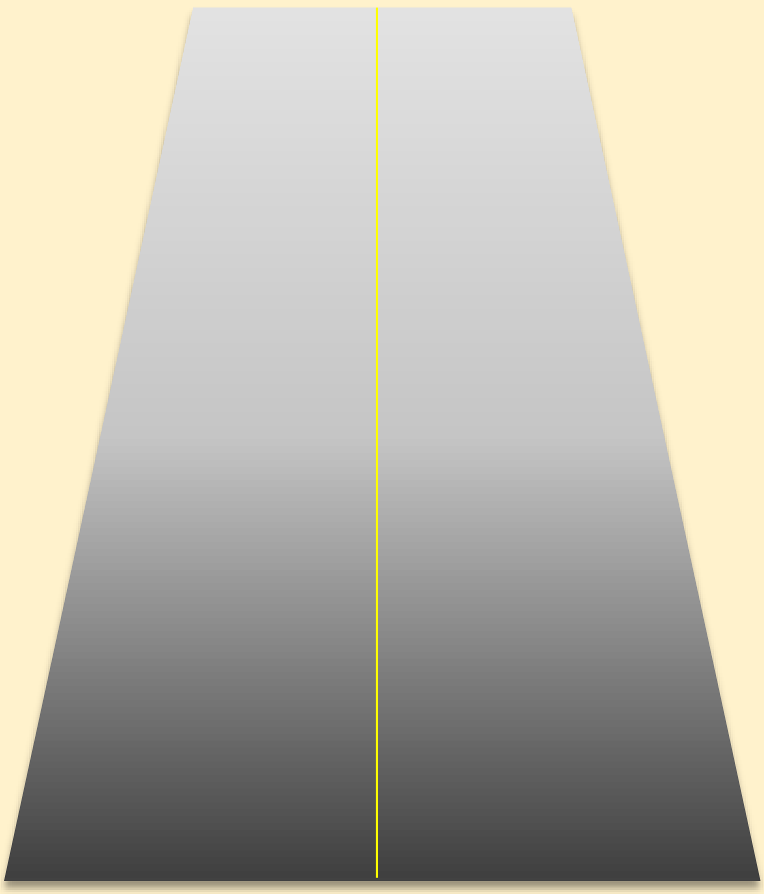
Taxiwayz

Airport Ground Mapping System



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Executive Summary

While major advances have been made to provide pilots with real-time position information during flight, much less attention has been given to support ground operations. The FAA estimates that twenty-five percent of annual runway incursions result from ground operations. This safety challenge presents an opportunity to employ leading-edge technology which can increase safety with the added benefit of reducing aviation costs.

The proposed solution is an iPad application (aka, app) to provide electronic “follow-me” guidance to aircraft during ground operations for aircraft and ground vehicles. The proposed Taxiwayz app will utilize multiple features in an easy-to-read and intuitive format that will allow pilots to navigate unfamiliar airports and complex taxiway configurations with support from digital graphic directions, thus substantially reducing runway incursions from ground operations including aircraft taxiing.

Pilots are very familiar with following the magenta line in the air, as are most of the general populace, due to the popularity of apps such as Google maps. Taxiwayz will build on this familiarity and will be easily adopted by pilots for ground operations. The “draw a line” format will provide pilots with real-time, easy to follow directions, which will enhance safety, even in low visibility conditions and at unfamiliar airports.

Overall, Taxiwayz will provide increased safety, decreased costs, increased situational awareness, and decreased runway incursions. All of these benefits will be realized with an initial cost of $162,000 and $72.5 million dollars of benefit, which provides an excellent cost-benefit ratio and an excellent opportunity to improve safety.

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2. Problem Statement and Background

Navigating around airports is often a daunting task. With many possible routes to traverse, communications that must be conducted in the midst of other tasks, and directions that may not be intuitive, there is an opportunity for human error. According to a report from the FAA, twenty percent of annual runway incursions involve ground vehicle operations (FAA, n.d). Even worse, in 2005 a group reviewed NTSB data and found that 43% of ground-related incidents involved vehicles and aircraft (Grabowski, Baker, & Li, 2005).

While not all of these occurrences are attributable to navigation errors, it is clear that lessening the workload related to taxiing or driving around the airport would act as a mitigation tool and would be expected to lower the number of runway incursions.

Attempts have been made to reduce and eliminate runway incursions. Jeppesen created the Airport Moving Map (AMM) which loads the appropriate airport diagram into the Electronic Flight Bag (EFB) and shows the aircraft's location on the airport in real-time (Jeppesen, n.d.) While this system greatly improves situational awareness compared to the standard paper charts, this system does not clearly point out taxi directions or provide warnings on the AMM itself, which would be beneficial to flight crews, especially in low-visibility conditions at unfamiliar airports.

3. Literature Review

3.1 Ground Incidents

A review of NTSB data about airport ground crew injuries and fatalities in *Ground Crew Injuries and Fatalities in U.S. Commercial Aviation* found that approximately 43% of ground incidents were collisions between aircraft and ground vehicles (Grabowski, J. G., Baker, S. P., & Li, G , 2005). Factors associated with the majority of these incidents are poor situational awareness and ineffective communication. A goal of the project is to create an application that assists in both of these factors to help minimize risks of causing a collision.

Runway incursions are potentially the most dangerous type of ground incident since they involve interference with areas that directly affect the safety of flight. Runway incursions are classified according to four alphabetical categories. A category A incursion is an incident in which a collision was narrowly avoided. A category B runway incursion is when there is significant potential for a collision, but less immediate risk than a category A incident. A category C runway incursion is when there is a potential for a collision, but there was ample time to avoid the collision. Finally, a category D incident is one that meets the definition of a runway incursion ("incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and takeoff of aircraft") but there were no immediate safety consequences (FAA, 2015a). If an actual collision takes place, the event is classified as an "accident" and investigated in a different manner.

Ground vehicles make up approximately 20% of annual runway incursions (FAA, 2015a). The FAA has identified procedures to minimize the risk of a runway incursion caused by ground vehicles. For example, the FAA recommends availability of airport diagrams to vehicle operators, maintaining contact with Air Traffic Control to ensure correct execution of movement instructions, and requirements for vehicle operator training (FAA, 2015b) prior to driving on the airfield. A key aspect of maintaining a safe aviation environment is understanding airfield signs and markings, as well as right-of-way rules which require that ground vehicles yield to aircraft. Knowledge and practice of these procedures can greatly reduce the potential risk of incursions.

3.2 Vehicle Tracking Solutions

One example of a vehicle tracking solution is the SAAB VeeLo NexGen. This system is encapsulated within a weather-resistant module that attaches to airport ground operation vehicles (aka, airport ops vehicles). The modules require minimal power consumption, so they can be operated via the vehicles' accessory power outlet. The VeeLo NexGen uses ADS-B (Automatic Dependent Surveillance-Broadcast) transmissions to provide data regarding position and identification of a vehicle. Vehicle identifiers are configurable via a personal computer and can be used with several devices to create a map of vehicles. Another SAAB product that offers real-time vehicle tracking solutions is the VL-4G. This product uses transponders and a 4G cellular network (rather than ADS-B) to send vehicle position and identification data to the VeeLo NexGen, and is designed to be used with SAAB's Collaborative Decision Making Suite. Images on SAAB's website suggests use for aircraft as well as ground vehicles, but explicit data on this was not available (SAAB, 2015).

A similar system developed by a company known as INDMEX Aviation is the AirBOSS portable vehicle tracking transponders. These vehicle mounted tracking devices use cellular communications networks to broadcast data, or use ADS-B like the SAAB VeeLo NexGen mentioned above. Per the AirBOSS webpage, "The external FAA transponder integrates with the FAA's NextGen traffic monitoring system utilizing UAT (978 MHz) technology. This system has been specifically designed to meet the FAA's technical requirements for use at airports equipped with the FAA's ASDE-X or ASSC surveillance systems. The vehicle traffic data generated and transmitted from the system is visible to air traffic controllers and pilots through the existing ADS-B infrastructure and promotes safety by facilitating vehicle-to-aircraft separation (INMEX Aviation, n.d.).

The systems to track vehicles are promising in terms of potential to increase safety but there are possible concerns. One concern with such systems is the ability to interfere with the signal broadcasted by a Global Positioning System mounted to a ground vehicle or aircraft. An incident took place at Newark Liberty International Airport (EWR) where an individual was able to jam the signal of a GPS device attached to the vehicle this individual was operating, which then allowed to operator to mask the location of the vehicle from their employer (Storm, 2013). The ability to interfere with such systems is a possible issue with the implementation of such a system and would need to be addressed before this type of system could be deemed fully reliable.

3.3 Data Communications

Data communications or Data Comm is a relatively new technology recently implemented by the FAA as part of NextGen. In traditional aviation, controllers have communicated information, such as clearances and advisories, to pilots using voice over radio communications. There are known issues with radio communications including voice clarity, and in some cases, accents, although the impact is lessened with the use of standard aviation phraseology. Radio transmission can also be impacted by local weather conditions, which can make it difficult for the controller to understand the pilot (or vice versa). Another issue with radio communication is that voice communication is time consuming and labor intensive, especially relative to the FAA’s proposed solutions, Data Comm. Data Comm gives air traffic control (ATC) and pilots the ability to transmit information and requests to each other via text. This information includes “flight plans, clearances, instructions, advisories, flight crew requests, reports and other essential messages with the touch of a button”. Data Comm can be used to reduce delay caused by outside circumstances; for example, in the event of a flight being rerouted because of weather, the crew using Data Comm can receive a new flight plan more quickly and efficiently than a crew using verbal communication (FAA, 2014). Data comm can also be used to maintain scheduling by giving more precise taxi instructions based on an aircraft’s actual scheduled departure time, rather than once the crew is ready to depart.

Data Comm is now operational at 62 ATC towers throughout the country. The rollout of the Data Comm service was under budget and completed ahead of schedule, so more towers were included in the project, increasing the impact and benefits than originally expected. Data Comm testing for high altitude airspace (rather than at airports) is currently being tested at three sites in the United States (FAA, 2018).

3.4 ACRP Published Resources

The Airport Cooperative Research Program (ACRP) provides access to documents, webinars and other resources for airport managers and consultants; these supplement other resources that inform the proposed use of the Taxiwayz app. Our group found several ACRP documents helpful in the development of the Taxiwayz concept. One document discussed the Next Generation Air Transportation System (NextGen), a series of federal programs that were established to aid in modernizing the National Airspace System (NAS) (*NextGen for Airports, Volume 5: Airport Planning and Development,* 2017). The purpose of NextGen also involves the “implementation of innovative new technologies and airspace procedures after thorough testing for safety” (FAA, 2018). This purpose is consistent with the Taxiwayz system because Taziwayz is designed to help modernize the management of air traffic at an airport while creating and maintaining a safer operating environment. To implement the proposed Taxiwayz app, ideally, it would be appropriate to work with NextGen programs and the FAA to develop the application for use in commercial aviation.

Another document utilized is the guidebook for “Safety Risk Management for Airports”. This document provided guidance on conducting safety risk management processes and the different components of a safety management system (*A Guidebook for Safety Risk Management for Airports*, 2015). A safety risk assessment was undertaken by the Taziwayz team as a part of our development process, and the ACRP document proved to be an excellent resource for this assessment. A critical component required to determine the feasibility possibility of implementing Taziwayz in a real environment is an accurate determination of the risks involved with the project. These risks could be of a physical nature, affecting the safety of humans and aircraft, or of a digital nature, affecting the safety and security of information that could be mishandled in a way that could cause harm, such as damage to safety, personal privacy or damage to financial assets. ACRP also provided resources for risk mitigation management, an important part of safety and risk assessment. Strategies for mitigation are needed to “modify or reduce the risk of an identified hazard” (*A Guidebook for Safety Risk Management for Airports*, 2015).

3.5 ForeFlight

A popular mobile app, ForeFlight, is used in the aviation industry to aid in navigation and flight planning. One potential way to address the identified problem statement is to leverage a part of ForeFlight called “custom content packs”. ForeFlight custom content packs allow users to import their own content into the ForeFlight app. These packs are supported for all “Plus”, Business Performance, and MFB Performance plans. This appears to be modified PDF files that can be overlaid with “waypoint files’. Waypoint files are a series of coordinates that correlate to the location of a user’s chosen markings and can be in KML or CSV format. This does not allow the user to create custom GPS mapping; this also does not allow for any interaction with ATC, both of these characteristics limit the ability of this program to meet the goals of this project. Pilots may create custom maps along with waypoints given by ATC, but this cannot be used on the ground without extensive modification (ForeFlight, 2018). ForeFlight is a useful service but will not provide the depth of detail that we are looking for in our app. Furthermore, ForeFlight does not have a package designed for ground vehicles, which is an important component for this project.

3.6 Forecasting Development Costs for a Mobile App

Since the launch of the Apple App Store in July 2008 with approximately 500 apps, mobile app development has seen explosive growth. Likewise, the number of mobile app developers and the variation in services and quality provided have also seen explosive growth. This rapid market expansion and the variations in app requirements make it difficult to forecast the associated costs for app development.

The general subject of mobile app development has been widely examined and documented, however, there is minimal scholarly information or evaluation regarding the implementation of specific apps and the associated costs. There are a number of other industry and online sources that examine mobile app development costs. While these sources may have somewhat more bias than would be expected in a scholarly work, due to the lack of scholarly sources, they were examined and are presented for the data they provide.

One key factor in determining the expected costs of a mobile app is complexity, particularly with respect to the extent the app interfaces with other platforms. For instance, an app that pulls in data from Google Maps will cost more to develop than one that does not.

4. Problem Solving Approach & Design of Taxiwayz

4.1 Design Overview

Navigating airfields and following air traffic control instructions at the same time can be a challenging task for new airport operations personnel, for unfamiliar pilots, and at airports with complex geometry, and changes to the airfield due to airport construction projects. Although radio communication terminology is mostly standardized, some individuals struggle to understand the exact route prescribed by controllers. This may be exacerbated for younger pilots, who are accustomed to GPS navigation and as a result, may not have intuition for “old fashioned” static maps and diagrams. In order to assist pilots and operations personnel and reduce the potential for misunderstanding, our team has developed a program that presents a pictorial representation of controller instructions that utilizes that the current airfield diagram. Leveraging data comm and voice recognition technology, this app utilizes the airport diagram and illustrates the directions provided by air traffic controllers so that users have another tool to ensure that they are following the proper and authorized course.

4.2 User Interface

Creating an effective user interface for an app is a crucial step in a successful program. The app must be appealing, easy to use, and most importantly it should be functional, and reflect best practices for human machine interface. While our suggested technology has not been previously developed before, there are other apps and devices that offer similar features. For years, global positioning system (GPS) manufacturers such as Garmin have outfitted both aircraft and cars with moving maps to enhance navigation. When a destination of choice, such as an address for cars or a fix/waypoint for an aircraft is loaded into the GPS, a line or directional aid of some form is drawn on the map; this line marks current location to enhance situational awareness. New aviation apps such as ForeFlight offer similar capabilities, as a line is drawn between the user's location and the desired destination or location. While other companies specialize in navigation in the air or navigation on roadways, our proposed app will bring together these concepts and support aircraft and airport operations vehicles on the ground, enhancing situational awareness by providing information regarding runways, taxiways, and movement areas. Apps like ForeFlight show the airport diagram with your location placed on the map when an aircraft lands, but unlike other GPS areas, it does not "draw a line" to your desired location once you are on the ground like it does in the air. By drawing this line, the pilot or airport operator will have a much better sense of situational awareness, especially at unfamiliar airports and during low visibility conditions. While the app would not necessarily work with ForeFlight or look anything like ForeFlight, it will leverage the idea that your location is visible on the airport diagram. The major difference is that unlike other apps, Air Traffic Control (ATC) will be able to give taxi instructions to both aircraft and airport vehicles per usual, the pilot will read-back his instructions, and the app will listen to the pilots voice through voice recognition and "draw the line" utilizing whichever taxiways and runways ATC has assigned. With this, confusion about taxi instructions would be minimalized, low visibility operations would be greatly enhanced, airport operations could theoretically become more efficient, and airports could potentially see a decrease in runway incursions. Overall, the goal of this app is safety. By creating a visual interface to support ATC's verbal or data comm, we believe the proposed app will make the airport safer and more efficient.

Users of Taxiwayz will find an interface comparable to Google or Apple maps where they are given upcoming directions and are able to see the road they are currently on as well as those surrounding. In this case however, roads will be exchanged for airport surfaces. As seen in Figure 1, the user interface is neatly laid out with upcoming pictorial directions in the upper left-hand corner, a speed estimate and time in the lower right-hand corner, the menu in the upper right-hand corner, and lastly the route shown with an aircraft symbol representing the user. In this picture, we can see that the aircraft or ground vehicle is currently on Taxiway Alpha and is supposed to turn right onto Taxiway Charlie in 200 feet. Nearby airside features can also be seen, such as Runway 23 which is to the left of the user in Figure 1.

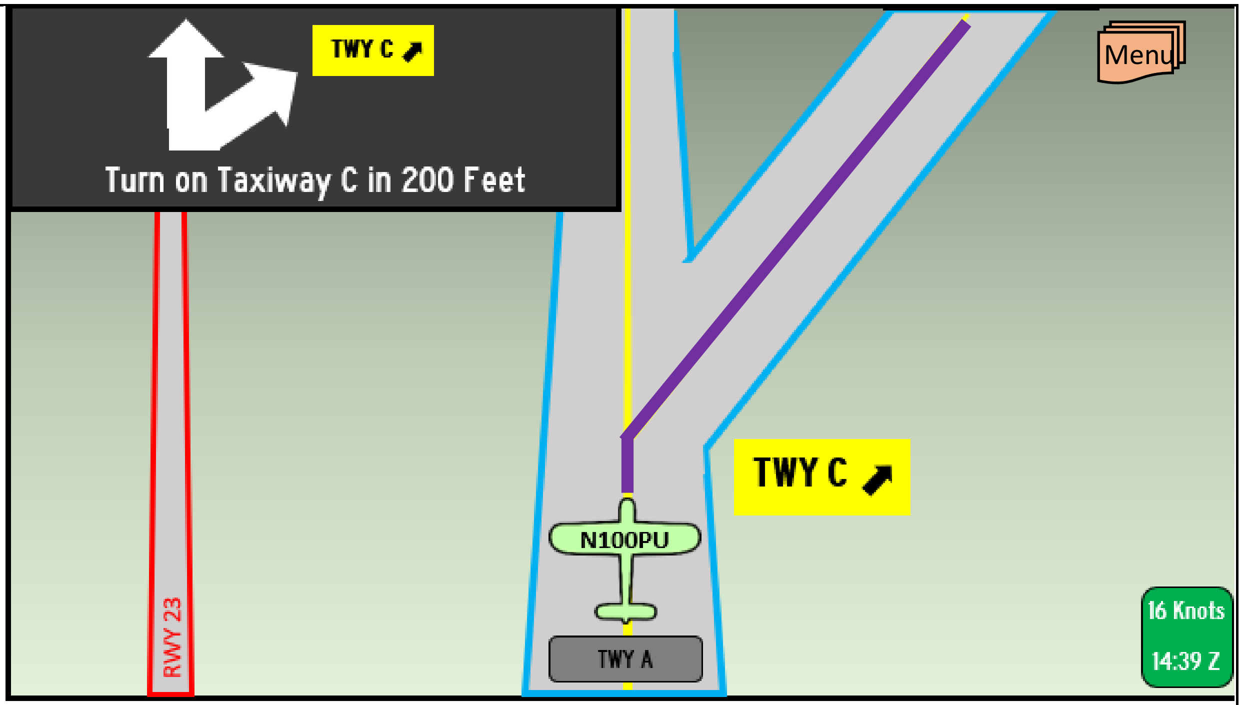
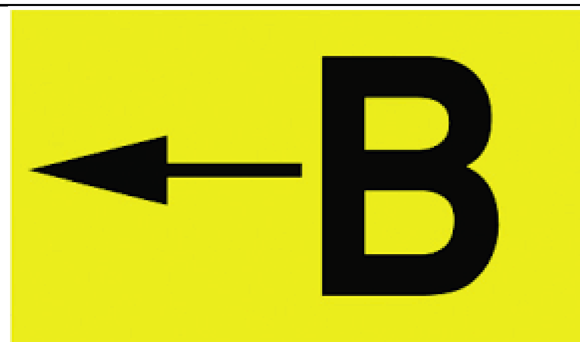


Figure 1. Aircraft Taxis on Taxiway Alpha with the Direction to Turn on Taxiway Charlie

The aircraft shown represents a aircraft or ground vehicle and depicts the user in a minimalistic form. The location of the user icon will sync to the position received by the system and will reflect the location in real-time based although electronic interferences may rarely affect this.

In terms of routing, each type of surface is given colors that match the color of the standard airfield markings (Figure 2). For taxiways, the outline color is a blue for consistency with the edge lights and the centerline is solid yellow line as painted on the pavement. Runways are shown in red as the nature of this surface is one of great importance and concentration (Color & Vision Matters, 2018). Surfaces that do not pertain to the directions of a user will be shown nearby, but without any detailed information. This can be seen in Figure 1 as Runway 23 is simplistic and no corresponding information is available as it is there only to remind a user of their location.

Pilots are often presented with a magenta line on their navigational flight display which shows the route they have programmed into the aircraft and will follow to their destination. Taxiwayz shares this standard color to represent the route which a user needs to follow.

	
2.1 Runway Signage	2.2 Taxiway Directional Signage
Figure 2. Standardized Airport Signage (FAA, 2005)	

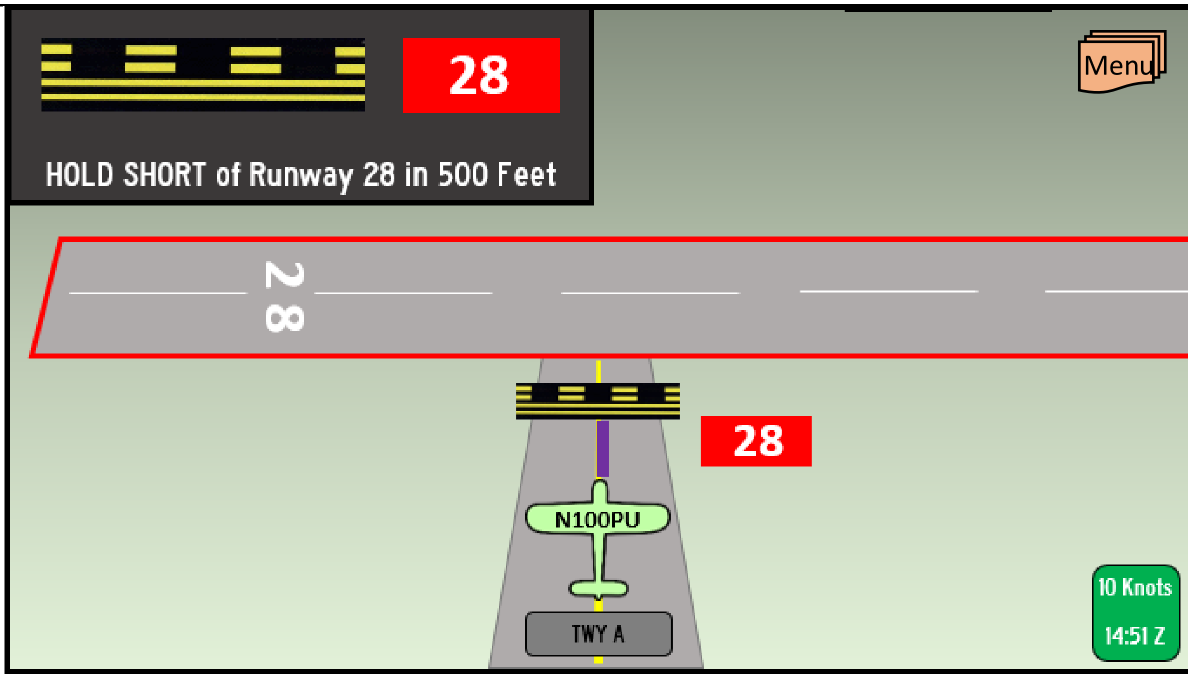


Figure 3. Taxiwayz User Approaching Runway

As seen in Figure 3, the aircraft or ground vehicle is approaching Runway 28 and must hold short of it in 500 feet. To increase awareness, the term hold short is completely capitalized. Furthermore, the color red is the most distinct color on the screen, drawing attention to the sensitivity of operation near the runway.

4.3 User Interface Flow

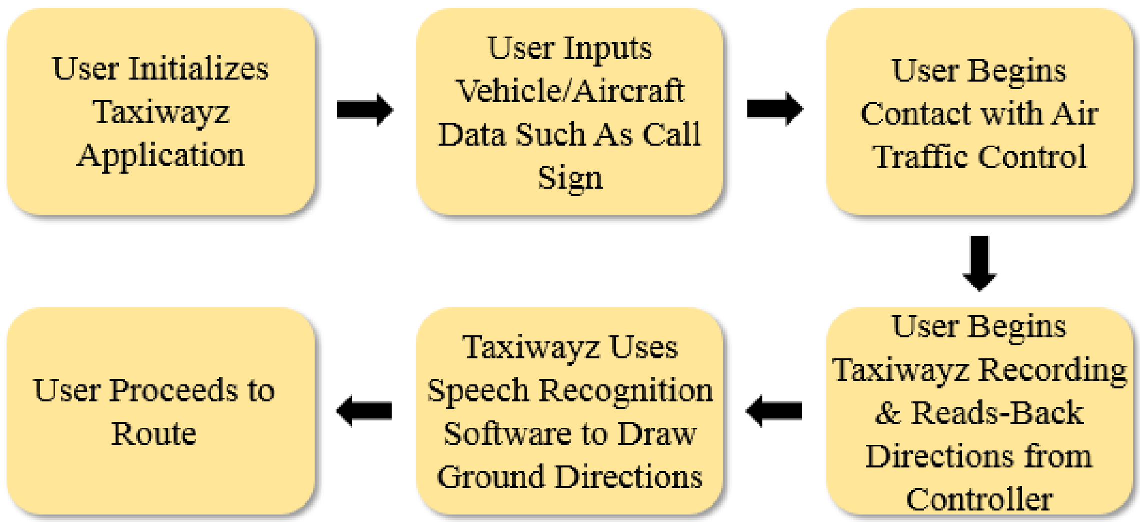


Figure 4. Process Chart of Taxiwayz

4.4 User Display

Taxiwayz is an app designed to benefit the user, and the greatest benefits will be gained if it is compatible with multiple devices that may reflect a variety of screen sizes. To reduce workload, Taxiway provides only information about the vehicle or aircraft relative to the airfield, which is the minimum useful information required, and is consistent with use on small screens. Consistent with this philosophy and to simplify the operational requirements, other traffic is not displayed on the screen and users must maintain an awareness of other vehicles and aircraft in the environment.

The most important feature of the display is that a replica of the signage one will see at their next directional event is shown in the upper left hand side of the screen. This means that as a user approaches the taxiway they will be turning onto, the physical sign will be shown as well as a turn indication to signify the direction of the turn. Matching the Taxiwayz digital sign to the physical sign increases safety and eliminates confusion.

4.5 Communications

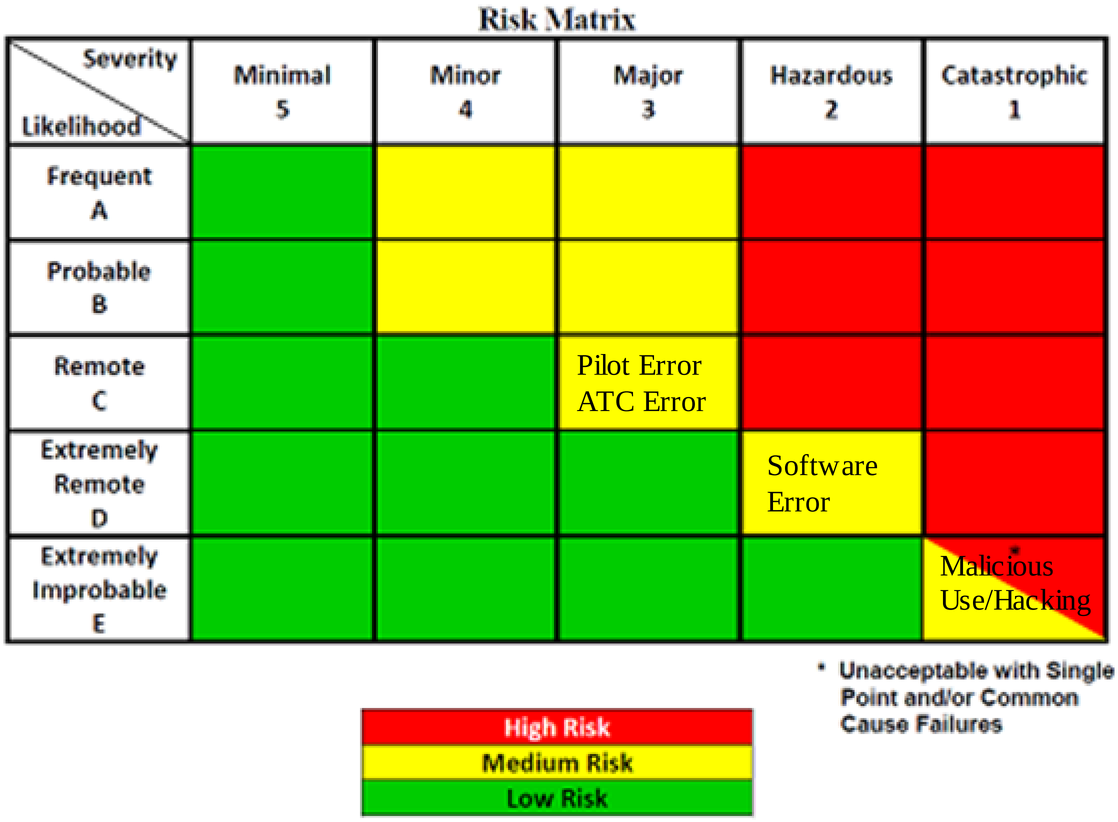
One of the most crucial parts of Taxiwayz is communications related. In order to illustrate air traffic control's directions, the software must be equipped with voice recognition technology that will understand a pilot's readback from air traffic control and use an algorithm to create the directions. To initiate the drawing process, a user will touch a button on the screen that will begin listening to the words of the pilot. A user will most likely begin the sequence when they are ready to read back instructions from ATC. The app will translate the readback into the directions on the screen as they have been stated by the user. If the readback is not correct, the user can restating the directions to Taxiwayz. Another option is to not initiate the listening sequence until the aircraft is already taxiing. This is similar to operating an automobile and turning on the GPS system after the trip has already started.

4.6 Additional Features

A possible feature for future development in Taxiwayz is the ability to sense objects using collision avoidance technology from a vehicle. While this feature is limited to airport vehicles, it would increase safety. The ability to pair a phone with a vehicle, combined with advanced collision avoidance vehicle sensors, could allow future capabilities in which users can open Taxiwayz and initiate a setting which allows for sensing vehicles, objects, or aircraft during low visibility or nighttime conditions.

5. Safety and Security Risk Assessment

The Taxiwayz team conducted a safety and security risk assessment of the app in order to determine possible hazards with the usage of the software. The FAA System Safety Process steps manual, the goal of a safety assessment is to undertake the "…systematic, forward-looking identification and control of hazards throughout the life cycle of a project, program, or activity" (FAA, 2005). In doing so, the team analyzed a variety of factors associated with Taxiwayz including safety risks for pilots, Air Traffic Control, software errors, malicious use of the software and hacking of the software. Several industry experts interviewed for the Taxiwayz project also provided valuable insight into the safety concerns of the app, as described in greater detail below.



Risk Matrix

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A					
Probable B					
Remote C			Pilot Error ATC Error		
Extremely Remote D				Software Error	
Extremely Improbable E					* Malicious Use/Hacking

* Unacceptable with Single Point and/or Common Cause Failures

High Risk
Medium Risk
Low Risk

Figure 5. FAA Risk Matrix (FAA, 2017)

5.1 Pilot Error

5.1.1 Hazard Identification: Taxiwayz is a human operated system relying on human input and interpretation for the system to work, which means that there is an inherent risk that errors will occur by human users of the app. A pilot may misinterpret the visuals on the map which could lead to being on an incorrect taxiway, a runway incursion, or at worst a collision.

5.1.2 Risk Assessment: A pilot will need to be able to read and clearly understand the directions from ATC and the Taxiwayz app, otherwise the risk of an incident occurring increases. If a pilot cannot clearly see the route which they are to follow, they may take more time to clarify directions which can lead to a less efficient airport operation as a whole. In the situation where misinterpreting the ATC directions on Taxiwayz leads to a collision, this can result in runway or taxiway closures that cause significant delays in regular airport operations. Based on the FAA guided risk matrix, the severity of this risk was identified as major because of the potential consequences of a pilot error in interpreting the Taxiwayz visual display (FAA, 2017). The likelihood that pilot error would occur is was deemed as remote. While pilot error in communicating and interpreting Taxiwayz visuals may occur, there are measures in place to minimize such an event from happening such as the repetition of directions on the screen.

5.1.3 Risk Management/Treatment: Situations where pilot error can be managed with several different methods. While error may not be eliminated due to the human operation, it can be minimized through various means. Using displays that gives pilots paths in bright, contrasting colors can mean less confusion in where the taxi path is supposed to go. Providing clear indication of which taxiways to use with onscreen markings indicating names/numbers is also a means to reduce risk. Being able to communicate with ATC conventionally is also a factor in reducing risk. While communicating with ATC may take extra time, it can further minimize the risk of an incident occurring in an active airport environment.

5.2 ATC Error

5.2.1 **Hazard Identification:** Air traffic controllers work in very fast paced and demanding environments, so there is a potential for misdirecting routes in the same way that there is a risk for that in the present way of ATC communication. A controller may place the pilot on a taxiway that is already occupied or give confusing instructions for the pilot to follow. At worst the air traffic controller may place two aircraft on a course in which they may collide.

5.2.2 Risk Assessment: A controller communication error is unlikely, but it is a possible event. If such an event were to occur, the controller would have to take time to reposition the aircraft onto its proper course. This could lead to an increase in the stressful workout of the controller, as well as delays for aircraft that need to be repositioned or held back because on the controller error. The frequency of this possible error was deemed to be the same to that of a pilot error. Both errors rely on human factors leading to circumstances which can cause incidents. The two possible errors are really the two opposite sides of what can cause an error in most aviation environments. The consequences of both pilot error and ATC error were also deemed to be similar, so the severity of an error would also be seen as major.

5.2.3 Risk Management/Treatment: Managing the risks of an ATC error are similar to managing the risks of a pilot error. Providing a visual that clearly shows the path of an aircraft and the taxiways of an airport means that an air traffic controller is less likely to make a mistake when directing a plane to and from a runway. Making sure the user interface is easy to understand as well as intuitive helps lessen the risks of ATC error by making it so that a controller cannot misclick easily to send an aircraft on an incorrect travel path. When there is a problem, having a direct line of communication to an aircraft as it is now can also help remedy difficult situations.

5.3 Software Error

5.3.1 Hazard Identification: As with all software, there is a possibility of issues in the code to appear and impact the usage of the Taxiwayz app. Should an app be properly developed, a bug in the software would be very unlikely, although it is still possible. Programming errors can lead to issues with drawing out a path for an aircraft, ATC changing instructions for an aircraft, or other interactions involving ATC. Other issues could be with the visual display, where a bug could mean that a path is not drawn on the screen of both a pilot and ATC or that a map of the airport environment is not shown, amongst other possible errors.

5.3.2 Risk Assessment: Software error can lead to the Taxiwayz system being completely ineffective in achieving its goal of making taxiing around an airport easier to do. If the map of the pilot does not update correctly, the app becomes useless. Software errors may also limit the functionality of the app, leading to pilots taking incorrect taxiways. This can impact the operation of an entire airport because if the system does not work, then another more conventional means of directing airport traffic will need to be implemented until the Taxiwayz app can be made functional.

5.3.3 Risk Management/Treatment: If the Taxiwayz app is developed properly, and beta tested to assure software is robust and error free, the likelihood that an extreme error would occur is very minimal. Based on the FAA Risk Matrix, it would be deemed as extremely remote. However, the consequences of a significant software bug could mean that the entire Taxiwayz software package would be unsafe for use at airports. However, should the Taxiwayz software fail, conventional methods of managing airport traffic would still be available, meaning that a software failure would not be deemed catastrophic. Instead it would be deemed as hazardous.

5.4 Malicious Use of Software & System Hacking

5.4.1 Hazard Identification: Taxiwayz is designed to be a secure system available only to pilots ground vehicles to help direct air traffic in airports. The system will feature security measures to prevent the use of the system by unauthorized individuals or groups, such as usernames or passwords. Preexisting measures also exist to aide in the security of the system. Physical security exists in some form at all ATC operating towers or centers. This would be locking doors, keycards, physical barriers, etc.

5.4.2 Risk Assessment: If a malicious user were to enter the system in a position that allows them to manipulate the direction of ground traffic in an aviation environment, the potential consequences could be catastrophic. A user could intentionally direct planes to be on a collision course with one another. Several planes could be directed onto an active runway at once. This could cause severe confusion and bring operations at an airport to a standstill. At worst, a malicious takeover of the software would lead to a severe collision between aircraft with fatalities.

5.4.3 Risk Management/Treatment: The best way to manage the risk in this scenario is to provide and maintain as many security measures as reasonably possible. In many cases, the malicious takeover of software is not discovered until after it has occurred, so preventative action is required for the system to be secure. Training pilots and air traffic controllers safe practices with passwords and usernames is vital to keeping a safe system intact. Maintaining tower security is vital to ensuring that no group or individual may interfere with ATC operations as well. The likelihood of such an event would be extremely improbable, but if it were to occur the consequences could be catastrophic.

6. Project Impacts

6.1 Benefit Analysis

Current ground operations have changed little since the 1950's. Use of verbal instructions from air traffic control and airport diagrams to navigate on the ground are the same tools that have been available to pilots for decades. The ability to access airport diagrams via electronic devices is about the only change that has taken place.

Taxiwayz advances ground operations into modern standards of technology. Using GPS and specialized software, Taxiwayz provides pilots and ground ops personnel with visual confirmation of verbal air traffic control instructions, reducing or eliminating the possibility of misunderstanding the instructions given. This reduces unneeded radio communications (e,g., progressive taxi directions) which would improve overall efficiency. In addition, Taxiwayz provides a visual path for pilots to follow on their airport diagram, reducing or eliminating confusion about the taxi route and incidents of mistakenly taking the wrong path. This would be especially helpful in low visibility situations and overall lead to increased situational awareness.

A well-known example of an air disaster associated with mistakes in following taxi instructions is the Tenerife air disaster in which poor visibility and lack of signage to identify runway exits contributed to the collision of KLM Flight 4805 and Pan Am Flight 1736 resulting the loss of 583 lives (Smith, 2017). While this disaster occurred in 1977 it remains the deadliest air disaster of all time. Arguably, if the crew had had Taxiwayz available to identify the proper runway exit, the disaster could have been avoided. It is difficult to quantify the benefit of accidents avoided, but it is but reasonable to believe that airports and the aviation community would embrace tools that would avoid the repeatof this kind of an event. In addition to serious runway incursions, however, there are daily incidents of confusion and mistakes associated with taxiing. This is substantiated by the fact that the Pilot Safety Institute includes not having a taxi diagram out during taxiing as the 12th leading cause of incursions and confusion on its list of “Top 25 Mistakes Pilots Make” (Pilot Safety Institute, 2014). The convenience of having the Taxiwayz app available for taxiing goes directly to eliminating these incursions and incidents of confusion while taxiing.

While the benefit in preventing major incidents is incontrovertible, it is difficult to quantify the overall cost benefit of implementing Taxiwayz due to numerous hard to quantify benefits. In order to provide a working estimate of cost benefits, we looked at the FAA’s NextGen business case and associated cost benefits. NextGen will implement eleven leading-edge technologies with a total cost benefit of $160.6 B over a twenty-year period (FAA, 2016). For this study, we took each of these improvements as equally contributing to the overall benefit resulting in an estimate of $14.6 B in benefit per improvement which equates to $73 M per year. Subtracting a cost of $582,000 (initial development of $162K plus $10,500 per airport for 40 airports initially as detailed in section 6.2 below equals $582,000) results in an overall net benefit of approximately $72.5 M for the air transportation system generally.

6.2 Cost Analysis

This cost analysis considers costs associated with app development in two major categories: first, costs associated with the base app development, and second, implementation costs for each airport to customize their airport data for use in the app. If a substantial number of airports develop their airport diagrams in conjunction with the app development, costs could be reduced an estimated 10 to 20% (Hyperlink InfoSystem, n.d.). This reduction reflects economies of scale and the benefits developing multiple maps simultaneously.

The Taxiwayz app utilizes both “front end” and “back end” development. The front end is the user facing portion of the app providing both the user interface both in term of user input of information and the visuals a user will overserve while using the app. The back end is interaction with servers and other devices. One vital element of Taziwayz is accurate GPS positioning. While onboard device GPS has proven accurate enough for surface operations many pilots use an offboard GPS device for greater accuracy in the air. Therefore, in would be ideal for Taxiwayz to support either onboard or offboard GPS.

App development costs can vary substantially depending on the desired features and complexity. Taxiwayz could provide substantial benefits in a basic version but enhanced features could allow for added convenience and usability for users. Further, sync capability would allow users to sync various devices and between other apps such as ForeFlight to provide seamless transitions from air to ground and back. For these reasons, Table 1 provides a stepwise implementation of Taxiwayz and associated costs.

Since costs change rapidly, the estimates in the tables below reflect cost data from a leading app developer we interviewed. For Table 1. 8-hour days, 5 days a week at $150 per hour typical of app development in the United States were used (Hyperlink InfoSystem, n.d.). Costs could be substantially reduced by offshoring development to tech centers in India at $15 per hour (Hyperlink InfoSystem, n.d.), however, because of the importance of specific of app implementation needed for success and safety of the app, we chose to consider United States app development rates for Taxiwayz.

Table 1. Taxiwayz App Development Costs			
Version	Front End	Back End	Total
1.0 – Basic Functionality	7 weeks = $42,000	3 weeks = $18,000	$54,000.00
2.0 – Enhanced interface	6 weeks = $36,000	3 weeks = $12,000	$48,000.00
3.0 – Sync capability	2 weeks = $12,000	8 weeks = $48,000	$60,0000.00
	Grand Total for Fully Featured App		$162,000.00

In addition to app development costs, cost to develop airport diagrams for individual airports are estimated in Table Y below. Calculations were based on interpolation of industry estimated costs per similar app feature (Hyperlink InfoSystem, n.d.).

Table 2. Airport Chart Development Costs	
Airport Size	Cost per Stand Alone Development
Small	20 Hours @ $150 = $3000.00
Medium	35 Hours @ $150 = $5250.00
Large	70 Hours @ $150 = $10,500.00

It should be noted that once and airport paid to develop their airport diagram for use by the Taxiwayz app there could be future associated costs. If the airport made changes that would affect the GPS tracking such as moving, renumbering, or eliminating a taxiway or other airport feature these changes would need to be uploaded to Taxiwayz. If a limited number of airports and airlines adopted the use of Taxiwayz these costs might inure to those limited users. However, it is much more likely that Taxiwayz would be widely adopted and in that case updating would be folded into user costs and when distributed among many users would be nearly unnoticeable as a direct cost.

In addition, individual users would need a device to access Taxiwayz. Taxiwayz, particularly in basic functionality version could be accessed by an iPad costing anywhere from $300 to $1500 (Apple Inc., n.d.). A favorite among pilots is the Apple 10.5" iPad Pro with a price of approximately $600 (Apple Inc., n.d.). This model is preferred because it fits easily on a knee board.

Overall, a basic version of Taxiwayz with one airport diagram could be developed for less than $60,000 using United States app developers or $6,000.00 using offshore developers (Hyperlink InfoSystem, n.d.). As detailed in Section 6.1 above, these costs are minimal in comparison to the potential benefits.

7. Industry Interaction

Dr. Chien-tsung Lu

Dr. Chien-tsung Lu is a professor at Purdue University. His aviation education experience includes a PhD. in aviation administration, a MS in aviation safety, and earned his A&P and FCC avionics license at Houston Rice Aviation College. For several years, he also acted as dean of the Nanshan Aeronautical College. Aside from academics, Dr. Lu served as the Chairman of Qingdao Airlines and board director for Virgin Australia Airlines.

When presented with Taxiwayz, Dr. Lu immediately liked the concept, but as a safety advocate, the idea of using an app, which may fail at any time, raised some concern. For utilization in the aviation field, all devices and software must be certified or permitted, usually through the FAA. In the case of our designed app, it too would need to be allowed, especially for commercial pilots. In terms of malfunction, Dr. Lu recommended a backup system which for an iPad app, is difficult to do.

Using his airline experience, he examined the idea through a manager's perspective and spoke to the usability of such a system. Regardless of certification, users must be able to afford it and also find it valuable enough to take the time and establish its usage as a regular part of their routine. He made sure to make a point of saying that the app cannot interfere with any current processes. Should managers choose to bring about Taxiwayz, they will need to receive support from their pilots or drivers. As Dr. Lu points out, some employees may see this technology and claim that it is unnecessary because "they were trained to do their job" and should be able to complete their tasks without assistance.

Lastly, he discussed the design of the interface as well as the usage. Reaffirmed by other industry input, users should not make the app a go-to for all their navigation issues. Rather, they should receive the crucial information displayed on the screen through audible alerts.

Denver Lopp

Professor Denver Lopp is a Professor Emeritus at Purdue University, at which he taught for many years. He has experience in virtually all areas in aviation, including operations, airlines, and maintenance. Denver is also a private pilot and in addition possesses his airframe and power plant certificate. Professor Lopp was very intrigued by the idea and had a great deal of information to help with the project. He brought up the issue of pilots or vehicles being unable to make a certain taxiway and how fast the controllers could give an amended taxi clearance, as airplanes are fast-moving objects. He, like Dr. Schreckengast, likes the idea of making voice recognition redundant with the controllers being physically able to draw out a route and send it to whomever necessary. With this being said, with the help of Professor Lopp, we would like to incorporate a similar technology to that of Google Docs. With this, the pilot would be able to see instantaneously what the controller is assigning. Once again, redundancy is vital for the success of this project.

Michael Nolan

Our air traffic control interaction came from Purdue professor Michael Nolan. Prior to working for the university, Professor Nolan was employed as an air traffic controller for over ten years. At Purdue, he has served as the head of the air traffic control program which gives students a chance to take a course on basic air traffic control methods and tasks.

When presented with the proposed technology, Professor Nolan’s first comments were regarding current air traffic control technology. In today’s system, controllers have a “picture in their mind" and have the task of conveying that picture via voice communications to a pilot or ground vehicle so that they too have the same picture in mind.

Dr. Stewart Schreckengast

Dr. Stewart Schreckengast (RAeS) gave us a great deal of insight into the airport safety aspect of our project, as he has been a specialist in airport safety for many years. Dr. Schreckengast is a Certified Member of American Association of Airport Executives, Member of the International Society of Air Safety Investigators (ISASI), an FAA Certified Flight Instructor (Single and Multiengine Helicopter and Airplane, Instrument Instructor Airplane), FAA Commercial Pilot (Helicopter, Single and Multiengine Land Airplane and Single Engine Sea Licenses). He is also a former US Naval Aviator (Commander), Technical Consultant with ICAO, a Senior Aviation and System Safety Analyst for FAA, a Consultant with MITRE, and a Researcher and Educator. When presented with the information, Dr. Schreckengast was very supportive of this topic. His comments mainly revolved around safety and how ATC could deliver the taxi instructions. One great point he had regarded airports with intersecting runways. He would like to see the app be able to show aircraft if LAHSO (Land and Hold Short Operations) are in effect or if the aircraft is able to cross the intersecting runway. A simple way to mitigate this issue is to use color coordination regarding LAHSO. Theoretically, if the runway lights up green, the pilot/operator can cross the intersecting runway, and red if not. One idea he also proposed is an alternative to voice recognition in regards to delivering the taxi instructions. He mentioned the controllers being able to physically draw a route on an airport diagram, which could be sent to the pilot or ground vehicle operator. This would make the voice recognition system redundant. Overall, Dr. Schreckengast was very interested in the idea and was a tremendous help.

Dr. Thomas Carney

Dr. Carney is a retired professor of Purdue University where he taught courses pertaining to meteorology, high performance turbine operations, high altitude flight, and corporate flight management. At one time, he also served as the department head of Purdue's Aviation Technology program. A highly skilled pilot, Dr. Carney has received numerous awards related to his profession which document his high-caliber impact on the industry.

Dr. Carney was presented with the Taxiwayz concept in its early stages and helped shape the design. When he first heard about it, he quickly pictured a similar technology to that of Apple Maps which is the map app for Apple products. He envisioned the ability to see upcoming directions on the screen so that drivers or pilots could match their physical surroundings to those being shown on the app. His claim was that Taxiwayz was a "great idea" because it ultimately increases safety for anyone at an airport. The app would thrive in the night time environment especially because of its ability to recreate a simplified version of the physical environment on the screen in the light.

He had a few concerns related to the ability of certifying the app through the FAA. Firstly, the app needed to match FAA standards and once that was completed, ensuring that the app never malfunctions was next. There is no room for error in the airport environment and should something go wrong, the app is found at fault. Another point Dr. Carney made was that with normal roadway mapping, there is the "recalculating route" option where a user can return to a previous location and try again. In the airport environment, there is no room for backing up or turning around because someone may have missed their exit.

A few suggestions were made in terms of the design of the app. The first being the addition of audible alerts for the user so they can be made aware of areas they are approaching or other important situations. Another was, as previously mentioned, the ability to see the upcoming direction in route form. Dr. Carney attested to Apple Map's ability to keep him on track by showing him the roadway signs he would see ahead. His last suggestion was the ability to declutter the screen and let users select the information they want displayed. If a user is receiving unwanted information, it may cause distraction or become an anger-inducing annoyance.

Josh Jensen

Josh Jensen was our industry expert relating to app development and programming. Mr. Jensen currently works as an independent app developer. To create an app, he begins by first determining the need of the customer and turning that into the needs for the app. The second step is arguably the biggest as data is needed to make the program operate correctly. Whether this data comes from the field or is static data stored on a computer, it must be sourced and changed into a format useful for developing an app. Accessing the data, especially in the case of positioning and mapping, can be incredibly expensive aside from his hourly charge of 125 dollars an hour. Mr. Jensen added that because Taixwayz would involve the FAA, even greater mapping detail is needed compared to a traditional road map. "You'd need details on airport layouts, taxiways restrictions, acceptable pathways through taxiways and more". After the creation of sufficient data, designing an interface which humans interact properly is next. Human factors is a large subject in aviation, but Mr. Jensen states that due to the aviation environment, any action a pilot or ground vehicle operator takes might be as a result of the app and should it be wrong, trouble may arise.

Appendix A. Contact Information

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Appendix B. Description of the University

Purdue University is a 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 many avenues for learning for undergraduate and graduate students. The department of Aviation and Transportation Technology is under the Purdue Polytechnic Institute, formerly the College of Technology, and includes three majors of Professional Flight, Aviation Management, and Aeronautical Engineering Technology. Purdue's aviation programs are based at the Purdue University Airport (KLAF), the second most-busy airport in the State of Indiana by operations. According to *Niche* and *The Best Colleges*, Purdue is ranked as the top aviation program in the world.

Appendix C. Non-University Partner

Our non-university partner was independent app developer Josh Jensen. Josh was interviewed by our team to learn more about app development of software that includes positioning and mapping data.

Appendix D:

Full competition guidelines and all updates are posted on the Competition Website:
http://vsgc.odu.edu/ACRPDesignCompetition/

Title of Design:	Taxiwayz Airport Ground Mapping Syster
Institution(s):	Purdue University
Design Challenge Area:	Runway Safety/Runway Incursions/Runway Excursions
Specific Challenge Selected:	Mobile tools for pilots, pedestrians and vehicle
Level(s) of Student(s) Involved:	( ) Undergraduate ( ) Graduate (•) Both

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Contact Information for Second Faculty Advisor (Optional):

First Name:	
Last Name:	
Department(s):	
Street Address:	
City:	
State:	
Zip Code:	
Telephone:	
Fax:	
Email:	

Select number of team members: 4

Team Member(s) Name(s) list individually	Permanent Email Address	Student Level
Jason	Hart	( ) Undergraduate (•) Graduate
Will	Arnett	( ) Undergraduate (•) Graduate
Alissa	Brown	( ) Undergraduate (•) Graduate
Tim	Miller	(•) Undergraduate ( ) Graduate

Estimate number of other participants: 0 Other, please describe

How did you hear about the ACRP University Design Competition for Addressing Airport Needs?

- [x] I previously participated in the Competition.
- [x] I was referred by a colleague.
- [ ] I received information from a Competition Partner (AAAE, ACC, ACI-NA, NASAO, and UAA.)
- [ ] I found it on the VSGC/ACRP website.
- [ ] I received an email from the Virginia Space Grant Consortium.
- [ ] I saw it on Social Media.
- [ ] I received the Competition guidelines at a Career Fair/Conference that I attended.

Appendix E. Evaluation of Educational Experience Provided by the Project Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The ACRP contest provided a valuable learning experience for the team in that it allowed us to participate in a professional development process in a relevant field of study to our respective majors. The competition facilitated learning about new developments in flight and flight related technologies as well as their implementations in the current state of aviation.

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

The main challenges our team had to overcome during the process of the ACRP competition was organizing times to meet and work together. Since our team compromise of four students (three graduate students in Aviation Management and an undergraduate student in engineering) with demanding and diverse schedules, finding times to work together and compose a complete project was difficult.

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

Our team addressed our hypothesis by researching the problems plaguing the aviation industry via a literature review. After we had narrowed down the subject areas, we presented the ideas to professors and aviation professionals to receive feedback on what they felt was most important. Once the majority agreed, we decided upon the examination of ground aircraft and vehicle traffic.

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

Industry participation was incredibly important as Taxiwayz is a system that was designed by pilots and airport personnel. Rather than base our development solely on our life experiences, we were able to learn from those who have been dealing with these subject areas for a longer period of time to truly understand the impacts an app like Taxiwayz would have on an airport or the industry as a whole.

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?

Questions For Faculty Members:

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

The ACRP contest has been excellent educational experience for the participating students this semester. The students had the opportunity to define a project and scope of work, develop a plan and schedule, identify tasks to be completed, execute the tasks cooperatively, and document the findings in a report. These activities provided an opportunity for students to leverage their educational experience and aviation knowledge, and apply it to a real problem.

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

The learning experience was appropriate to the course level and area of study. The project team included graduate students and undergraduate students, and students from aviation and engineering. Students leveraged their discipline knowledge as well as their personal strengths to work together and complete this project.

3. What challenges did the students face and overcome?

The students faced challenges common to group projects, including coordination of schedules and activities, and the need to identify and work with industry professionals to complete the project. The students overcame these challenges with persistence and by combining individual efforts with project management skills for coordination and outreach.

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

I will use this competition as an educational vehicle in the future since it does provide an excellent opportunity for students to apply the things they have learned in school through project-based learning. This provides an excellent opportunity to refine skills that will be needed upon graduation.

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

I think the competition is excellent "as is"; there is nothing I would change.

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