we put him in charge of risk assessments of our designs. Jim Martin, who has worked in the automotive manufacturing industry for over ten years, was put in charge of developing the industry implementation and impact of our design. Also, Brad Grube was put in charge of constructing any 3D models or representations of our ideas because of his experience with computer modeling programs. As a team, we have constructed a literary review that will be built from the collaboration of all of our research. Our work is continuously under the guidance and review of Dr. Mary Johnson. After the final editing and revisions are completed, we submitted the final draft for her approval before it was entered into the design competition.

Figure 6: iTUG vehicle representation

Technical Aspects Addressed

Collision Avoidance System

The implementation for the collision avoidance system will consist of several parts. Firstly, the GSE vehicle will be fitted with four Kinect sensors strategically located at 90 degree increments (see figure 7) from one another. These sensors have a broad spectrum of visual advantages from floor recognition, object placement in space, distance calibration, and personnel visualization. The location of these sensors allows for an excellent 360 degree view which would be displayed on a Multi-Function Display (MFD) within the cabin of the vehicle. The display could be utilized and customized by the operator for convenience and familiarity to accommodate specific operations. Coupled with a MFD and the power of the Kinect sensor the operator will have an ultimate view of his/her surroundings with visual aids to iterate possible incursions and proper routes to be obtained.

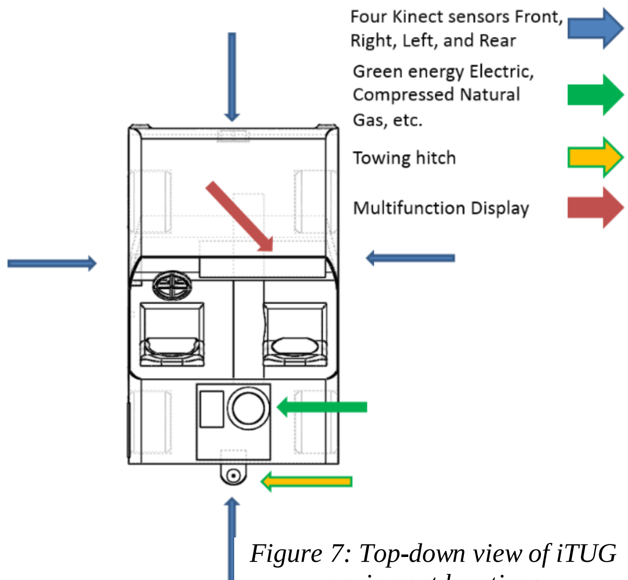

Figure 7: Top-down view of iTUG equipment locations

A visual representation of the capabilities of this system is pictured in figure 8. The operator will be able to see what the Kinect sensors can see and will have many tools at their hands to efficiently and effectively navigate the ramp and other territories. End point destinations and delivery drop locations can be marked and displayed as well as an estimated time of arrival for maximum time management. When approaching an aircraft to be pushed or pulled, the rear facing Kinect can be utilized to fully see the hitch and landing gear and display overlays on the MFD to help guide the GSE to connecting to the aircraft with accuracy and precision.

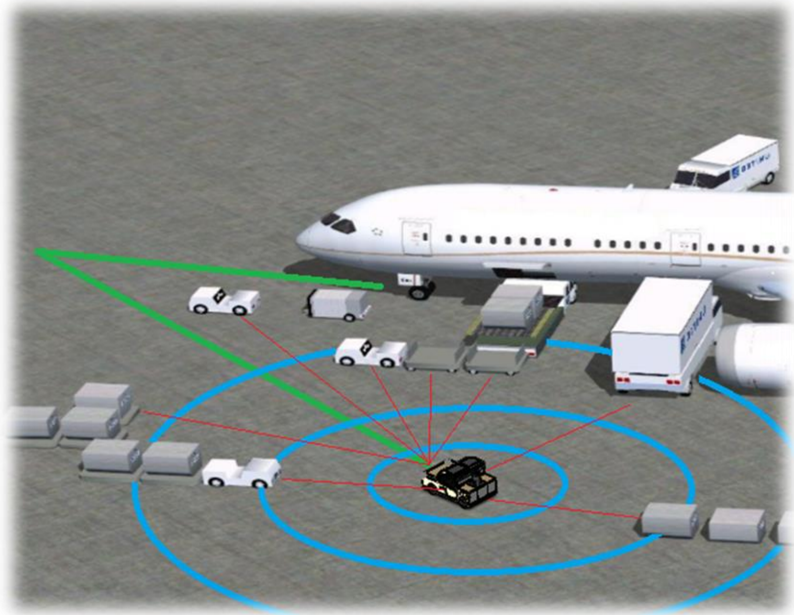

Figure 8: iTUG using 360° spatial mapping to avoid collisions

Visual Communications System

We specifically intend to reduce ramp and GSE delays caused by miscommunications, congestion, and poor prioritizations leading to more efficient use of existing GSE equipment as well as the cost savings such efficiencies generate. Currently, technology of two way radios do not provide message permanence and are hampered by the noisy conditions the workers operate in. The iTUG vehicle contains a touch screen inside the cab which is a weatherized, and rugged computer screen (figure 8) that displays information in a text format, similar to the Wherenet System from Zebra Technologies (Zebra Technologies, 2014). This provides message permanence and reduces miscommunication and misunderstanding. It is also allows the operator to communicate in real time with all other operators equipped with this system. This means that if work details change after the vehicle has left the terminal, such as in the case of a gate change, the operator can be notified via a message on the display, while in route and reduce the reaction time. All messages will auto-save to a history so that the operator can review previous messages to reduce the need of repeating information. The iTUG system can also be utilized in improved training programs. Our systems ability to track the movements, routes, written instructions and notes, or other functions of the GSE can help the veteran worker point out details to the trainee novice that may have been otherwise overlooked. These same functions can help provide reminders to the newly trained who might otherwise be overwhelmed by a surplus of new information.

Figure 8: Example of weatherized touch screen tablet

Real-Time Locating Device

Another technology we will deploy is small scale GPS or near-field token based tracking systems, similar to Q-Track which is a company that specializes in real-time tracking and location devices (Q-Track, 2014). The location information from the iTUG vehicle can be used in three ways. First, accurate traffic flow data can be gathered allowing the study, simulation and implementation of smoother and more efficient use of chokepoints for ground traffic, thus improving traffic flow and reducing delays. A second use of this technology is preventing and controlling runway incursions and security breaches. The system can deny access to any area at any time, it can stop an equipped vehicle if desired, and also track its past whereabouts. The third use is for improved maintenance tracking of the vehicle itself. Precise usage information of each piece of equipment can be gathered into a log and used to calculate scheduled maintenance and to improve maintenance practices on GSE vehicles.

The iTUG system will add to these benefits and improve on them by incorporating collision avoidance, runway incursion prevention, traffic data tracking, and improved maintenance recordkeeping. The benchmark for measuring this improvement would be the test case of Guangzhou Baiyun International Airport whose system is based on the Huawei model.

Figure 9: Guangzhou Baiyun International Airport

Guangzhou Baiyun International Airport (figure 9) was China's 2nd busiest and world's 19th busiest airport in terms of passenger traffic, with 45,040,340 people handled. As for cargo traffic, the airport was the 3rd busiest in China and the 21st busiest worldwide. Guangzhou airport is also the 2nd busiest airport in terms of traffic movements in China. The old system dispatching system could not satisfy the increasing passenger and cargo requirements (Huawei Technologies, 2013).

Interactions with Industry Experts

Industry experts, employees of commercial airlines, and an AAE/AAAE member were contacted to obtain information about this issue. These sources were able to confirm a lot of the claims of working conditions and runway safety that we would be addressing in this design. The interviews were conducted in person and their responses instigated more questions about airport operations.

An interview was conducted with Betty Stansbury, current Purdue University Airport Director and former employee at George Bush Intercontinental Airport in Houston Texas, in her office at the Purdue airport. She provided us with information on the condition of the GSE fleet in Houston and similar airports, which confirmed our beliefs that there was room for improvement on current GSE efficiency. Upon asking about ground service personnel training, she provided us with some literature that is distributed by the FAA to aid in the training efforts of ground service employees.

Ben Tolley is an operations agent at Southwest Airlines working at the Akron-Canton regional airport. He provided us with insight into the day to day difficulties in communicating in the ramp environment. He also provided us with feedback on the efficacy of our proposed tug with an extremely pragmatic 'man on the ground' point of view.

Information gathered by interactions and interviews with Bill Yacko of Subaru of Indiana Automotive Inc. (SIA) during this process provided valuable insight and knowledge about what the state of prior art is in these areas. These interactions have been daily and ongoing in nature during the entirety of this project. Although SIA is not an aviation company many of its challenges are the same or similar to those faced by this project in that what Aviation calls GSE heavy industry calls Material Handling which is Bills forte. Regardless of what it is called it is the process of moving objects from place to place inside the operation as safely and efficiently as possible. Control and communication between ground personnel can eliminate many of these delays and accidents.

Project Analysis and Impacts

Implementing automatic collision and incursion avoidance and visual communications will require the development of new tugs that incorporate those technologies from inception or potentially retrofitting existing tugs. Given the purely mechanical nature of the majority of tow tractors currently in operations today the technical feasibility of a retrofit program seems questionable at best. Since the technologies we propose to incorporate into next generation tractors are at a high level of maturity and are commodity components in other industries development by GSE manufacturers or a prototype in a research context should be straight forward. The most difficult and costly part of implementation of the development of the software running on the onboard processor to control the collision and incursion avoidance system, for wide spread adoption perhaps the best method of implementation would be an open source development of the software amongst university and industry stake holder curated by the FAA.

This would distribute development costs of the software amongst the stake holders in the industry and lower the purchase price of the tugs when they come to market. A logic diagram for the system is presented in Figure 10.

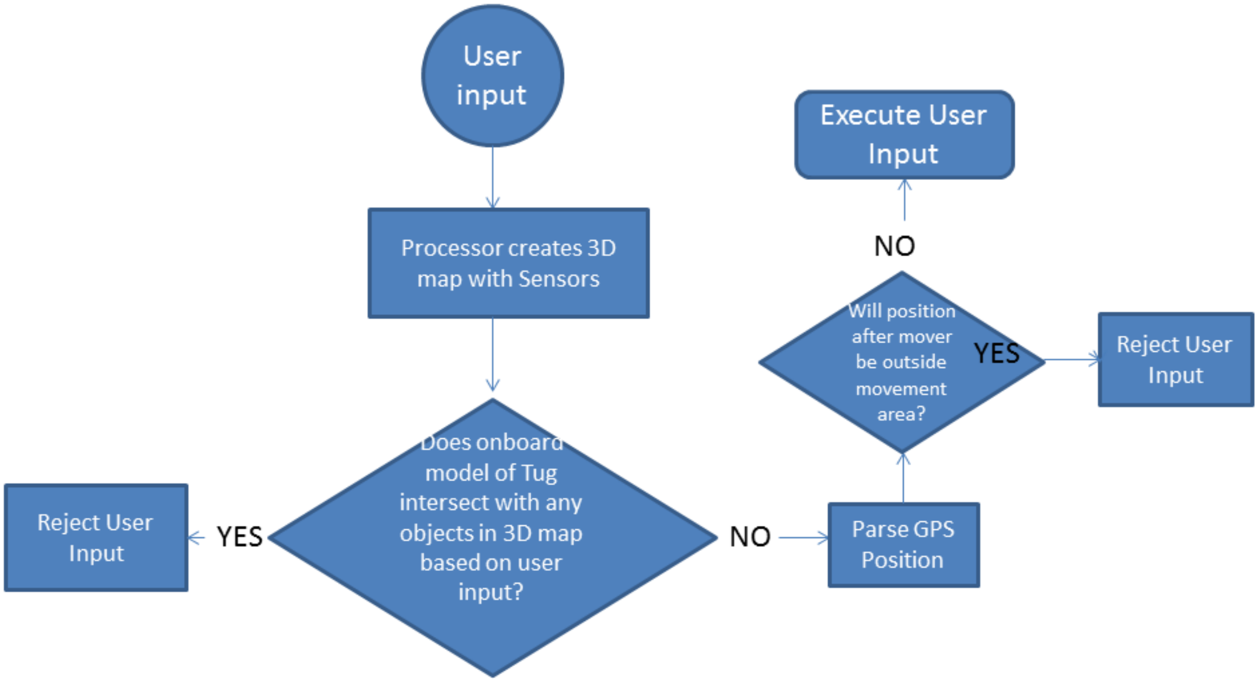

Figure10: Logic diagram for the collision avoidance system

The visual communications system will be relatively straight forward to implement both technically and operationally. From the technical perspective the touch screen interface will be integrated into the commercially available tablet that will also house the processor for the collision and incursion avoidance system. As was previously noted the 802.11 standard is both safe and has regulatory permission to be used in the airport environment. Off the shelf industrial visual messaging software may be used or if so desired airline specific software can be developed by the end user. Applications of this nature are straight forward and their development is both swift and low cost.

Operationally being able to send text and diagram based operational instructions to ground crews will yield increased productivity by eliminating the ambiguity of the current hand signal and two way radios used by ground crews. In interviews with airline ramp agents the inability to hear instructions passed on verbally due to the airport noise environment was a common complaint. One agent currently employed with a major US flagged carrier noted that at least once, an aircraft turn agent would misunderstand an instruction leading to such mistakes as misleading cargo, dropping bags at the wrong claim conveyor, or returning to the loading area erroneously seeking to pick up last minute luggage. Each of these mistakes represents both a financial cost in lost productivity and an emissions cost in unnecessary fuel burn. By providing work instructions and a pathway for communications that isn't hampered by the noise environment and hearing protection the impact to airline efficiency could potentially be significant. Factories that have implemented similar communications systems have noted 5-10% increases in worker productivity and averages of 2 minutes (or 20%) increase in available loading time at turn. (Huawei, 2013). It is also likely to be readily adopted by the workforce, with the omnipresence of smart-phones and tablets the use of similar systems in the workplace should be readily and enthusiastically accepted.

Risk Analysis

The collision avoidance and visual communications capabilities we propose implementing are highly mature technologies utilizing commercially available off the shelf components, so the risk associated with technology develop is low. When introducing a new technology and capability to the airline environment though the operational risks need to be considered as well as the technical risks.

The risks of system failure of the automatic collision avoidance system and visual communications link are tabulated bellow (table 1) in failure mode, effects, and criticality analysis (FMECA). All of the components in question are solid state and they have an extremely long mean time between failures leading to an extremely reliable system. In addition to system reliability, the effects of system failure are relatively benign with the tug reverting back to purely manual operation, or the ground crew having to receive instruction either via two way radio or person to person, as is the current practice.

The biggest risk associated with the system as designed is an event in which the automated collision avoidance system fails and the operator is unaware the vehicle is in purely manual operation, if that driver has become reliant on the automated collision avoidance system and routinely drives aggressively around aircraft and GSE with the expectation that the system will do his braking for him that could lead to the aircraft damage that the system was intended to avoid. To mitigate this risk the system should include large visual as well as audio annunciators for when the automatic collision avoidance system is offline. This can also be coupled to the screen of the visual communications system further attenuating the risk of the driver not noticing.

Another risk to be considered is the radio frequency spectrum used by the visual communications system, in an airport environment interfering with aircraft communications or navigation is certainly something to be concerned about. The system we are proposing utilizes the IEEE 802.11ac standard which is the 2.4 GHz range. At the transmitter power levels (bellow 1 watt) utilized by the visual communications system both the FAA and FCC place no restriction on their use around aircraft. At such low transmitting powers the likelihood of interfering with aircraft systems is essentially zero.

Table 1: FMECA analysis of collision avoidance systems and visual communications systems

Subsystem	Potential Failure Mode	Potential Causes of Failure	Failure Effects	Occurrence	Severity	Detection	RPN	Reccomended Actions
Automatic Collision Avoidance System	Looses visual input from Kinect Sensors	Extreme physical damage	System looses space map, goes offline	1	2	3	6	Total loss of signal easy to detect, trigger annunciator
		Dirt/contamination on enclosure	System looses space map, goes offline	1	2	1	2	partial loss of signal harder to detect, software needs to be tested to interpret when it looses point map
	Stepper motor Failure	physical damage to motor	System looses ability to steer and or brake, goes offline	2	2	5	20	Might not be immeadietly apparent, software-hardware self test on start up needs to be implemented to detect.
		Wiring Harness Damage	System looses ability to steer and or brake, goes offline	1	2	5	10	Might not be immeadietly apparent, software-hardware self test on start up needs to be implemented to detect.
	Control Computer Failure	Electrical fault	Total system failure	0.5	2	1	1	Total failure of primary control would be imeadietly obvious, only risk would be opperator error.
Visual Communications System	System unable to communicate with base station	Out of range	System fails to send/recive messages	1	1	1	1	Visual indication of signal strength on user interface will let operator know when out of range
		Radio chip failure	System fails to send/recive messages	1	3	1	3	Radio chip failure would render the system inoperable with no easy fault check. No immediate opperator or aircraft risk however.
		Antenna damage	System fails to send/recive messages	3	2	1	6	Physical damage to the antenna may occur in airport environment. Easy to detect and replace, degraded communications more likely than total failure.
	Screen fails	Physical Damage	System fails to display messages and user interface	2	3	1	6	Renders system inoperable, immediately aperant
		Connector fault	System fails to display messages and user interface	2	3	1	6	Renders system inoperable, immediately aperant

The analysis has shown that our proposed system is reliable and safe. No single failure mode has an RPN above 20 and more importantly no failure mode has a severity over 3. Our largest RPN is attributed to stepper motor failure in the automatic collision avoidance system due to physical damage. During software development additional attention should be paid to self-test and diagnostics in the control software to help attenuate this risk. Also training materials should explain the effects of this failure so that it can be recognized by users. Similar measures should be taken to try to mitigate the risks of our second highest RPN which is stepper motor failure due to wiring harness damage.

Our third highest RPNs occur because of physical damage to either the antenna or tablet controller. Other than ruggedizing these components to the highest degree possible during design and manufacturing no other risk reduction efforts are necessary.

Balanced Score Card

In evaluating the new technologies we intend to implement on our improved tow-tractor design we have decided to take a balanced score card approach to provide an all aspects look at the impact of the design. We are taking the 'Three-P' approach looking at people, profit, and pollution. People represent the operational and social impact these technologies will have on the personnel that use them. Profits look at the fiscal impact and ramifications on the enterprises in which these technologies will be used. Lastly, pollution will look at the ecological impact these technologies will have in trying to create more environmentally sustainable airlines and airports. Changes to the GSE considered in the score card will be given a grade of +2 for a large positive impact, a +1 for a small one, a 0 for no impact, a -1 for a small negative impact, and a -2 for a large negative impact. The balanced score card is presented in tables 2 and 3.

Table 2: Active Collision Avoidance Balanced Score Card

People		**Profit**		**Pollution**	
Increases safety	+2	Reduced likelihood of lost revenues due to AoG accidents	+2	End of life E-Waste	-1
Reduces potential for user error	+1	Reduced Aircraft MX costs	+2	Decreased APU burn waiting for post collision inspection	+1
May invite carelessness due to dependency on automation	-1	Reduced workman's comp claims thanks to increased safety	+1	Decreased energy costs associated with part production/transport	+1
May require some retraining	0	Increased procurement costs	-1		
Totals:	+2		+4		+1

Total Score: +7

Table 3: Visual Communications and Task Assignment Balanced Score Card

People		**Profit**		**Pollution**	
Decreased confusion	+1	Reduced ramp delays decrease a/c turn time	+1	End of life E-Waste	-1
No need to removing hearing protection to communicate	+1	Reduced APU fuel burn waiting for ramp crews	+1	Reduced APU fuel burn waiting for ramp crews	+1
Better time management	+1	Enables reduced staffing with more efficient personnel utilization	+1	Reduced GSE energy usage by preventing unnecessary trips.	+1
Totals	+3		+3		+1

Total Score: +7

Under the balanced scorecard evaluation metrics both collision avoidance and visual communications receive a +7 for a total net positive impact in all three areas of the score card. Active collision avoidance has its highest impact in profitability for reducing the risk of aircraft damage, also has a net positive impact on people and pollution. Many of these effects actually cross multiple categories of the score card. For example decreased APU fuel burn is a net environmental positive and also is a significant costs savings for the airline. Similarly, the increased safety offers a benefit to the people but also translates into lower workman's compensation claims for the bottom line.

The visual communications systems impact was more evenly distributed then the active collision avoidance system with the greatest benefit being conferred equally to profit and people with a +3. Decreasing confusion on the ramp certainly benefits both the people and the profit thanks to increased worker productivity. This improvement also yields additional profit and pollution impact by reducing time aircraft need to run their APUs waiting for ground personnel.

Conclusions

Ground support equipment (GSE) has found success in its current form, and is noteworthy for surviving this long without having to undergo any evolution. This project has shown that through the incorporation of two existing capabilities that were developed for other industries, the traditional airport tractor can transcend its humble origins to become iTUG. The two capabilities are visual communications devices and collision avoidance systems. Through the use of real time 3D mapping, we can engineer active collision avoidance that makes aircraft damage from GSE collisions a thing of the past. By incorporating GPS into the same system, we can put an end to the possibility of accidental movement area incursions. Finally, through the use of open wireless standards and omnipresent touch screen interfaces we can alleviate the stress of data and task management for the user. In addition, iTUG capabilities facilitate the reduction of fuel usage because vehicle is being used more efficiently and it will help to create a more safe and efficient workplace. With iTUG implemented, airports and airlines are closer to reaching the 2% global annual fuel efficiency goal improvement goal by 2018.

Appendix A: Contact Information

Students

Tyler Futch
tfutch@purdue.edu

Zachary Tolley
ztolley@purdue.edu

Bradly Grube
bgrube@purdue.edu

Jim Martin
martin20@purdue.edu

Advisors

Mary Johnson
Purdue University
Assoc. Professor, Aviation Technology
mejohnson@purdue.edu

Non-University Contacts

Betty Stansbury
Purdue University Airport Director
bmstansbury@purdue.edu

Ben Tolley
Southwest Airlines Operations Agent
Declined to disclose email

Bill Yacko
Subaru-SIA, Group Leader
william.yacko@subaru-sia.com

Appendix B: Description of University

Purdue University is the state of Indiana's land-grant university and a Carnegie Foundation tier-one research institution for very high research activity. The University's main campus, situated on 2,602 acres in West Lafayette, Indiana, enrolls nearly 30,000 undergraduate students and 9,300 graduate and professional students in approximately 200 undergraduate majors, 70 master's and doctoral programs, as well as professional degree programs in pharmacy and veterinary medicine. Four regional campuses combine for a student enrollment of nearly 75,000 and a system-wide budget of more than $2.32 billion. Purdue is ranked fourth in the nation in a 2010 *Wall Street Journal* survey of corporate recruiters for preparing students for the workforce (Purdue University Office of the Vice President for Research, 2013).

The Department of Aviation Technology is widely recognized as a leader in aviation education. Students learn from faculty with rich industry experience and ongoing research that will improve the future of aviation. From air traffic control to Next Gen aviation research, the department is leading the way to produce the best graduates and best knowledge in the aviation and aerospace industry. A part of the department's success is its top-of-the-line fleet that includes almost two dozen airplanes and several virtual training simulators. Aviation Technology is focused on providing the education and skills necessary to create and build airworthy machines, manage all facets of the aviation industry, and safely pilot planes for a variety of consumers (https://tech.purdue.edu/departments/aviation-technology).

.

.

Appendix C: Description of Involved Non-University Partners

Purdue University Airport

Purdue University Airport is West Lafayette's local airport and is situated about a quarter of a mile southwest of Purdue main campus. It serves as a local transportation hub with multiple ground transportation services situated on its grounds. It also supports a vibrant local general aviation community as well Purdue's Aviation Technology department which utilizes it both for flight training and research.

Subaru of Indiana Automotive

Subaru of Indiana Automotive is a wholly owned subsidiary of Fuji Heavy Industries and is a state of the art factory that produces vehicles for both Subaru and Toyota. It is a 2.3 million square foot integrated production facility that supports the production of vehicles from stamping to final assembly and delivery. It was the first automobile factory in the United State to achieve zero landfill status.

Southwest Airlines

Southwest Airlines is a low-cost airline based out of Dallas's Love Field. They are the world's largest operator of Boeing 737s. Founded by Rollin King and Herb Kelleher in 1967 Southwest is known for its unique culture and processes among airlines.

Appendix E: Evaluation of Educational Experience

Appendix E Student Response: Tyler M. Futch

Competing in the FAA Design Competition has been a meaningful learning experience for me because it has allowed me to spend time collaborating with fellow colleagues about how to solve real problems that airport ground service personnel are experiencing every day. I have a great interest in utilizing modern technology to assist with airport operations because since increasingly more people are flying, it would be beneficial to begin constructing a more efficient ground support system to increase airport safety.

Some examples of challenges that my team and I encountered while working on this competition would include time management. Everyone in the team has a totally different schedule except for the one day a week that we meet for class so that encouraged us have to work on a lot of the project individually. Also, at the beginning of the project we had five team members, and about three weeks into working we lost a team member due to time constraints. This resulted in distributing the extra load to the remaining members.

When our team began developing our hypothesis we tried to think of some real problems that are occurring at airports that are causing unsafe working conditions or inefficiencies in the system. With the majority of the team coming from an aviation maintenance background, we thought about all of the different safety factors that ground support personnel have to constantly be aware of. We also knew that technology has advanced enough to be able to increase safety, communication, and organization.

I found contacting industry experts to be somewhat helpful. It helped us to not only think of new questions about the project but to pretty much validate our research in the matter. When speaking to them about past and current conditions, they helped confirm our notions of improving ground and runway safety.

Participating in this design competition has greatly increased my knowledge of airport ground operations as well as how to effectively work as a team. Being able to collaborate with a team such as this allows me to improve upon my problem solving skills as well as my methods of communicating with team members with busy schedules. I believe that these are all important skills to have in the workforce because of the dynamic nature of the industry, we need to be able to think outside of the box.

-Tyler M. Futch

Appendix E Student Response: Zachary R. Tolley

I think that participating in the design completion has been a valuable educational experience for me; in fact I think it's served as a useful capstone to my graduate work which is concluding at the end of this semester. I think one of the reason it was a usefully learning experience was that given the time constraints of everyone involved in the project, the firm deadlines that had to be met, and the scope of the project work had to be equitably split amongst those working on the project and coordinated to form a complete whole. Accomplishing this by itself is a non-trivial task, and in accomplishing it I feel like I am now better equipped to handle the projects and subordinates under me as I launch my career.

The challenges we had to face were mostly of time management, one of our team members is a non-traditional student with a full-time job and family, several of us are involved in research and have employment outside of academia, and personally have had to coordinate a significant amount of recent traveling and planning a cross country move with my academic pursuits. Finding times we could all meet and coordinating our efforts remotely when we could not was the largest challenge we face and overcame.

Our design process was informed by the fact that three of our group members hold Airframe and Powerplant certificates and we all have some degree of exposure to the operational airline environment. This understanding, and knowing that the state of the art in GSE has remained unchanged since essentially the dawn of the airline industry led us to ask the question, is there a better more sustainable way to design GSE. Since the tow-tractor is the most common piece of GSE used today it seemed like a logical place to focus our design efforts. From there we sought to identify the largest problems associated with GSE and how we could reasonably solve them with extant technology.

Contact industry proved to be useful, if not critical in our design process. They confirmed our conclusions about GSE being the most common cause of aircraft damage leading to flight cancelation as well as the difficulties of communicating on the ramp. Our conversations with AAE and AAAE members certainly informed our design decisions and helped us refine our design for a next generation tow-tractor.

-Zachary R. Tolley

Appendix E Student Response: Bradly R. Grube

For me working on a FAA design competition has been a pleasure. At the beginning of the semester our group within Purdue’s 581 Aviation Sustainability graduate class decided to enter the FAA design competition under Dr. Mary Johnson’s direction. Immediately after our group was constructed we found that all of our members have had some sort of a technical background whether it is an Airframe and Power plant certificate, research experience, or manufacturing experience. I am the only undergraduate within the class and it has been an amazing experience working with all the educated individuals within the group and our professor as well. Every member within our group has had a definitive direction for the project and communication has been excellent. Time management has been a fundamental part of effort, with a member that has a family and full time job, members traveling for job interviews, and members conducting research it was quite difficult for everyone to find a time where we could all meet in person.

My favorite experience within the group is how my group members treated one another with utmost respect. I truly have not seen better communication in all my time being in college. This made brainstorming for the project an enlightening experience since all the members had open minds and were not afraid to voice their constructive criticism. We all had a plethora of fantastic ideas for the innovation of general service equipment. With most GSE in aviation being ancient machines compared to today's standard of technology, it was no surprise we had several applicable ideas that would directly and immediately benefit the industry. Narrowing down our scope to a reasonable size was likely the most difficult part of our project. Once our scope was set it was much easier to move forward and focus towards an end goal.

-Bradly R. Grube

Appendix E Student Response: Jim A. Martin

I have found this project stimulating and enjoyable, both from a technical standpoint but perhaps even more from an interpersonal dynamics standpoint. I am a non-traditional student of middle age with substantial work and family responsibilities. That part is nothing new for me. However what I was most impressed with is how quickly this group went through the normal team forming phases, and because of this I found this to be a meaningful learning experience.

For nearly a quarter century I have worked in a Japanese auto plant steeped in a culture of teamwork and accountability. This experience plus my age has often lead to me be defaulted to a leadership role in groups with younger students. However, it has been a rare pleasure for me to not have that happen with this group. I was impressed seeing how quickly and effectively tasks were divided, responsibilities shouldered, and performance achieved in a short time among my teammates. Each of these young men showed excellent problem solving and team building instincts. I enjoyed the change and enjoyed the project even more than I might have otherwise done because I saw the other members of the group step up and take on work willingly and this solved the challenges we encountered in this project.

I have also enjoyed the project from a technical standpoint. For many years my exposure to the technical work has been limited to auto assembly and the things that relate to it. Learning how much has changed in Aviation, the use of computers (Google Docs for example) in school and hearing the perspectives of people 20 years younger has been refreshing for me.

Our group was particularly effective in brain storming and vetting the ideas generated to workable solutions. I think this was largely due to the diverse backgrounds of our group as well as our contacts which encompassed agriculture, aviation, industry, aerospace, and robotics. This wealth of information helped us to better understand the state of prior art in related areas and create effective solutions efficiently. Personally I learned how to use google docs, which I believe will be useful.

-Jim A. Martin

Appendix E Faculty Advisor Response: Mary E. Johnson

The value of the education experience is that the team must combine technical and soft skills to understand, communicate and solve a real problem facing aviation. Authentic aviation problems are essential whether as identified in the FAA announcement or combined with the problems identified by our industry contacts. The students found a problem, imagined possible solutions, investigated existing technologies, and applied the technologies to improve the type of tug used at airports around the globe. One student has an extensive automobile background and the students with aviation backgrounds both learned from him and taught him in a peer-to-peer fashion.

The learning experience was appropriate for this graduate level course in aviation sustainability. Submitting a report to this competition was one of the ways offered in the course syllabus to demonstrate competency in understanding the impact that technology improvements may have on aviation sustainability. Addressing the airport operational challenges and combining that with understanding the impacts on sustainability gave the chance for the students to become intrinsically motivated.

Time management is a particular challenge for students who are working on an open-ended project in a one semester course. Another challenge was prioritizing the multitude of ideas into a coherent set of improvements.

I plan to use this competition again in a future graduate level course. The problems are real, timely, and challenging.

This is the first time that I have had a team in the competition in several years. At this time, I have no suggestions for improvement. I decided to use the competition again in classes because of the expanded categories in the design challenges.

-Mary E. Johnson

.

Appendix F: References

adafruit.com. (2013, December 10). Adafruit ultimate gps breakout - 66 channel w/10 hz updates. Retrieved from http://www.adafruit.com/products/746

Airport Cooperative Research Program, Transportation Research Board. (2012). *Airport ground support equipment (GSE): Emission reduction strategies, inventory, and tutorial* (Report 78)

Buehler, M., Iagnemma, K., & Singh, S. (2009). *The DARPA Urban Challenge: Autonomous vehicles in city traffic*. Berlin: Springer. Marks, P. (2012). Hands off the wheel. *New Scientist*, *213*(2858), 19-20.

Chu, J. (2013, August 27). *3-D mapping in real time, without the drift - MIT News Office*. Retrieved from http://web.mit.edu/newsoffice/2013/3d-mapping-in-real-time-without-the-drift-0828.html

FAA. US Department of Transportation, Federal Aviation Administration. (2012). 2011-2012 runway safety report (2012-AJS-475). Retrieved from ATO Communications website: https://www.faa.gov/airports/runway_safety/publications/media/2012-AJS-475-FY2011-Runway-Safety-Annual-Report.pdf

Federal Aviation Administration, (n.d.). *FAA guide to ground vehicle operation: A comprehensive guide to safe driving on the airport surface* (TC11-0200)

Federal Aviation Administration, (2014). *Destination 2025*. Retrieved from website: www.faa.gov/about/plans_reports/media/Destination2025.pdf

Foster, MD, P. M. (2011, October 12). From the FAA: Runway incursions - not just a pilot problem. Retrieved from http://www.aviationpros.com/article/10444162/from-the-faa-runway-incursions-not-just-a-pilot-problem

Huawei Technologies. (2013). *Broadband wireless network improves airport ground handling efficiency*. Retrieved from www.huawei.com/ilink/cnenterprise/download/HW_200452

M2P Consulting. (2006, April). In Michael Clarke (Chair).*The costs of delays and cancellations:analysis and means for reductions*. Presentation delivered at AGIFOR , Dubai, UAE. Retrieved from http://www.agifors.org/document.go?documentId=1579&action=download

Purdue University Office of the Vice President for Research. (2014, January 16). *Purdue University general institutional description.* Retrieved from http://www.purdue.edu/research/vpr/rschdev/proposal_prep_resources.php

Q-Track. (2014). *About Q-Track*. Retrieved from http://q-track.com/about-q-track/

SAE International (2009). *Aircraft Damage Caused by Ground Support Equipment*(AIR1589A). Retrieved from http://digitallibrary.sae.org/content/air1589a

Velodyne (2014, March 2). *Velodyne Lidar HDL-64E*. Retrieved from http://velodynelidar.com/lidar/hdlproducts/hdl64e.aspx

Weaver, J. F. (2013, November 22). *Autonomous car legislation backs Google's vision of the future over Ford's*. Retrieved from http://www.slate.com/blogs/future_tense/2013/11/22/autonomous_car_legislation_backs_google_s_vision_of_the_future_over_ford.html

Zebra Technologies. (2014). *Wherenet technology*. Retrieved from http://www.zebra.com/us/en/solutions/technology-need/wherenet.html