FAA Airport Design Competition for Universities
Design Package Submission Form

Participating individuals or teams are required to submit the design package using this form. In additon, one hard copy of the full proposal plus the original of the Sign-off (See Appendix D in Design Submission Guidelines) form must be mailed to the Virginia Space Grant Consortium, 600 Butler Farm Road, Suite 2253, Hampton, VA 236666. All electronic and hard copy submissions must meet the 5 pm (Eastern Daylight Time) deadline on April 20, 2007. It is strongly recommended that a mail service that certifies delivery be used. All submissions will be acknowledged via email.

By proposal submission, Competition participants are agreeing that their proposal may be publicly shared. In addition, participants are giving permission that photographs that may be taken as part of Competition activities can be used for public information purposes and to promote the Program.

If you have questions regarding the Design Package submission process, you can contact the Virginia Space Grant Consortium between 8 a.m. and 4:30 p.m. EST on weekdays at 757/766-5210. Click here for Detailed Submission Guidelines.

Full competition guidelines and all updates are posted on the Competition Website:
http://www.faa.gov/runwaysafety/design_competition.htm.

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Institutions(s):	Georgia Institute of Technology
Design Challenge Area:	Runway Safety/Runway Incursions
Specific Challenge Selected:	Both
Level(s) of students(s) involved:	Both
Estimated number of participants:	8 Undergraduate 3 Graduate 2 Faculty Advisors 0 Other, please describe:

Four components of the Design Package in PDF Format.

Executive Summary

Main Body

Required Appendices

Optional Appendix

Approve/Reject: (◉) Approve ( ) Disqualify

Reasons for Disqualifcation:

Submit

EXECUTIVE SUMMARY

This work addresses the Runway Incursion Challenge of the FAA's Office of System Safety's Airport Design Competition. The report begins by thoroughly reviewing the known causes of runway incursion, supplemented by directly observing control tower at Peachtree Dekalb Airport (PDK) and ramp operations at Atlanta's Hartsfield-Jackson International Airport (ATL) as well as conversing with a number of FAA and industry aviation safety experts.

While many solutions were considered, the report focuses on the Controller Clearance Broadcast System (CCBS). The controller is provided by an integrated graphical interface displaying airport and aircraft surface movements. The CCBS identifies suitable clearances for the controller to then select through the interface for broadcast using both analog voice radio channels with a recorded voice and digitally using ADS-B. The additional digital transmission would allow aircraft equipped with ADS-B and flight deck systems designed as part of this project to view their clearances both graphically on a moving map and textually in line-by-line instructions. The report and the supplemental appendix describe the design, referencing pictures of the displays.

The report includes a plan to fully develop CCBS and to bring it to the marketplace. The report also includes a summary of the estimated cost of implementing CCBS and the anticipated benefits to the air transportation system: 1) An increase in operational efficiency; 2) A decrease in the numbers of pilot deviation and operational errors; 3) A decrease radio channel congestion; and 4) The ability to 'remote tower' smaller airports.

This report is submitted by the Runway Incursion Challenge Design Team from the Georgia Institute of Technology. The team consists of eleven graduate and undergraduate students and two advisors. The title of our proposal is the Controller Clearance Broadcast System.

1 PROBLEM STATEMENT AND BACKGROUND

1.1 Definition of Runway Incursion

The FAA defines runway incursions as "Any occurrence in the airport environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to take off, landing, or intending to land." [1] ICAO defines runway incursion similarly as an "incorrect presence … on the protected area." [2] According to the FAA 2005 Runway Safety Report, at current rates a runway incursion will occur on average once per day with one collision per year. [1]

1.2 Runway Incursion Classification

The FAA classifies a runway incursion based on the last link in the chain of events leading to it: operational errors/deviations, pilot deviations, and vehicle/pedestrian deviations. Operational error (OE) is an action by the air traffic controller that results in either less than the required separation distance between two or more aircraft and/or ground vehicles/pedestrians/ equipment, or an aircraft landing or departing on a closed runway. Operational deviation (OD) occurs when the correct minimum separation is maintained but an approved aircraft, vehicle, pedestrian, or equipment has entered a landing area designated for another aircraft. Pilot deviation (PD) is a pilot action that violates FAA regulations. For example, a PD occurs if the pilot does not follow clearances given by the air traffic controller. Vehicle/pedestrian deviation (V/PD) is an action in which other surface objects (vehicles, pedestrians, or ground equipment) enter a moving area without authorization and interfere with airport operations.

1.3 Causes of Runway Incursions

Runway Incursion (RI) has been widely studied by the FAA and other agencies [1,2,3], and increased traffic volume has been named a top contributor of runway incursions. Larger airports typically have a greater number of RIs because the greater volume increases the likelihood for an RI to occur. Other significant contributors to RI are airport specific, i.e., infrastructure, procedural, operational, and environmental issues. The FAA recognizes that, while it is not possible to completely eliminate runway incursion, it is necessary to continually seek to reduce the number of incursions and to mitigate the impact of those incursions. Table 1-1 summarizes common causes of runway incursions:

Table 1-1: Typical Runway Incursion Contributors by Type of Incursion

RI Type	Common Causes Leading to Runway Incursion
Operational Error	• Forgetting about aircraft, closed runway, or previously given clearance • Failure to anticipate required separation distance • Errors in communication
Operational Deviation	• Forgetting about aircraft, closed runway, or previously given clearance • Inadequate coordination between controllers • Errors in communication
Pilot Deviation	• Inadequate signage/markings • Pilots having to perform mandatory head down tasks leading to loss of situational awareness • Incomplete, non-standard, or obsolete taxiing instructions
Vehicle/Pedestrian Deviation	• Failure to obtain clearance • Errors in communication • Failure to report correct current positions • Inadequate training

1.4 FAA Programs to Mitigate Runway Incursions

As part of the FAA's overall mandate to improve the safety, it has undertaken several runway incursion mitigation programs. The following sections summarize these efforts.

1.4.1 Established Programs

Runway Marking Standardization: The FAA has created a set of standard airport markings. The markings identify runways, taxiways, gates, traffic directions, closed/restricted areas, and intersection areas. [4]

ASDE-3 Radar System: The ASDE-3 (Airport Surface Detection Equipment – Model 3) was one of the earliest radar systems used to track the ground locations of aircraft and airport vehicles. It can increase the controller's situational awareness during low visibility, but cannot provide detailed information about specific aircraft.

1.4.2 Current Programs

Sterile Cockpit Policy: The Sterile Cockpit Policy limits distractions during critical stages of flight and is mandated through the FAA's "Flight Crewmember Duties" FAR. [5]

AMASS: The Airport Movement Area Safety System (AMASS), an extension of the ASDE-3 system, uses data from the ASDE-3 system to predict the probability of a runway incursion based on aircraft and vehicle positions, velocities, and accelerations.

ASDE-X: The latest ground surveillance system is the Airport Surface Detection Equipment Model-X (ASDE-X). An upgrade to the ASDE-3 system, it uses multi-lateration from multiple radars, ADS-B systems, which use the Global Positioning System (GPS) for navigation, aircraft transponders, and other receivers to redundantly identify aircraft position.

A-SMGCS: The Advanced-Surface Movement Guidance and Control System (A-SMGCS) provides routing, guidance, surveillance, and control to aircraft and vehicles in order to safely maintain operations during low visibility levels. The basic version of A-SMGCS consists of taxi and runway status lights to guide the pilot along a desired path. More advanced versions utilize aircraft GPS location to display on-screen map in the cockpit with the current location. This requires additional equipment in both the airport and aircraft. [4]

Taxi Centerline Enhancement: This system uses alternating green and yellow lights to inform pilots that they are entering a runway environment/runway safety area. [6]

FAROS: The automated Final Approach Runway Occupancy Signal warns pilots that entry to the landing runway is unsafe by flashing warning lights at the runway entrance.

1.4.3 Ongoing Program Impact

Each program is aimed at reducing operational error/deviation, pilot deviation, and/or vehicle/pedestrian deviation. The following chart summarizes the primary goal of each safety enhancement based on the three classifications of runway incursions.

Table 1-2: Safety Enhancements and Their Goal

	Operational Error / Deviation	Pilot Deviation	Vehicle / Pedestrian Deviation
Runway Marking Std.	○	●	●
Sterile Cockpit	○	●	○
ASDE-3	●	○	○
AMASS	●	○	○
ASDE-X	●	○	○
Edge Lighting System	○	●	○
Taxi Centerline En.	○	●	○
FAROS	●	●	○

● = addresses cause; ○ = does not address cause

2 LITERATURE REVIEW

We reviewed a large body of literature to better understand the causes of RI. The FAA Runway Safety Report [1] provided a comprehensive summary of the underlying causes of RI. Other helpful sources of information included FAA regulations [7] and Advisory Circulars, the National Transportation Safety Board, the International Civil Aviation Organization, the Governmental Accounting Office, and Congressional hearings regarding aviation safety.

Further, the human factors literature was explored to gain a deeper understanding of the human processes underlying the causes of RI. [8] Other literature served more specific purposes, such as industry and military standards for flight deck systems.

3 PROBLEM SOLVING APPROACH

Our design team consisted of eleven students divided into three working groups: the pilot group, controller group, and system architecture group. Together, these three groups took into account all aspects of a suitable total solution. The pilot group focused on RI issues relevant to pilots, and the controller group on RI issues relevant to air traffic controllers. The system architecture group was responsible for developing requirements, investigating necessary technology to deliver the functionality required, developing any requisite algorithms, and creating a prototype to demonstrate the system's feasibility.

Our team consulted with aviation experts from a wide variety of educational and experiential backgrounds, including aerospace engineering, computer science, industrial engineering, safety investigation, aviation, human factors, and psychology. Our interdisciplinary team worked together to gather strengths and foster creative, comprehensive design solutions.

3.1 Design Approach

We took a two-pronged approach for designing, identifying, and developing solutions to reduce RI. First, as human error can not be completely prevented, we propose a design for a system that will double check the actions of both the controller and pilot to prevent any errors from turning into RI. However, our second method of reducing runway incursions addresses root causes. Thus, our design addresses both collision prevention and contributing action prevention. We supplemented the literature with our own data gathered from subject matter experts (SMEs). We continually evaluated our design's ability to consider all elements of the system – the underlying human processes that lead to causes of runway incursions, the procedures for airport surface operations, and the technologies involved.

3.2 Methodologies Employed

We used several established methodologies as part of our design process. We gathered information from SMEs through interviews and questionnaires, including general aviation (GA) and commercial pilots, airline and FAA safety analysts, and air traffic controllers. We observed air traffic controllers, and used a high-fidelity air transport flight simulator to gain experience with aircraft ground operations. In addition, we iteratively used feedback from SMEs to refine the design, and created a software prototype demonstration of the system's core functionality.

4 SOLUTION DESCRIPTION

4.1 Desirable Solution Characteristics

Any system that aims to decrease the number of runway incursions must have the following qualities:

- It must reduce the risk of runway incursions by both addressing root causes and providing built-in "error tolerance";
- It must be compatible with existing, fielded technologies;
- It must be applicable to a variety of aircraft equipage levels; and
- It must not cause such an increase in workload for the pilot or the controller that it creates other significant risks.

4.2 Controller Clearance Broadcast System (CCBS) Description

It is our belief that the key to further reducing RI is to incorporate knowledge of clearances into a computer based system which can then double-check controller actions. To that end, we propose a Controller Clearance Broadcast System (CCBS) which incorporates controller clearance information into an integrated clearance collection broadcast and review system. As an alternative to issuing clearances verbally, CCBS will also allow controllers to select clearances from an automatically-generated list of contextually-appropriate clearances. The CCBS will then issue the clearances to the aircraft both via current voice radio using recorded voice, and via digital transmission to dedicated flight deck systems. Accordingly, the CCBS consists of two complementary subsystems – one based in the control tower, TowerVision, and the other based in the flight deck, TaxiVision. Additionally, CCBS will automate some of the routine tasks that controllers normally perform, provide assistance for other tasks, and incorporate an alerting system to catch potential RIs.

4.2.1 Subsystems Overview

The control tower subsystem enables the selection of clearances through a computer interface. This mechanism allows the system to know not only actual aircraft position, but also the clearance history required to reliably detect deviations. Specifically, detailed knowledge of clearances can be used to detect aircraft deviations and warn the pilot, the controller and other affected aircraft. Entering clearances through this interface will also reduce the controllers' verbal communication, yet still allow the controllers to revert to the current method of voice communication whenever they choose. TowerVision is described in more detail in Section 4.2.3.

The flight deck subsystem consists of an interface that enables the pilots to see the clearances issued to them both pictorially in the form of a moving map and textually as a list of step-by-step clearances. A range of interfaces have been designed to accommodate different aircraft types, including three standalone systems (the TaxiVision Elite, TaxiVision Plus, and TaxiAide), and the TaxiVision software application for pre-existing multi-function displays (MFDs). Any of these will assist the pilot in maintaining her positional awareness on the airport surface via a moving-map display. These interfaces are also capable of showing the location of other proximal aircraft on the airport surface, as well as information relevant to airport surface operations such as weather, radio frequency information, and check lists. Future extensions may allow for the inclusion of information about ground vehicles.

4.2.2 Runway Incursion Causes and CCBS

CCBS addresses multiple causes of RI, as identified in the 2005 FAA Runway Safety Report (**Error! Reference source not found.**). Pilot deviations and controller deviations were the focus of our efforts, with vehicle / pedestrian deviations were given a lower priority, as these RI types are the least likely to occur. [1] CCBS is designed to build error tolerance into the system by, first, attempting to prevent operational and pilot deviations and, second, detecting any deviations quickly.

Table 4-1: CCBS by Runway Incursion Type and Underlying Cause

Runway Incursion Classifications		CCBS	
Runway Incursion Type	Underlying Cause	Flight Deck (TaxiVision)	Control Tower (TowerVision)
Pilot Deviation	Loss of position awareness	●	○
Controller Deviation	Forgetting essential aspects of the airport surface	○	●
	Miscommunication between pilot and controller	●	●
	Insufficient coordination between air traffic controllers.	○	●
Vehicle/Ped Deviation	Vehicle/ pedestrian loss of position awareness	○	●
	Unfamiliar with aviation terminology/signage	○	○
	Misunderstanding air traffic control instructions	○	○
Error Tolerance	If a cause cannot be eliminated, protection against a collision resulting from it	●	●

● = addresses cause; ○ = does not address cause

4.2.3 Control Tower Subsystem -- TowerVision

The CCBS TowerVision system will help to prevent runway incursions by providing five main functions: 1) Displaying real-time aircraft positions to controllers; 2) allowing controllers to select feasible clearances for broadcast to the pilots both aurally and visually; 3) maintaining a record of all clearances issued and those clearances' situational context; 4) identifying hazardous clearances before they are issued; and 5) identifying aircraft deviations from clearances.

Via ADS-B reports, the TowerVision display shows the location of each aircraft on the ground at a given airport. In addition, the TowerVision display may incorporate additional information from other sources such as ASDE-X where available, increasing the systems' robustness. By integrating accurate information about all aircraft on one screen, controllers will have more reliable information than that possible by looking out the window, especially during periods of reduced visibility and for surface areas obscured by terrain or buildings.

The functions of collecting and storing issued clearances, checking for hazardous clearances, and monitoring aircraft for clearance deviations are all interrelated. With clearances issued via the TowerVision interface, it is possible for an alerting system to provide controllers and pilots with timely and accurate alerts of improper compliance to clearances. Similarly, the system can also advise a controller of a potential problem with clearances before they are issued, or suggest a more efficient routing. Compared to current voice communication, visual display of clearances will reduce short-term memory errors by controllers and pilots, and will let controllers plan taxi routes ahead of time. Both issued clearances and pending clearances are shown on the display. Thus, the controller can distribute his/her workload so that at low tempo periods preferred or standard taxi routes can be created for later use. Additionally, the system only allows legal taxi routes to be drawn. This feature reduces the need for the controller to remember relevant regulations; if there is a potential conflict or crossing of taxi routes, TowerVision issues an alert.

4.2.3.1 EXPERT SYSTEM FOR CLEARANCE PREDICTION

An important part of CCBS design is the realization that the number and variety of clearances issued by controllers is finite and follows a regular pattern. Specifically, the clearances are organized by the geographic location of the recipient aircraft and the history of the clearances previously issued to it. Therefore, we developed an expert system using these two inputs to determine likely clearances for the controller to issue, with similar clearance request/template sets for all possible aircraft locations at a civil airport.

The clearances via voice communications have been purposefully designed over the years to be a regularized language to maximize clarity and understanding. The expert system in CCBS uses a newly developed template language, Controller Clearance Protocol (CCP), mirroring this language and the established structure of clearances. The CCP is detailed in Appendix G.

4.2.3.2 USAGE

Peachtree-Dekalb Airport (PDK) and Atlanta's Hartsfield-Jackson International Airport (ATL) airports will be used to illustrate the system's usage at a smaller business aviation airport and a larger commercial airport; detailed description is provided in Appendix G.

Controller Usage

Figure 4-1 shows the TowerVision touch screen interface, in this example portraying ATL. The controller first selects an aircraft by touching it with a finger or stylus. Then, they have three options for establishing a clearance:

1) **Direct Drawing** - To directly draw a taxi route, the controller can select an aircraft with a stylus or finger and then draw a short path, or select points along the path by tapping along a series of points on the airport surface. The route will then be displayed on the diagram, with the corresponding text clearance automatically displays in the *Aircraft Info* block on the left. If satisfied, the controller can tap *Issue Clearance*, and a prerecorded voice will be broadcast on the appropriate radio frequency, mirroring the current method of voice communication.
2) **Computer-Assisted Drawing** - The controller selects an aircraft, then its destination. All the possible routes for the aircraft are then displayed for the controller to select from. The system also portrays the step-by-step taxi instructions for each, which the controller can modify by identifying any part of a clearance and adjusting it with the buttons at the right.
3) **Preset Routes** - Individual controllers can program a number of preset taxi routes tailored to their airport configuration. Displayed as 'Presets 1-6' in the example, these labels can be edited to be more descriptive. To use a preset, the controller selects an aircraft and then touches the desired preset route.

When the desired route is selected, the clearance is displayed in the *Aircraft Information* area on the left of the screen. If the controller is satisfied with what is displayed, the *Issue Clearance* button will broadcast the clearance which the controller will hear on their voice frequency. If at any time there is a situation out of the ordinary, the controller can select the blue *Talk to Pilot* button to speak directly with the pilot. Pilots will need to verbally acknowledge clearances using current voice communication procedures. Further explanation, including differences between ground and local controller configurations, can be found in Appendix G. Additional figures can be found at http://www.cognitiveengineering.gatech.edu/CCBS.

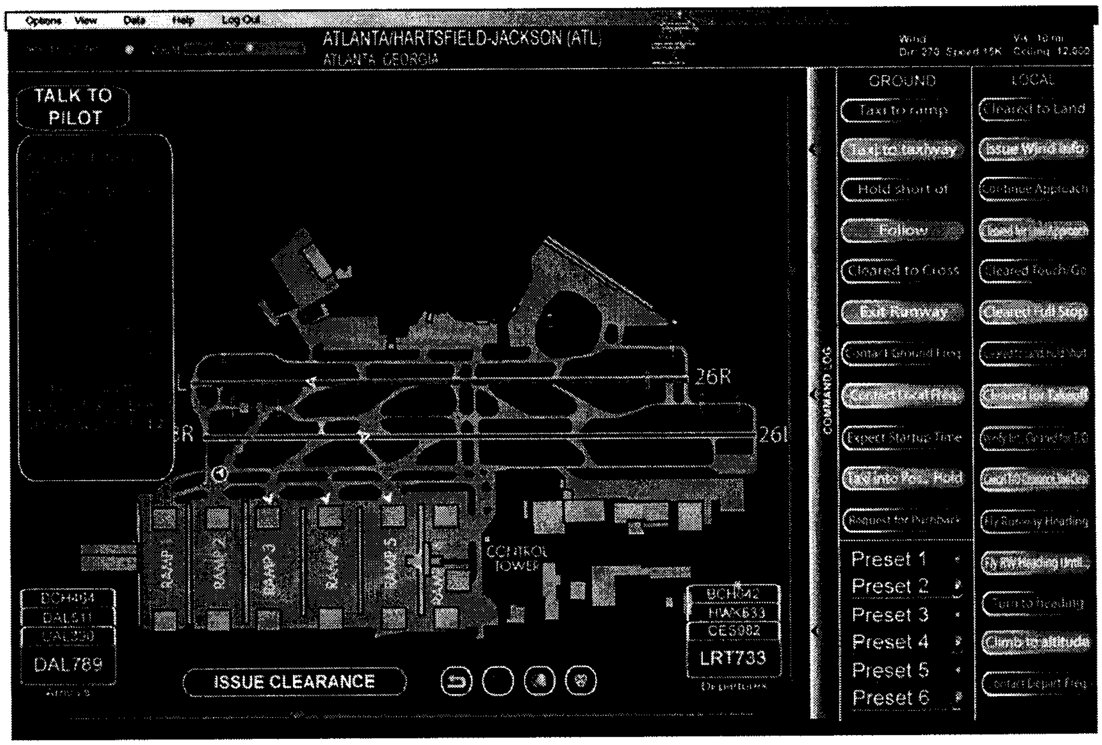

Figure 4-1: TowerVision Controller Interface

4.2.3.3 ADVANTAGES OVER CURRENT SYSTEMS:

The CCBS TowerVision system is designed to directly address the shortcomings currently experienced in local and ground control during runway incursion incidents. Voice radio communication is still a part of CCBS, but it is augmented by standardized clearances transmitted digitally and by system knowledge of clearances issued to each aircraft. Thus, TowerVision system provides an additional visual reference to the controller of clearances issued and aircraft assigned, with the same display regardless of visibility conditions or airport configuration to engender familiarity through habitual use.

While AMAS and ASDE-X provide similar aircraft position information as TowerVision, they require controllers to divide their attention between displays and visual reference out the window. TowerVision allows the controller to issue clearances with reference to one screen, engendering good situational awareness while not preventing visual reference when possible. Incorporating clearance history enables alerting with much greater accuracy (i.e., timely alerts without a high false alarm rate) then achievable from aircraft location and velocity alone.

Controller workload is often cited as a frequent contributor to runway incursions. While there is still no substitute for human decision making, the use of preset taxi routes in common situations allows controllers to give more attention to any unusual situations at hand. TowerVision will reduce the controller workload by allowing the controller to preplan routes, including drawing taxi routes for multiple aircraft before issuing their clearances, and by catching potentially hazardous clearances.

Likewise, insufficient controller training is a cause of runway incursions at time when much of the controller workforce in the United States is approaching retirement age[9]. The TowerVision system will reduce this hazard by its alerting functions, and by an interface design intended to be intuitive and consistent between airports and airport configurations.

4.2.4 Flight Deck Subsystem – TaxiVision

While many of the safety benefits of CCBS can be realized without the introduction of any additional technology into the flight deck, the addition of an ADS-B receiver and one of four TaxiVision displays will give the pilots the advantage of a moving map display on which their clearances are displayed. The FAA has recently embraced such displays to improve situational awareness [10], but the addition of the TowerVision coupled with TaxiVision will allow pilots to not only see their own location and the location of other traffic, but also where they are cleared to go. Figure 4-2 through Figure 4-5 illustrate the four versions of TaxiVision.

4.2.4.1 EQUIPAGE LEVELS FOR FLIGHT DECK CCBS

The minimum set of functions provided by TaxiVision variant is given in Table 4-2, and Table 4-3 identifies which functions are available in the CCBS Flight Deck subsystems by equipage. Aircraft with ADS-B can use TaxiVision systems with the most functionality. However, aircraft without ADS-B can still benefit from the reduced functionality of TaxiAide. The TaxiVision software application requires a Multi-Function Display (MFD) (common to modern air transport, corporate and light general aviation aircraft) and the ability to receive digital clearances via ADS-B.

Table 4-2: CCBS Flight Deck System by Capability

	TaxiVision Elite	TaxiVision Plus	TaxiAide	TaxiVision Software Application
Moving Map Display of airport surface	●	●	●	●
Textual Display of Clearances, based on ADS-B data (includes alerts)	●	●	○	●
Graphical display of clearance route overlaid on moving map, based on ADS-B data	●	●	○	●
Display Airport Hotspots	●	●	○	●
Own Craft Deviant Alerting System	●	●	○	●
Other Craft Deviant Alerting System	●	●	○	●
Display Weather Information	●	●	●	○
Display Radio Information	●	●	○	○
Display Information of Proximal Aircraft	●	●	○	○
Zoom in/out	●	●	●	○
Pan	●	●	●	○
Rotate	●	○	○	○
Moving Map Display based on GPS	●	○	●	○

● = includes function; ○ = does not include function

Table 4-3: CCBS Functionality by Aircraft Equipage

Aircraft Type	General Aviation		Turbo Props and Executive Jets		Commercial Passenger Airliners	Commercial Cargo Aircraft
ADS-B	No	Yes	No	Yes	Yes	Yes
Functions						
Moving Map Display of airport surface	•	•	•	•	•	•
Textual Display of Clearances, based on ADS-B data (includes alerts)	○	•	○	•	•	•
Graphical display of clearance route overlaid on moving map, based on ADS-B data	○	•	○	•	•	•
Display Airport Hotspots	○	•	○	•	•	•
Own Craft Deviant Alerting System	○	•	○	•	•	•
Other Craft Deviant Alerting System	○	•	○	•	•	•
Display Weather Information	•	•	•	•	•	•
Display Radio Information	○	•	○	•	•	•
Display Information of Proximal Aircraft	○	•	○	•	•	•
Zoom in/out	•	•	•	•	•	•
Pan	•	•	•	•	•	•
Rotate	○	○	○	•	•	•
Moving Map Display based on GPS	•	○	•	○	○	○

• = function available at that equipage level; ○ = function not available at that equipage level

4.2.4.2 PILOT USAGE

When activated, the flight deck CCBS system begins with the moving map. TaxiVision can be turned off at any time. As the plane moves on the airport surface, the display will update accordingly. With the standalone versions of TaxiVision, pilots can select other features, such as weather, in greater detail. They can also interact with the menu and custom display parameters at any time. Once the pilot has departed the airport, the display will display other information such as weather or terrain. The pilot can also preview static maps of airports when airborne. For the TaxiVision application for MFDs, the screen can only be toggled to a different display. It is important to note that the pilot will need to verbally acknowledge all clearances.

4.2.4.3 IMAGES OF TAXIVISION MODELS

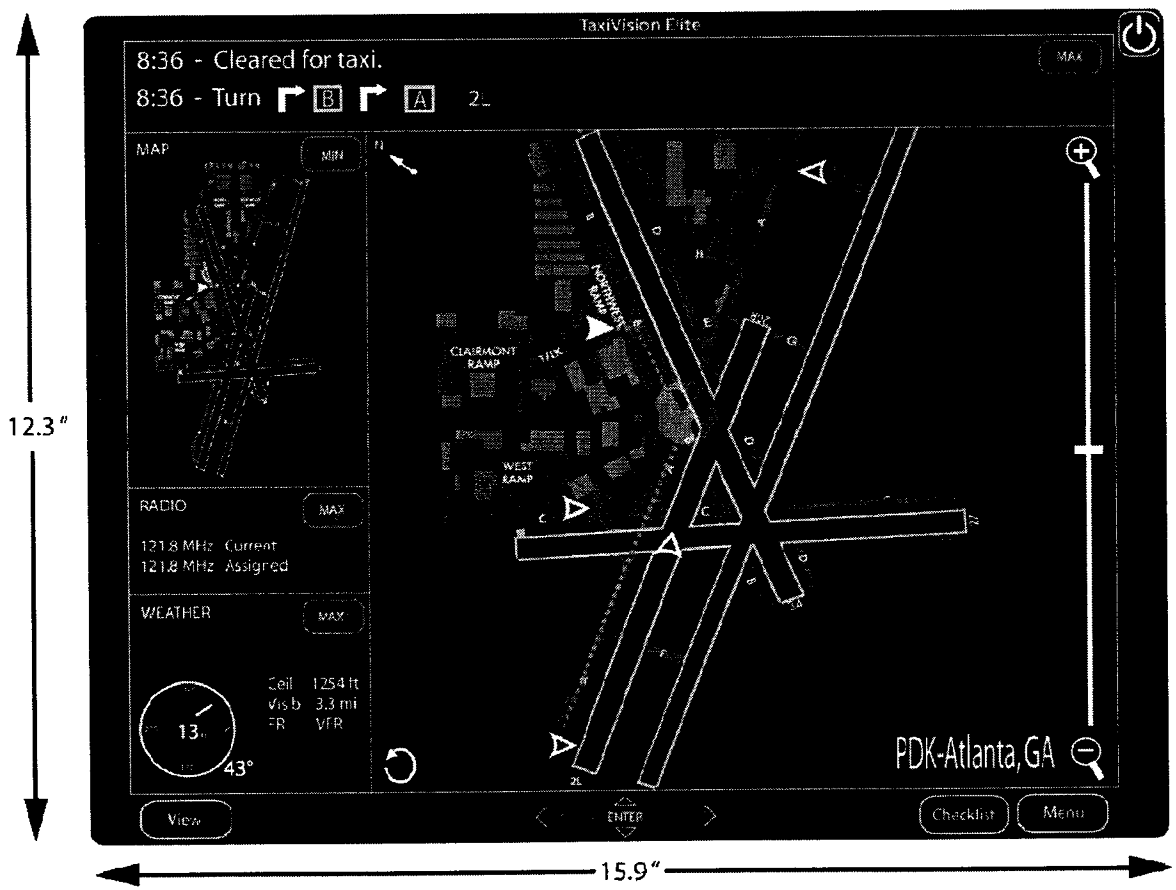

Figure 4-2: TaxiVision Elite

TaxiVision Elite: Designed for ADS-B Equipped Commercial and GA Aircraft

- Physical Size: 15.9" x 12.3" x 2.2" (W x H x T)
- Physical Screen Size: 14.6 x 11.2
- Viewable Screen Size: 15"
- Touch Screen LCD
- Pixel Pitch: 0.297 mm
- Vertical Refresh Rate: 56 ~ 75Hz
- Contrast Ratio : 450:1
- Brightness: 250 cd/m²
- Response Time: 16 ms
- Maximum Resolution 1024 x 768
- Internal Memory: 1GB Available to user

TaxiVision Plus: Designed for ADS-B Equipped Commercial and GA Aircraft

- Physical Size: 4.6 x 3.3" x 0.5". (W x H x T)
- Viewable Screen Size: 4.255" x 2.6427" (W x H)
- Touch Screen LCD
- Resolution: 800 x 600
- Pixel pitch – 0.213 mm sq
- Brightness – 3 to 750 nits
- Internal Memory: 256MB Available to user
- Expansion slot: Support for MultiMediaCard, SD & SDIO cards

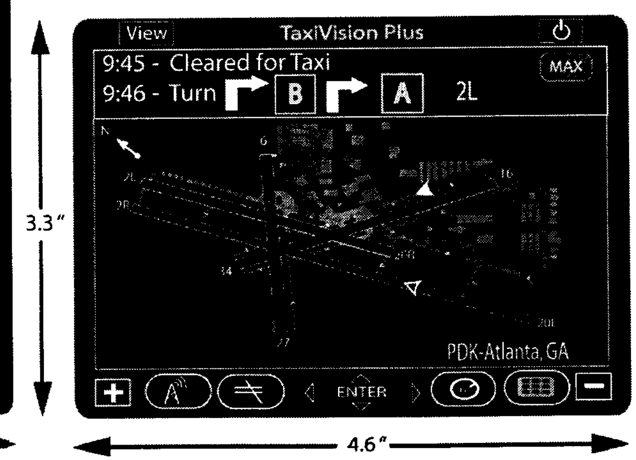

Figure 4-3: TaxiVision Plus

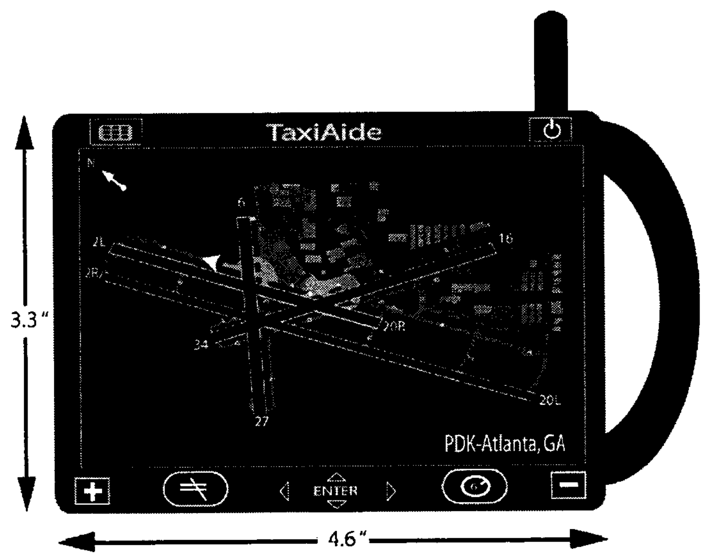

Figure 4-4: TaxiAide

TaxiAide: Designed for GPS Equipped GA Aircraft (no ADS-B)

- Moving Map Display based on GPS
- Displays owncraft only
- Zoom in/out and Pan
- Physical Size: 4.6 x 3.3" x 0.5". (W x H x T)
- Viewable Screen Size: 4.255" x 2.6427" (W x H)
- Resolution: 800 x 600
- Landscape mode
- Pixel pitch – 0.213 mm sq
- Brightness – 3 to 750 nits
- Contrast ratio – 350:1
- Internal Memory: 256MB Available to user
- Expansion slot: Support for MultiMediaCard, SD & SDIO cards

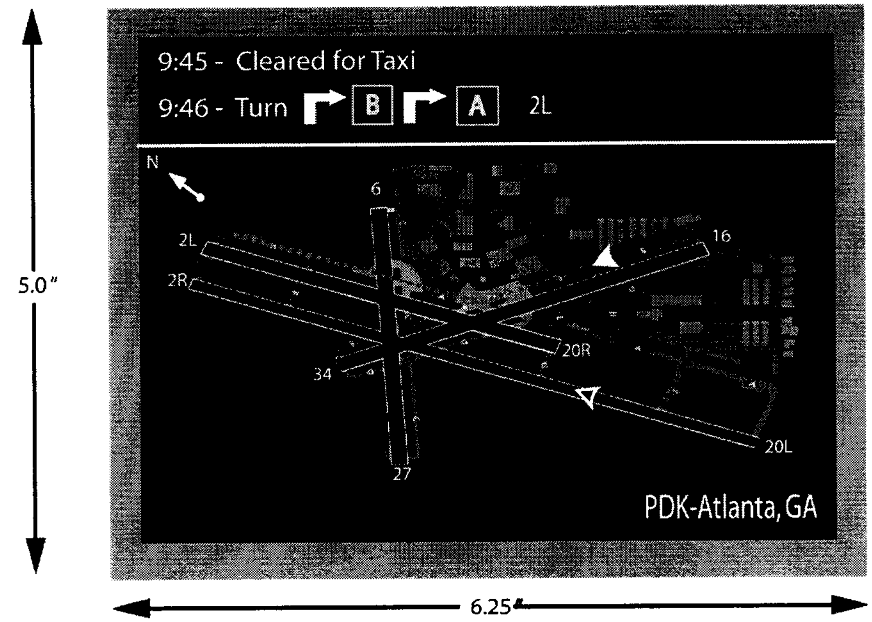

Figure 4-5: TaxiVision Software on a MFD

TaxiVision Software: Designed for Aircraft with a MFD.

Functionality is based on the capabilities of the MFD.

4.2.5 System Infrastructure

To support the features defined in the TaxiVision and TowerVision designs, the underlying system infrastructure must provide three primary services: communication, computation, and information flow management. The clearance visualization and warning features in TaxiVision require the underlying infrastructure to provide computer-accessible communication paths between aircraft and the tower. To support the predictive alert systems of TowerVision, it must provide a specific set of computation and alerting services, the most important one being the digitization of controller clearances. Finally, the system infrastructure must have a reliable, general, and scalable mechanism for managing disparate flows of information, all while operating within a tight set of cost and equipment availability constraints. This will maximize the effectiveness of computer oversight, and leverage a wide range of information sources.

4.2.5.1 DESIGN APPROACH

The central characteristic of our system architecture is the adoption of ADS-B as the key enabling technology. ADS-B allows for sophisticated communication between aircraft and the tower, and its status as a future standard portends reasonably-priced and widely-available commercial off-the-shelf (COTS) ADS-B hardware. While CCBS is designed to maximally leverage ADS-B, concern for flexibility and scalability is also a key aspect of our design. To that end, CCBS is intended to allow the system architecture to integrate the data provided by ADS-B as well as a range of external radar and sensor sources, via established data fusion systems, although this data fusion may incur additional development cost and may not be required in all installations. Finally, our design embraces the idea of automated alerting and clearance generation, specifying the inclusion of sophisticated software algorithms to minimize the required pilot and controller effort.

4.2.5.2 SYSTEM COMPONENTS

The CCBS system architecture can be decomposed into several subsystems. Within each subsystem there are one or more components, each encompassing the hardware and software necessary to provide specific logical functions and behaviors. Finally, components and subsystems are connected through communications media called channels. Figure 4-6 illustrates the CCBS system architecture, showing the three major subsystems, their components, and the channels shown as arrows connecting them. The compartmentalization of the architecture makes CCBS provides flexibility for use by many different aircraft and airports.

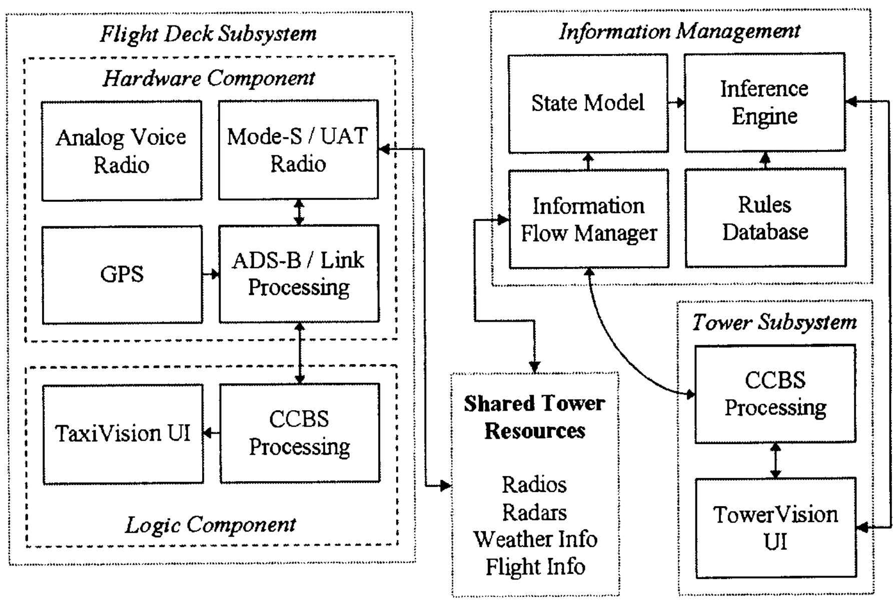

Figure 4-6: CCBS System Architecture

Subsystems

CCBS specifies three primary subsystems: the flight-deck subsystem, the tower subsystem, and the information management (IM) subsystem. Each flight-deck subsystem is associated with a specific aircraft. It encompasses the hardware required to support one of the TaxiVision user interfaces, along with the hardware necessary to provide appropriate sensor data and communications functions. The tower subsystem is associated with each controller station. It encompasses the hardware required to support the TowerVision interface, along with the hardware necessary to connect to the IM subsystem. Finally, the IM subsystem is associated with a control tower. It encompasses the sensing and communications hardware necessary to detect and communicate with aircraft. At any given airport there will be a single IM subsystem, 2-8 tower subsystems and potentially many flight-deck subsystems.

Components

Each subsystem is divided into one or more components. The flight-deck subsystem consists of two components: a hardware component, which provides GPS sensing and ADS-B communications, and a logic component, which supports the TaxiVision interface and its attendant processing tasks. The tower subsystem also consists of two components. A hardware component provides a local link to the information management subsystem, and a logic component supports the TowerVision interface. The IM subsystem is divided into three components. The data-source component encompasses both sensing devices, such as radar, and communications devices, such as radios. The data-management component handles abstraction of data sources into higher-level forms consumable by other systems. Finally, the inference component is responsible for analyzing all the available data, and applying the data-source component to send appropriate messages as necessary.

Data Flow

The overall data flow within CCBS is organized to maximize the amount of information available to the computer oversight mechanism. All digital traffic is routed through the IM subsystem. For example when a clearance is issued in TaxiVision, a message is passed to the IM subsystem, which then broadcasts that message to flight-deck subsystem. This routing ensures that the inference engine within the information management subsystem can then use this knowledge of clearance history for accurate alerts. The various flows of data within the CCBS system is shown in Figure 4-6, with specific data flows represented by one-headed arrows, for unidirectional, or two-headed arrows, for bidirectional data flows.

Communication between the flight management subsystem and the IM subsystem occurs over the Mode-S ES or UAT radio underlying the ADS-B system. Since these radios are broadcast media, the link is shared with every flight deck subsystem within range. As a result, the IM subsystem broadcasts all messages meant for all aircraft via the shared radio link, and each flight deck subsystem must listen for the messages addressed specifically to it. One key exception to this general data flow is voice traffic, which still flows directly from the ATC to the pilot over the existing analog voice channel. This organization was motivated by the desire to enable the system to function with mixed equipage and minimize the disruption to the current ATC work flow centered on voice communications. For flexibility, the various data links in the system can be implemented using a wide range of suitable technologies, as appropriate given cost constraints and availability.

4.3 Prototype Description

To explore the feasibility of the CCBS design we constructed a simple prototype system. The prototype consists of a Java application that implements a stylized and simplified version of the TowerVision and TaxiVision interfaces. Additionally, it contains a basic implementation of the Controller Clearance Protocol (CCP), the language used to capture controller clearances. The primary goals of the prototype were to test the general controller workflow proposed in the TowerVision design, to validate that CCP could encode the clearances generated by TowerVision, and to validate that CCP messages could be used to reconstruct the controller's instructions in the manner required by TaxiVision.

5 ROLE OF SUBJECT MATTER EXPERTS IN DESIGN PROCESS

Insight from aviation industry and FAA representatives helped shape and refine the design of the CCBS. The contributions of these individuals, experts in their respective fields, offered perspectives encompassing issues faced by pilots, air traffic controllers, engineers, and flight safety analysts. These contributions also included information regarding FAA initiatives to help reduce RIs.

5.1 Industry Representatives

5.1.1 Ralph Hicks, Delta, General Manager Flight Safety Programs

Mr. Ralph Hicks, General Manager of Flight Safety Programs at Delta Airlines, discussed with the team the issues faced by pilots in airport ground operations. Team members visited Delta headquarters for instruction into tasks pilots encounter during all phases of ground operation, including takeoff and landing. This instruction included a three-hour demonstration of taxi procedures in a full-motion Boeing 737-800 simulator. The experience greatly increased the team's knowledge of the pilots' workload, tasks, and perspective as well as, and factors that may hinder pilot situational awareness.

5.1.2 Mark Boguski, Thales ATM, Director of Sales and Marketing

Mark Boguski has proved to be a valuable resource for our design team because of his experience with, and ability to explain, the often extensive process of industry responses to FAA rule-making. In addition to explaining the rule making process, he also provided us with a number of documents explaining ADS-B technology and the role envisioned for it by the FAA. Mr. Boguski also organized a Thales team which conducted a 'red team review' of the design, identifying potential refinements in the technical design of the system and our documentation.

5.1.3 Pilot Surveys and Interviews

For more extensive insight into pilots' needs and concerns, and for feedback on preliminary designs, the pilot system group conducted surveys and interviews. Pilots who participated represented a broad range of the pilot community, including general aviation, commercial air transport, and a retired military pilot.

5.2 FAA Representatives

5.2.1 Dan Cilli, FAA/STI, Air Traffic Analyst

Mr. Dan Cilli, an FAA/STI Air Traffic Analyst, met with the team and gave a presentation highlighting runway incursions and their causes. Mr. Cilli provided important statistics which helped the team focus its goals on developing a comprehensive system, as well as a historical overview of recent and current FAA programs. During development of the expert system for TowerVision, Mr. Cilli also provided feedback concerning ATC communication that helped to define the CCP's estimation of potential clearances based on the location and clearance history of the target aircraft.

5.2.2 Dianna Cliatt, FAA, PDK Tower Supervisor

Dianna Cliatt was the contact for tours and observation at PDK airport in Atlanta, GA. Ms. Cliatt first helped to arrange a tour for the entire airport design team to visit the PDK airport control tower. Having worked for the FAA for many years, Cliatt was able to identify parts of airport operations at PDK that would be most useful for our team and put us in touch with controllers at the tower to teach basic controller concepts and answer our more detailed questions. In addition, Dianna Cliatt arranged subsequent visits to PDK for the controller design subgroup of the team; members of the controller subgroup were able to extensively observe controller duties for an additional block of three hours after the initial visit. Ms. Cliatt also helped to brief the controllers with whom the observers would interact so that they would know ahead of time the goals of the design project.

6 SOLUTION IMPACT

6.1 Solution Support of FAA Goals

The Joint Planning and Development Office (JPDO) predicts that air traffic will at least double or triple in the next twenty years. To design a system to safely operate within such high density operations, we first sought to understand the current state of the air traffic management system. The activities of the FAA currently include:

- Regulating civil aviation, including commercial service airports to promote safety
- Encouraging and developing civil aeronautics, including new aviation technologies.
- Developing and operating a system of air traffic control and navigation for both civil and military aircraft
- Researching and developing the National Airspace System and civil aeronautics.
- Developing and carrying out programs to control aircraft noise and other environmental effects of civil aviation.
- Regulating U.S. commercial space transportation

Long term, the JPDO is currently pursuing an initiative called the Next Generation Air Transportation System (NGATS, often called 'NextGen'). In contrast to today's system, the NGATS will be more flexible, resilient, adaptive, and highly automated – meeting the additional demand in air traffic. The vision for NGATS includes security, safety, and efficiency of passenger, cargo and aircraft operations. Aircraft will use information technology in a more robust way, with enhanced capabilities in the cockpit, better navigation and landing capabilities, and far more comprehensive and accurate knowledge of weather and traffic conditions in real time. Passengers will have more choices and will move from airport curb to their airplanes in 30 minutes or less with more security and less intrusion. Based upon an internet-like satellite system, NGATS will accommodate multiple aviation communities (commerce, law enforcement, defense, recreation) while handling new types of aircraft such as uninhabited aerial vehicles and remotely piloted vehicles. CCBS can serve as an important element within NGATS with its ability to provide accurate, integrated information to pilots and controllers, increase safety, and aid in the efficiency of airport operations.

In the shorter term, the FAA has a number of goals related to improving safety, capacity, and organizational excellence. Specifically, CCBS will help the FAA meet the following goals:

- **Safety**
  - Limit three-year rolling average fatal accident rate to 0.1 fatal accidents per 100,000 departures
  - By FY '09 reduce the number of general aviation and nonscheduled Part 135 fatal accidents from '96-'98 average of 385 per year to no more than 319 per year
  - By 2010, limit Category A and B runway incursions to a rate of no more than 0.45 per million operations and maintain or improve through 2011
  - Limit Category A and B operational errors to a rate of no more than 4.27 per million activities through FY '08
  - By FY '10, apply Safety Risk Management (SRM) to at least 19 significant changes in the NAS
- **Capacity**
  - Achieve an average daily airport capacity for the 35 Operational Evolution Plan (OEP) airports of 104,338 arrivals and departures per day by FY '11
  - Sustain adjusted operational availability at 99.7% for the reportable facilities that support the 35 OEP airports through FY '11
  - Achieve a NAS on-time arrival rate of 88.76% at the 35 OEP airports by FY '11
- **Organizational Excellence**
  - By FY '11, reduce the time it takes to fill mission critical positions by 7 percent to 51 days over the FY '06 baseline of 55 days
  - Maintain air traffic control workforce at or up to 2% above the projected annual totals in the Air Traffic Controller Workforce Plan

Our design seeks to reduce the risk, frequency, and extent of runway incursions through improved technology, infrastructure, procedures, and training programs. We examined current state-of-the-art approaches to this problem, as well as future concepts, when designing our own system to synergize with ongoing operational improvements.

CCBS supports these goals by, first, decreasing the likelihood of category A or B runway incursions by increasing the situational awareness of both controllers and pilots. Additionally, CCBS will increase controller reliability and decrease training time by providing a system to double check all clearances before they are issued, and by ensuring the system is intuitive and common to all airport configurations. CCBS will also enable more efficient operations at busy airports by allowing controllers to pre-program desired taxi routes, providing guidance to controllers about efficient taxi routings, and freeing controllers from the requirement to provide progressive taxi instructions to those pilots equipped with CCBS. Finally, CCBS could serve as the interface enabling 'remote-tower' operations, thereby allowing cost-effective tower services to be provided to airports with occasional or seasonal air traffic demand.

6.2 Commercial Design Potential

6.2.1 Description of the Aviation Marketplace

The commercial aviation industry is sizeable, with $18.5 billion spent on aircraft alone in 2001. The industry is growing steadily, with passenger and freight aircraft expected to have a total market value of $2.6 trillion by the year 2025. US commercial aviation growth will also be significant, estimated at a 4.9% average annual growth rate until 2025, with 9,490 new aircraft being delivered to the US at an estimated cost of $740 billion.[11] While the commercial design potential of a runway safety system is not directly linked to the size of the aviation industry, it is a good indicator of success because growth in air transportation serves to further increase the need for a system capable of increasing safety and improving the efficiency of airport surface operations.

6.2.2 System Versatility

CCBS can be implemented in a wide variety of aviation operations. TaxiVision can be installed in general aviation aircraft, turbo props and executive jets, and commercial passenger and cargo aircraft. The lowest-level TaxiVision can even be equipped on aircraft without ADS-B or an MFD. TowerVision also fits into a wide range of airports, from small general-aviation airports to large metropolitan hubs, and potentially 'remote-tower' operations. Implementation of CCBS can derive tangible benefits from any combination of TaxiVision and TowerVision.

6.2.3 Product Development Timeline

The product development timeline for CCBS can be divided into three phases, as shown in Table 6-1. The order of implementation will begin with Focus-35 airports with a projected installation rate of 2 airports/year, followed by GA-35 at 3 airports/year, OEP-35 at 5 airports/year, and resuming the installation at all other airports at a rate of 10 airports/year. With this implementation scheme, CCBS is projected to be installed at all 500 towered airports by the year 2084. While this target date may seem longer than expected, it is a rather conservative estimate based on data for actual implementation rates for ASDE-3X systems.[12] If additional resources were to be allocated toward the implementation of this system at a higher rate, the projected timeline will be shortened substantially.

Table 6-1: Potential Product Development Timeline for CCBS (Conservative)

Schedule	
Phase One	Begin Certification (Target Date 2008)
	Rule Making Project Team Established
	Request for Offer
	Contract Awarded
	Hardware and Software Development
	Economic Assessment
Phase Two	Preliminary Design Review
	Critical Design Review
	Final Rules Assessment and Approval
	Begin Training in FAA Academy
	Implement in Initial Test Site (Target Date 2015)
Phase Three	Phased Implementation in Towers
	All towers equipped (Target Date 2084)
	Most planes equipped (Target Date 2033)

6.2.4 *Usability*

The CCBS prototype has been developed based on data from users, subject matter experts, and knowledge of user's tasks. In this way, efforts have already been made to ensure good usability. However, usability evaluations with working interfaces should still be conducted to ensure that the design of the interface does not pose any safety issues before full-scale production commences. During usability testing, the following factors should be assessed. [13]

- Learnability: how long does it take for the user to become familiar with the device?
- Efficiency: how much can the user accomplish in a given amount of time?
- Memorability: when a user takes a break from using the system, how easy is it for re-establish their situation awareness of the current situation?
- Errors: how often and when does the system incorrectly indicate information? How often and when does the user make mistakes?
- Satisfaction: do users like using the system, or is it an extra burden?

To assess these factors, the user should be given a specific task to complete in a given situation, representative of actual working tasks and conditions. During the usability evaluation, data should be collected to assess the above mentioned factors, as well as to identify situations in which errors occur and aspects of the design which contribute to, or mitigate, these errors.

In addition to usability, workload and situational awareness should also be assessed with metrics such as the NASA TLX measures of task demand, subjective descriptions of actual situation awareness relative to that required, and recall of important elements in SAGAT-type tests.[14,15] The measures could then be compared to traditional methods of doing the same task, to ensure that the system at least does not hamper performance relative to current operations, and, assuming it increases performance, describe the benefits for refined cost-benefit analyses. Further iteration can maximize the benefit of the system and address any weaknesses identified in the CCBS design.

6.2.5 Safety Certification

Once the final design has been developed, the system must be certified before mass production and roll-out can occur. As part of the process to ensure the system is FAA-compliant, five phases of certification would have to occur: conceptual design, requirements definition, compliance planning, implementation, and post-certification.[16] In addition, the corresponding safety-analysis process should be consistent with SAE-4754.[17] This process will ensure that the components integrate with each other smoothly to avoid unsafe operating conditions and system failures.

6.3 Cost Benefit Analysis

An initial measure of a system's cost examines the explicit monetary costs. To determine the overall cost of our ATC/Cockpit system upgrade, each component (both hardware and software) was priced, as shown in Table 6-2. Some components are currently readily available and so our estimated price was based on the current market price, such as the servers and networking routers for use in airport towers. Other items that are not currently produced required a price estimate based on similar market items, with an additional cost factored in for product R&D, which we established in consultation with our industry contacts. An example is the TaxiAide hardware, which shares components with present-day personal data assistants (PDAs). After each component was priced, they were separated into groups depending on their implementation location (cockpit, control tower, or ground). To accommodate the wide range of pilot spending, many different configurations can be assembled with our system, and a few typical configurations are priced based on Table 6-2. For the control tower, full equipage is based with the specified quantity of each component; likewise, full equipage on the ground calls for both a Mode-S and UAT ground station. These numbers can apply for a major commercial airport such as Atlanta's Hartsfield-Jackson Airport.

Table 6-2: Estimated Equipage Costs

Product	Price	Avg. Qty	Component Cost	Totals
Flight Deck				
Mode-S Receiver	$8,000	1	$8,000	Config. A
UAT Tranceiver	$6,000	1	$6,000	$18,495
TaxiVision MFD Software	$1,495	1	$1,495	Config. B
TaxiVision Elite H/S	$2,599	1	$2,599	$17,599
TaxiVision Plus H/S	$1,295	1	$1,295	Config. C
Taxi Aide	$995	1	$995	$12,295
GPS Receiver	$3,000-10,000	1	$3,000 - 10,000	Config. D
Installation/Maintenance	$350	n/a		$9,995
Controller				
24" Touch Screen Monitor	$3,500	2	$7,000	Full Equipage
Customized PC's	$15,000	2	$30,000	$484,000
Networking (routers, etc)	$2,000	1	$2,000	
Servers	$3,000	10	$30,000	
Expert System	$50,000	1	$50,000	
TaxiVision Hardware	$150,000	1	$150,000	
Recorded Voice Database	$10,000	1	$10,000	
TaxiVision Software	$100,000	1	$100,000	
Mode-S & Radio Comm.	$5000	1	$5000	
Installation	$50,000	1	$50,000	
Hardware Certification	$50,000	1	$50,000	
Maintenance	$10,000	n/a		
Ground*				
Mode-S Ground Station	$200,000	1	$200,000	Full Equipage
UAT Ground Station	$200,000	1	$200,000	$400,000

Config. A = Mode-S Receiver + TaxiVision MFD Software + GPS Receiver (for High End Crew/Cargo Aircraft)

Config. B = Mode-S Receiver + TaxiVision Elite H/S + GPS Receiver (for Crew/Cargo Aircraft)

Config. C = UAT Transceiver + Taxivision Plus H/S + GPS Receiver (for General Aviation Aircraft)
Config. D = UAT Transceiver + Taxi Aide H/S + GPS Receiver (for Basic Level General Aviation Aircraft)
*Cost after current FAA ADS-B implementation plan

6.3.1 Cost Characteristics Information

A preliminary measure of cost is shown in Table 6-3. Each required component was rated based on its current availability and future expectations. The products' current availability and future expectations can create sunk costs that may lower our overall system upgrade costs. The software criticality level is estimated for this cost analysis, but would normally be derived from a formal safety analysis process as described in SAE 4754, with the least crucial level as an E and most crucial as an A.[17, 18] The final columns describe additional costs that may arise with future needed upgrades and training. Figure 6-1 contains a timeline for the installation of a standard CCBS TowerVision system, and Figure 6-3 projects these costs across the entire deployment timeline.

Table 6-1: Cost Characteristics

Component by Location	Currently Available	Future Plan for Equipage	Needed Upgrade	Software Level	Certification Needed	Level of Mod.'s Needed	New Training Needed
Flight Deck							
Mode-S Receiver	●	●	○	--	○	Low	○
UAT Transceiver	●	●	○	--	○	Low	○
GPS Receiver	●	○	○	--	○	Low	○
TaxiVision Elite H/S	○	○	●	B	●	High	●
TaxiVision Plus H/S	○	○	●	B	●	High	●
Taxi Aide	○	○	●	C	●	High	●
TaxiVision MFD Software	○	○	●	B	●	High	●
Control Tower							
24" Touch Screen Monitor	○	○	●	--	●	Low	●
Customized PC's	○	○	●	--	●	Low	○
Networking (routers, etc)	●	○	○	--	○	Low	○
Servers	●	○	○	--	○	Low	○
TaxiVision Hardware	○	○	●	--	●	Low	●
Recorded Voice Database	●	○	○	D	○	Low	○
Mode-S & Radio Comm.	○	●	○	--	○	Low	○
Expert System	○	○	●	B	●	High	●
TowerVision Software	○	○	●	B	●	High	●
Ground							
Mode-S Ground Station	○	●	○	--	○	Low	○
UAT Ground Station	○	●	○	-	○	Low	○

Hardware + Software   Software   Hardware
● = Yes ○ =No

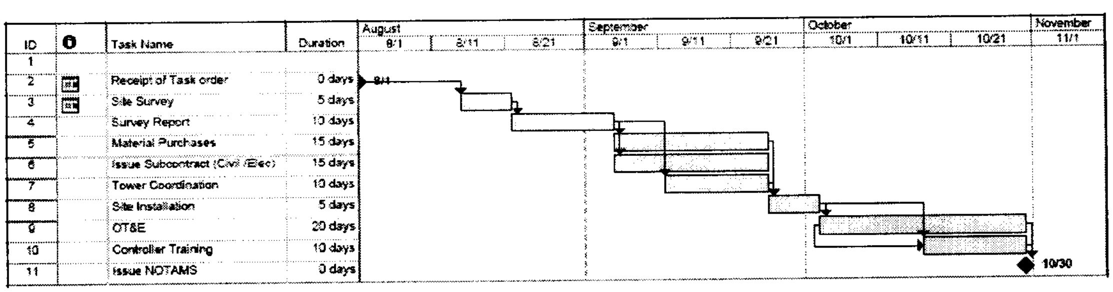

Figure 6-1: Estimated Installation Timeline for Standard TowerVision Implementation

Figure 6-2 highlights the major developments during each phase with its associated cost. Software development costs for TowerVision and TaxiVision are based on projections utilizing the COCOMO model,[19] taking into account factors such as number of lines of code, number of software developers on the project, average salary per software developer, and number of months to complete software development. Using David Wheeler's SLOCCount program [20], these factors were translated into development costs for both systems. TowerVision hardware acquisition costs were based on Table 6-2 for a basic test system. Hardware development costs for four custom TaxiVision models were based on projections from Thales ATM representatives after a thorough design review. Certification costs were modified from Boeing 777 data [21] by applying a certification inflation factor of four on top of the development costs for TowerVision and TaxiVision. The first aircraft to be equipped with TaxiVision will occur five years after rollout of CCBS with an initial installation in an estimated 0.5% of all aircraft. An annual installation rate increase of 1.4% for TaxiVision is projected, taking into account increases in demand for air travel and TowerVision implementation rates over subsequent years.[13]

6.3.2 Benefit Analysis:

6.3.2.1 SYSTEM LEVEL BENEFITS

CCBS provides benefits at the system level by leveraging existing investments, and by increasing the attractiveness of new technologies. The flexibility of the CCBS IM subsystem allows it to leverage the information provided by existing ASDE-3 or ASDE-X installations, preserving the investment into them. CCBS can allow addition of other data sources, although this may require data fusion capabilities with some increased cost. For example, it could be connected to a ground vehicle tracking system to monitor for potential collisions with food service or maintenance vehicles. Finally, TaxiVision gives pilots a tangible reason to invest in ADS-B by providing taxi instruction and taxiway navigation services, helping spur its adoption.

Project Timeline	Schedule	Cost
Phase 1 Milestones:		
1. Software Development for TowerVision (Non-certified, based on COCOMO model)	2008 - 2013	$16.6 Million
2. TowerVision Hardware Acquisition		$338,500
3. Software Development for TaxiVision (Non-certified, based on COCOMO model)		$4.5 Million
4. Hardware Development for 4 custom TaxiVision models (Non-certified)		$200,000
Phase 2 Milestones:		
1. Implementation of prototype system in control tower of selected major airport	2008 - 2015	$484,000
2. Training of ATC on the operation of TowerVision system (Taken from FAA Air Traffic Instructional Services contract for 54 air traffic facilities for FY2010)		$51.3 Million
3. Completion of certification of both TowerVision and TaxiVision systems		$85 Million
Phase 3 Milestones:		
1. Expansion of TowerVision system in Focus 35, GA 35, and OEP 35 airports	2008 - 2084	$16.94 Million/35 Airports
3. Implementation of TowerVision system to all 500 towered airports in the United States		$242 Million

Figure 6-2 Project Timeline

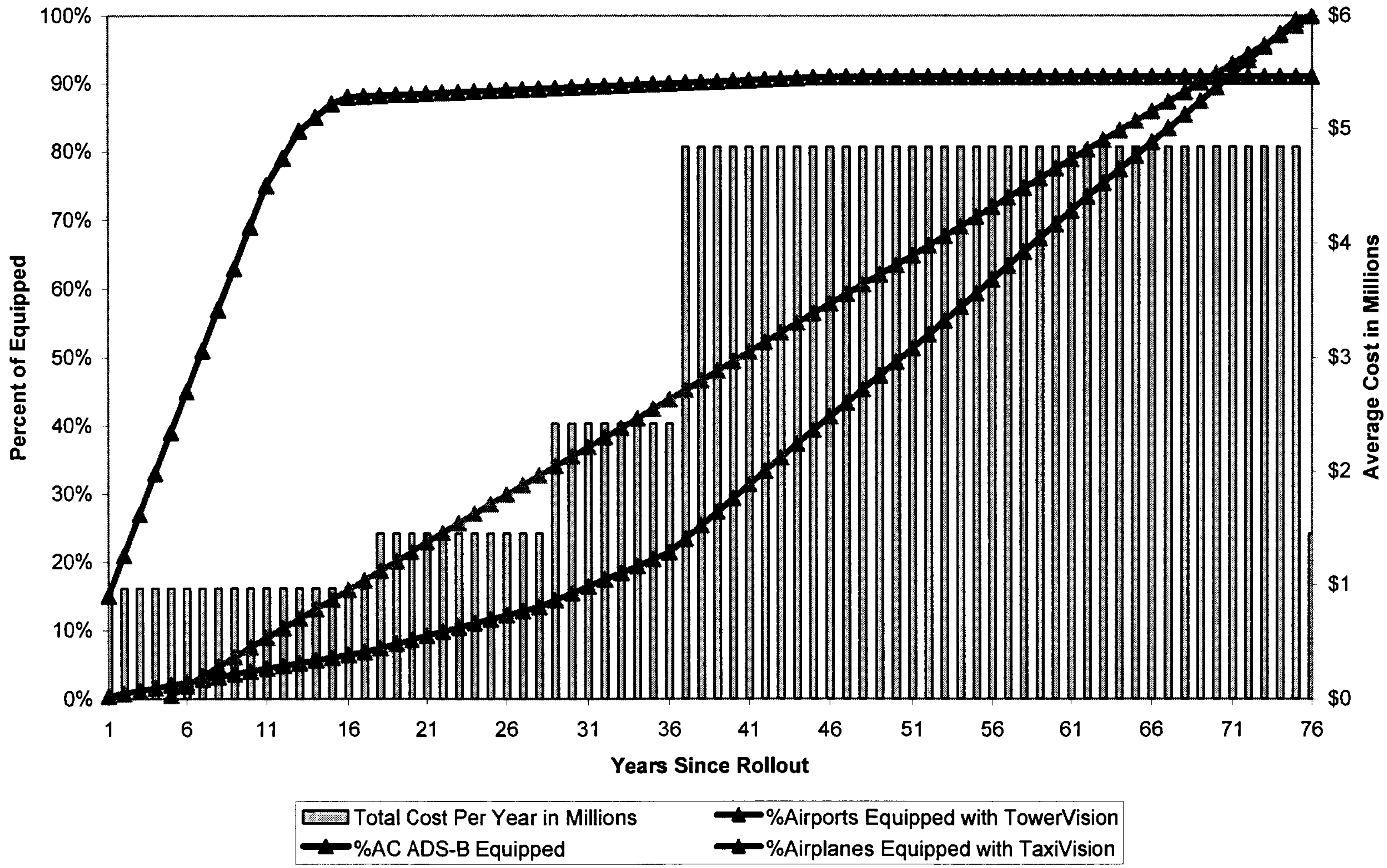

Figure 6-3: CCBS Implementation and Average Yearly Cost

6.3.2.2 TOWER AND GROUND BENEFITS

TowerVision provides four distinct benefits to its users. First, it allows controllers to create a streamlined set of orders and procedures to taxi aircraft to and from the runway. Controllers can customize which elements they wish to see. This allows the controller to navigate numerous aircraft around the airport efficiently. TowerVision also provides algorithms to provide optimal routes for aircraft accounting for other traffic and closed runways, reducing the number of decisions required of controllers, especially those that are repeatable and predictable.

Second, TowerVision includes an extensive alerting system to alert controllers to both operational and pilot deviations. It provides controllers with an error monitoring function which will alert them to hazardous or infeasible clearances before they are issued. Additionally, TowerVision attempts to mitigate non-pilot deviations and provide error tolerance to give early warnings to potential collisions between aircraft, vehicles, pedestrians, and other obstructions in the aircraft's direction.

Third, TowerVision will reduce the radio frequency congestion by transmitting clear and concise clearances to pilots without background noise, as well as digital versions of clearances directly to the TaxiVision system. The addition of the digital clearances being displayed visually on the TaxiVision system should reduce confusion and number of clearance repeats and clarifications. Within the cockpit, the TaxiVision system can provide progressive taxi instructions to pilots without the controller needing to broadcast them over the voice frequencies.

Fourth, as the data necessary to run the TowerVision software can be accessed from anywhere within the airport's network where ADS-B data (and, if available, other data sources such as radar) are provided, CCBS will enable "remote access" or "remote towering," thereby bringing tower services to airports without towers. This may be particularly useful for small airports with highly seasonal traffic.

Although the benefits to pilots and the reduction in pilot deviations are dependent upon ADS-B and TaxiVision equipage, the other benefits are independent of the percentage of aircraft equipped with either ADS-B or TaxiVision. Instead, substantial benefits will be available with the installation of the TowerVision portion of the CCBS at airports with surface surveillance radar and multi-lateration. The minimal version of CCBS will still be capable of alerting controllers to pilot deviations (although it may not reduce their occurrence) as well as catching operational deviations, thereby greatly mitigating the impact of RIs.

6.3.2.3 FLIGHT DECK BENEFITS

Our goal with the implementation of TaxiVision is to increase pilot's positional and situational awareness, to reduce radio frequency congestion, and to decrease the number of pilot deviations on the airport surface. On average, pilot deviation accounts for 58% of all runway incursions per year.[1] TaxiVision provides unique support for pilots' situational awareness. Although currently there are moving map displays derived from GPS data, unlike TaxiVision they cannot notify the pilot when he/she has deviated from a clearance. By alerting the pilot to a deviation, he/she can take corrective actions to prevent an incursion with another aircraft. Additionally, TaxiVision will also identify any deviation by another aircraft which brings that aircraft into conflict with the pilot's aircraft, and will notify the tower, the deviating aircraft, and any affected aircraft of the deviation.

6.3.2.4 USER ACCEPTANCE AND BENEFITS

One of the keys to a successful change in work practice is user acceptance, where the user knows the benefits of the new system from their point of view outweigh the transition costs. These costs include not only the monetary cost of the new technology, but also intangible costs such as training and adopting new procedures and work practices. For CCBS to be readily accepted, pilots need to perceive the benefits of increased self-sufficiency and safety as being greater than the system's adoption costs. These system costs for pilots and airlines are more concrete than those of controllers, because TaxiVision will not drastically alter the procedures or duties of pilots. Since taxi procedures will remain the same, the purchase of new equipment is the major cost, and still, the cost of this new equipment required should be small because TaxiVision uses ADS-B for much of its functionality. Once an aircraft is ADS-B in+out equipped, aircraft owners will incur little additional cost. A possible financial incentive for pilots to cover the increased cost of the new system may be to have lower insurance rates for aircraft equipped with TaxiVision.

Controller acceptance will also need to be carefully considered. One aspect of our design fostering controller acceptance is the usability of its interface, and the additional, integrated information is provides them. In addition, the interface is not intended to change staffing levels or controller roles and authority, but instead has been designed from the start to support their current work practices, including the structuring of the CCP around current clearance structures and vocabulary.

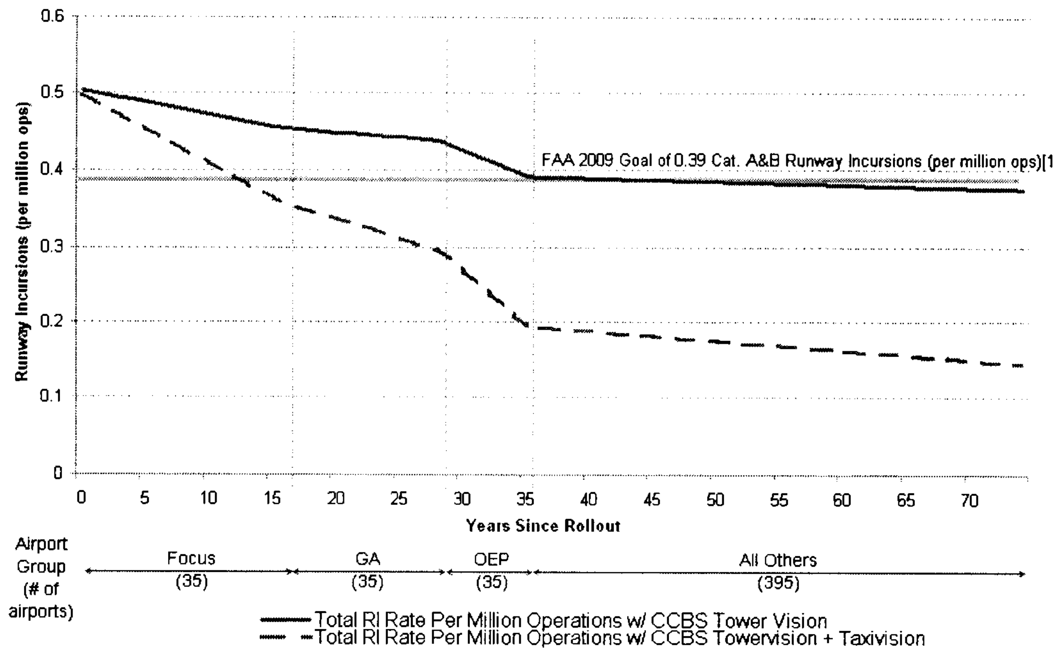

Figure 6-4: Runway Incursion Reduction Predicted from the CCBS Implementation Schedule

6.3.3 Projected Safety Improvements

Figure 6-4 shows the projected reduction in the rate of runway incursions per million operations based on FY '06 RI rate of 0.507 per million operations.[22] For maximum initial benefit, initial CCBS implementation should start with the Focus-35 airports identified by the FAA as the most significant contributors to runway incursion, followed by the GA-35 and then the OEP-35, following the implementation schedule shown in Figure 6-2. The changes in slope of the lines in Figure 6-4 illustrate the increasing benefits derived from implementation of CCBS at additional airport sets. We assumed 95% of all operational deviations can be eliminated with the implementation of the TowerVision portion of CCBS. We further assumed 85% of all pilot deviations and errors can be eliminated by equipping with some version of TaxiVision (excluding TaxiAide which does not provide visual clearances).

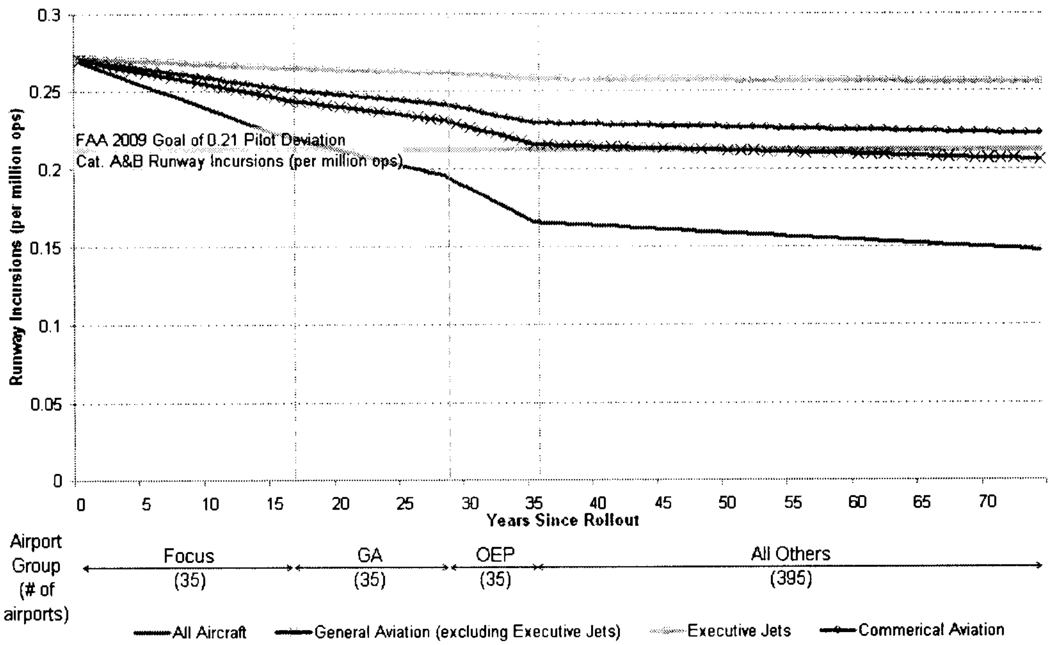

Figure 6-5: TaxiView Runway Incursion Reduction Due to Reductions in Pilot Deviation, Based on Implementation Schedule

Figure 6-5 shows the percentage drop in RI after the implementation of TaxiVison in the years following rollout. The drop in RI is based on the schedule deployment shown in Figure 6-2. In this table, only the RIs caused by pilot deviation were accounted for, as the TaxiVision system does not reduce RI caused by other sources. By taking the average percentage of pilot deviation RIs (nearly 54% of national RI), an estimated maximum FAA goal was set at 0.21 RI per million operations, based on the stated 0.39 RI per million operations.[1] Each aircraft type contributes a different average number of incursions, which results in the varying line slopes. Executive jets were separated from other general aviation aircraft to distinguish the expected users of TaxiAide and TaxiVision, as executive jets are expected to equip with full ADS-B systems at a higher rate then other general aviation aircraft.

7 SUMMARY

CCBS is a solution to prevent and reduce the severity of runway incursions on many levels. CCBS addresses the root causes of many runway incursions as well as mitigating the impact of those that do occur. The design solution incorporates visual displays for tower controllers and pilots, an expert system (CCP) to improve operational efficiency, and an alerting system to detect incompatible clearances and provide warnings during an aircraft deviation. Additionally, the system is highly flexible, with its accommodation of various levels of equipage.

CCBS has been designed through an inter-disciplinary team as an educational activity at Georgia Tech. Its design has been collaborative, including feedback from technical reviewers at Thales ATM, air traffic controllers, and numerous pilots. The CCBS project culminated in a prototype showing TowerVision's and TaxiVision's display functionality, and showing the feasibility of our solution. The design team is confident that given implementation, CCBS will effectively reduce runway incursions and improve communication between pilot and tower controller.

Additional descriptions of CCBS are located in Appendix G, including a thorough description of the Clearance Protocol, the expert system used in the Information Management subsystem, and a description of the prototype architecture. In addition, Appendix G contains detailed descriptions of the Flight Deck and Control Subsystems along with multiple figures showing the different modes and alerting states.

APPPENDIX A

A.1 Participant List

Participants	Email Address	Contact Number	Fax Number
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Ray Stanley	rms@gatech.edu		
Tyler Trawick	gtpd@gatech.edu		

APPPENDIX B

B.1 Description of University

The Georgia Institute of Technology is one of the nation's top research universities, distinguished by its commitment to improving the human condition through advanced science and technology. Accredited by the Southern Association of Colleges and Schools, the Institute offers many nationally recognized programs in the Colleges of Architecture, Engineering, Sciences, Computing, Management, and the Ivan Allen College of Liberal Arts. Georgia Tech consistently ranks among *U.S. News & World Report*'s top ten public universities in the United States, and the 'home school' of many of the students, Aerospace Engineering, currently ranks 2nd in undergraduate education and 5th in graduate education. In a world that increasingly turns to technology for solutions, Georgia Tech is using innovative teaching and advanced research to define the technological university of the 21st century.

Georgia Tech, home of the Yellow Jackets, is an innovative intellectual environment with more than 900 full-time instructional faculty and more than 17,000 undergraduate and graduate students. The university is a national and international leader in scientific and technological research and education, receiving more than $355 million in research awards in fiscal 2005. In 2004, Georgia Tech helped attract more than $112 million in new capital investment and helped create or save more than 11,000 jobs statewide.

In addition, Georgia Tech's College of Engineering is consistently ranked in the nation's top five by *U.S. News*. In terms of producing African American engineering graduates, *Diverse Issues in Higher Education* ranks Tech No. 2 at the bachelor's level, No. 1 at the master's level, and No. 3 at the doctoral level. These impressive national rankings reflect the academic prestige long associated with Georgia Tech's curriculum, faculty, staff, and students.

However, Georgia Tech does not have an aviation program, or any formal instruction targeted specifically at design of avionics systems for air traffic control. Thus, the activities of the students in this project, while recognized for many by course credit, did not represent part of their required curriculum. Likewise, Georgia Tech does not have an integrated program in aerospace human factors spanning schools; thus, the interdisciplinary design process pursued here represents a unique opportunity for these students to work in a team representing Aerospace Engineering, Industrial and Systems Engineering, and Psychology.

APPPENDIX C

C.1 Description of Non-university Partners

Thales is a leading international electronics and systems group, serving defense, aerospace, and security markets worldwide, supported by a comprehensive services offering. The group's civil and military businesses develop in parallel to serve a single objective: the security of people, property, and nations. Leveraging a global network of more than 20,000 high-level researchers, Thales offers a capability unmatched in Europe to develop and deploy critical information systems. Thales Air Traffic Management's (ATM) mission is to support the Air Transportation Community on a worldwide basis by building safe, efficient, and inter-connectable Communication Navigation Surveillance/Air Traffic Management systems. Thales solutions are based on consistent global development processes, programmed management, and systems engineering, combined with a predictable quality baseline. Thales supplies a full range of ATM products and services, including radar systems, control centers, communications, navigational aids, and landing systems. Thales USA provided a financial gift to the Georgia Tech Foundation in support of this team, used for team supplies and to provide modest stipends to some of the students based on their self-reported financial need.

Delta Airlines is a major airline based in Atlanta GA. Representatives from Delta kindly volunteered their services to provide insight into flight safety and flight deck operations. Students were provided by Delta with the opportunity to visit a ramp operations tower at Atlanta Hartsfield-Jackson airport, and to learn to taxi a Boeing 737-800 around major airports following runway/taxiway signage in a high-fidelity simulator.

APPPENDIX E

E.1 Student Assessments

The student assessments of the educational experiences and merit of this design project are summarized below. Specific individuals were chosen to share their thoughts so that the evaluation committee might see the breadth of experiences provided by this competition.

E.1.1 Prateem Amin

The FAA Airport Design Competition has given me an opportunity to work with a team of highly motivated individuals, each of whom has something unique to contribute towards the solution of our design. This experience has introduced me to runway incursions, its consequences, and the great effort the FAA has put in over the years to help prevent its occurrence. Furthermore, it has also given me a chance to expand outside of the classroom and gain real-world experience by interacting with airline pilots, avionics manufacturers, and FAA representatives to create a unique design incorporating their respective viewpoints.

E.1.2 Jessica Calhoun

Being a participant in this year's FAA Design Competition has been a rewarding experience for me. While I have always had a love for airplanes and flying, I never thought to consider the possibilities of runway incursions. I have learned that runway incursions are serious, costly, and deadly. I have also learned that most runway incursions are a result of human errors.

In my opinion, runway incursions can be decreased significantly. With all the current technology and resources in which airports can get up-to-date information about the location and speed of any aircraft on the surface, our design is just an additive resource to current innovations. The great thing about technology is that while it can not stop a human from committing an error. It can help us recognized our error and give us possible solutions. TowerVision and TaxiVision will do just that. Using current technology, it will give controllers and pilots the information they need, right when they need it. It is my goal to see these systems incorporated into every Class A airport in the United States and I hope that in the years to come the work that my team and I have done will be used to reduce the number of runway incursions.

E.1.3 Karen Feigh

As the team lead on this design project, I can honestly say that I learned not only about core issues of runway incursion, their causes, and preventative programs currently in place, but also about what collaborative environment aviation really is. I learned much about the interactive relationship between pilots, controllers, airlines, and the technologies at their disposal. I also learned much about project management and team leadership, and that what motivates some does not necessarily motivate others. I have a new appreciation for the dedication and creativity of my team. Given ambiguous goals, and an ambitious time line, my team was incredibly productive.

E.1.4 Rayiner Hashem

Working on this project was immensely satisfying for me. It gave me exposure to an area of aviation with which I was not previously familiar, and allowed me to exercise some skills that are not normally called upon in my schoolwork. CCBS is very interesting from a technical point of view, and that motivated to delve into the details of the design to a level that hopefully yielded some interesting results. Of course, the greatest thing about working on the project was interacting with our very capable team. Having great teammates makes an effort such as this one infinitely more enjoyable, and I am thankful to have had them.

E.1.5 Daniel D. Hegeman

I think it goes without saying that myself and the other members of the team learned a great deal from this experience. Personally, I became more aware of the dynamic air traffic system that fills the skies overhead; specifically the number and variety of activities associated with daily airline operations. I also learned about the responsibilities that the FAA holds to protect and improve the lives of passengers and the general public. Of most interest was the research of new, interactive systems that will improve the jobs of controllers and pilots by enhancing situational awareness. I hope that accidents like the one in Lexington, KY in August 2006 (my hometown) can become rarities, if not impossibilities, with the implementation of this technology.

E.1.6 Brian Lee

While typical aerospace engineering classes teach textbook materials and assign problems with strictly governed solutions guided by pre-determined syllabi, the Runway Safety/Incursion Challenge broadened our opportunity to expand the use of our creativity, resources, and skills to devise a viable solution to a real-world situation. The grand task of this challenge was unique in a manner that the participants were responsible for all aspects of achieving the goal: time management, information gathering, analysis, collaboration, synthesis of ideas, and compilation. Trips to airport control towers and meetings with experienced professionals were unusual strategies from other information gathering techniques, but they were necessary to gain an in-depth view of airport operations. While we hope to win the competition, we relished networking with professionals, increasing efficiency of our team-working abilities, and the chance to have our ideas considered for a potential resolution to runway incursions.

E.1.7 Marcus Lowther

As a part of Georgia Institute of Technology's FAA Airport Design Competition Team, there are many areas of air transportation of which I learned much. My participation on the controller solution side of our system allowed me to spend several days at PDK airport in Atlanta observing exactly what goes on in an airport control tower and through research of the topic I also learned what the greatest short falls of the Air Traffic Management system on the ground are. In addition, my responsibilities of drawing what the control tower display would look like (TowerVision) forced me to know what each component of an airport diagram referred to and also human factors issues of the colors, sizing, and symbols that would make the most effective and easy-to-read display. Having never used Adobe Illustrator before this project, I have also come away with a little bit of graphic design experience, something unexpected when one hears the term 'airport design.' Overall, this competition has been invaluable in understanding ATM ground traffic concerns, as well as the ATM system in general, and in learning the technologies currently available and on the horizon for airport ground activities.

E.1.8 Micaela Newman

Throughout this competition, I have repeatedly been surprised by the lessons learned. It is easy to note that I had to learn a new computer program, flew in a full scale simulator, and use new forms of research. But beyond these, I also took away valuable lessons on group design. The frustration of being badly utilized, the time conflicts, and the seemingly mundane tasks had just as much of a positive influence on my future endeavors. The negatives helped me rethink, relearn, and reevaluate my ideas and that to me is the most important lesson.

E.1.9 Alex Rivas

Before embarking on this adventure, I knew just about as much as any normal person who flew a few times a year. I knew just as much as I could see out of the window as the plane took off and landed. After starting this design challenge, I spent the first weeks simply studying the ATC system: the hardware, software, and the procedural side. I have a solid grasp on the operations that take place to safely and effectively control airport movement. Now when I enter an airport, I can notice the work going on to help me get to my destination. I've gained valuable information that will extend outside of my classroom education and into everyday life as I continue to travel through our nation's airports.

E.1.10 Ray Stanley

As a graduate student in Engineering Psychology, this design competition has given me the unique opportunity to take knowledge from the classroom and laboratory and put it into practice. In this design competition, I served the role as human factors consultant - I worked with an interdisciplinary team to solve a design problem, with realistic limitations in time, money, and technology. I had the opportunity to do task analyses, heuristic analyses, and guide design decisions based on what I know about how humans work. Although I still feel I have much more to learn about human factors consulting, I feel that this experience has convinced me that working on design teams is an exciting and rewarding activity that I hope to pursue after my studies have finished. The value of this experience has been so great to me that I am investigating the integration of this sort of experience into our graduate program's curriculum, so others can experience this hands-on education.

E.1.11 Tyler Trawick

My experience working with the Georgia Tech design competition team was a very positive one. I was mostly tasked with developing a computer simulation of our proposed solution, which was exactly the type of task I had signed up for. This allowed me to build and improve upon my previous classroom experience writing programs in Java, and apply it to a real world situation. In addition to writing Java codes I assisted the other members of my system architecture group in assessing the feasibility of our proposal, which included taking input from our corporate sponsor Thales Air Traffic Management. Working with a team of talented students and professionals on a challenging real-world problem was a rewarding experience indeed, and will provide some guidance of what shape my future endeavors shall take.

E.2 Faculty Assessment

E.2.1 Amy Pritchett

Changes in engineering practice present and will continue to present challenges to our graduates and to us as engineering educators. This and related issues have been discussed, both very broadly and in specific detail, in several recent reports and books (see especially "Educating the Engineer of 2020" (see http://www.nae.edu) authored by a National Academy of Engineering committee chaired by GT President Wayne Clough). Of the many issues currently being raised, some of the key challenges of the global work environment faced by our graduates are:

- Understanding interdependent, interdisciplinary considerations in design.

- Understanding the needs of designing complex systems suitable for real operations, and methods for interacting with operations when they are not neatly laid out in a traditional engineering model.
- Industry practices, including not only writing and teamwork, but also practices such as internal reviews and critiques.

Students in this design team made significant advances with respect to these concerns. As a pre-test, the entire team was part of our first observations and discussions with controllers and operators of Peachtree-Dekalb (PDK) airport. The team members were tentative, and described best by their enthusiasm rather than by their knowledge. In comparison, as a post-test, the week before submission of their final report, our sponsor (Thales USA) generously agreed to conduct a red team review by their engineering staff. Following Thales' review of the document, the entire Georgia Tech team participated in a teleconference with the Thales review team, led by the Thales USA CEO Wayne Dohlman, Thales International Director of Innovation Olivier Brigaud, and Thales ATM Director of Sales and Marketing, Mark Boguski. The Thales team was sufficiently impressed with their technical work to treat them as true professionals, as evidenced by a detailed review of every aspect of their project. Throughout, the students demonstrated their mastery of the technical aspects of the project in response to questions and suggestions, and acted as confident, capable members of the team.

As a major component of this project, team members participated in interdisciplinary discussions. The team composition included both young undergraduates and senior graduate students, from a range of interests in Aerospace Engineering, Industrial and Systems Engineering, and Psychology. At the beginning they were asked to describe the project individually, and their responses reflected their limited knowledge and isolated disciplines, as well as more knowledge of analysis than of design. By the end of the project, in contrast, their discussions were sufficiently collaborative that distinctions between the three sub-groups (pilot systems, controller systems, and system architecture) were no longer necessary, and they could collectively discuss trade-offs and design solutions.

A pervasive element of their project was their interaction with an airport operator, pilots, controllers and industry. Their activities here included:

- Meetings with the PDK airport operators and controllers
- Extensive observations of operations at PDK
- Surveys, meetings, interviews, and design reviews with staff specializing in flight safety at Delta airlines, with pilots (general aviation, airline, and retired military) and a recently retired controller
- Search for and reference to technical and operational documents, ranging from FAA documents such as 7110.65 and other FARs, to technical standards for current and future air traffic technologies, to technical consultations with staff at Delta Airlines and Thales, as well as others.

Many of these activities were conducted independently by the students, limiting my ability to directly assess their professional growth in the skills they required. However, my observations of their performance, especially at the end of the semester, were overwhelmingly positive. Likewise, the quality of their final report, and the uniformly positive feedback I received from industry and operators that I received about the professionalism of their interactions, highlight the level of educational benefit that this activity engendered.

In summary, my educational assessment is that the students on this project, through their own initiative in responding to the competition's goals, received a unique and extensive opportunity to learn to function in an inter-disciplinary team in a professional setting, achieving a design solution that industry has recognized as suitable for their own further development. Throughout, the students also acquired extensive knowledge of airport operations and aviation systems through first-hand observations, detailed design, and extensive interviews and design reviews with aircraft operators, pilots, controllers, and technical staff from an airline and an avionics manufacturer.

E.2.2 Daniel Bruneau

The initial formulation of the student team for the FAA airport design competition saw an exciting array of students from many disciplines showing an interest in tackling issues concerned with runway incursions. To this end, the make-up of the team consisted of students from Aerospace and Mechanical Engineering, Computer Science and Psychology. Indeed, for the majority of the students, this was their first experience of working on a collaborative team design project in which different academic disciplines were represented and as such, it was exciting to witness the student's development in such a challenging, yet rewarding environment.

During the first few team meetings, both Dr Pritchett and I emphasized the need that the Georgia Tech contribution to the competition would be primarily a student led initiative (although guidance from faculty and associated resources would never be far away). As faculty advisors, we felt that the students would benefit most from the experience if they were to take on the responsibility of driving their own ideas forward, understanding the challenges of working in a team, not only with respect to the type of work being generated, but also ensuring that scheduling and communication requirements were met. In essence we wanted the students to feel that this was their work and, ultimately, a project that they would feel intimately proud of, regardless of the final outcome.

The student team was led by an experienced PhD student, Karen Feigh, whose strong leadership skills and adeptness at motivating the other student members (especially with respect to key deadlines) provided the team with a sense of direction and purpose. Through a determined and measured approach to the design of controller and pilot display aids for reducing runway incursions, the Georgia Tech Airport Design team has demonstrated that is has been able to acquire numerous new skills in areas not previously encountered. In addition to learning new software for designing the displays, students were also exposed to elements which required them to conduct research in very disparate disciplines. For instance, significant research was required to understand how designs such the TowerVision and TaxiVision could be developed for 'real-world' use. Such an applied approach also required a strong commitment on the team's part to engage in conversations with actual controllers and pilots, gauging their views and opinions on the designs produced. Not only did this endeavor illustrate to students the importance of validation and idea iteration within the conceptual design process, it also exposed them to the skill of working with teams outside the traditional university realms and engaging with industry participants who often have differing views to those based solely in academia. Such a task was also particularly fruitful for the team in enabling them to gain a strong sense of understanding of the business requirements for bringing the designs to market.

With respect to overall team development, initial team meetings and brainstorming sessions saw individuals staying within their respective academic disciplines that they were most familiar with. However, as consensus grew on the ideas being generated, it was clear that many students understood the need to look beyond their area of expertise. This was particularly evident with respect to the consideration of core human factors principles when it came to the design of the TaxiVision and TowerVision interfaces. Many members of the team had not been exposed to the scientific principles of human factors but quickly understood the importance of considering the human element in the designs that they were producing.

Importantly, one of the greatest challenges posed by formulating such a team concerned the dynamic workings of the design team itself. Whether based in industry or academia, there are many challenges related to working in a multi-disciplinary design team, especially with respect to coordination and ensuring sound communication within the team on design issues. These were issues that, for the most part, were unfamiliar to students and while there certainly was a marked learning curve, overall the Georgia Tech design team proved to be highly successful in its collaboration. This strong sense of 'teamwork' was edified by the fact that the students initially worked in small specialist teams at the idea conception stage before working as a single unit in the final phases of the project. Importantly, even during the phases where specialist teams worked on a specific area related to the overall design, there was always a weekly meeting during which the whole team came together and discussed their work. As such, it was very encouraging to witness the student's strong sense of sensitivity towards fellow teammates' needs and concerns. Importantly, this awareness of other people's work within the group enabled the students to lead their own specific tasks, including learning new design skills and software packages along the way, while still pursing the goals that were team driven.

APPPENDIX F

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