Touchscreen Airtraffic Management System (TAMS)

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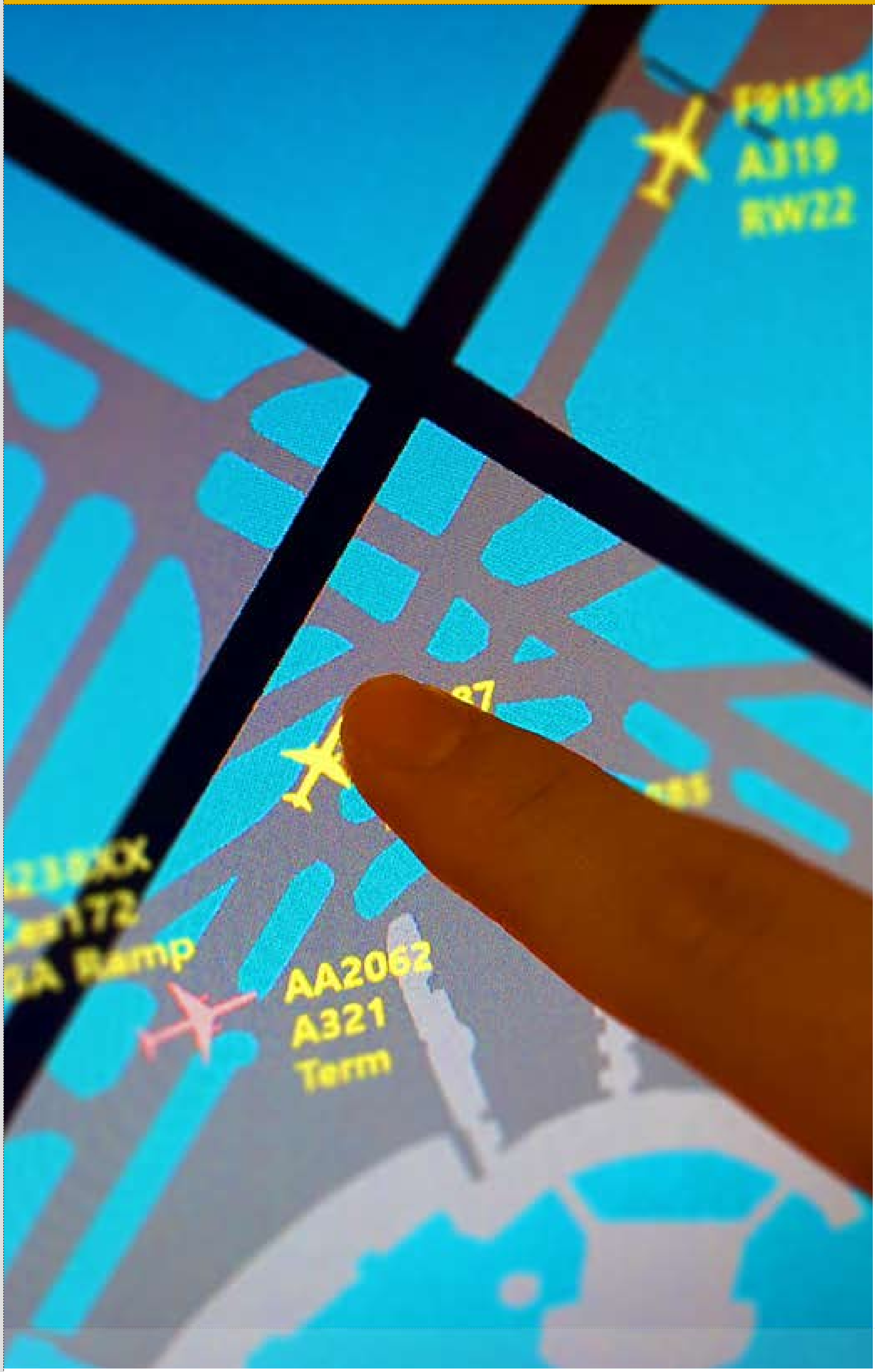

Purdue University

School of Aviation and
Transportation Technology

COVER PAGE

Title of Design: Touchscreen Airtraffic Management System (TAMS)

Design Challenge Addressed: Runway safety/incursions – Enhancing airport visual aids

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Executive Summary

In the years since Archie League first used red and green flags to coordinate aircraft ground operations in 1929, technology has certainly advanced. However, essential communication of “Stop and hold”, “Proceed”, “Clear” and other key information directives still relies much on controller to pilot voice communication. And sometimes the human element of communication remains a potential single-point failure, especially in modern global operations due to technical and linguistic limitations. The design concept of Touchscreen Air-traffic Management System (TAMS) was created to enable an enhanced visual component to the communication link between pilots and Air Traffic Controllers (ATC). Traffic controllers can simply draw a taxi instruction on a map displayed on a touchscreen interface send a similar visual instruction to a flight crew display using datacomm. The flight deck Flight Management System (FMS) converts the instruction into a navigational map. TAMS is designed to work together to enhance existing voice communications and will provide an additional layer of safety and operational efficiency during aircraft taxi operations, especially at high density airports. Ultimately, TAMS is designed to reduce runway incursion and taxiway collision by improving ground navigation visibility and situational awareness of pilots and air traffic controllers.

Keywords: Nextgen, Touchscreen, data communication, ASDE-X, CPDLC

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2. Problem Statement and Background

In the early days of aviation, primitive aviation communication consisted of hand signals combined with flags, flares and signage (Nolan, 2011, p. 5). As technology evolved, the method moved to radio communication using Morse code and later high frequency voice communication. While English is primary language used in aviation, even regional variations exist. To minimize communication error, global bodies like International Civil Aviation Organization and International Telecommunication standardized radiotelephony signals.

As of 2016, radio voice remains a primary mode of communication. While direct voice communication is usually thought of as the richest form of communication, there can be drawbacks. Aural information processing relies heavily upon short term memory. Voice communication, especially during high work load situations usually remains temporary perishes soon after it is spoken. This can be a problem during high workload situations combined with complex instructions. As an example, at airports like New York's JFK, taxi instructions can consist of a long string of assigned taxi ways, and memorizing complex taxi instructions may be difficult, especially to pilots unfamiliar with JFK. The average taxi time of JFK in 2015 was 26.73 minutes (Bureau of Transportation Statistics, 2016), and it is believed pilots are at risk of forgetting taxi instructions during these extended times.

All industry experts interviewed for this project indicated that radio communications can sometimes be unreliable due to the nature of the radio equipment. Dr. Tom Carney, who has more than 11,100 hours as a commercial pilot, stated radio communication can be interrupted by various anomalies with the equipment. Major communication problems could include poor reception, faulty headsets, inadvertent low volume settings and overlapping transmissions on one channel. Language barriers are also a problem with voice communication. Pilots who fly internationally must communicate with local air traffic controllers whose first language may not be English. Even within the United States, dialects vary for Southern, Eastern and Western regions. Misunderstanding instructions reduces operational efficiency and increases the chance of error. The Tenerife Disaster was caused by mutual radio interference due to simultaneous radio call and miscommunication among the air traffic controller, KLM and PanAm pilots (Ministerio De Transportes y Comunicaciones, 1978, p. 38-48).

The Federal Aviation Administration (FAA) is currently working to replace or improve vocal communication by implementing data communication infrastructures and software. One of the FAA's programs is controller-pilot data link communication (CPDLC) which is currently limited to a departure clearance communication (2015a). Aircraft taxi consists of two dimensional movements making it relatively easy to convert instructions onto a map.

Currently, the FAA's data comm implementation plan does not include a data communication system focusing on improving controller-pilot communication for taxi operations (RTCA, 2014, p. 29). The Touchscreen Airtraffic Management System (TAMS) design allows air traffic controllers to trace or draw a taxi instruction or line on a map and send the instruction via data communication. The sent taxi instruction is converted onto an airport map in the flight deck electronic flight bag. In other words, the system is capable of sending a map created by a traffic controller to the flight deck. TAMS will significantly reduce density of voice communication and miscommunication between pilots and air traffic controllers during ground taxi operations. The system's touch screen incorporates existing airport surface detection equipment mode x (ASDE-X) to display aircraft locations, improving visualization and communication. TAMS is not designed to replace existing voice communication, but to help mitigate weakness of the current voice-dominant system.

3. Literature Review

3.1. The effects of verbal and nonverbal teacher immediacy

During normal face to face conversation, people use their bodies to add contextual emotion or meaning to a conversation. This was researched during a study by Judith A. Sanders and Richard L. Wiseman (1990). The study looked at the use of nonverbal and verbal communication in a classroom. Nonverbal communication was found to improve the effectiveness of the teaching. Next they studied verbal communication which changed meaning with each student. When people speak, assumptions are made based on tone, sentence structure, and emotions which can give students a different meaning. Finally, verbal and nonverbal communication were used together to teach students. The students reported that they understood the teachings more fully which made them feel more comfortable. The study concludes that the use of both verbal and nonverbal communication creates more understandable directions.

3.2. Data Communication

The Federal Aviation Administration has been working on Nexcom and controller-pilot data link communication (CPDLC) to improve or replace current spoken communication between pilots and the air traffic controllers. Nexcom is a new radio communication method replaces traditional high frequency radio. Nexcom is consisted of Very High Frequency (VHF) Digital Link Mode 3 (VDL3) to enable both improved voice communication via voice over internet protocol (VoIP) and data communication (FAA, 2012). CPDLC utilizes Nexcom interfaces such as VDL2 and VDL3 to support data communication between air traffic controllers and flight deck flight management system (FMS). With CPDLC, pilots can get departure clearance through FMS, and ATC departure clearance automatically update standard instrument departure (SID) on FMS. FAA is currently planning on expanding data communication capabilities to full en route services in two separate phases (RTCA, 2014, p 29).

3.3. Airport Surface Detection Equipment, Model X (ASDE-X) and TAMS Interface

In order to display aircraft and airport vehicles on the touchscreen interface, TAMS requires aircraft flight information and location data of aircraft and ground vehicles. The data needs to be real time, reliable and accurate to minimize information discrepancies in any condition. Airport Surface Detection Equipment-model x, also known as ASDE-X, is an existing ground air vehicle tracking system meets requirements of the TAMS. ASDE-X is designed to display aircraft and vehicles on the ground or flying within 5-mile vicinity to increase situational awareness of the air traffic controllers. ASDE-X achieves its accuracy and reliability by using several layers of redundant data sources such as surface surveillance radar, multilateralization sensors, airport surveillance radar (ASR-9), ADS-B and terminal automation system (FAA, 2014a). Ground vehicles entering controlled air side are required to be equipped with ADS-B transponders to be traceable on the ASDE-X system.

ASDE-X has already been approved and implemented at 35 major airports including New York JFK, La Guardia, Chicago O’Hare and Los Angeles International Airport. Due to high implementation rates at major airports, adaptation cost for the proposed TAMS add on can be reduced.

4. Problem Solving Approach

4.1 Design Overview

Current air traffic control relies heavily on audio communication which can result in information discrepancies due to bad distortion of word, language barriers and poor audio quality. To improve communication between air traffic controllers and pilots, the team decided to create a communication system enabling air traffic controllers to communicate with pilots using visual information with a touch screen interface.

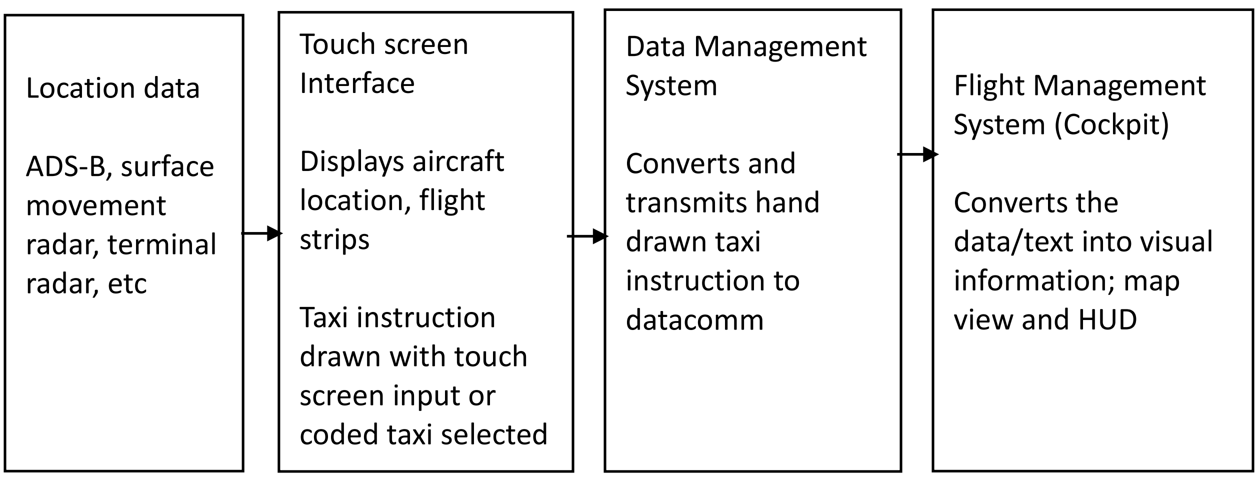

Figure 1 Design overview of Touchscreen Airtraffic Management System (TAMS)

The touch screen interface utilizes ASDE-X which displays aircraft location data from ADS-B, surface movement radar, terminal radar and other data sources. Aircraft location is displayed on a high contrast digital airport map. Air traffic controllers can give taxi instruction to corresponding aircraft by touching and tracing/drawing a taxi instruction on the touchscreen. Controllers can also choose from standardized coded taxi routes. The drawn taxi instruction is converted into Nexcomm text data by the Touchscreen Airtraffic Management System (TAMS), and TAMS sends the converted data to the flight deck FMS for visual display. TAMS also has capabilities to send to a certified smart device via cellular networks, or even to automated towing tractors such as TaxiBot (Israel Aerospace Industries & TLD Group, 2015).

4.2. Touch Screen User Interface

4.2.1. Touchscreen Interface Design Overview

TAMS touch screen interface will utilize existing Airport Surface Detection Equipment Mode X (ASDE-X) for location data collection and map displays. TAMS requires a larger multi-touch screen than the conventional ASDE-X screen for more accurate drawing of taxi routes. As shown on Figure 2, TAMS could retain the ASDE-X map with additional functionality; by touching the aircraft icon on the map, controllers are able to provide additional visual taxi instructions to the selected aircraft. The top left of the map has an *Emergency* icon for an emergency notification to the airport fire department. Bottom left *Cancel* button allows cancellation of any ongoing task and return to the app view. On the right of the map, TAMS displays logged in user, time, wind and electronic flight strip. The integration of the ASDE-X map and the electronic flight strip reduces the number of monitors and interfaces for the air traffic controllers, enabling controllers to select aircraft on the map by touching the flight strip.

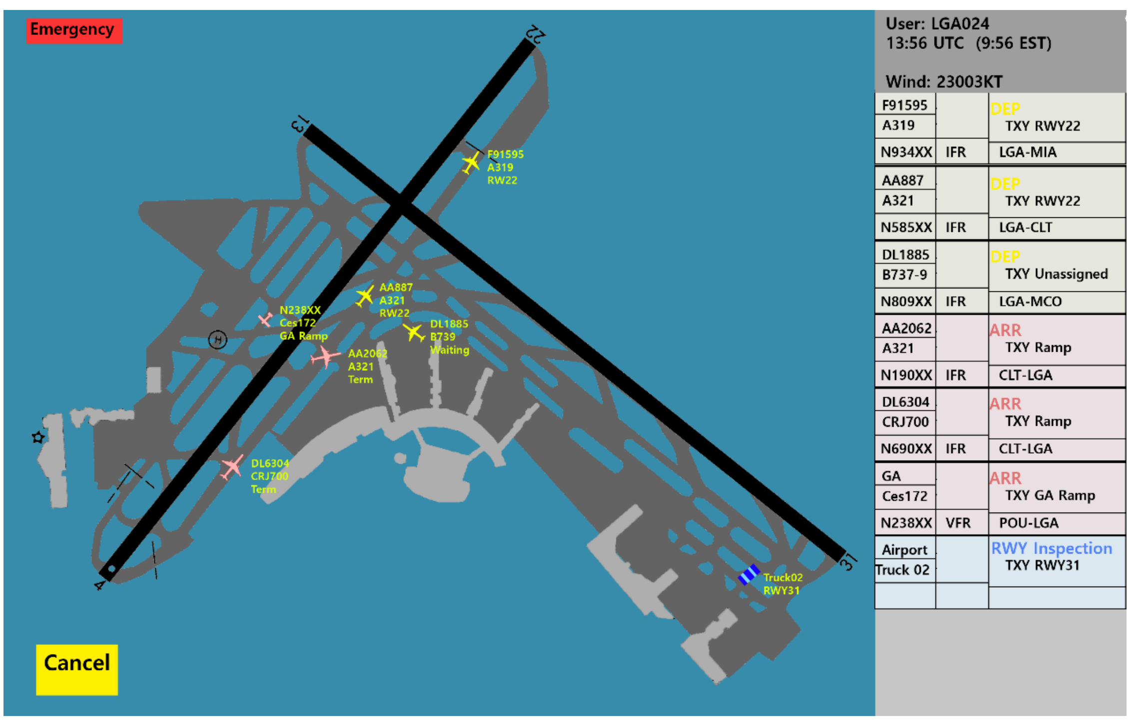

Figure 2. Touchscreen Airtraffic Management System (TAMS) user interface

4.2.2. User Interface Flow

TAMS user interface is similar to many smartphone interfaces, for familiarity among millennial age groups, and could therefore minimize error and reduce training time.

In order to assign a visual taxi instruction to an aircraft, the controller can touch the aircraft on the ASDE-X map or on a corresponding electronic flight strip. After selecting the aircraft, the ground destination is selected from list of runways and ramps or, can be directly picked from the map. After selecting the aircraft and the destination, the controller determines which taxi route generator mode to use. TAMS features three route generator modes:

1. Manual Drawing
2. Standard (coded) taxi routes, or
3. Follow another aircraft.

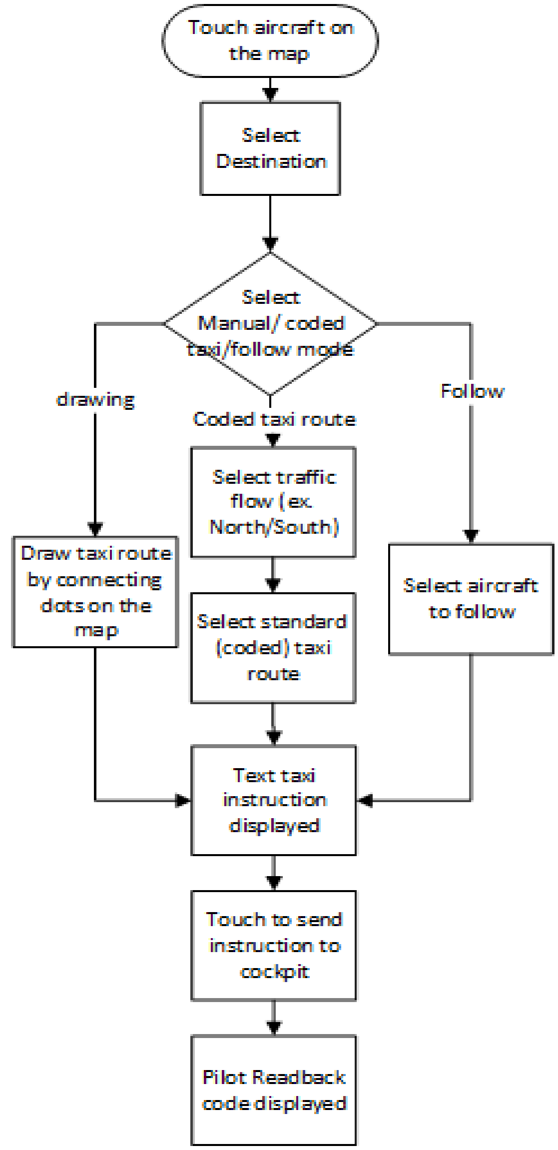

Figure 3. TAMS user interface flow chart

For the manual mode, the traffic controller draws aircraft taxi routes by connecting the yellow dots as demonstrated in Figure 4 on page 13. Selected dots turn red and a yellow taxi line is displayed between the selected dots. A ‘connect the dots’ design was selected to reduce errors caused by inadvertent touch when drawing the taxi

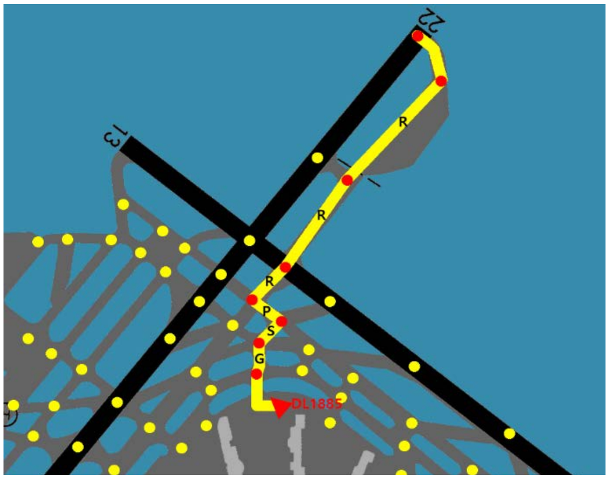

Figure 4. Manual taxi route drawing

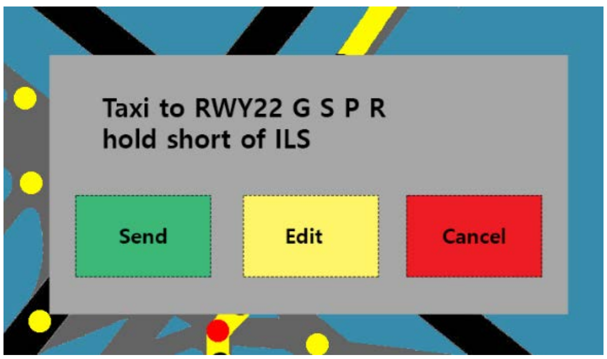

Figure 5. Taxi route review page

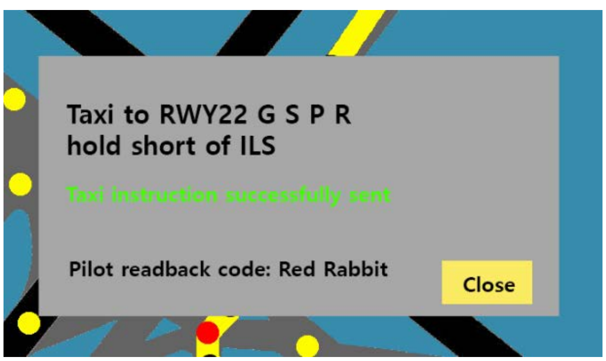

Figure 6. Confirmation page

route. Standard (Coded) taxi route can be selected from the list available for the airport for each traffic flow pattern. For the Follow Aircraft mode, the controller selects an aircraft to follow from the electronic flight strip or the aircraft displayed on the map.

When the taxi route is finalized, a pop-up window displays text taxi instruction. The air traffic controller can send this instruction to the aircraft, edit the route or cancel the selected route as illustrated in figure 5. After sending the instruction, the window displays a confirmation page with data communication status. If the data communication is successful, it will display ‘successfully sent’ as shown on Figure 6. If data communication failed, it gives controllers options to resend or cancel the instruction.

To safeguard against inadvertent misread or failure to read a visual taxi instruction, the confirmation page also contains pilot read back validation code. The code consists of randomly generated words sent with the instruction for display. Pilots have to read back the code confirming successful data communication. If the read back code is not displayed or differences in visual and vocal communication are detected, pilots report the error to the air traffic controller.

Air traffic controllers have to check the pilot's read back of taxi instructions and the code to ensure the pilot checked both instructions.

4.2.3. Operation Preset

Airports frequently change their runway and taxi configuration for new construction projects or to satisfy new operational standards. Using the touch screen interface, TAMS can change taxi routes to meet new airport configurations as they arise. When there are closed taxiway routes due to construction, tower managers can remove the taxiway from the map. The removed taxiway will not be selectable when drawing the taxi routes. TAMS also features operational weight and wing span limits for each taxiway and runway. Aircraft beyond the weight or wing span limit cannot be assigned to the taxiway or the runway by the TAMS system.

4.2.4. Security measure for TAMS

TAMS is designed to be a secure system. In addition to being located within existing security of designated FAA control towers, it is equipped with layered systems to safeguard information and its access. TAMS is first operated by a user ID along with a secure password which must meet special requirements. The password can be set to require a routine change/update, so information cannot be compromised if a user leaks their access codes. The TAMS software scans the user's background in the system and checks for revoked access or training. TAMS users must also provide a fingerprint for scanning. The fingerprint scanner matches user prints to those designated at the time of employment. Several fingerprints are saved in the database to provide more security.

4.3. Flight Deck Displays

The TAMS visual instruction is converted into text data and sent to flight deck FMS through an Ultra High Frequency datalink, ADS-B or satellite communication. When the data is received, the flight deck FMS converts the text instruction to a visual instruction. The visual instruction can be displayed in a form of map on the electronic flight bag as illustrated on figure 7. With the map, the electronic flight bag also displays text instruction and the pilot read back confirmation code (refer p. 13). Additionally, aircraft with head-up displays (HUD) can display taxi instructions in augmented reality visualization technology. The HUD taxi instruction enables pilots to taxi without looking down at the airport map or the electronic flight bag.

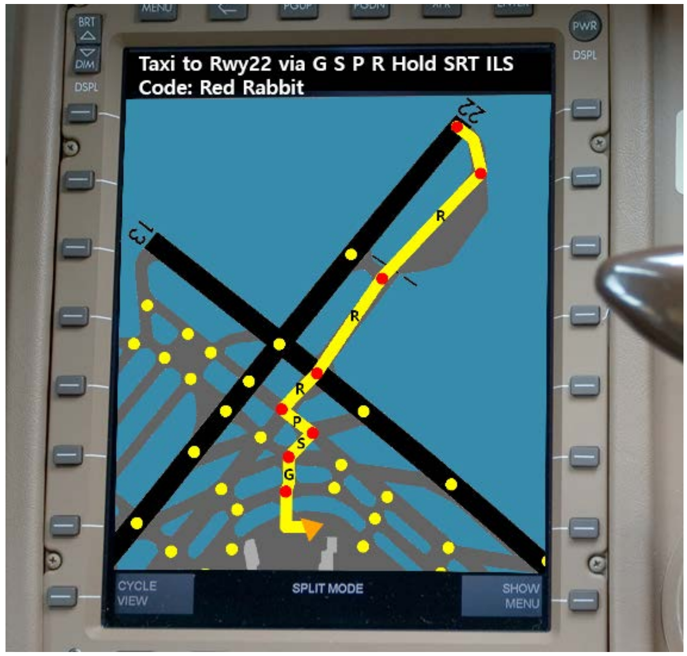

Figure 5. TAMS taxi instruction display on an electronic flight bag of B777-200*
*Photo credit: Tim De Groot (2005)

4.4. Communication Procedures

TAMS is designed to minimize changes to current communication procedures for taxi. Rather, it offers additional options for air traffic controllers to draw or select taxi routes for flight deck visual displays. Pilots are required to validate both visual and vocal communication to ensure accuracy of the instructions. Each step of the pilot and traffic controller communication procedures is illustrated on figure 8 on page 18.

4.4.1. Taxi Route Generation

The Touchscreen Airtraffic Management System (TAMS) taxi process starts with the pilot's request for taxi using normal verbal radio communication. After receiving the request from the pilot, the air traffic controller (ground) selects the aircraft by touching on the aircraft icon on the touchscreen map. After selecting the aircraft, the air traffic controller chooses between Manual taxi route mosde, Standard (coded) taxi route mode, or Follow mode. If Manual mode is selected, the ground controller draws the taxi route on the interactive map. If Standard taxi route mode or Follow another aircraft mode is selected, the controller can choose among the options provided by the TAMS.

4.4.2. Drawing to text/data

Once taxi routes are finalized, the TAMS screen displays a text version of the taxi route as demonstrated on Figure 5 on page 13. At this phase, the ground controller reviews the taxi route and is able to edit or cancel the selected route. After reviewing the text instruction, the controller sends the instruction to the aircraft by touching 'send'.

4.4.3. Text/data to visual & vocal

After sending the digital instruction through data communication, the controller reads the taxi instruction on the display using the vocal communication through high frequency (HF) radio. The traffic controller can add additional information to the instruction to warn the operational risks to the pilots. The digital instruction sent through data communication is converted into visual information by FMS. The instruction can be displayed as a navigational map on the electronic flight bags as illustrated on figure 7 on page 15, or it can be displayed as augmented reality (AR) animated overlay visualization on a heads up display (HUD) or Smart Glasses.

4.4.4. Taxi instruction confirmation by flight deck

After receiving both visual and vocal taxi instructions, the pilots match both instructions to validate accuracy. If the instructions do not match, the pilots report the faulty instruction to the ground controller to fix the error. If the instructions match, pilots read back the instruction with the confirmation code displayed on the visual displays.

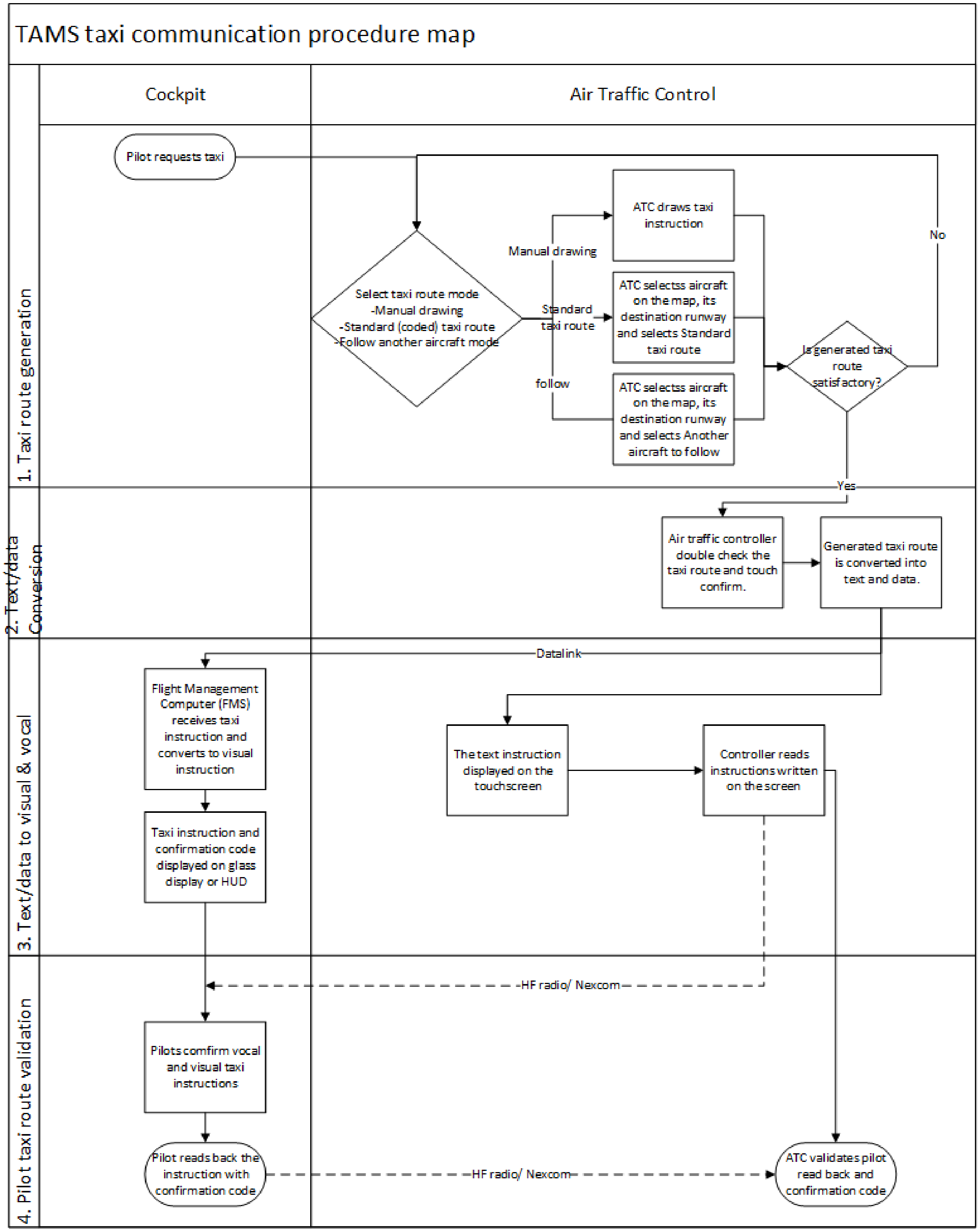

Figure 6. TAMS taxi communication procedure map

4.5 Additional Features

4.5.1. Smart device Support for Ground Vehicles and General Aviation

Most ground vehicles and general aviation (GA) aircraft do not have capabilities to data communication or flight management system to support TAMS. In order to implement TAMS for GA aircraft and the ground airport vehicles, cellular communication capability is required for TAMS to communicate with cellular devices such as smart phones and tablets. Cellular communication would be one-way communication without feedback from the devices to minimize the chances of a security breach through vulnerable cellular networks. The smart devices can also be used on snow plow vehicles and airport emergency vehicles. This feature will be perhaps the most affordable method to introduce TAMS to general aviation and to improve operational safety on the taxiway.

4.5.2. Automatically Generated Taxi Route

The automatic taxi route generator creates the taxi routes based on the statistically most used taxi routes by the traffic controllers. The automatic mode collects taxi data from aircraft movement data from ASDE-X, drawn taxi routes, and other frequently selected standard (coded) taxi routes. With the collected data, the auto generator creates the shortest route using the most frequently used taxiways for each origin/destination. Unlike the coded taxi routes, operators do not need to predefine the taxi route, but the mode requires time to collect the taxi route data for the taxi route generator. Each ground controller may use historic or system wide data to generate the taxi route.

4.5.3. Synthetic voice

Synthetic voice is an optional feature of Touchscreen Airtraffic Management System (TAMS) to replace the vocal communication by the air traffic controllers. Instead of the traffic controllers speaking separately after approving the visual taxi instructions, TAMS could utilize a synthetic voice engine to speak vocal instructions upon approval of the visual instruction. The traffic controllers only need to intercept the voice communication when there is an error in the system or an emergency occurs.

The team decided to exclude this feature from the original design due to two obstacles using the synthetic voice that would exceed the R&D time frame for this phase of the project. The first problem is the inflexibility of the synthetic voice system. In case of emergency, it is faster to speak to affected aircraft directly than typing the instructions for synthetic voice. The second problem is the confusion caused by two voices giving the instructions. When two different controller voices are mixed in one channel, they may cause confusion to the pilots. Further evaluation and testing are required, but could yield value added results to TAMS in the future.

4.5.4. Communication Capabilities with Taxibots

Volatile oil prices have resulted in several innovative approaches to save fuel in airport ground operations. One innovation is the robotic towing tractor moving aircraft from gate to runway, replacing traditional aircraft engine propelled taxi (Israel Aerospace Industries & TLD Group, 2015). TAMS will have the capability to send taxi instructions to the towing robots directly using data communication used for visual taxi instruction displays. Just like regular operations, air traffic controllers can draw or select a coded taxi route, and send instructions to a flight deck for visual displays and to the robotic taxi tractors to give automated taxi coordinate orders. This feature could minimize route programming time for the robot and streamline taxi process.

5. Safety & Security Risk Assessment

Referencing FAA Advisory Circular 150/5200-37 (FAA, 2014b) the team performed a hazard analysis and assessment for operational safety and security risks associated with TAMS. Safety risks for pilots, ATC, system programming errors and system hacking entry were identified and evaluated for safety and security issues. Industry experts interviewed for this project concurred with the team's realization of the prevailing human element as continue to be the biggest risk factor for just about any design.

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				System & Program error	
Extremely Improbable E					System Hacking

Figure 7. Safety & Security Risk Assessment

5.1. Pilot error

Hazard Identification: Because TAMS is operated by workers, they have the ability to increase errors. It is very possible for a pilot to misinterpret the graphics or the voice. If a pilot does not cross-reference the text and image but instead only looks at the drawing, the pilot can misinterpret the directions.

Risk Assessment: If a pilot does not cross-reference all of the pieces of directions, he creates a higher likelihood of major problems. One of the biggest problems they can cause is taxiway collisions. If they do not follow directions and disregard the ATC audio, they may not hold short at a specific position. When there are collisions, the runways or taxiways must be closed leading to inefficiency. This problem has few remote chances to occur. Pilot error can cause serious damage to aircraft and passenger injury. Team decided not to label pilot error as hazardous or catastrophic since there are other safety layers such as the read back codes which mitigates the risk.

Risk Treatment: Error situations causing pilot error are constant within a busy flight deck. Error can perhaps not be eliminated, but early recognition and prevention from culminating into an accident could be. The best way to deal with this error is by ensuring continuation of existing CRM and communication confirmation protocols Pilots must be kept in the loop as participants within the system, without being too automated out of it and relaxing too much

5.2. ATC Error

Hazard Identification: With air traffic controllers facing dynamic and high stress workloads, potential exists for misrouting directions just as in spoken communication directives. Although TAMS gives a text instruction with the graphic, it is possible for ATC to improperly input a direction. If a controller gives two different directions, a pilot will be dealing with confusion.

Risk Assessment: Even though it is unlikely, a controller could give incorrect directions to a pilot. Besides causing major confusion with the pilots, the controller may create a more stressful workload causing them to have to reposition aircraft and hold others back. The lack of efficiency could cause pilot aggravation or, serious damage to aircraft and injury to the passengers. Just like the pilot error, the assessment for major damage or injury was deemed to be remote given existing mitigating standardized safety layers already in place within the ATC ground operations system.

Risk Treatment: TAMS was created to coexist with the current ASDE-X system and air traffic control radio. The controllers must be trained to focus on their verbal instruction while then drawing after they have given it. Pilots must also be trained on rejecting a direction when they give their code. They are supposed to use discretion on the graphic and determine if they have been given a safe and appropriate route.

5.3. System & Program Error

Hazard Identification: Like all software, TAMS has the possibility of software errors. When a pilot or air traffic controller uses TAMS, the software errors are very unlikely to occur. The unfound software bug during development is possible to occur during the initial phase of TAMS implementation. The programing error is not limited to TAMS. Program errors can also occur in flight management system (FMS) or HUD software.

Risk Assessment: Because the software is an addition to current systems, it will not hinder current control tower operations. However, miscommunication generated by a programing error could create a large information gap which could result in a hazardous event. For example, when aircraft do not match up to the ASDE-X system, a controller may improperly direct an aircraft. They may also misjudge the placement of future planes. This issue can be quite hazardous if unnoticed by pilots and air traffic controllers.

Risk Treatment: The team utilized a Mean Time Between Failure or “Bathtub” curve used as one method to describe system and component failure rates. This curve states that during testing and the first uses of a system, there will be start up issues which progressively decline to a steady operating state. However, air traffic controllers must be trained to focus outside as well as down at the TAMS system. Although it is important for them to draw the directions correctly, they must not use TAMS as a replacement for what they can actually visualize or from other assistive data in real time. To mitigate the possibility of error in aircraft tracking, controllers would be trained to double-check the aircraft outside with the TAMS system so that they do not make a wrong move that could cause a collision. Airlines would institute training for pilots to cross reference both vocal communication and visual displays to find the programing error.

5.4. System Hacking

Hazard Identification: TAMS is designed to operate as aa secure system. The possibility of the system being hacked is extremely improbable but must be considered. The system is fitted with a normal username and password and is also reinforced by a fingerprint scanner, in addition to physical FAA security controls already in place at ATC operating towers/centers.

Risk Assessment: In the case of a hacking, the damage would be catastrophic. The first layer of safety is the FAA tower security which must be compromised before anyone can access TAMS. If anyone attempts to gain unauthorized access to TAMS, they must first have a valid username and password. If they also get past the fingerprint scanner, they have the ability to cause a lot of damage. Even though the software only controls the taxiways, a hacker can manipulate aircraft into others causing major collisions and harming individuals.

Risk Treatment: The solution to this hazard is to maintain security at all costs. To do so, training is the most important. For starters, controllers must be trained to maintain a secure password with their username. They are not to use simple passcodes. Besides passcodes, it is very important to maintain tower security so that access cannot be gained in the first place.

6. Industry Interaction

6.1. Michael Nolan

Our first contact for the project was Purdue Professor Michael Nolan. Nolan is the head of the Purdue air traffic control program and also teaches other courses. He is also in charge of the unmanned aerial systems students. He worked as a FAA air traffic controller for more than 10 years. Nolan is a certified flight instructor and also has his airframe and power plant certificate. Besides teaching, he has written and published three textbooks and worked on two others.

Professor Nolan expressed deep concern over visualizing his airport. Whenever he was in the tower, it became very difficult at times to visualize where planes are and where they would be in future time. He expressed concern over verbal communication. For Professor Nolan, pilots could vary in experience meaning they all have their own understanding of what an air traffic controller says. He even admitted that sometimes he would feel the need to reiterate what he had said or repeat himself regularly.

Besides human error, he also mentioned that regularly a pilot could have a faulty radio or a lower quality one. They may even just turn it down to the point that they cannot hear air traffic control. With pilots continuously relying on low quality voice, it became evident that there needed to be an additive. “When I talk, I have a visualization of what I want to tell you. I have a mental image. For perfect communication, you have to have the same mental image. How do I move my mental image EXACTLY into your brain? If it doesn’t work, somebody dies. We’re talking cross cultural. The best way for me to show you is to draw a picture.” After speaking with Professor Nolan, it became evident that TAMS was the perfect solution to his issues.

Another concern that was expressed was that text is not the best way to communicate. Although TAMS also adds text-based directions onto graphic representation, Nolan stressed that the text cannot be alone. He mentioned that “voice has advantages and tones. Text messages don’t have tone.” He went on to add that based on a person’s culture, the meanings behind their tones can change and be distorted. Because of his concern, it was clear that TAMS cannot replace voice but must be used side-by-side with normal air traffic control operations.

Professor Nolan’s final concern was the use of NextGen technology in air traffic control operations. He enforced the idea that you can’t change the system but instead you incrementally tweak it. With that came a reminder that air traffic control cannot be stopped at any time to implement technology. The most important piece of information he brought though was that “any technology will cause more accidents at the time it is brought in. Long term, it’s safer. Short term, it may not be.” The TAMS team continued to make safety our main focus and ensure there are ways to train users and incrementally bring the software into towers without disrupting any functioning parts.

6.2. Brian Inniger

Brian Inniger is the current tower manager of the Purdue University Airport in West Lafayette, Indiana. Inniger has had past experience at Indianapolis International Airport as an approach controller and a supervisor. Combining his experience in Purdue University Airport and Indiana International Airport, he has total 8 years of experience in air traffic control. He also participated in CPDLC implementation at Indiana International Airport. As a tower manager, Inniger supervises other controller, manages tower operation and coordinates with the airport manager.

Inniger’s biggest issue was workload. Because of his experience at Indianapolis International, Inniger’s biggest issue was FedEx. Because Indianapolis is a big hub for them, he would deal with a huge amount of them and especially during the nighttime. He suggested that he would like to see TAMS use colors to designate certain routes. “If you go to a large airport, it is very common to give the same airplanes the same routes. To be able to name that route, maybe coded as a color, would be helpful. Airport geometry has grown organically and the runways have congested spots.”

He pointed out that not only does pilot experience differ but language skills differ. TAMS solves this issue. By giving pilots and air traffic control a way to communicate using verbal and nonverbal communication at the same time creates a very safe atmosphere that is very easy to understand.

When asked if TAMS would have assisted him in all the facets of his job, he said, “Yes, for my situational awareness and the pilots.” Another issue he brought up was that by being up high in a tower, sometimes weather blocks the entirety of their view below. With TAMS, Inniger said that he would no longer have to use a laminated whiteboard to direct planes but instead have a live feed to direct planes without any visuals. “There were times where I could not see anything. I would definitely feel safer if I could know what’s out there. This is a great idea and I’d love to have this.” He really enjoyed how he could “interrogate” a pilot and confirm if they received the message. “You send them a challenge and then receive a response.”

6.3. Dr. Thomas Q Carney

Our next contact was pilot and Professor Dr. Thomas Carney. Dr. Carney is the former head of the Purdue Department of Aviation Technology. He has been a pilot for over 48 years gaining more than 11,100 flight hours. He holds the Airline Transport Pilot certificate with multiengine rating and is also a certified flight instructor. He is also very experienced with aviation meteorology, high performance turbine operations, and corporate flight department management. Carney has published thirteen pieces with two being textbooks.

Dr. Carney said he was often stressed and to the point where he had to pay attention and listen to everything. “If you didn’t follow things, everyone’s “dominos” fall.” His main statement was that every airport is different and every pilot varies in professionalism. The same issue develops in asking for repetition of a direction too many times. He said that you better not make it a common occurrence because if you ask them to repeat, “They will break you.” TAMS lets pilots avoid the problem of missing something over the radio but ensures that they have read the direction and seen the graphic depiction when they are forced to respond.

One of the main points Dr. Carney made was with the pilot interaction to TAMS. The TAMS team worried that the system to could fall to the same fate as circuit breakers did on Northwest Airlines Flight 255 where an annoying take-off warning alert system during a prolonged taxi time was believed disabled by the flight crew. To ensure that the system would be used and not overlooked or silenced, the team asked Dr. Carney if he was ever guilty of silencing a system in a cockpit. “Of course. Sure I have. If you have a warning, you need less confusion so it’s easy to reach up and kill it.” When using TAMS, pilots receive directions that are then agreed to or accepted by the push of a button. Even though it is only one button, pilots cannot ignore the readings as they need them to move forward to take flight.

When asked his opinion on TAMS being implemented, he said “If it always worked, and was used by everybody, I would feel safer knowing that all the aircraft would be on the same page.” He added that as long as it is not a distraction or significant addition to the workload, he would enjoy the system especially at places he is unfamiliar with. “Pilots will embrace it if it makes them safer and works a time or two.” Carney says that of his many hours of flight experience, a lot of them have been spent in bad weather where he has had low visibility and wishes he could have had TAMS. With TAMS, pilots can maneuver more safely during nighttime operations and extreme weather conditions creating safer runways and taxiways.

7. Project Impact

7.1. Cost Analysis

For the cost analysis, the CPDLC implementation cost was originally considered to be used for the TAMS implementation cost. Both CPDLC and TAMS have similar data communication capabilities with flight management system. However, there are not publically available costs for CPDLC. On page 16 of FAA's The Business Case for the Next Generation Air Transportation System (2015b), FAA states 'the cost required to develop any specific NextGen improvement cannot be directly determined.' Brian Inniger, who participated in CPDLC implementation at Indianapolis International Airport, was not able to provide us the price. Furthermore, airports already implemented Nexcom infrastructures only require monitor, fingerprint scanner, software and server costs to operate TAMS.

Table 1.
TAMS implementation cost per airport (dollars)

Software	285,714
30" Touchscreen monitor	3,000
Finger print reader	100
Total per airport	288,814

Instead of referencing the implementation cost from FAA, we decided to estimate the software cost from the cost of an enterprise resource planning (ERP) software. Enterprise resource planning (ERP) refers to a type of software system that assists business owners and management in monitoring and controlling resources efficiently. ERPs are designed to collect and manage corporate data to deliver proper information to right department or personnel on time when it is needed. ERP's functionality is similar to TAMS. TAMS collects location data from ASDE-X, electronic flight strips, flight information, runway status and delivers the data to air traffic controllers and pilots. Typically, the cost of ERP software for a large business is around $10 million dollars (Oracle, 2016). Assuming we are installing TAMS to all 35 airports with ASDE-

X, TAMS software will cost about $285,714 dollars per airport. With 30-inch touchscreen monitor and finger print reader, the TAMS system implementation cost was projected to bet $288,814 dollars per airport, and $10,108,490 dollars for 35 airports.

7.2. Benefit Analysis

TAMS offers operational safety and efficiency benefits for air traffic controllers, airlines, and airports. TAMS improves air traffic controller's efficiency and safety by increasing situational awareness of the ATC. The controller is able to identify aircraft location on the map and visualize taxi routes, congested routes and possible traffic conflicts. Improved efficiency can reduce overall taxi time, fuel cost and carbon output for the airlines. With TAMS, airports benefit from increased capacity of the taxiway. Since TAMS adds additional layer of taxi safety, it is expected to reduce accidents during taxi. It will improve pilot's situational awareness, reduce radio chatter congestion.

For the benefit analysis, it is very hard to determine the real monetary benefit of the TAMS system. We decided to determine the monetary benefit by benchmarking the monetary benefit estimated for ASDE-X. TAMS' benefits to air transportation system are similar to the benefits of ASDE-X or even more. According to FAA (2015b, p.31), ASDE-X is estimated to give total future benefits of $533 million dollars for the next 15 years. That means ASDE-X gives approximately $35.5 million dollars per year (interest not adjusted). Assuming TAMS gives same amount of benefit to the air traffic system, benefit of $35.5 million dollars is subtracted by cost of 10.1million dollars results in net benefit of $25.5 million dollars. From this estimation, TAMS provides $25.5 million dollars of net benefit to the air transportation system.

Appendix A

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Appendix B

Purdue University is a coeducational, state-assisted system in Indiana. Founded in 1869 and named after benefactor John Purdue, Purdue is one of the nation's leading research institutions with a reputation for excellent and affordable education. Purdue University is accredited by the Higher Learning Commission of the North Central Association of Colleges and Schools. The West Lafayette campus offers more than 200 majors for undergraduates, over 70 masters' and doctoral programs, and professional degrees in pharmacy and veterinary medicine. Purdue University's College of Technology is one of the largest and most renowned technology schools in the nation with more than 34,000 living alumni. More than 5,500 Purdue students are currently pursuing their education in the College of Technology. The College of Technology consists of eight academic departments, and resides in ten Indiana communities in addition to the West Lafayette campus. The Aviation Technology department is one of the eight departments within the College of Technology. Three undergraduate programs are offered within the department: Aeronautical Engineering Technology, Aviation Management, and Professional Flight. Graduate studies in Aviation Technology are also offered. In addition, the department pursues signature research areas that embrace tenets of the emerging Next Generation Air Transportation System, which include Hangar of the Future aircraft maintenance technology innovation, National Test Facility for Fuels and Propulsion, and Safety Management Systems.

Appendix C

Our non-university partner is Brian Inniger, a manager of air traffic control tower at Purdue University Airport. Team members interviewed Brian Inniger and obtained his permission to use interview records for the ACRP design competition.

Contact Information:

Brian Inniger

Appendix E:

For student members:

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?

Through the challenges we've faced and the creation of our design, we gained meaningful insight into the aviation industry. It was an eye-opening experience as we sought out the professionals to help guide us in developing our system. When creating TAMS, it was important to keep the users in mind. While building TAMS, we were able to learn more about the people and their positions that affect the system.

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

Our biggest challenge was figuring out how to implement TAMS into any air traffic control tower without causing a disruption in the current system. We learned that to accomplish this, we had to develop the system with simplicity in mind. TAMS overcame the problem through research and the industry interaction. The team needed to search and find out how much of a workload a user can handle before they become frustrated or overwhelmed. After discovering that a few minor buttons would not bother anyone, we developed TAMS to focus on basic equipment with basic functions.

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

To develop our hypothesis, we had to first seek out gaps in the current communication methods in use around the aviation industry. Once we discovered that there was a gap in the identified communication method, we brain stormed hypothesis and solutions to improve the current technology. Team hypothesized visual communication will improve vocal communication's weaknesses by adding another layer. The additional communication layer is TAMS, which enables visual to visual communication between flight decks and the towers. We sought out professionals in our area who could give us insight on how to solve the problems and suggest ways to arrive at a design.

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

The participation by the industry was very important and useful in the development of TAMS. Without having feedback and guidance on the software, the team would not have created a system that would benefit controllers and pilots simultaneously. It was very appropriate to contact individuals as they have had years of experience in the fields we have yet to fully discover. It was most useful to find contacts that had a background in the kinds of technologies we were utilizing.

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?

Our team learned a lot during the TAMS project. Through research we discovered technologies whose existence was previously unknown to us. We were able to find potential gaps in their systems and find possible fixes and solutions so that we could improve our own design. We had to learn how to work together as a team and develop the project while listening to each other's thoughts and ideas. By being a team who developed a project, we are prepared to go into the workforce to be team players who will help companies grow. Altogether, this the ACRP project has helped us learn more about ourselves and about all the facets of the aviation industry.

For faculty members:

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

As an instructor, I can lecture on a topic or assign readings, but students quickly fall into passive learning roles and are seldom able to scale their learning to solve different problems. The great thing about this experience is the active self-learning research initiative it forces the students to take. Because it combines technologies with real world operations they were forced almost minute-by-minute to assess their presumptions and ideas against the actual "live" realities of airport operations. The result is a solution oriented learner looking at scalability and utility (broader impact for the industry).

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

Learning experience was definitely at a challenging and appropriate level for this mixed graduate and undergraduate group. As cited in item one above, I observed once again the competencies of problem-solving, collaboration, problem synthesis and overcoming innovation challenges requiring the students to go beyond just formulas.

3. What challenges did the students face and overcome?

Each student had technical expertise, a vision and assumptions about how the project could be developed and implemented. Probably the biggest challenge was describing a unified vision and eliciting the level of technical and process feedback from industry experts. I believe this (preparing and engaging in interviews where their innovative idea had to be described) was actually one of the biggest successes I observed – it forced them to describe their solution succinctly and to take constructive feedback.

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

I will continue to use this competition as an excellent leveraging tool for project design and development challenges. I base my research center Hangar of the Future using similar problem-based hands-on projects.

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

Nothing to change per se, I think it is excellent to see the scope of the competition expanding to stay relevant with disruptive technology areas (mobile computing, Internet of Things etc.).

Appendix F

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