2010

Integration of Engineered Material Arresting System and End-Around Taxiways

FAA Design Competition for Universities

Runway Safety / Runway Incursions

Team Members

Andrew R. Mackley

Naghma Hassan

Abdullah J. Habibzai

Faculty Advisor

Dr. Carlos C. Sun

Professor, Department of Civil and Environmental Engineering

Executive Summary

Congestion is rising in airports because of the yearly increase in air travel. This congestion not only causes the dreaded delays at airports but also many safety concerns, including runway incursions (RI). A RI is the presence of an aircraft or a vehicle on a runway where it is not supposed to be. Safety has always been a primary concern in the aviation community. The first section of this report reviewed the current technologies and strategies that are used to prevent RIs. The second section of this report described a design solution to mitigate the occurrences of RIs. This design included the integration of two current technologies: Engineered Materials Arresting Systems (EMAS) and end-around taxiways (EAT). EMAS is a crushable concrete that is placed at the end of runways in order to stop the failed takeoff or landing of a fully loaded airliner. EATs are taxiways that are used in conjunction with parallel runways to allow aircrafts to bypass a runway instead of crossing it. The combination of these two technologies has never been used before, so a preliminary design was carried out in order to investigate the benefits and feasibility of this solution to effectively mitigate the occurrence of RIs. A benefit/cost analysis studied the costs of taxiway and EMAS installation, maintenance, benefits of safety, capacity increase, taxiing time decrease, and right-of-way. The analysis showed that the ratio was significantly larger than 1 for medium-sized airports such as MCO and even larger for busier airports such as ATL. In accordance with the Safety Management Systems Manual, a safety risk assessment was conducted of this design.

Table of Contents

1 Problem Statement & Background

1.1 What is a Runway Incursion?

The definition of a RI that has been recently adopted by the FAA (FAA, 2009) from the International Civil Aviation Organization (ICAO) is "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft." An aerodrome is the same as an airfield. According to the Manual on the Prevention of Runway Incursions (ICAO, 2007) some scenarios of runway incursions are:

a) An aircraft or vehicle crossing in front of a landing aircraft
b) An aircraft or vehicle crossing in front of an aircraft taking off
c) An aircraft or vehicle crossing the runway-holding position marking
d) An aircraft or vehicle unsure of its position and inadvertently entering an active runway
e) A breakdown in communications leading to failure to follow an air traffic control instruction
f) An aircraft passing behind an aircraft or vehicle that has not vacated the runway

The United States has over 500 airports with air traffic control towers that employs over 15,000 air traffic controllers. In 2008, nearly 600,000 aircrafts made more than 58 million takeoffs and landings (FAA, 2009). Table 1 shows the number and rate of RIs from 2005 to 2008. Based on the recent definition adopted from ICAO, there were 1009 incidents of runway incursion out of 58 million movements in the US, which is a 13 percent increase since FY 2007 (See Table 1). Though the number of operations has slightly decreased, the number of RIs has increased from 2005 to 2008. Runway incursions are near the top of the list of National Transportation Safety Board's (NTSB) necessary areas of improvements for runway safety

Table 1. Number and Rate of RIs (FY 2005 to FY 2008), Adopted from FAA (2009). (NTSB, 2010).

1.2 Types of Runway Incursion

	FY 2005 est.	FY2006 est.	FY2007 est.	FY2008 est.	Total
Number of Runway Incursion	779	816	892	1,009	3,496
Rate of Runway Incursions per Million Operations	12.3	13.4	14.6	17.2	14.3

The 2009 FAA safety report described three types of RIs: operational errors/deviations (OE), pilot deviations (PD), and vehicle/pedestrian deviations (VPD). These definitions are intended to categorize types of errors. A PD is an action by a pilot that violates any FAA regulation. An OE is an action by an air traffic controller that results in less than the minimum separation between an aircraft and either another aircraft, equipment, vehicle or personnel. An OE also includes the action of an air traffic controller that results in an aircraft landing or departing on a closed runway. A VPD is when a vehicle, pedestrian, or other object enters into an unauthorized area and interferes with aircraft operations.

1.3 Causes of Runway Incursion

Runway incursions are typically caused by the lack of communication and situational awareness. Although these two causes are inherent in the system, proper training and engineering can mitigate their consequences. Communication breakdowns can be between controllers and pilots or can be an intra-controller problem. The most common type of error associated with pilot deviations is an incorrect maneuver after a read-back of a controller's instruction (FAA, 2008). Situational awareness is caused by lack of attention and lack of preparation. Lack of attention can be a problem of the controller and/or the pilot. The most common type of error associated with operational error/deviation is a controller temporarily forgetting about an aircraft (FAA, 2008). This has led to many serious runway incursions.

1.4 Severity of Runway Incursion

The severity of runway incursions that do not result in an accident is broken down into four categories with "A" being the most severe and "D" being the least (FAA, 2009). Table 2 shows the definitions of these categories. The probability of occurrence of category A and B incidents, which have a significant potential for collision, is as low as 3%.

1.5 Recent Incidents That Prompted Action

The FAA cited two recent incidents (FAA, 2009) that have prompted fresh research into runway incursions prevention. The first happened on March 21, 2006 at Chicago O'Hare. The incident involved an Airbus A319 and an Embraer E145. Both aircrafts were cleared to takeoff on separate but intersecting runways. Controllers recognized the impending disaster and cancelled the takeoffs of both aircrafts who had to apply maximum braking. The proximity of the two aircraft was reported to be 100 feet horizontal.

On July 11, 2007 at the Fort Lauderdale/Hollywood airport, another catastrophe was nearly avoided. This incident involved an Airbus A320 who missed a turn while taxiing and ended up on a runway without clearance. A Boeing 757 was cleared to land but was issued a go around command from the air traffic controller. The 757 barely missed the A320 by 50 feet.

Table 2. Runway Incursion Severity Categories (FAA 2009)

Category	Description	Distribution
Accident	Refer to ICAO Annex 13 definition of an accident (ICAO, 2007)	
A	A serious incident in which a collision was narrowly avoided.	2%
B	An incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/ Evasive response to avoid a collision.	1%
C	An incident characterized by ample time and/or distance to avoid a Collision.	38%
D	Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no Immediate safety consequences.	59%

1.6 Current Strategies to Prevent Runway Incursions

The 2009 FAA "Annual Runway Safety Report" describes runway safety and the prevention of runway incursions as a mutual responsibility between air traffic controllers, pilots, and vehicle operators/pedestrians. Currently, FAA initiatives are trying to reduce the severity, number and rate of RIs by applying a combination of infrastructure, technology, procedures and training interventions. Even though the RIs of category "A" have recently decreased, the overall increase in RIs (See Table 1), including some specific close calls, have led the FAA to mitigate the occurrence of future serious RIs. FAA's "Call to Action for Runway Safety" (2009) pursued more than 40 aviation leaders to identify where the National Airspace System (NAS) might be vulnerable to human error and a potential for RIs. The "Call" focused on: a) cockpit procedures,

b) air traffic procedures, c) airport signage and safety markings, d) technology, and e) training (FAA, 2009). Cockpit procedures address the vigorous communications that happen during all phases of flight between members of a flight crew from pushback to arrival.

Communications between flight crew and between aircraft and air traffic tower must be crisp and accurate to ensure that the crew works as an effective team and that a sterile cockpit operating environment is maintained. The FAA asked air carriers to examine cockpit procedures to identify and develop a plan to address factors that contribute to pilot distraction during taxiing. Out of the 112 active air carriers, all have replied that they are in compliance with standards. Air traffic procedures include the coordination between the flight crew and air traffic controllers. Pilots must effectively coordinate with traffic controllers, and controllers must coordinate with other controllers to sustain constant situational awareness and positive control of activities on the airport surface. The FAA has developed numerous strategies to improve communication and address explicit taxi instructions between flight crews and controllers. One such effort is Hearback/Readback Awareness Month.

Airport signage and safety markings provide guidance and increase situational awareness for pilots and airport service vehicle operators for how to move safely during routine movements around an airport. As part of the FAA strategy to update standards for runway marking and signs, the 75 busiest U.S. airports completed improvement of their surface markings in FY 2008. According to a safety review, application of the FAA initiatives resulted in reducing serious runway incursions by 50 percent.

Technology assists operators to design airport environment, control tower and cockpit in their compliance to procedures and recognition of potential hazards in the runway environment. The FAA, assisting airports all over the country, implements runway safety-enhancing technologies such as Runway Status Lights (RWSL), Airport Surface Detection Equipment, Model X (ASDE-X), and Final Approach Runway Occupancy Signal (FAROS). Currently Low-cost ground surveillance systems are under evaluation. Training provides ground and flight crews and air traffic controllers with the skills they need to safely perform their jobs. The FAA provides an advisory training for initial and regular recurrent ground movement for all individuals with access to airport movement areas. The updated guidance, soon to be released, was particularly designed for tug and tow operators to complement the current air carrier tug and tow training programs.

The NTSB has issued a request for improvements of cockpit technologies, operating procedures, and air traffic control policies. NTSB recommends a safety system that provides pilots and flight crews with direct warning capabilities. This could include a moving map display that informs pilots of other aircrafts' movements and current closures of runways and taxiways. Another recommendation is the requirement of air traffic controllers to give explicit clearance for an aircraft to cross individual runways (NTSB, 2010).

The FAA has proposed a "hearback/readback" initiative to increase awareness of best-practice communications between controllers and pilots (FAA, 2009). "Hearback/readback" insures as best as possible that pilots hear and understand instructions given to them by air traffic controllers. Miscommunications have been credited to many serious runway incursion incidents (FAA, 2008). The FAA Runway Safety Management Strategy comprises of two parts: technical and non-technical. The technical part of the strategies, which is discussed in this literature, focuses on technology and infrastructure improvements while the non-technical part concentrates on "outreach" and "awareness" of aviation community.

Through the outreach activities the FAA informs the aviation community such as pilots and airport personnel about the importance of runway safety and FAA's efforts to reduce the RIs. The awareness strategy provides the FAA employees the latest safety procedures and programs through trainings on regular basis in order to keep their knowledge and skills sharp.

1.6.1 Technology

Technological advancements make runways safer and increase runway capacity. Recently, FAA, with close collaboration of aviation industry, worked to develop, test, and deploy a number of technologies that enhance runway safety. These technologies provide situational awareness to flight crews and air traffic controllers to prevent RIs. Some new technologies are still under evaluation in one or two sites. Technologies are of special importance during diverse operating conditions such as loss of communications, poor visibility, or heavy traffic. In the following sections, the FAA explanations of current technologies are summarized (FAA, 2009).

Runway Status Lights (RWSL): Being still under evaluation, RWSL is a technology that will alert pilots to potential runway incursions by embedding a system of lights into runway surfaces. This technology will be a supplement to existing pilot procedures, training, and visual monitoring by assisting pilots to identify possible conflicts with other surface traffic. The RWSL systems comprise of Runway Entrance Lights (RELs), which indicate when a runway is unsafe for entry, and Takeoff Hold Lights (THL), which indicate when a runway is unsafe for takeoff due to additional traffic. At Dallas/Fort-Worth International Airport (DFW), RWSL works in combination with Airport Surface Detection Equipment, Model X's surface surveillance systems to detect the presence of aircraft or vehicles on the runway. Whenever a runway is occupied, the RWSL system illuminates RELs and THLs (FAA, 2009).

Airport Surface Detection Equipment: Model X (ASDE-X) is the latest example of surface detection equipment technology. Displaying the position of aircraft and vehicles on an information screen, surface detection systems such as ASDE-X enable air traffic controllers to detect potential runway conflicts by tracking the movements of vehicles and aircraft on an airport surface. These systems are particularly helpful in limited visibility conditions. Depending on unique configuration of a surface detection system of an airport, it can be integrated with other technologies such as RWSL to provide further safety. As of February 2009, 17 towers are using ASDE-X; 18 additional control towers are scheduled to be operational by end of spring 2011 (FAA, 2009).

ASDE-X is superior in all weather conditions than earlier ASDE systems such as Airport Surface Detection Equipment, and Model 3/Airport Movement Area Safety System (ASDE-3/AMASS). Some of the busy US airports including Seattle, St. Louis, Atlanta-Hartsfield, and Washington-Dulles Airports have recently replaced their ASDE-3/AMASS systems with ASDE-X. New York LaGuardia and Las Vegas McCarran plan to replace older systems with ASDE-X technology between FY 2010 and FY 2011.

Low Cost Ground Surveillance: FAA is testing the effectiveness of low-cost ground surveillance systems. These systems may be a practical technology that can mitigate the risk of RIs at small and medium-sized airports where budgetary constraints limit the use of expensive ASDE-X and ASDE-3/AMASS systems. Spokane International Airport is currently evaluating early versions of commercially available low-cost ground surveillance systems (FAA, 2009).

Electronic Flight Bag: Electronic Flight Bag (EFB) is a computerized display system that provides pilots with information about multiple aviation topics thus making paper flight charts obsolete. EFBs can either be stand-alone or displayed on laptop-like equipment on a variety of platforms in an existing aircraft, high-end displays fully integrated into the cockpits of newer aircraft, or components that are portable but use power and data directly from the aircraft's systems. Most EFB systems are integrated with Airport Moving Map Display (AMMD) technology, which uses Global Positioning Systems (GPS) to show pilots their real time positions on the airport surface. AMMD technology system enables the pilots to see exactly where their aircraft is located on the airfield in real time, thus decreasing the chances of losing situational awareness and being in the wrong place.

The FAA (FAA, 2009) is currently conducting Capstone 3, a demonstration program that will examine how EFB and AMMD improve cockpit situational awareness to enhance surface safety. In exchange for several air carriers to equip some of their fleets with EFB and AMMD technology, each air carrier is obligated to collect feedback from flight crews. Such feedback will be shared with the FAA and used to determine the value that EFB and AMMD provide in improving situational awareness and runway safety.

Final Approach Runway Occupancy Signal: Final Approach Runway Occupancy Signal (FAROS) is a technology that activates a flashing light visible to the pilot of an approaching aircraft to warn that the runway is occupied and hazardous. The FAROS test system at Long Beach-Daugherty (LGB) is a cost-efficient, fully automated system using inductive loop sensors embedded in the runway and taxiway surfaces to detect aircraft and vehicles entering and exiting monitored zones. The DFW eFAROS (enhanced FAROS) system is more sophisticated and works in combination with ASDE-X to monitor the entire runway surface. Operational evaluation of FAROS systems has been taking place at LGB since 2006 and at DFW since October 2008 (FAA, 2009).

1.6.2 Improved Infrastructure

Although technology is vital for improvement of the runway safety, a well-developed infrastructure must also be present. Pilots depend on clearly marked surfaces to maintain situational awareness. The presence of clearly marked, un-obstructed, and efficiently accessible space result in safe traffic operations. Sufficient sprawl is required to prevent confusing, unsafe, and operationally inefficient taxi and runway crossings. The FAA is working with aviation industry to develop innovative solutions to deal with physical constraints, legal issues, and environmental concerns (FAA, 2009).

Runway Safety Area: According to FAA (FAA, 1989) Runway Safety Areas (RSA) are un-obstructed areas around the perimeter of a runway to improve safety in the event that an aircraft undershoots, overruns, or encroaches to the side of the runway. Standard RSAs extend from 240 feet to 1,000 feet beyond the ends of runways and are between 120 feet and 500 feet wide (See Figure 1). The size of RSAs depends on the kind of instrument approach procedures and size and type of aircraft served by the runways. Airports that contain a greater proportion of instrument approaches and service a higher number of commercial aircraft generally need the biggest RSA. Large and unobstructed RSAs will make them effective. The FAA requires that all Navigational Aids (NAVAIDs) inside the RSA to be mounted using bolts that are frangible at a height of no more than 3 inches from the ground, allowing the NAVAID to easily break-away upon impact with an aircraft.

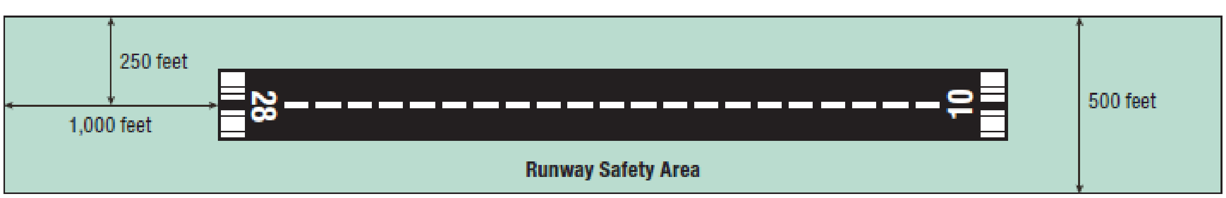

Figure 1. Runway Safety Area (FAA 2009)

In FY 2002, FAA launched a program to speed up RSA improvements for commercial service runways that did not meet FAA standards. 83 percent of priority RSA improvements will be complete by the end of 2010, and 68 improvements will be made to meet the 2015 goal.

Engineered Materials Arresting System: EMAS is an enhancement that provides airports the safety benefits equivalent to RSA in cases where it is not possible to have a standard dimension RSA such as when the right-of-way is limited. This system uses a light-weight, crushable concrete material, placed beyond the runway departure end to stop or greatly slow an aircraft that overruns the runway. EMAS is currently installed on over 41 runway ends at 28 airports. Over the past years, EMAS has successfully stopped three aircraft at JFK Airport with minimal damage to the aircraft and no serious injuries. The EMAS with crushable concrete is currently the only FAA approved alternative for RSAs. However, FAA and Transportation Research Board's (TRB) Airports Cooperative Research Program (ACRP) is working with aviation industry groups to inspect future development of EMAS for better runway safety (FAA, 2009).

Airport Surface Markings: Enhancement of taxiway centerline markings at the 75 busiest US airports was one of the first items identified by the FAA "Call to Action" (FAA, 2000). Establishing a boundary for safe operational distance from an active runway, improved taxiway centerline markings are intended to increase pilot and airfield driver situational awareness when they are approaching a runway hold-short line. Previously, less-noticeable solid yellow lines were the taxiway centerline marking. As shown in Figure 2, the FAA has changed the taxiway centerlines marking standard to include dashed yellow lines on either side of a solid line in the vicinity of a runway.

Figure 2. Enhanced Taxiway Centerline Markings (FAA 2009)

Previous Marking **Enhanced Marking**

Perimeter/End-around Taxiways: The construction of perimeter/EAT infrastructure at airports with sufficient space improves the airfield surface safety by decreasing the number of runway crossings. A taxiway's location, alignment, width, and operational use are important in improving runway safety at airports. Reducing the number of aircrafts crossing a runway is a priority in the design of an airport to improve runway safety. A study of the Category A and B RIs at the Operational Evolution Plan (OEP) of 35 airports from 1997 to 2003 found more than 50% of RIs involved taxiing aircrafts crossing an active runway, as shown in Figure 3 (Jacobs, 2007). Perimeter taxiways create an alternative taxiway for aircrafts to taxi between the runway and the apron without crossing another runway. Airports with parallel runway arrival and departure configurations may also recognize the additional advantage of increased traffic capacity and logistical efficiency. EATs reduce the need for communications between pilots and controllers thus mitigating radio frequency congestion.

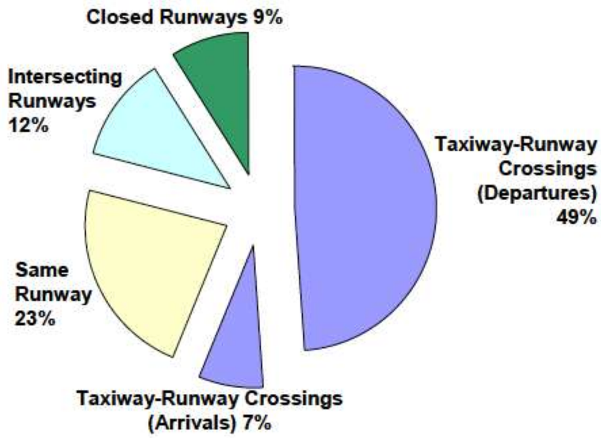

Figure 3. Operational Characteristics of Category A and B RIs at the OEP 35 Airports (Jacobs 2009)

Recently, DFW and Hartsfield-Jackson Atlanta International Airport installed perimeter taxiways, which eliminate hundreds of aircraft crossings a day. NASA's Ames Research Center is collecting data on some of DFW's taxiways to inspect approaches to optimize its operations. Although a perimeter taxiway can decrease the number of runway crossings (see Figure 4) and therefore the number of possible incursions, there are some challenges associated with them. The

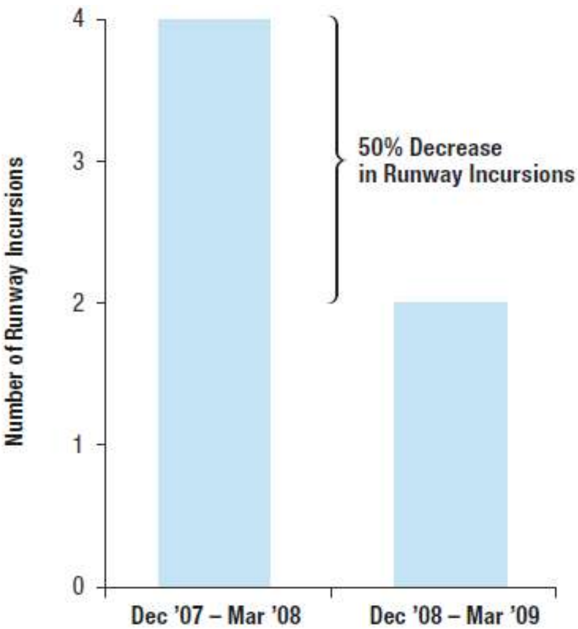

Figure 4. Runway Incursion for DFW Between December 2008 and March 2009 (FAA, 2009)

installation of end-around taxiways often encounters geometry and land use/configuration challenges. One special challenge is the limited right-of-way at the end of RSAs (FAA, 2009).

2 Summary of Background and Literature Review

To reduce the number and severity of RIs, the NTSB, FAA and their aviation industry partners are developing, evaluating and implementing better prevention strategies. To enhance runway safety, the FAA assists airports in using technologies such as Runway Status Lights (RWSL), Airport Surface Detection Equipment, Model X (ASDE-X), and Final Approach Runway Occupancy Signal (FAROS). These technologies were described in the previous section. Some of the technologies such as low-cost ground surveillance systems are still under evaluation. Although technologies have been largely successful by providing accurate and real time positional mappings for both pilots and controllers, in some instances these technologies have limitations. One of the limitations is the inability to completely address the miscommunication between users of this technology. However, these limitations can be addressed through re-design. The future technology for the NAS management will be the Next Generation Air Transportation System (NextGen). According to the FAA (FAA, 2008), NextGen, as defined by the FAA, is the transformation of the ground-based air traffic control system to a satellite-based system.

To achieve the safety goals of the FAA, an efficient infrastructure must also integrate the technology. As described in the previous section, the current infrastructure improvements include RSA, EMAS, Airport Surface Markings, and EATs. The FAA requires airports to have sufficient RSA to provide better landing and takeoff safety. However, some airports have limited right of way and cannot accommodate expansion of their RSAs. This problem requires the use of alternate solutions to RSAs. Currently, EMAS is the only approved alternative to RSA. Another prevention approach is installing EATs for reducing the number of active runway crossing.

However, construction of EATs is challenged by airport geometry, and land use/configuration constraints.

The project team discovered that there is no unique solution to the RI problem. Considering the variety of RI scenarios, a diverse set of technology and infrastructure improvements is necessary. Therefore the project team researched alternative prevention approaches to both technology and infrastructure considering their significant impact to the industry in the following categories: safety and capacity improvements, monetary savings to airlines and airports, environmental/carbon footprint, and noise pollution. A potential solution the team found is using EMAS at the end of RSAs where there is insufficient right-of-way for EAT installation. This solution might reduce the size of RSAs, thus providing enough space for installation of EATs. This incursion countermeasure will improve safety through reduced runway crossings, provide monetary savings, and mitigate environmental impacts.

3 Problem Solving Approach to the Design Challenge

The literature review showed that the installation of EAT is often challenged by airport geometry and land use/configuration constraints. These challenges are present in many airports such as Hartsfield (ATL), Dallas/Fort-Worth (DFW), O'Hare (ORD), and Orlando (MCO). The integration of EMAS and EAT overcomes the problem of limited right-of-way. This solution might not be feasible at all airports but might be a good fit for some. A case study of a combined EMAS and EAT design will illustrate the benefits and costs at a typical airport.

MCO was selected as a case study after investigating different parallel runway airports that were challenged by right-of-way limitations. The outcomes of a benefit-cost analysis could be categorized into the following:

1. The benefit-cost ratio is significantly higher than 1 and the proposed system is practical for a broader range of airports.
2. The benefit-cost ratio is close to 1 or the proposed system is practical for a smaller range of airports.
3. The benefit-cost ratio is significantly smaller than 1 or the proposed system is not practical for any airport.

3.1 Orlando International Airport Case Study

Being one of the top tourist destinations in the world, Orlando is located on the east side of Central Florida and offers attractions such as Walt Disney World, Universal Studios, SeaWorld and the Convention Center, which is the second largest conference facility in the U.S. MCO is approximately 12 miles southeast from downtown Orlando (CFASPP, 2010). MCO is primarily served by domestic and international passenger airlines, charter airlines, air cargo operators and the military. The airport ranks 13th in the U.S. in total passenger traffic and is also in the top 25 in the world. Presently, the largest aircraft that regularly serves MCO is the Boeing 747-400, but the airport is capable of handling the new A380 aircraft. Thus the Airport Reference Code (ARC) for MCO is design group VI.

MCO has 13,300 acres of land with four north-south parallel runways ranging from 9,000 to 12,005 feet in length. These runways have separations that provide massive long-term capacity capable of providing simultaneous triple flow instrument landings and takeoffs. Figure 5 shows that runway 18L/36R lies between 18R/36L and the terminal and as a result, aircrafts cross over runway 18L approximately 291 times daily estimated from daily departures and landings at MCO (Orlando International Airport, 2010). Since these two runways are the longest in the airport, it is estimated that both runways contribute to 80% of the 304,000 yearly operations of the airport, which equals 243,200 operations. Runway crossing is the main cause of runway incursions and any reductions in runway crossings can reduce the number of RIs proportionally. The case study considers a design life cycle of 20 years as recommended by the FAA (FAA, 2004). For conversion of values to present value, FAA recommends a discount rate of 7%.

Figure 5. MCO Design Location (Google Earth)

3.1.1 Technical Design

End-Around Taxiway Design: The first major design decision for the EAT is the need for the elevation of the taxiway to be lower than the current ground elevation of the terrain. This will raise the cost of construction significantly but is necessary for two reasons. One, a problem arises with the installation of EATs due to the perception of a runway incursion.

Because of the length of runways, it is difficult for pilots to determine if an aircraft is crossing the runway or is on the EAT. Pilots departing on a runway towards the EAT will mistake an aircraft using the EAT for a runway incursion. This will lead to aborted takeoffs and/or unnecessary maneuvers in order to avoid a collision. AC 150/5300-13 (FAA, 1989) suggests the installation of a visual screen to partially or completely block the view of aircrafts in the EAT from departing aircrafts. For the proposed design, a visual screen is unnecessary due to the depression of the EAT. According to the AC 150/5300-13, a depression of 29 feet or more will mask enough of the design group aircraft within the EAT to effectively eliminate the perception of a runway incursion. The second reason for the depressed elevation is to allow the EAT to be closer to the end of the runway while assuring that the tail sections of the design aircraft does not penetrate the inner-approach object free zone (OFZ) which starts 200 feet after the threshold and slopes up at a ratio of 50:1 (FAA, 1989). Depending on the runway's declared distances which depend on additional unavailable information of the surrounding area, the depression of the EAT may need to be deeper. For this design, we will assume that 29 feet depression will not affect the threshold significantly enough to decrease the capabilities of the 12,005 feet long runway. A large quantity of earth will need to be excavated in order to depress the taxiway.

The dimensions of the taxiway found from AC 150/5300-15 are listed below in Table 3. The EAT was designed for group VI aircraft but could be lowered to group V if very few group VI aircrafts would use the EAT. This would lower the cost of construction as well as the amount of excavation needed. The EAT consists of four 90 degree turns. These turns will be designed for cockpit-over-center movements that require less complex maneuvers than judgmental oversteering (FAA, 1989). Cockpit-over-center movements will require more concrete for the taxiway but will provide a more efficient flow of traffic as well as reducing the complexity of the negotiating the EAT.

The vertical profile is designed with crest vertical curves leading into the EAT that connect to a sag vertical curve. The sag curve drops to a low point of 29 feet below the elevation departure end of the runway at the runway's centerline extension. To provide minimum grade changes, the lengths of the vertical curves will be as long as possible. This means that the ends of the crest curves connect to the ends of the sag curve. According to AC 150/5300-13, the maximum grade change between vertical curves is 3 percent and the maximum grade of a taxiway is 1.5 percent. Therefore, the EAT will have grades no larger than 1.5 percent in order to meet both of these design standards. Table 3 presents the dimensions and costs of the proposed EAT.

Table 3. Design Detailed Values

Item	**Dimensions**	**Cost**	**Quantity**
Taxiway Width	100 ft	Excavation cost	\$0.80/CY
Taxiway Edge Safety Margin	20 ft	Total cost of excavation	\$645,168
Taxiway Shoulder Width	40 ft	*Installation cost	\$15/ft^2
Taxiway safety area width	262 ft	Taxiway installation cost	\$3,966,000
Taxiway object free area width	386 ft	**Taxiway maintenance cost	\$0.05 /ft2
Total taxiway length	2,644 ft	Annual maintenance cost	\$13,220
Taxiway pavement area	264,400 ft^2	Present value of maintenance cost	\$136,637
Earth excavation	806,460 yds^3	**Total**	**\$4,747,805**

* Source: Florida DOT (2010)
** Source: Benefit-Cost Analysis of Airport Infrastructure: The Case of Taxiways (Daniel, 2002)
Note: All totals are present value costs.

EMAS Design and Cost Estimation: The service life of EMAS is designed to be 20 years. To design the EMAS, the maximum take-off weight of the aircraft that imposes the greatest demand upon the EMAS and the range of aircraft expected to use the runway is considered. The study of EMAS design of JFK international airport indicated that MCO design inputs are similar to those of JFK. Although detailed information of JFK EMAS system is not available, the available data indicated that both airports have similar design aircrafts and runway layout. The B-747 is the largest aircraft of MCO and was stopped safely by the JFK EMAS system on January 2005. As a result, the 400 ft EMAS length is assumed for runway 18L. Now the space saved for installing the EMAS is standard RSA length – assumed EMAS length – initial setback length = 1000 ft – 400 ft – 75 ft = 525 ft which is longer than the 386 ft required for EAT installation. Therefore the integration of EMAS and EAT is practicable in this airport. Since the area available is larger than that required for the installation of a standard EMAS designed to stop the design aircraft at an exit speed of 70 knots, the start of the EMAS will be placed 1000 ft -386 ft -400 ft = 214 ft away from the runway end. This value, 214 ft, is the final setback length. The design is shown in Figures 6, 7, and 8 and the cost estimation for a 20 year life cycle is shown in Table 4. As shown in Figure 8, this design does not relocate any physical objects and uses the existing RSA.

Table 4. EMAS Dimensions and Costs for 20 Year Life Cycle

Item	**Quantity**	**Item**	**Cost**
EMAS length	400 ft	Cost for site preparation	$1,719,200
Runway width	200 ft	Cost for EMAS	$6,240,000
Set Back length	214 ft	Subtotal installation cost	$7,959,200
EMAS area	80,000 ft^2	Maintenance cost	$26,667/yr
Site preparation area	122,800 ft^2	Maintenance cost for 20 years	$268,242
* Unit cost for site preparation	$14/$ft^2$	Replacement cost after 10 years	$3,394,147
* Unit cost for EMAS	$78/$ft^2$	**Total**	**$11,621,589**

* Source: Adopted from Order 5200.9, Federal Aviation Administration (FAA, 2004).
Note: All totals are present value costs. The EMAS does not need maintenance at year 10 and 20 for material replacement.

Order 5200.9 (FAA, 2004) provides a limiting value for determining the financial feasibility of EMAS, which is based on the EMAS manufacture's benefit/cost analysis. Since the EMAS width is 200 ft the 1.33 value is multiplied by the value estimated from Figure 4 of Order 5200.9 to estimate the maximum feasible cost of EMAS improvement. Therefore, the maximum feasible cost is 1.33*$17,500,000 = $23,275,000. For a total EMAS area of 80,000 ft^2, Table 4 shows the cost of the site preparation to be around $1.7 million and the cost of construction to be around $6.2 million. The maintenance cost is relatively small but the replacement cost is after ten years is approximately $3.4 million. Since the total EMAS life cycle cost of ~$11.6 million is less than the maximum feasible cost, the EMAS design is financially feasible.

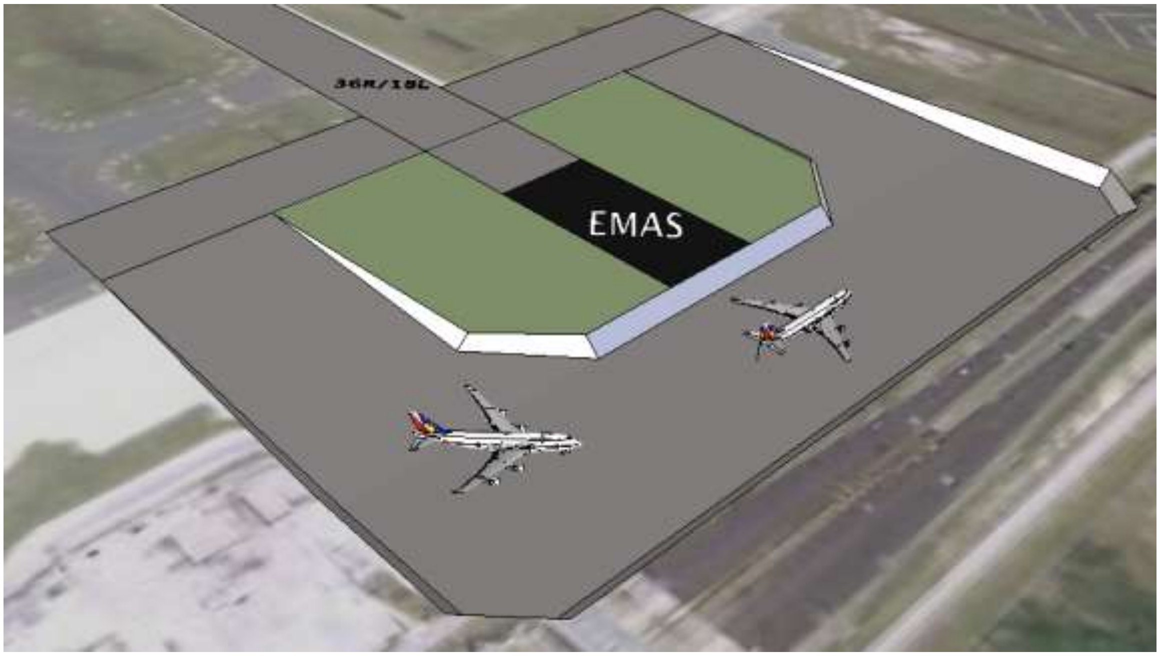

Figure 6. EMAS and EAT Concept Sketch 1

Figure 7. EMAS and EAT Concept Sketch 2

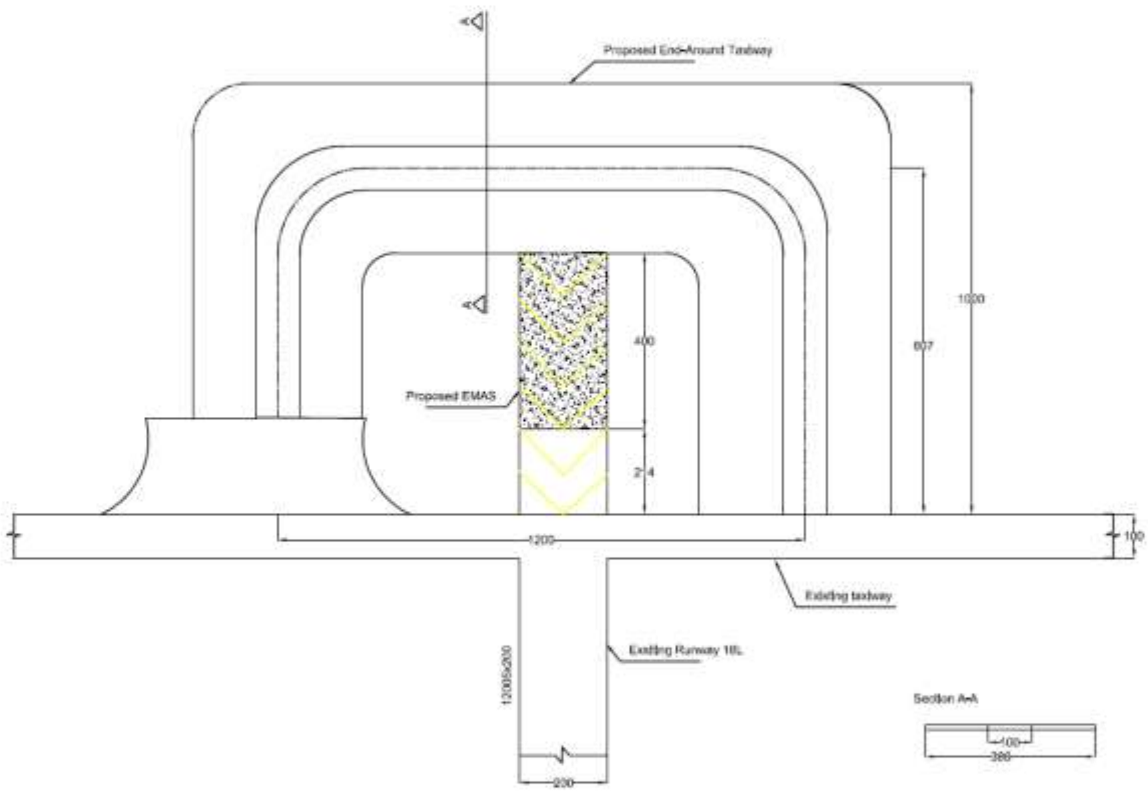

Figure 8. EMAS and EAT Design

4 Safety Risk Assessment

4.1 Safety Risk Management (SRM) Process

According to the Safety Management Systems Manual (FAA, 2008), safety is the freedom from unacceptable risk. A change to the NAS could affect various systems and procedures that have been previously established. The SRM is a formalized approach to identify safety hazards, determine risk associated with these hazards, analyze the risk, and develop ways to mitigate the risk when a change to the NAS is presented.

4.2 Description of the Existing System

The current airfield layout of MCO consists of 4 parallel runways, two to the east and two to the west, with the terminal area in the center. The east airfield consists of two staggered runways of

9,000 feet and 10,000 feet, both 150 feet wide. The west airfield has two non-staggered runways of 12,005 feet and 12,004 feet, both 200 feet wide. The west airfield supports the majority of the traffic at MCO and most of the aircrafts that are group IV and larger. The runways are all oriented north south with the designation of 18L/36R and 18R/36L for the west airfield runways. Both runways allow for visual and instrument flight rules with the presence of lights and navigational aids. Runways 18L/36R and 18R/36L often support both arrivals and departures. For this safety assessment, hazards and risks associated with runway crossings will be discussed.

4.3 Identification of Hazards Associated with Existing System

The event of a runway crossing becoming a runway incursion is the hazard associated with the current system. In the event of an incursion, the aircraft's crew must recognized and avoid a potential collision. The air traffic controller (ATC) is relying on procedures and ground surface detection systems to identify and alert aircrafts in an incursion incident. Scenarios where these courses of action will be necessary are conceivable. Failure in one of these processes might lead to a catastrophic event. The assessment and list of hazards and risks associated with the existing system are shown in Table 5. Even though ES1, ES2 and ES4 could be catastrophic, they are either extremely remote or extremely improbable.

Table 5. Identified Hazards of Existing System

Hazard Reference	Hazard Description	Hazard Severity	Likelihood
ES1	Arriving aircraft on 36R crosses 36L without ATC clearance. Departing aircraft on 36R.	Catastrophic, risk of injury and fatalities; aircraft separation reduced; considerable crew, operator, and passenger distress	Extremely Remote
ES2	Departing aircraft en-route to 18R crosses 18L without ATC clearance. Arriving aircraft on approach for 18L	Catastrophic, risk of injury and fatalities, aircraft separation reduced, considerable crew, operator, and passenger distress	Extremely Remote
ES3	Departing aircraft en-route to 18R crosses hold line for 18L but does not enter runway. Arriving aircraft landing on 18L	Hazardous, risk of injuries and fatalities possible, aircraft separation reduced.	Remote
ES4	ATC giving clearance for aircraft to cross 18L/36R and forgetting about departing/arriving aircraft on 18L/36R.	Catastrophic, risk of injury and fatalities, aircraft separation reduced, considerable crew, operator, and passenger distress	Extremely Improbable
ES5	Runways 18L/36R and 18R/36L operating near capacity and causing congestion of aircrafts wanting to cross 18L/36R	Minor, aircraft separation slightly reduced, possible pilot or ATC error due to increased workload and stress	Probable

For description of hazards, refer to Safety Management Systems Manual (FAA 2008)

4.4 Assessment of Risk

The worst-case outcome of the potential hazards is a catastrophic accident. Accidents are rare events, and the actual rate of occurrence is difficult to be determined. Current practices and procedures are in place in order to reduce the risk of costly accidents but failure is possible. All five of the stated hazards in Table 5 are occurrences involving runway crossings. With the current system in place, runway crossings are required. The possibility of a runway incursion is extremely remote but considered likely to occur in the lifespan of the system.

4.5 Treating the Risk (Designed Solution)

The proposed design attempts to greatly reduce the risks identified from the existing system. The proposed EAT will allow aircrafts that land on runway 36L to taxi around runway 36R and not cross over it. Aircrafts that are scheduled to depart from runway 18R can use the EAT and not cross over runway 18L. Because half of the aircrafts that land on 18R/36L aircrafts do not have to cross the runway 18L/36R, hazards ES1, ES2, and ES3 will be eliminated by approximately 50%. A 50% reduction in RIs is assumed considering the fact that the EAT is installed only at north end of the runway and not at both ends. ES4 will be eliminated because the ATC does not need to issue clearance to cross the runway. When the airport is operating at or exceeding capacity, the EAT will allow ground movements of aircrafts to continue uninterrupted and therefore mitigate ES5.

4.6 Identification of New Hazards

The hazards associated with the new proposed design are described in Table 6 as follows.

Table 6. System Hazards Associated with the Proposed Design

Hazard Reference	Hazard Description	Hazard Severity	Likelihood
DS1	Aircraft departing on 36R takes off past TODA with a large aircraft in the EAT	Hazardous, risk of injury and fatalities, aircraft separation reduced, considerable crew, operator, and passenger distress	Remote
DS2	Aircraft landing on 18L undershoots runway and contacts EAT	Catastrophic, risk of injury and fatalities, severe infrastructure damage	Extremely Remote
DS3	Aircraft departing on runway 36R abort takeoff and exit the departure end of the runway	Minor, risk of injuries and fatalities not likely, considerable infrastructure damage	Remote
DS4	Pilots of aircrafts unfamiliar with navigating the depressed EAT while taxing	Minor, little risk for injuries, increased workload for crew	Probable

4.7 Analysis of Hazards

The hazards identified listed in Table 6 involve situations where an aircraft is using the EAT or an aircraft encroaches upon the EAT. DS1 can occur if a departing aircraft takes off past the declared distance available for takeoffs (TODA) and a large aircraft is within the EAT. The departing aircraft must be aware of reduced TODA while the EAT is operational. For the case of DS2 the event of a landing undershoot will cause the aircraft to contact the EAT. The EAT will be depressed and not allow area for the aircraft to safely touchdown prior to the runway. Pilots must be aware of the presence of the EAT and the reduced landing distance available. DS4 occurs when an aircraft has a failed or aborted takeoff and leaves the end of the runway, the aircraft will be stopped by the EMAS and will not proceed into the EAT. The EMAS was included for this very reason. DS5 is the case where some pilots will be unfamiliar with the EAT and confusion will arise. Pilots must study and understand how to navigate the EAT.

4.8 Assessment of Risk

The first two hazards have a risk for a catastrophic accident. If an aircraft contacts a tail section of an aircraft within the EAT, the result will be catastrophic for both aircrafts. The likelihood of this event is thought to be remote or even extremely remote but since no system like the one design has been attempted, the assessment is not based on actual data. The event of an aircraft undershooting the runway and contacting the EAT will destroy both the aircraft and cause severe damage to the infrastructure. An undershoot is extremely remote but is possible in the lifespan of the system. The risk of an aircraft leaving the end of the runway and coming in contact with the EMAS system is only minor structural damage to the aircraft. EMAS systems have been proven to work effectively. Finally, the likely case of pilots being unfamiliar with the EAT designed system has the risk of slowed operations of the EAT. The severity of this safety risk is minor or no risk at all. Once pilots are familiar with the system, the risk will be minimized.

4.9 Treatment of Risks

Although the designed system was created in order to eliminate hazards of the existing system, it resulted in new risks that must be mitigated. The establishment of proper declared distances can lessen the first two new hazards and the risks associated. The TODA could possibly be altered if the EAT is in operation or at times of low visibility. The undershoots can be mitigated by displacing the threshold of the landing to allow for a proper area for undershoots. Because the runway is very long, the reduction of declared distances will not have a large impact on the use of the runway. The risk of an aircraft having a failed takeoff and leaving the departure end of the runway has already been treated with the installation of the EMAS. Proper signage and education for pilots will decrease the navigation problems within the EAT.

5 Projected Impacts of Design and a Benefit-Cost Analysis

The proposed design has a variety of benefits including safety improvements, usage of existing right-of-way, enhancement in operational efficiency, decreased load on radio systems, and decreased emission. Even though it is difficult to quantize and monetize these benefits, a careful and conservative analysis was performed using reasonable assumptions.

5.1 Safety Benefits

The safety improvement is believed to be the primary benefit of the proposed design. As previously discussed, the proposed EAT decreases the number of runway crossings made through runway 18L. To quantize and monetize the safety benefits, the following assumptions are made:

1. The RIs can occur while two inner-runways are crossed by the aircrafts landing in or departing from the two outer runways. Considering the number of operations using the 18L and 18R, which are the longer two of the four runways, and geometric characteristics of the runways, the proposed design decreases the number of crossings of the airport by approximately 20%. This value was assumed because the proposed design reduces the number of crossings of only one end of runway and probably during high-visibility.
2. Fatalities and injuries are caused by category A and B incursions, and property damage (PDO) to the aircrafts is caused by category C and D. However, the PDO values are calculated to be 15% of fatalities and injuries costs based on historic data (FSF, 2009).

3. Although no fatality has occurred in MCO due to RIs; on the average, approximately 1 fatality and 1 injury per year are assumed to occur during design life due to RIs. This value was assumed by studying the overall RI fatality trends in the US.

Table 7 shows the annual safety benefits by severity and the total benefits. Using the forecasted annual operations, the total annual benefit for each severity was computed and subtotaled. The resulting total benefit for 30 years was estimated to be around $2.58 million.

Table 7. Quantization/Monetization of EMAS and EAT Safety Benefits

Year	Forecasted Operations	Forecasted Category A & B Incursion	Number of Fatalities	Number of Injuries	Values of Fatalities	Value of Injuries	Value of PDO
2011	320,064	0.03	0.03	0.03	138,514.80	7,064.25	21,760.24
2012	336,477	0.03	0.03	0.03	136,091.49	6,940.67	21,379.54
2013	353,068	0.03	0.03	0.03	133,459.70	6,806.44	20,966.10
2014	365,838	0.03	0.03	0.03	129,239.97	6,591.24	20,303.19
2015	379,268	0.03	0.03	0.03	125,219.06	6,386.17	19,671.52
2016	390,446	0.04	0.04	0.04	120,476.25	6,144.29	18,926.44
2017	401,960	0.04	0.04	0.04	115,914.97	5,911.66	18,209.88
2018	413,836	0.04	0.04	0.04	111,532.43	5,688.15	17,521.39
2019	426,075	0.04	0.04	0.04	107,318.65	5,473.25	16,859.42
2020	438,696	0.04	0.04	0.04	103,268.78	5,266.71	16,223.20
2021	451,710	0.04	0.04	0.04	99,375.95	5,068.17	15,611.65
2022	465,128	0.04	0.04	0.04	95,633.55	4,877.31	15,023.73
2023	478,962	0.04	0.04	0.04	92,035.44	4,693.81	14,458.48
2024	493,220	0.04	0.04	0.04	88,574.95	4,517.32	13,914.85
2025	507,929	0.05	0.05	0.05	85,249.04	4,347.70	13,392.35
2026	523,098	0.05	0.05	0.05	82,051.35	4,184.62	12,890.01
2027	538,741	0.05	0.05	0.05	78,976.69	4,027.81	12,406.99
2028	554,865	0.05	0.05	0.05	76,019.05	3,876.97	11,942.35
2029	571,503	0.05	0.05	0.05	73,176.20	3,731.99	11,495.75
2030	588,662	0.05	0.05	0.05	70,442.31	3,592.56	11,066.26
2031	629,868	0.06	0.06	0.06	70,442.31	3,592.56	11,066.26
	Subtotals	**0.87**	**0.87**	**0.87**	**2,133,012.94**	**108,783.66**	**335,089.60**
						Total	**2,576,886.20**

Notes: Rate of category A & B incursion = 0.45 per million operation (FAA, 2009)
PDO = 15% of fatality and injury values (FSF, 2009)
Life costs are adopted from National Safety Council (NSC 2009)
All totals are 2011values

5.2 Right-of-Way Benefits

If the EAT was to be installed beyond the end of runway 18L and out of the 1000 ft RSA limit, then it would have been possible to simply acquire the land beyond it. This land acquisition required shifting Bear Road, Florida 528 Toll Road, and North Frontage Road at least 386 ft to the north. Shifting these roadways involves reduction in toll benefits, purchase of extra right-of-way, and roadway reconstruction costs as estimated in Table 8. The major benefit of the proposed design is that it does not require extra right-of-way, thus eliminating the need to acquire extra land. Essential land required for EAT installation is gained by EMAS installation. It is assumed that only one lane is closed during reconstruction phase and traffic diverted to alternate routes for four months. This diversion results in reduction of 20% of toll incomes which is equal to: average toll (cell A) * AADT (cell B) * 20% * 120 days = 1.4 million as shown in Cell C. From Figure 5 required taxiway area is 386*(1200+2*100) = 0.5 million ft^2 equivalent to 4.3 million. Likewise the value of reconstructing the 6-lane toll way in the new location would be as shown in cell J. Finally the total benefit of not acquiring right-of-way is shown as approximately $22.8 million in Table 8.

Table 8. Right-of-way Benefits of Integration of EMAS and EAT

Item	Quantity	Item	Quantity
*A: Average toll ($/vehicle)	1.50	***G: Expressway construction ($/lane/mile)	5,354,166.67
^B: AADT	39,313.00	H: Length of road (miles)	0.53
C: Subtotal toll value ($)	1,415,268.00	I: No. of lanes	6.00
D: Required taxiway area (ft2)	540,400.00	J: Subtotal road reconstruction value ($)	17,035,984.85
**E: Average land rate ($/ft2)	4.01	**K: Total value**	**22,785,260.85**
F: Subtotal land value ($)	4,334,008.00		

* Source: Expressway Authority (2009) *** Florida's Turnpike Enterprise (2010)
** Source: Showcase (2010) ^ Source: Florida Department of Transportation (2009)
Note: All totals are 2011 values

5.3 Efficiency Benefits

The efficiency benefits of the proposed design include increasing the capacity of runway 18L and 18R and decreasing the taxiing time of the aircrafts that originally cross the runway 18L. Each of these two benefits is explained further in detail as follows.

5.3.1 Increase in Runway Capacity

The capacity of the two parallel runways, 18L and 18R, was estimated using the Airport Capacity and Delay advisory circular (FAA, 1983). The Mix Index of MCO's west airfield runways, 18L/36R and 18R/36L, was estimated to be 131.6. The cumulative capacity of both runways is approximated 340,000 annual operations. On the other hand, the forecasted operation in 2018 would exceed the capacity thus necessitating an increase in the capacity of the runways in 2017. To find the capacity benefits of EAT, MCO was compared with the DFW EAT. A FAA Technical Center report (AOSC, 2005) indicated that the full DFW EAT at four quadrants would add 30% additional efficiency at a cost of approximately $260M and postpone the need for a $1.3 billion runway project . The report assumed an improvement in the airport capacity benchmark by 3% in good weather and by 17% in adverse weather. Since the EAT at MCO is considered in one quadrant it consequently provides only the 25% of capacity benefit that EAT at DFW provided, and multiplying it by 0.56, the ration of MCO to DFW operations, the total benefit is approximated 26.5 million in 2011 dollars,. It was estimated that the proposed EAT would increase the capacity of MCO by 5%, thus delaying for two years the need for improving the capacity of the runway. The monetary benefit of capacity increase would be the two year interest of the investment.

5.3.2 Taxiing Time Reduction

Originally the airplanes that want to take off or land in runway 18R/36L need to stop for clearing the runway 18L/36R which increases taxiing time. Taxiing time of half of these airplanes, assumed approximately 20% of MCO operations, would be reduced approximately by 1 minute while traveling through the proposed EAT as shown in column C of Table 9. This value was obtained by comparing the current travel time to historical travel time (ASPM, 2010). In addition, considering the variety of airplanes using the runway under study the approximate value of time was approximated to be $10/min (FAA, 1983). The time saving benefits are calculated in 2011 dollar in column D of Table 9.

Table 9. Taxiing Time Benefits of Integration of EMAS and EAT for MCO

Year (A)	Operations (B)	Time Saved by Aircraft Taxiing to 18R/36L(min) (C)	Taxiing Benefits (D)
2011	320,064	64,012.80	640,128.00
2012	336,477	67,295.40	628,928.97
2013	353,068	70,613.60	616,766.53
2014	365,838	73,167.60	597,265.57
2015	379,268	75,853.60	578,683.48
2016	390,446	78,089.20	556,765.20
2017	401,960	80,392.00	535,685.84
2018	413,836	82,767.20	515,432.52
2019	426,075	85,215.00	495,959.06
2020	438,696	87,739.20	477,243.11
2021	451,710	90,342.00	459,252.92
2022	465,128	93,025.60	441,957.92
2023	478,962	95,792.40	425,329.71
2024	493,220	98,644.00	409,337.53
2025	507,929	101,585.80	393,967.25
2026	523,098	104,619.60	379,189.58
2027	538,741	107,748.20	364,980.43
2028	554,865	110,973.00	351,312.10
2029	571,503	114,300.60	338,174.23

2030	588,662	117,732.40	325,539.90
2031	629,868	125,973.67	325,539.90
	Total	**1,925,882.87**	**9,857,439.75**

Note: All totals are present value costs.

5.3.3 Decreased Load on Radio Systems

The results of a joint FAA and NASA study performed in February 2003 indicated that the proposed EAT for DFW airport would reduce controller-pilot communications by approximately 25% (AOSC, 2005). Considering the ratio of average operations of MCO to DFW, the EAT at MCO would reduce the controller-pilot communication by 0.56*25% = 14%.

5.6 Summary of Benefit-Cost Analysis

Two possible scenarios are depicted. The first represents the scenario that the authority did not originally plan to acquire additional right-of-way, and consequently its benefits should be neglected. The second represents the scenario where the airport acquires extra right-of-way based on the airport authority's plans. As shown in Table 10, the B/C ratio is favorable towards the proposed design for either scenario.

Table 10: Summary of Costs and Benefits in two Possible Scenarios.

Costs		**Benefits**	
Taxiway Installation and Maintenance	$4,747,805	Safety	$2,576,886
EMAS Installation and Maintenance	$11,621,589	Capacity Increase	$26,563,359
Total	$15,724,225	Taxiing Time Decrease	$9,857,440
Scenario I B/C Ratio	**2.5**	Subtotal	$38,997,685
Scenario II B/C Ratio	**3.9**	Right-of-Way	$22,785,261
		Total	$61,782,946

Note: The totals are 2011 values.

6 Industry Interactions

Greg Cecil, who is the Chairman of the board of advisors for Columbia Regional Airport (COU) gave an overview of COU operations and addressed questions related to our FAA design. COU is the local airport serving the mid-Missouri region. It is located approximately 14 miles from the University of Missouri's campus. Mr. Cecil gave an overview presentation of COU, which included the airport's destinations, flight schedules, and an explanation of its role as a regional airport. From there, Mr. Cecil talked about the airport's layout, geometric design, primary aircrafts served, current enplanement statistics, and the airport's master plan. While talking about the master plan, Mr. Cecil discussed the future of COU and the plans to increase the number of destinations and airlines serving the airport. Our class was able to ask Mr. Cecil questions that inspired many ideas and gave our design a good direction early on.

On November 13, 2010, our team participated in a personalized tour of COU. Don Elliot, the airport superintendent, gave us a guided tour of COU's airfield. Mr. Elliot personally drove us around the taxiways and runways. Observing the taxiways up-close was essential for our understanding and visualization of our design. To properly understand runway incursions, it is necessary to see with one's own eyes the vantage point of a pilot. We were also able to observe multiple aircraft landing and departing.

On October 19, 2010, David Sparks, P.E. from Kimley-Horn and Associates, traveled from Memphis, TN to Columbia, MO in order to discuss with our class. Mr. Sparks gave a presentation on the design and construction of a runway and discussed the design projects of student groups. Our team was able to describe the design project, ask questions about feasibility of integration of EMAS and EAT, preliminary design ideas that helped our understanding of the feasibility of our ideas, the potential costs, and certain considerations to explore. He stated that the design is technically feasible and his only comment about our design was whether it would be financial feasible and later we found out that our design was.

Mark E. Williams, P.E., who is the Associate Vice President of HNTB in the Kansas City, KS office, spoke with our class on class November 11, 2010. Mr. Williams has many years of experience in airport design and gave a presentation about the airport engineering industry. His presentation covered topics including bidding on projects, public interaction/awareness of airport development, environmental issues, and actual airfield design. Mr. Williams specifically spoke about HNTB's involvement with DFW. Our team was able to ask questions about the new EAT located at DFW. Mr. Williams was also recently involved with the installation of an EMAS and gave our team further design considerations.

7 Conclusion

Integration of EMAS and EAT is unique in that it has never been implemented before and so there is no empirical evidence of its benefits. This case study which considered an average airport, MCO, discovered that this design is practical and produces a significant benefit-to-cost ratio. In scenarios both including and excluding the right-of-way benefits, the benefit-cost ratio was significantly larger than 1. However, this ratio would increase even more for busier airports such as ATL which includes a higher number of operations and runway crossings, and more expensive right-of-way. In addition, if environmental benefits such as reduced emission are taken into account the ratio would increase further. The only limitation might be that airplanes with taller tails would enter the runway protection zone. If this problem does exist, then depressing the runways further and limiting the EAT operations during low-visibility weather can achieve minimum safety.

8 Appendices

8.1 Appendix A: Contact Information

Faculty Advisor

Carlos Sun, Ph.D., P.E.
Associate Professor and Director of Graduate Studies,
Department of Civil and Environmental Engineering
Adjunct Professor, Department of Electrical and Computer Engineering
Associate Director, Transportation and Infrastructure Center
University of Missouri
E2509 Lafferre Hall
Columbia, MO 65211
sunc@missouri.edu
Tel: 573-884-6330
Fax: 573-882-4784

Team Leader:

Abdullah J. Habibzai

1033 Southpark Dr. Apt 5
Columbia, MO 65201
ah8b4@missouri.edu
Tel: 573-639-2841

Team Members:

Naghma Hassan

109 N Stadium Blvd Apt 48
Columbia, MO 65203
nh4zd@missouri.edu
Tel: 573-639-9437

Andrew R. Mackley

3800-303 Saddlebrook Place
Columbia, MO 65202
armckf@mail.missouri.edu
Tel: (573) 356-9413

8.2 Appendix B: Description of University

The University of Missouri was founded in 1839 as the first public institution for higher education west of the Mississippi River. The University of Missouri, also known as Mizzou, enrolls over 32,000 students and offers 210 degree programs. Mizzou is the flagship campus of the University of Missouri System, which includes four campuses statewide, and is one of the few campuses that is a major land-grant institution as well as the state research university. Mizzou is considered one of the nation's top-tier universities. Over 248,000 people world-wide are proud to call themselves alumni.

The Engineering School at the University of Missouri has 9 academic departments covering all disciplines of engineering. The school sustains 18 research programs with the hard work of 110 faculty members, 400 graduate students, and many dedicated undergraduates. Students can get involved in any of the 30 engineering student organizations. The transportation engineering program includes 5 exceptional faculty members and 20 of the brightest up and coming engineers. Mizzou is one of the few schools that offers a course specifically for airport engineering. The class presents the unique opportunity for students to learn about all facets of airport design. Topics covered include: design, planning, capacity analysis, terminal layouts, and safety management.

8.3 Appendix C: Description of Non-University Partners

N/A

8.4 Appendix D: Design Proposal Submission Form

University University of Missouri

List other partnering universities if appropriate

Design Developed by: ☐ Individual Student **[X]** Student Team

If Individual Student

Name

Permanent Mailing Address

Permanent Phone Number Email

If Student Team:

Student Team Lead Abdullah Jan Habibzai

Permanent Mailing Address 1033 Southpark Dr. Apt 5, Columbia MO, 65201

Permanent Phone Number 573-639-2841 Email ah8b4@missouri.edu

Competition Design Challenge Addressed: Runway Safety/Runway Incursion

Certification & Signature:

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed *Date* *4/15/11*

Name Carlos Sun

University/College University of Missouri

Department(s) Civil Engineering

Street Address E2509 Lafferre Hall

City Columbia State Missouri Zip Code 65203

Telephone 573-884-6330 Fax 573-882-4784

8.5 Appendix E: Team Reflections

Abdullah Jan Habibzai

The FAA Design Competition provided a significant learning experience by applying the knowledge of theory of engineering to a real-world situation that required innovative techniques of problem solving. As a team member, the challenge provided me multiple constraints that needed to be overcome in order to produce a quality and effective solution.

The focal challenge my team and I faced was producing a solution to the problem of RI that, in one hand, did not duplicate work done by existing solutions, and on the other hand, to be technically feasible. To overcome this challenge I and my team had a detailed understanding of what solutions already existed. Through investigating different approaches which could possibly reduce the number of RIs I encountered different difficulties. Although only one of the studied approaches could produce the desired solution, investigation of each approach provided us a deep understanding of specific parts of economics and airport engineering including cost-benefit analysis, runway and taxiway design, airport operation, EMAS, and team work management.

In addition, the method that produced the most effective solution, integration of EMAS and EAT, forced us to have a detailed understanding of necessary methods to monetize safety, right-of-way, roadway and airport construction, and aircraft taxiing. Although I have successfully completed an airport engineering course which included numerous class projects and FAA competition project, I believe that this project was the best learning experience of mine in field of airport engineering.

Andy Mackley

On the eve of the deadline for submitting or project for our class grade, I sit here and think about what I have learned as a result of this competition. The first word that comes to mind is determination. For the past few months my team and I have strained our eyes staring at a computer screen for hours on end, researching, determined to bring our ideas to reality. That brings me to my second thought, reality. When our team first proposed our idea I thought, no way, that will never be financially feasible. I now know that our design is in the realm of reality and no matter how crazy an idea may seem, research it before you write it off.

Besides the fact of whether our design will ever actually be used or not, I came to another conclusion. As research engineers, we are essentially scientists. To a scientist, a failed result is just as educational as a successful result. In the weeks leading up to completion, while not totally convinced of our idea, I became equally curious to see if our idea would not work, as I was to see if it would.

Finally, and most pertinent to the educational experience, I can confidently say that my knowledge of airport design and planning is exponentially higher than it was when we first started. I know the ends and outs of FAA Advisory Circulars as well as the Safety Management Systems Manual. I also have an infinitely better idea of the financial implications of airport infrastructure improvements.

I also want to mention an incredible opportunity that this project gave me. I was able to work with two extraordinary students that have come to the University of Missouri to study from halfway around the world. It was a tremendous experience to take breaks from learning about airport design and learn about each other’s culture and backgrounds. I have this competition to thank for that.

Naghma Hassan

Working in this FAA design computation affected my knowledge and experience a lot. Going through the project not only increased my information in airport field but also in other aspect of transportation engineering. I learned how important the safety of runway systems for aircraft, passengers and the whole air industry, factors that increase capacity, and decrease delay for overall efficiency of the aviation system. I learned that different students gather their work and increase their knowledge by sharing, and expressing various ideas and talents that each student has. The challenges that I faced through this project was collecting different statistics and data which was required to evaluate the cost-benefit analysis. Besides the project work, I received beneficial information from the guest speakers in the airport engineering classes who shared their experience in aviation industry.

8.6 Appendix F: References

1. Airport Obstructions Standards Committee (AOSC). (2005). Decision Document #06 Dallas / Fort-Worth End-Around Taxiway System. Federal Aviation Administration.
2. CFASPP (2010). Orlando International Airport Retrieved. Nov, 10, 2010.http://www.cfaspp.com/FASP/AirportPDFs/orlando_intl_%28mar2010%29.pdf
3. Daniel I. J. (2002).Benefit-cost analysis of airport infrastructure. The Case of Taxiways. Journal of Air Transport Management 8. 20 (14) 149–164.
4. Expressway Authority. (2009). Toll Schedule as of April 5, 2009 .Retrieved. Nov, 7, 2010.http://www.expresswayauthority.com/Corporate/travel/assets/TollRateSchedule2009.pdf
5. Federal Aviation Administration (FAA). (2009). Annual Runway Safety Report 2009. Washington DC. Federal Aviation Administration.
6. FAA (2010).Aviation System Performance Metrics (ASPM). Retrieved. Nov, 11, 2010. http://aspm.faa.gov/aspm/ASPMframe.asp.
7. FAA. (2008). Runway Safety Report June 2008. Washington DC .Federal Aviation Administration.
8. FAA. (2008). Safety Management Systems Manual. Federal Aviation Administration.
9. FAA. (2005). Engineered Materials Arresting Systems for Aircraft Overruns. AC 150/5220-22A. Federal Aviation Administration.
10. FAA.(2004). Financial Feasibility and Equivalency of Runway Safety Area Improvement and Engineered Material Arresting Systems. Order 5200.9. Federal Aviation Administration.

11. FAA. (2002). Orlando International Airport. [www.page] http://www.faa.gov/about/office_org/headquarters_offices/ato/publications/bench/DOWNLOAD/pdf/MCO_2004.pdf.
12. FAA. (1989). Airport Design, AC 150/5300-13. Federal Aviation Administration.
13. Federal Aviation Administration. (1983).Airport Capacity and Delay, AC 150-5060-5, AC5-12 pg. 25.
14. FDOT. (2009). FDOT Traffic Online. Retrieved. Nov, 10, 2010. http://www2.dot.state.fl.us/FloridaTrafficOnline/viewer.html.
15. Florida Department of Transportation (FDOT). (2010).Airport Costs. Retrieved. Nov , 11, 2010. http://www.dot.state.fl.us/planning/policy/costs/Airports.pdf.
16. Florida's Turnpike Enterprise. (2010). Current Construction Projects. Retrieved. Nov, 8, 2010.http://www.floridasturnpike.com/construction_current.cfm.
17. FSF. (2009). Runway Safety Initiatives Briefing Presentation. Retrieved Nov, 12, 2010. http://flightsafety.org/current-safety-initiatives/runway-safety-initiative-rsi.
18. ICAO. (2007). International Investigation Standards. Retrieved. Oct, 16, 2010)
19. http://www.iprr.org/manuals/Annex13.html#defs.
20. International Civil Aviation Organization (ICAO). (2007). Manual on the Prevention of Runway Incursions. Doc 9870 AN/463. Brussels Belgium.
21. Jacobs. K. (2007). Engineering Brief No. 75: Incorporation of Runway Incursion Prevention into Taxiway and Apron Design. Federal Aviation Administration.
22. NSC, 2009, Estimating the Costs of Unintentional Injuries, <http://www.nsc.org/NEWS_RESOURCES/INJURY_AND_DEATH_STATISTICS/Pag

es/EstimatingtheCostsofUnintentionalInjuries.aspx> National Safety Council, Retrieved Nov 10, 2009.

23. National Transportation Safety Board (NTSB). (2010). Most Wanted Transportation Safety Improvements. Retrieved October 15, 2010 http://www.ntsb.gov/recs/mostwanted/runways.htm.

24. Orlando International Airport. (2010).Traffic Statistics. Retrieved Nov, 10, 2010. http://www.orlandoairports.net/statistics/.

25. Showcase. (2010). Orlando Airport Commercial Land for Sale - Orlando Airport Florida. Retrieved Nov, 10, 2010. http://www.showcase.com/Orlando/Orlando-Airport__Commercial-Land-for-Sale.