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The Next Generation of Aviation Safety: Utilizing Airport-GIS For SMS Oversight

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THE NEXT GENERATION OF AVIATION SAFETY: UTILIZING AIRPORT-GIS FOR SMS OVERSIGHT

by

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B.S., Southern Illinois University, 2009

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Public Administration Degree.

Department of Political Science
in the Graduate School
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INTRODUCTION

According to the National Transportation Safety Board (2010) there were 0.255 accidents per 100,000 departures in scheduled commercial service air travel during 2009. With such a low accident rate, it is difficult for airport operators to make further improvements to safety levels. To combat this situation, aviation providers have separated themselves from the reactive approach to safety by adopting a more proactive approach to risk identification and mitigation.

A common misconception in aviation accidents is that they are caused by human error, but that is not always the case. In recent studies, human error was found to be only the last link in a chain of events that leads to an accident (Ludwig, Andrews, Jester-ten Veen & Laque, 2007). Thusly, changing people will not avoid accidents; accidents may become less likely to occur only when the primary factors are addressed. This can be accomplished by adopting an integrated systems approach to managing safety. No matter the steps taken, risk can never be eliminated but it can be reduced to an acceptable level and mitigated. A Safety Management System (SMS) establishes a safety process that allows airports to identify risks and take action to mitigate their potential consequences before an accident or incident occurs.

By definition, SMS is a formal, top-down business-like approach to managing safety risk by expanding on the established safety principles at airport's (Federal Aviation Administration, 2007). As of November 2005, it is a requirement for member-states of the International Civil Aviation Organization (ICAO) to establish SMS at certificated international airports (FAA, 2007). To further promote the harmonization of international standards, the Federal Aviation Administration (FAA) has developed consistent safety regulations with ICAO recommended practices. The FAA aims to implement the SMS requirements in a way that complements the existing airport safety regulations, not mandate new safety policy requirements.

A safety management system reduces risk and increases safety by providing a proactive, systematic integration method to safety standards already developed by airport operators (Ludwig et al., 2007). By researching SMS, the procedures of safety risk management (SRM) can be explored to show the effectiveness of integrating risk analysis and assessment within airport information systems using GIS. Through promoting the integration of a systems approach to safety, SMS establishes itself within the Next Generation (NextGen) realm of aviation.

NextGen is an umbrella term for the ongoing transformation of the National Airspace System to evolve aviation from a ground-based system of air traffic control to a satellite-based system of air traffic management (FAA, 2010). Currently, NextGen is continuing to improve safety by further expanding the use of satellite-based surveillance, improving airport runway access and deploying Airport Surface Detection Equipment-Model X, a surface safety technology used at airports (FAA, 2010). Implementing these technologies as such will improve situational awareness of all aviation personnel by providing information that historically was unavailable. This information will be provided in real-time data transfers to all properly equipped vehicles for more precise tracking and information sharing via GPS transponders. This information can then be input into an airport geographic information system (A-GIS) for spatial analysis and data mining.

Implementing NextGen data into A-GIS will provide airports with enough information to look for trends in operations, disseminate safety reports and identify areas of concern on the airfield. The A-GIS initiative set forth by the FAA outlines a process for the collection and maintenance of uniform airport data to be input into an enterprise GIS system for management and analysis (FAA, 2010). This will ensure the demands of the NextGen airspace system are met.

The remainder of this paper provides an overview of the relevant literature relating to SMS and A-GIS and looks at the potential integration of the two disciplines. A critical examination of how GIS applications can be used in SMS oversight will be provided. Lastly, a case study for Will Rogers World Airport showing the potential outputs using theoretical data models will be examined for preliminary findings and implications of SMS and GIS integration.

OVERVIEW OF THE DEVELOPMENT OF SMS AND GIS

It is important that airports develop a safety culture of change to energize and motivate personnel about the benefits of adopting SMS. Integrating safety information and databases will make the A-GIS/SMS process a reality. The coming pages explore the ways SMS and GIS have evolved and provide information on how to gauge the benefit of integrating them.

SMS

Although the concept of SMS has been around for quite some time, it is relatively new to airports, especially in the United States. Many of the current safety standards employed at airports can be used to comply with the requirements of SMS. Currently, there is no regulation on how airports will incorporate SMS into their Part 139 safety requirements (FAA, 2007). The FAA is researching multiple ways to implement SMS at U.S. airports to provide the guidance and regulation for the standards set forth by them in future SMS requirements. Due to the lack of historical information of SMS adoption at airports in the United States, it will be most beneficial to look at SMS within other industries to understand how it has evolved into a safety standard for aviation.

System safety principles have been used in petroleum, nuclear, railroad and healthcare industries for decades (Ludwig et al., 2007). Historically, safety regulation in aviation has been reactive instead of proactive, meaning, waiting for the accident or incident to take place. Thereafter, the cause is determined and the issue is addressed so that future failures and additional costs are avoided. This is horribly inefficient in terms of safety risk, monetary losses, liability, cost and public perception to safety. According to Gonzalez, “it is essential to complement the regulatory approach to safety with a proactive approach. SMS is the most effective way of responding to the need for results-based supervision with a relatively small workforce,” (as cited in Ayres et al., 2009, p.8). To further understand what SMS is to aviation, a closer look as to what SMS has been to other industries in history will be presented in the following paragraphs.

Nuclear Industry

Like many industries, the nuclear industry’s primary concern is safety. In exploring two significant historical accidents, the industry has adopted new technology to help improve safety levels and motivate personnel on the advancement of SMS practices. In March 1979, a nuclear plant’s reactor core was starved of coolant on Three Mile Island resulting in fuel melting (Ludwig et al., 2007). Although the fuel was contained and no deaths occurred, the cost of the accident was recorded as $975 million which resulted in closure of the plant. The investigation concluded with a much greater emphasis for the agency’s responsibility for reactor safety and mandated improved formal risk assessment and safety analysis procedures.

In a similar case, in 1986 an electrical engineering experiment caused a reactor to lose its coolant in Chernobyl. The operators put the entire workforce in a dangerous situation by operating a poorly designed reactor while conducting potentially dangerous tests without complying with established operational procedures. The result was 56 immediate deaths and many more due to radiation exposure (Ludwig et al., 2007). The subsequent investigation revealed the lack of a safety culture and safety management system. These two accidents resulted in training of personnel in safety analysis, the development of a safety culture and the adoption of several SMS elements that assess and mitigate risk involved in nuclear operations (Ludwig et al., 2007).

Railway Industry

Historically, the railway industry has been a trustworthy and safe method of transport for people and goods. Although, from 1994 to 2005 train accidents increased from 3.67 to 4.09 per million train miles, leading to the adoption of system safety principles as outlined by a SMS (Ludwig et al., 2007). A case in the railway industry from 2005 in Graniteville, North Carolina cited a collision that resulted in the derailing of 16 cars, the release of chlorine gas and the death of nine individuals (Ludwig et al., 2007). The total damage amount surpassed $69 million and the NTSB investigation concluded that the cause of the accident was human error which resulted in the freight train entering the wrong set of tracks due to an improperly laid switch.

As a result of this accident, Congress passed a law that called for the development and use of a safety risk reduction program within the railway industry (Ludwig et al., 2007). This program outlined the requirements for a regular evaluation of safety risks, adopted tools to manage those risks when necessary and summarized approved mitigation strategies that could be used to lower all risk to acceptable levels. By adopting ongoing practices like these, the railway industry is continuously improving safety in order to avoid future accidents.

The FAA has opened a rulemaking project to consider a formal requirement for SMS at certificated airports (FAA, 2010). A total of 570 airports are certificated under 14 CFR Part 139, Certification of Airports, throughout the United States. To promote harmonization with International Civil Aviation Organization (ICAO) standards, the FAA adopted principles of SMS for aviation service providers and conducted two pilot studies for airports. In these pilot studies the FAA provided guidance for developing an SMS for each airport to follow and allowed them to share their experiences and SMS practices with other airports and the FAA (FAA, 2007).

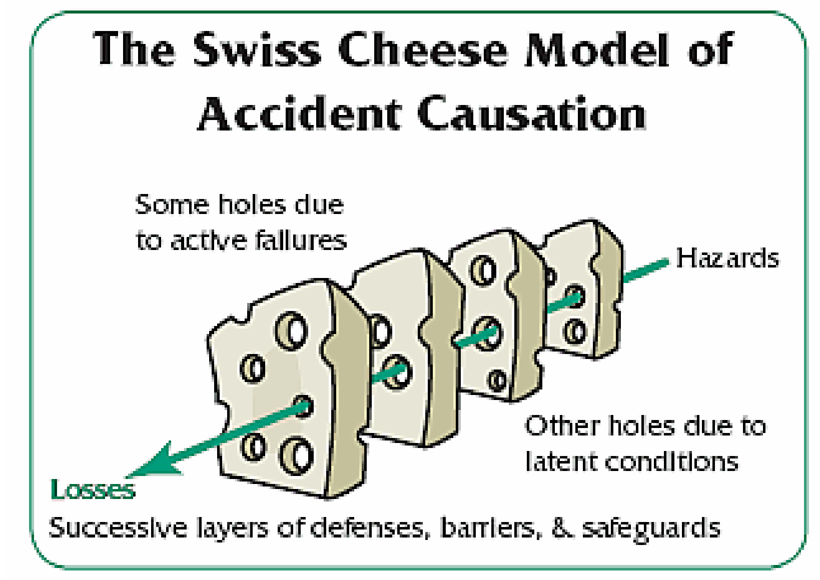
These pilot studies concluded with an array of valuable information to understand where the United States aviation industry is in terms of SMS adoption. The methodology of the study was to identify how well the 22 airports that participated met or exceeded the basic requirements of SMS. After the airports submitted their findings, the FAA found that 47.3% of the participating airports had a written safety policy that would meet the intent of SMS but only 5.9% considered themselves to have an existing SMS plan adopted (FAA, 2008). More importantly, the FAA (2008) also reported that only 7.7% of the airports stated that their written safety policies are effectively communicated to airport employees. It is the accountable executive's duty to make an ongoing commitment to SMS and effectively communicate safety objectives of the organization to all personnel. Of the reporting airports, 83.3% declare that they have an existing organizational structure to manage safety that would assure safety policies and objectives could be disseminated across the organization (FAA, 2008).

The FAA anticipates that the implementation of SMS at airports will provide a systematic, proactive, and well-defined safety program that will allow airport operators to continue to improve safety as passenger traffic grows (FAA, 2007). By first developing SMS in a controlled pilot group, the FAA better understood the experiences of developing the plan at varying activity level airports across the country. This approach gave the FAA ample results to gauge requirements on Airport Operators when developing a general U.S standard on implementation of SMS at airports of varying size and complexity (FAA, 2007). In order for a standard implementation strategy to work, the FAA and airports must first aim to identify gaps in safety requirements from 14 CFR Part 139 to be included in SMS.

The process of identifying existing safety components and comparing them to SMS program requirements is known as gap analysis. Conducting a gap analysis provides an airport operator an initial SMS development plan and roadmap for compliance (FAA, 2007). From this point in the process, this plan should not simply apply guidance to airports but establish benchmarks for safety rules that they may have to comply with. These safety benchmarks should complement the existing U.S. safety requirements in 14 CFR Part 139 and be consistent with Part 139, FAA Advisory Circulars, and the airport's Airport Certification Manual (FAA, 2007). This means that the FAA believes the SMS manual should identify which elements of the airport operator's existing practices and guidance materials currently meet SMS requirements, which elements do not, and how these latter practices and documents will be revised in the future for consistency with the SMS plan to increase safety at airports (FAA, 2007).

The majority of these safety practices may already exist in some form at U.S. airports. The implementation of SMS is not intended to completely change safety requirements and practices but to be a new safety management process, expanding past practices (Ludwig et al., 2007). By implementing a top-down commitment to safety the organization will increase the number of people watching for safety issues thus making it less likely that an accident or incident will occur. This is visually explained through the "Swiss Cheese" model of accidents presented in figure 1. Meaning each layer of the organization is responsible for safety at the airport but has holes that symbolize the potential for safety hazards to slip through. When these layers are unified by SMS principles, it becomes less likely that a hazard makes it though every layer without being identified and mitigated (Transport Canada, 2010).

Figure 1



Source: Transport Canada, 2010

This type of safety approach focuses on layers of safety risk management and eliminates hazards before they develop into something more serious. While SMS unifies these layers it does not add an additional block-all layer, it simply shifts organizational weaknesses into a seamless day-to-day safety operation (Ludwig et al., 2007).

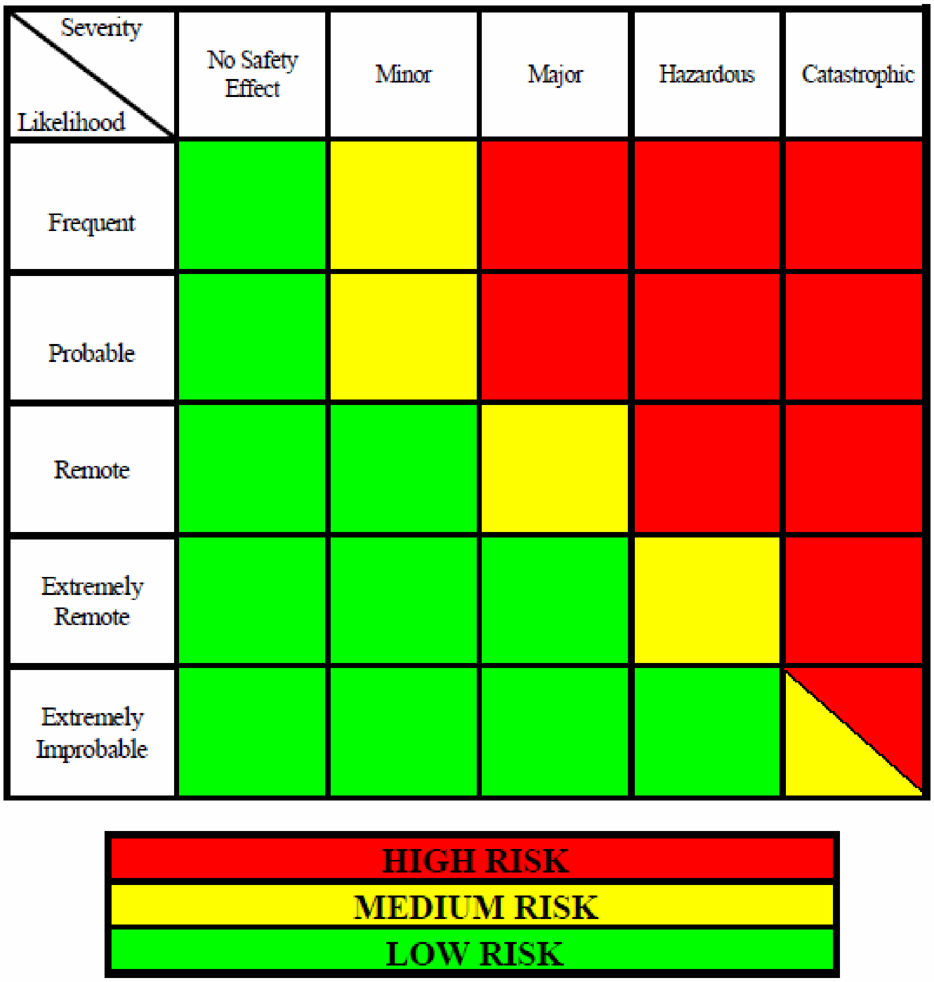
The structure of a successful SMS can take on many forms but the generally accepted standard, including the ICAO recommend format, includes four distinct pillars

(FAA, 2007). These pillars include safety policy and objectives, safety risk management, safety assurance, and safety promotion. To implement a successful SMS an airport must develop strong principles for the safety risk management pillar. Established as the operational core of SMS, safety risk management is the process in which the airport can identify hazards, determine potential risks, and design risk mitigation strategies aimed at avoiding losses that an accident/incident presents (Ludwig et al., 2007). If operational hazards and risks are properly identified through the means of airport inspections and communication, the information can be transferred to upper-level management to ensure unacceptable risks are mitigated.

Upon transfer, the potential consequence of each risk is determined based on severity and likelihood. The output assessment score is then used to rank identified safety risks. In doing so, upper-level management can fully analyze risks and explore all mitigation strategies before choosing their preferred option (Ludwig et al., 2007). Shown in Figure 2 is a risk matrix that is commonly adopted by airports to identify and assess operational hazards.

Figure 2

RISK MATRIX



Severity / Likelihood	No Safety Effect	Minor	Major	Hazardous	Catastrophic
Frequent	🟩	🟨	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Remote	🟩	🟩	🟨	🟥	🟥
Extremely Remote	🟩	🟩	🟩	🟨	🟥
Extremely Improbable	🟩	🟩	🟩	🟩	🟥🟨

🟥 HIGH RISK
🟨 MEDIUM RISK
🟩 LOW RISK

Source: FAA, 2007

After these risks have been assessed and evaluated, safety personnel can then implement any necessary controls to mitigate an unacceptable risk. Determining if a risk is acceptable or unacceptable depends on the consequence level based on the adopted risk matrix. The FAA (2007) defines risk levels to be used in matrices adopted by airports as:

- "High Risk – unacceptable level, the proposal cannot be implemented or the activity continued unless hazards are further mitigated so that risk is reduced to medium or low. Follow-up analysis and hazard tracking is required.
- Medium Risk – acceptable level, minimum acceptable safety objective, actions may be continued but hazard tracking and analysis must be performed.
- Low Risk – target level, acceptable without restriction or limitation, tracking and analysis is not required but documentation in safety database is," (p. 11).

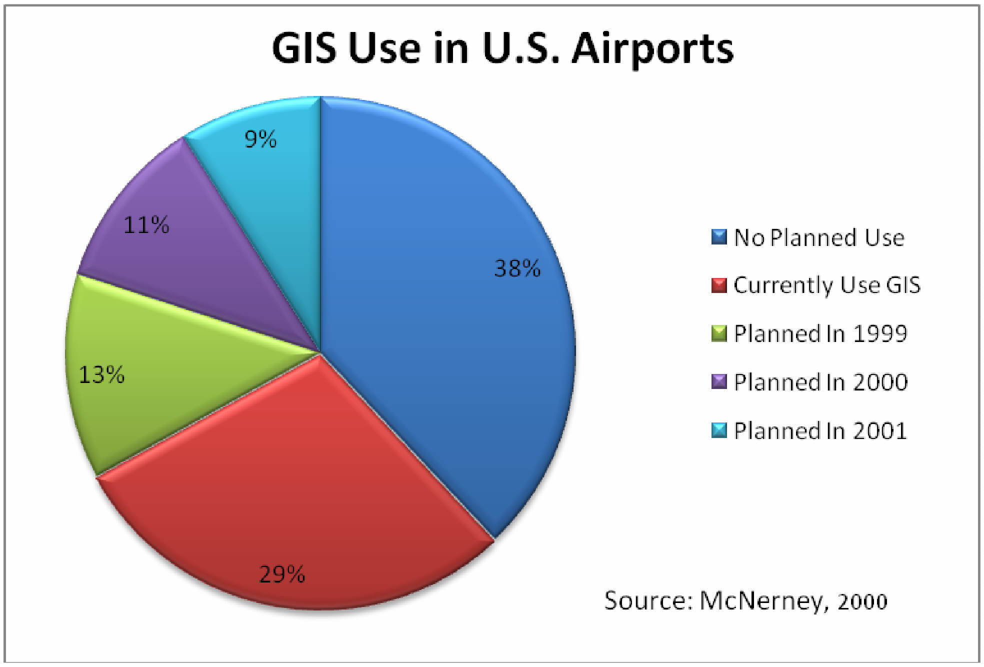
The type and amount of mitigation strategies associated with these risk factors are dependent on the risk level. For instance, any risk identified as high requires immediate termination of activity until the action is changed or mitigated in a way that reduces the risk to acceptable levels. Utilizing a ranking structure as outlined by the FAA allows airport sponsors to focus investments, both in monetary terms and invested manpower, on the risks that pose the greatest threat to the operational safety of the airport. These threats are typically determined using the formula of risk equals probability times severity to understand the determents each risk poses. It is important that airports understand exactly how GIS can help manage the thousands, if not tens of thousands, of safety records that will be stored in local databases as SMS continues to grow within the industry.

GIS

Computer based GIS has been used since about 1960, with similar applications being traced back more than 100 years (Coppock & Rhind, 1991). Although no substantial written documentation can be found, countries across the world were developing a certain “GIS” during this time. Notably, the history of GIS can be broken down into four overlapping phases of development. According to Coppock & Rhind (1991) these phases are: (1) the pioneer research period from the 1950s to about 1975 that included the United States and United Kingdom, (2) the formal research and government funded experiments phase which spanned the years 1973 to the early 1980s, (3) the commencement of GIS commercialization phase which began in 1982, and (4) the user dominance phase that includes corporate databases. Corporate databases can be accessed across networks that are integrated within other technology systems of spatial and non-spatial databases for the use of every individual not just a GIS specialist.

Databases containing locational information allows us to observe, recognize, question, interpret and visualize data in many ways that reveal interactions, patterns and trends in whatever output the user wants (Longley, Goodchild, Maguire & Rhind, 2006). In a survey conducted by McNerney (2000), 38% of reporting U.S. airports stated they had no planned use for GIS. Figure 3 outlines the results of the survey.

Figure 3



Source: McNerney, 2000

Many respondents stated they were unclear on the application of GIS for airports while a few others were apprehensive about the long term return on investment (McNerney, 2000). Like any technology, the advancements in GIS over the last decade have been tremendous and the application to the aviation industry is growing exponentially.

GIS helps users answer questions to unique and often unsolved problems by looking at data in ways that other programs cannot. The usefulness of integrating this technology into an enterprise information system is unrivaled and can be utilized to capture and distribute information instantly across an entire organization. Many airports across the country are realizing the wealth of applications that GIS provides and understand the potential that an enterprise system brings to their day-to-day operations.

Phoenix Sky Harbor International Airport

One of the most recent enterprise GIS solutions was adopted by Phoenix Sky Harbor International Airport in Phoenix, Arizona. Phoenix Sky Harbor is the tenth busiest airport in the world with approximately 100,000 passengers daily (Freeman, 2010). The enterprise system includes tools for aviation department personnel to manage the airport's operations and growing asset base. The data is consists of information such as: aerial photography and digital orthophotos of areas surrounding the airport operations area, aboveground features and underground utilities, a geodatabase with 300 feature classes ranging from smoke detectors and passenger monitors to noise contours and roof prints, interior floor plan data for buildings in an around the airport and integration with many existing information systems (Freeman).

There are about 85 users spanning 10 airport divisions who have no formal training in GIS or information technology but understand the usefulness of the data outputs and access the GIS portal weekly (Freeman, 2010). Since the inception of the enterprise GIS, Phoenix Sky Harbor airport has developed a multitude of user tools to increase safety and productivity at the airport. Examples of the tools that enterprise GIS bring to Phoenix range from operations to signage management.

To assist with the Fiscal Management Department, the GIS department completed a space accounting project that reported discrepancies in actual versus leased square footage that in the past would have been extensive in terms of computations and manpower to produce (Freeman, 2010). Additionally, one of the most critical tools in the GIS interface was the integration with the Aviation Department's work order management system. This allows a maintenance worker to access the portal to find the exact location for his or her work request as well as other issues near his or her work area due for maintenance. This maximizes productivity by combining work order requests to efficiently plan and distribute workers accordingly (Freeman). It is applications like these that allow the Phoenix Aviation Department to utilize GIS and save money. The airport is confident that with increased efficiencies and added tools in the future, GIS will pay for itself in a matter of years (Freeman).

Salt Lake City International

Winter operations is one of the most challenging and expensive times for airports. Accurate traction reporting is vital during these times to maintain a safe operating environment. GIS could allow operators to collect real-time pavement temperature and friction values to make intelligent decisions about when and where to apply de-icing/anti-icing chemicals and remove excess rubber (Lawson, 2009). Not only does this save the airport a vast amount of money in anti-icing chemicals, but, more importantly, it increases operational safety during tough times (Lawson).

Although winter operations are more commonly associated with testing friction values than rubber build up, excess rubber on runways can cause major safety concerns. According to the FAA, airports are required to maintain friction values no less than 0.42 for the standard airport friction tester at a speed of 40 mph to ensure aircraft safety during operation (FAA, 2004). This information can be tested and input into the A-GIS to produce a map of the specific areas where friction values are being affected. For friction evaluation of runway surfaces, accurate locations of values are important for thorough assessment (Ho & Romero, 2007).

Salt Lake City International Airport uses this GIS application to evaluate their pavement friction during both winter and summer operations. By mapping friction values, the airport can identify the friction loss areas and determine potential factors that cause the lower friction in these areas (Ho & Romero). This allows upper management to assess the situation and identify hazardous areas that require mitigation before the hazards cause a serious issue.

Integration of SMS & GIS

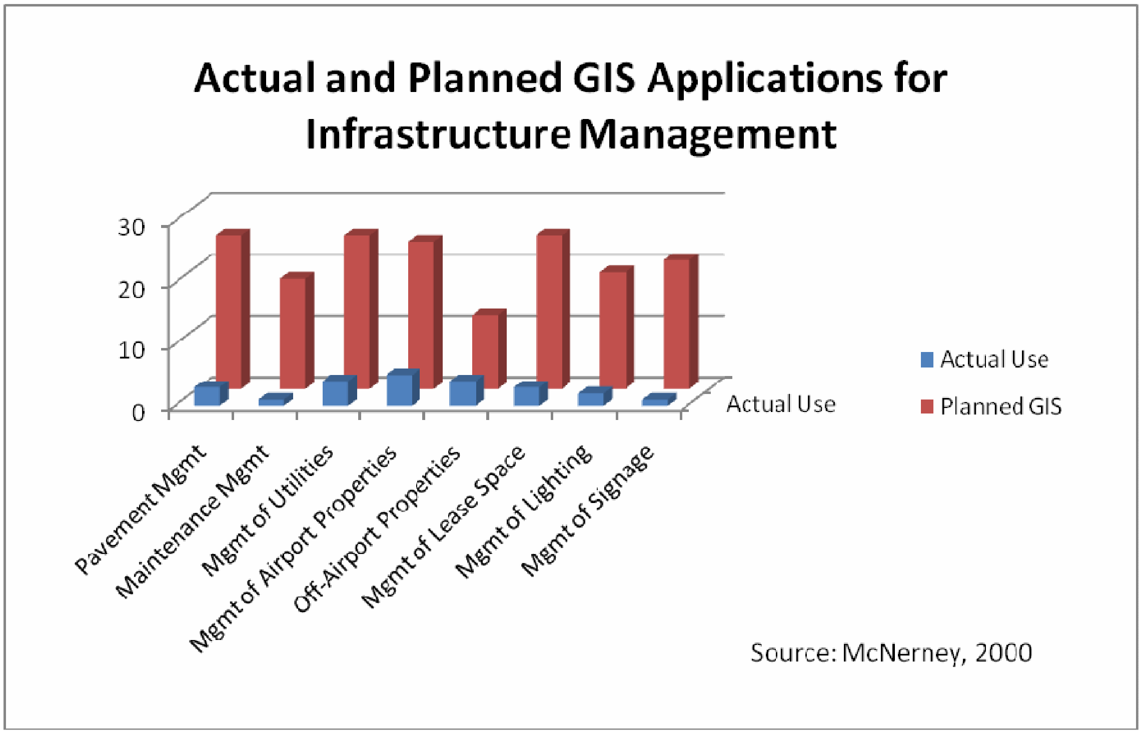
Historically, the data collected in aviation has numerous data gaps in the feeds from different organizations. For example, the FAA censors its data which creates significant data gaps for airports and air carriers (Ayres et al., 2009). A-GIS has been established as the lead provision being used to combat these gaps in data collection. A specific, uniform data format for airport layout plans will be uploaded onto FAA servers and provided to approved stakeholders to close the gaps in data feeds (FAA, 2007). This spatial data will be used to enhance safety practices, map security systems, develop new approach procedures, conduct obstruction analyses, produce utility maps, update airport diagrams and keep airport layout plans current (Nuemann, 2009).

The FAA A-GIS program provides a centralized location for the gathering, coordination, validation, storage, and display of airport data and imagery (FAA, 2007). The FAA has provided three advisory circulars that help airports collect and format the required data for submittal into the A-GIS system. Within these advisory circulars, the FAA establishes general guidance and specifications for the establishment of geodetic control for submission to the National Geodetic Survey (NGS) in AC 150/5300-16, airport imagery acquisition for submission to NGS in AC 150/5300-17, and field data collection and GIS standards in AC 150/5300-18. The use of GIS technology and the A-GIS system will play a major role in the next generation of safety in the aviation industry. As this modernization effort continues, the aviation industry must continue to rely on SMS, integrated safety systems and other proactive means of managing processes to reduce risk and continue superb safety standards.

Due to the recent adoption of NextGen practices, there are no sources that cover them all simultaneously. Although both initiatives have been around for quite some time, the benefit of implementing SMS using GIS is just now being realized. An integrated GIS database that allows airport personnel to query and manipulate airport related data will reduce costs to airports, air carriers, government agencies and aviation users. Creating a database that contains the information normally collected at an airport and that is readily available to personnel, will allow them to make queries and more informed decisions.

The objective would be to use the integrated information system for daily database management and maintenance but utilize GIS as a portal into this integrated system to improve the way airports are managed and operated (Carlson, 2009). GIS can support safety efforts by identifying potential points of failure and risk before a critical incident occurs. Airport's can use enterprise GIS to support efforts in planning, operations, maintenance and safety/security by adding spatial information and modeling in their continued effort to provide a safe operating environment (ESRI, 2010). Many airports are currently planning to utilize GIS throughout various departments to improve the efficiency and effectiveness of their employees. Figure 4 outlines which airport departments plan to use GIS.

Figure 4



Source: McNerney, 2000

A totally integrated airport can use GIS in SMS by applying the powerful analytical tools to daily applications for airport personnel. These applications include: daily airfield inspections, runway condition reporting, wildlife reporting, environmental inspections, vehicle inspections and data management and tracking. Safety inspections for airports can be completed more efficiently and effectively utilizing an airport GIS to understand existing vulnerabilities and pinpoint trends in safety incidents (ESRI, 2010).

Properly integrated, data-rich, GIS systems provide a tool for airport managers to understand how events relate to each other and the potential risk they present at the airport in the future (ESRI, 2007). To increase situational awareness of airport safety, GIS provides managers with spatial analysis and risk exposure maps that are associated with every accident and incident logged within the database. By utilizing information integration within GIS an airport can increase geocentricity, which is the ability to consume spatially oriented data within the activity workflow, to improve safety functions through predictive risk modeling based on historical and real-time data (ESRI, 2007).

Examples of airports that use GIS for information system integration include Baltimore-Washington International Thurgood Marshall, Southwest Florida International, Denver International, Orlando International and Philadelphia International. These airports use spatial analysis tools to more efficiently and effectively manage operational characteristics ranging from document and inspection management to airport layout and asset tracking analysis (Carlson, 2009). It is important to understand how to gauge efficiency and effectiveness benefits when utilizing GIS for airport management.

Simply put, efficiency benefits are seen when GIS is used to do an assignment previously completed without GIS and effectiveness benefits are realized when the quality of the output is improved using the technology (Gillespie, 1991). Also, effectiveness benefits can be observed when that airport produces an output using GIS that previously was not able to be done. Knowing this, the answer to measuring benefits is to identify the changes resulting from GIS. For efficiency, the output of the GIS project may be the same as the output of the project done manually but it is the resources needed to produce that output that show the benefits (Gillespie). An example would be the reduction in personnel costs and hours that would be invested in a project to manually complete difficult tasks related to mathematics, mapping and querying information. Integrating these tasks into GIS significantly reduces the number of personnel and man-hours spent to complete the same work and provided the same output.

Historically it is hard to measure effectiveness benefits but with GIS these benefits can be seen. Effectiveness increases when the output has changed in a way that the value of the output affects the user positively (Gillespie). If the output is presented in a way that could not have been done without using GIS, then it is an effectiveness benefit. An example of this would be the production of a population-at-risk map for specific routes that are being considered for hazardous material transport (Gillespie). Without GIS, there is no way to generate an accurate map of this type.

HOW TO ADVANCE SMS UTILIZING A-GIS – A CASE STUDY

This section provides an overview of the potential that airports could realize in taking A-GIS initiatives a step further by creating spatially oriented safety databases for SMS. It will begin by providing an overview of Will Rogers World Airport. After the case study airport is described, the definitions of the major concepts that were used to create the safety database will be presented. Finally, multiple scenarios with graphical representations of potential outputs from the safety database will be presented to illustrate a spatially oriented safety database.

Will Rogers World Airport

Will Rogers World Airport, or Will Rogers, is located in Oklahoma City, Oklahoma approximately 6 miles from downtown. The airport is owned by the City of Oklahoma City and leased to the Oklahoma City Airport Trust which acts as the principal sponsor for the management and oversight of the airport facilities (Will Rogers World Airport, 2010). Will Rogers is comprised of three major runways, two 9,800 ft parallel runways and one 7,800 crosswind runway. In 2010, the number of operations at the airport exceeded 120,000 (Will Rogers World Airport).

Representing the bulk of these operations are six commercial service air carriers that have daily departures to 19 nonstop destinations (Will Rogers World Airport, 2010). Other operators at the airfield include freight, military and corporate jets that help maintain the operation of 67 companies which employ over 10,000 people. Recently, the airport was chosen as one of five airports to participate in the FAA's A-GIS pilot study.

The pilot project consists of three parts: (1) obtaining high resolution aerial photography of the airport; (2) performing an accurate, detailed survey of the airport; and (3) digitizing all relevant airport features along with inputting attributes to describe the features (Will Rogers World Airport, 2010). By completing these project tasks, the airport will be digitized using ortho-rectified aerial imagery that is displayed accurately to a three inch pixel resolution. Using an airport that is currently undergoing such a leading edge GIS initiative was imperative for this case study. Accurate base layers allowed for the seamless integration of the created safety database for data mining and map output.

The spatial database that was created for this case study includes information that is typically found in various safety reports that airports file separately. Some of the common information from these reports has been integrated into one format for the creation of a single database for detailed extraction of data. Before presenting the SMS scenarios for this case study, it is vital that the definitions of key terms within the database be given for complete understanding of the outputs. The safety dataset contains multiple attributes that makeup the data that a user can query and display for analysis. Each of these attributes contains important metadata that users must understand in order to verify that they are properly analyzing the data.

Specifically, runway incursion types, runway incursion severity and risk categories all have separate but very vital subcategories for properly ranking and mitigating potential safety risks. The definition of high, medium and low safety risks for SMS has already been provided and maintained within the dataset. However, both runway incursions and surface incidents are classified by incursion type with incursions being further classified by level of severity. These types include operational errors, pilot deviations and vehicle/pedestrian deviations. As summarized by the FAA (2009) the definitions for incursion types are as follow:

- "Operational Error is an action of an Air Traffic Controller that results in less than the required minimum separation between two or more aircraft, or between an aircraft and obstacles (including vehicles, equipment and personnel on runways)
- Pilot Deviations is the action of a pilot that violates any Federal Aviation Regulation
- Vehicle/Pedestrian Deviation is an incident that includes pedestrians, vehicles or other objects interfering with aircraft operations by entering or moving on the runway movement area without authorization from ATC," (p. 1).

On October 1 2007, the FAA revised its definition of a runway incursion by adopting ICAO's characterization as any unauthorized intrusion onto a runway (FAA, 2007). By doing so, the entire aviation industry accepts a single definition for an incursion aimed at aiding the determination of common factors that contribute to these incidents. Incidents in the past that would have been classified as surface incidents are now considered category C or D runway incursions (FAA, 2007). A surface incident is "any event where unauthorized or unapproved movement occurs within the movement area, or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight," (FAA, 2009, p. 1).

The severity of incursions is classified using A, B, C or D. Each classification represents a different level of severity with A being the most severe and D being the least. By definition, a category D incursion has little or no chance of collision but meets the definition of a runway incursion, category C is a loss in separation but ample time and distance to avoid a collision is maintained, category B is separation decreases and there is a significant potential for collision and category A is lost separation with participants taking extreme action to narrowly avoid a collision (FAA, 2009). The distinction between these subcategories is of great importance because they affect the way the data is coded and queried.

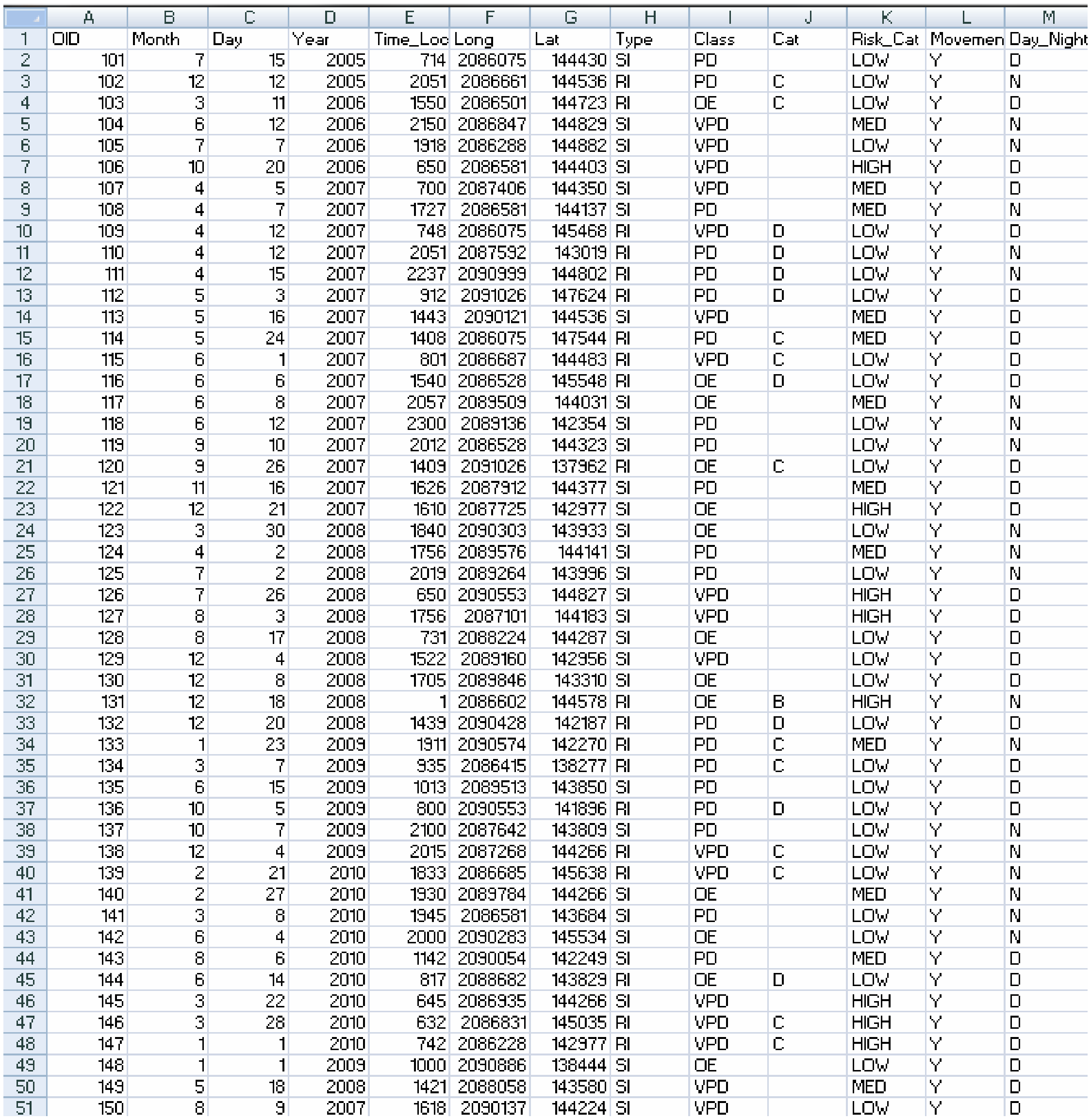
Scenarios

Casual factors of airport accidents and incidents, and the effectiveness of adopted mitigation strategies, can be fully understood and evaluated only if occurrence is examined in terms of type of event, conditions during that time, and location (Ayres et al., 2009). Understanding the relationships between and within safety records not only allows for more detailed investigation but also provides a means for the identification of commons causes over time. Inputting safety data into an A-GIS system provides airport personnel an efficient and effective way for accurately surveying hazard information for risk monitoring, forecasting, program evaluation, policy analysis, risk assessment and root-cause analysis. In order for airport management to adopt the most effective mitigation strategies for SMS, they must not only understand what each occurrence is and how it relates to daily operations, but where these occurrences are taking place. This situation is the foundation for the first SMS/A-GIS scenario.

Scenario 1

At the fundamental level, airports that choose to port their safety database from paper/electronic excel format into an A-GIS system allow their personnel the ability to instantly depict what they are viewing for clarity. Figure 5 represents what a current electronic safety database may look like for airports. Here, viewers may not understand what exactly the data represents and how to develop conclusions on the relationships that are present within the information. Also, it is important to note that this database only contains 50 records. Imagine trying to locate information for a specific record when the database contains 1000 or 10,000 records.

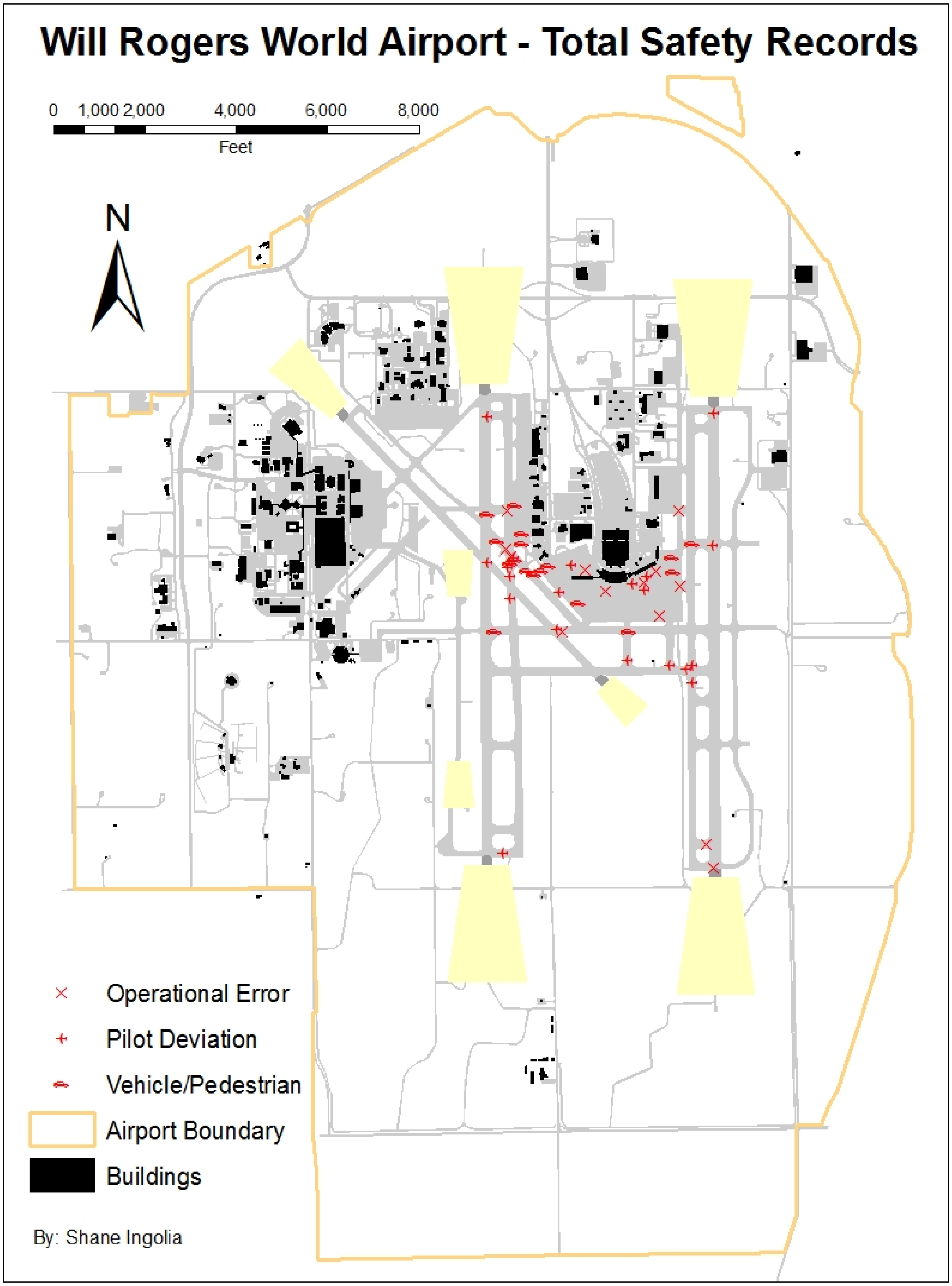
Figure 5



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	OID	Month	Day	Year	Time_Loc	Long	Lat	Type	Class	Cat	Risk_Cat	Movemen	Day_Night
2	101	7	15	2005	714	2086075	144430	SI	PD		LOW	Y	D
3	102	12	12	2005	2051	2086661	144536	RI	PD	C	LOW	Y	N
4	103	3	11	2006	1550	2086501	144723	RI	OE	C	LOW	Y	D
5	104	6	12	2006	2150	2086847	144829	SI	VPD		MED	Y	N
6	105	7	7	2006	1918	2086288	144882	SI	VPD		LOW	Y	N
7	106	10	20	2006	650	2086581	144403	SI	VPD		HIGH	Y	D
8	107	4	5	2007	700	2087406	144350	SI	VPD		MED	Y	D
9	108	4	7	2007	1727	2086581	144137	SI	PD		MED	Y	N
10	109	4	12	2007	748	2086075	145468	RI	VPD	D	LOW	Y	D
11	110	4	12	2007	2051	2087592	143019	RI	PD	D	LOW	Y	N
12	111	4	15	2007	2237	2090999	144802	RI	PD	D	LOW	Y	N
13	112	5	3	2007	912	2091026	147624	RI	PD	D	LOW	Y	D
14	113	5	16	2007	1443	2090121	144536	SI	VPD		MED	Y	D
15	114	5	24	2007	1408	2086075	147544	RI	PD	C	MED	Y	D
16	115	6	1	2007	801	2086687	144483	RI	VPD	C	LOW	Y	D
17	116	6	6	2007	1540	2086528	145548	RI	OE	D	LOW	Y	D
18	117	6	8	2007	2057	2089509	144031	SI	OE		MED	Y	N
19	118	6	12	2007	2300	2089136	142354	SI	PD		LOW	Y	N
20	119	9	10	2007	2012	2086528	144323	SI	PD		LOW	Y	N
21	120	9	26	2007	1409	2091026	137962	RI	OE	C	LOW	Y	D
22	121	11	16	2007	1626	2087912	144377	SI	PD		MED	Y	D
23	122	12	21	2007	1610	2087725	142977	SI	OE		HIGH	Y	D
24	123	3	30	2008	1840	2090303	143933	SI	OE		LOW	Y	N
25	124	4	2	2008	1756	2089576	144141	SI	PD		MED	Y	N
26	125	7	2	2008	2019	2089264	143996	SI	PD		LOW	Y	N
27	126	7	26	2008	650	2090553	144827	SI	VPD		HIGH	Y	D
28	127	8	3	2008	1756	2087101	144183	SI	VPD		HIGH	Y	D
29	128	8	17	2008	731	2088224	144287	SI	OE		LOW	Y	D
30	129	12	4	2008	1522	2089160	142956	SI	VPD		LOW	Y	D
31	130	12	8	2008	1705	2089846	143310	SI	OE		LOW	Y	D
32	131	12	18	2008	1	2086602	144578	RI	OE	B	HIGH	Y	N
33	132	12	20	2008	1439	2090428	142187	RI	PD	D	LOW	Y	D
34	133	1	23	2009	1911	2090574	142270	RI	PD	C	MED	Y	N
35	134	3	7	2009	935	2086415	138277	RI	PD	C	LOW	Y	D
36	135	6	15	2009	1013	2089513	143850	SI	PD		LOW	Y	D
37	136	10	5	2009	800	2090553	141896	RI	PD	D	LOW	Y	D
38	137	10	7	2009	2100	2087642	143809	SI	PD		LOW	Y	N
39	138	12	4	2009	2015	2087268	144266	RI	VPD	C	LOW	Y	N
40	139	2	21	2010	1833	2086685	145638	RI	VPD	C	LOW	Y	N
41	140	2	27	2010	1930	2089784	144266	SI	OE		MED	Y	N
42	141	3	8	2010	1945	2086581	143684	SI	PD		LOW	Y	N
43	142	6	4	2010	2000	2090283	145534	SI	OE		LOW	Y	N
44	143	8	6	2010	1142	2090054	142249	SI	PD		MED	Y	D
45	144	6	14	2010	817	2088682	143829	RI	OE	D	LOW	Y	D
46	145	3	22	2010	645	2086935	144266	SI	VPD		HIGH	Y	D
47	146	3	28	2010	632	2086831	145035	RI	VPD	C	HIGH	Y	D
48	147	1	1	2010	742	2086228	142977	RI	VPD	C	HIGH	Y	D
49	148	1	1	2009	1000	2090886	138444	SI	OE		LOW	Y	D
50	149	5	18	2008	1421	2088058	143580	SI	VPD		MED	Y	D
51	150	8	9	2007	1618	2090137	144224	SI	VPD		LOW	Y	D

As long as the airport management and the safety team invest in the fact that locational data must be attached to every safety record that is input into the database, the output transforms from the unclear, numerical representation into an informative graphical illustration as presented in Figure 6.

Figure 6

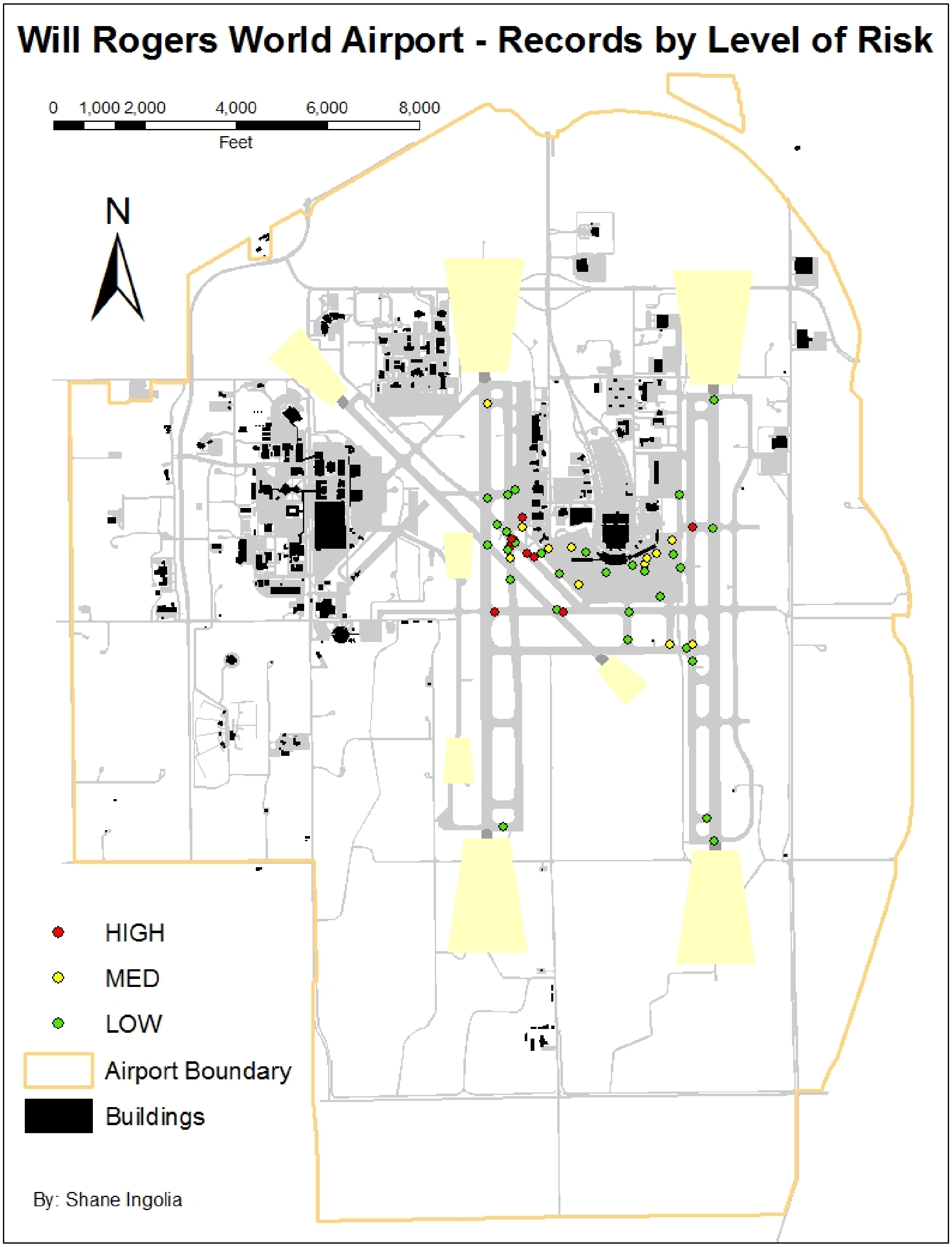

Will Rogers World Airport - Total Safety Records
0
1,000
2,000
4,000
6,000
8,000
Feet
N
Operational Error
Pilot Deviation
Vehicle/Pedestrian
Airport Boundary
Buildings
By: Shane Ingolia

Scenario 2

Hazards are identified through a means of reporting occurrences after an individual witnesses them or through identification during the SRM process. Either way, each record must be classified and prioritized to ensure airport management that mitigation resources are used to their fullest potential. Corrective action must be taken for all risks identified as high, whereas low risk is acceptable without restrictions. Understanding where these risks are located assist the safety team in developing risk control strategies that may lower risks to acceptable levels or eliminate them all together. SMS/A-GIS helps coordinate this prioritization by mapping safety records to allow for convenient identification and tracking measures. If utilized in an enterprise system, a real-time data update could present hazards and their associated risk levels as soon as they are entered into the safety database. Figure 7 illustrates the safety records at Will Rogers displayed by their risk classification.

Generation of a map of this type will allow airport personnel to identify the safety record, review the metadata it contains, recognize exactly where the incident happened and change the corresponding risk level after mitigation measures have been completed and the risk classified as acceptable.

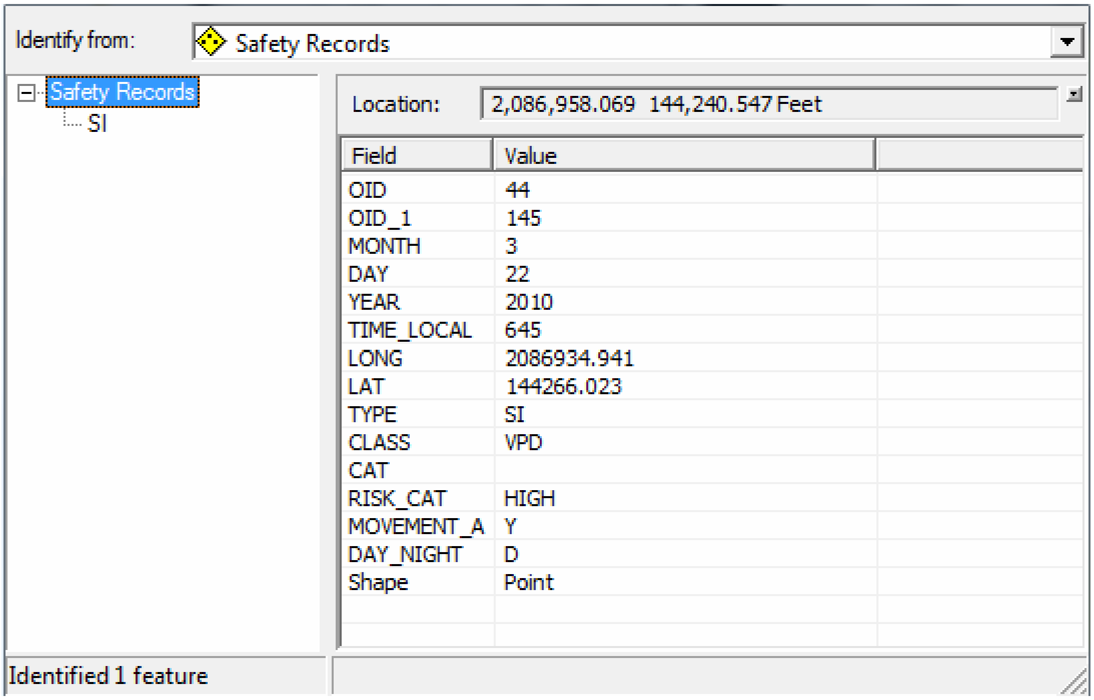
Figure 7


Will Rogers World Airport - Records by Level of Risk
0
1,000
2,000
4,000
6,000
8,000
Feet
N
HIGH
MED
LOW
Airport Boundary
Buildings
By: Shane Ingolia

Scenario 3

As a follow-up to mapping every safety record across the entire airport, safety personnel must be able to easily identify and extract data about a specific record. After the data is input into the A-GIS system, a single record can be located by searching the database or using the identify tool. When the record is located, all of the attribute data attached to the record will be displayed for analysis and assessment. As information changes through mitigation and follow-up, the SMS coordinator can change the attribute data by simply editing each input. Illustrated in Figure 8 is the window displaying record data for a single hazard in the Will Rogers database.

Figure 8



Location: 2,086,958.069 144,240.547 Feet

Field	Value
OID	44
OID_1	145
MONTH	3
DAY	22
YEAR	2010
TIME_LOCAL	645
LONG	2086934.941
LAT	144266.023
TYPE	SI
CLASS	VPD
CAT	
RISK_CAT	HIGH
MOVEMENT_A	Y
DAY_NIGHT	D
Shape	Point

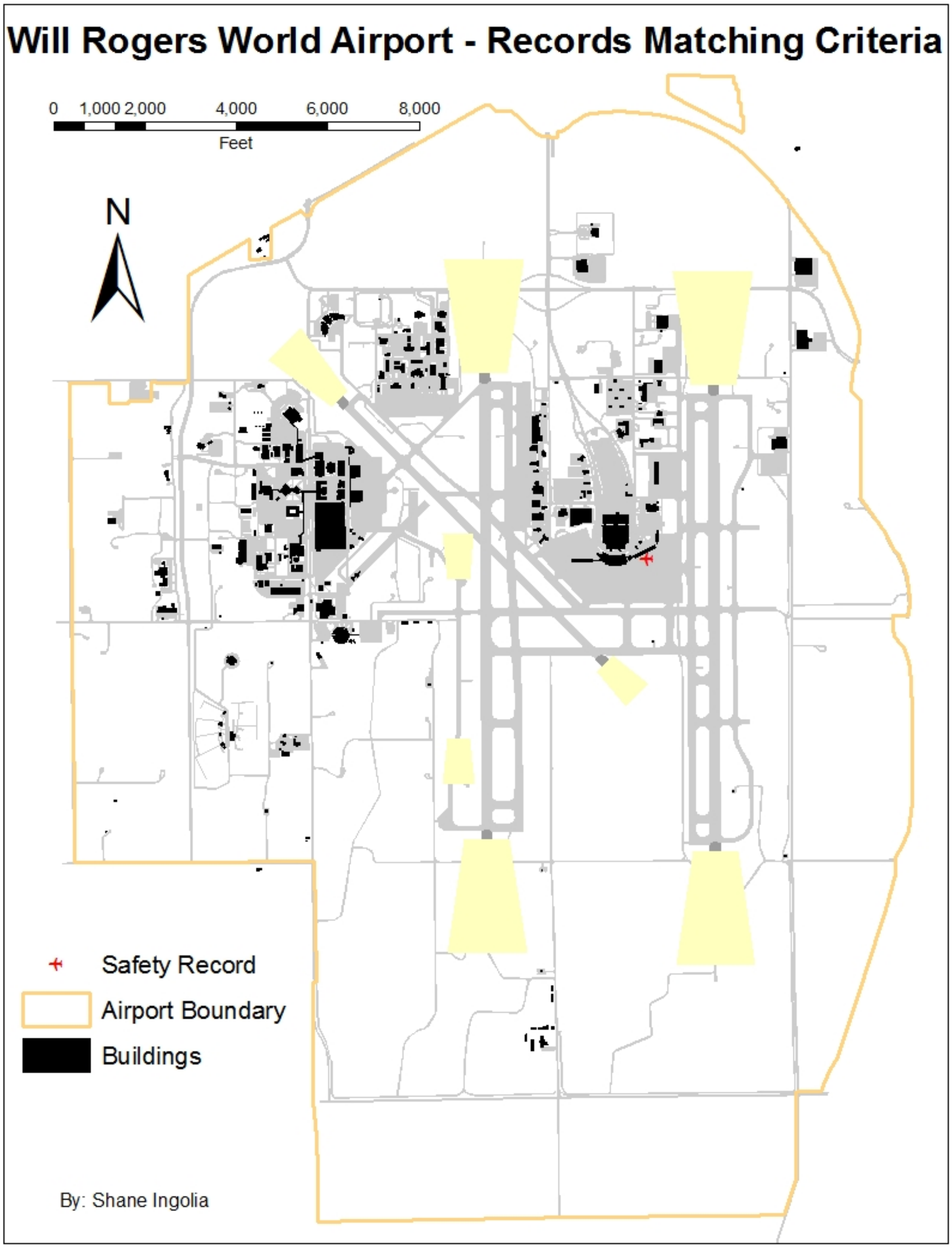
Identified 1 feature

Scenario 4

As time passes and SMS is well established in the operating environment at U.S. airports, more and more safety records will be stored within airport databases. Airports must be able to quickly and accurately query these databases to extrapolate relationships and common factors that may span over many years. Using SMS/A-GIS, airport management would be able to select safety data that meet specific criteria. This enables individuals to identify common characteristics within hazards and determine the root cause of accidents, incidents, and incursions. In doing so, a corrective action plan may be developed and implemented for a hazard that you may not otherwise "see" by simply looking at monthly or yearly data. These hazards may relate to specific situations that change like weather, equipment, seasons or personnel.

Figure 9 displays a map with safety records that meet these criteria: a date of 2008, at night, and medium risk. The usefulness of this type of search criteria is unparalleled and can be accomplished in a matter of minutes. This gives airport management an understanding if each hazard is a single incident in time or complex web of interrelationships that require a change in airport procedures or processes to eliminate the associated risks. In time, airports will require a means to query on-going databases and SMS/A-GIS provides that.

Figure 9


Will Rogers World Airport - Records Matching Criteria
0
1,000
2,000
4,000
6,000
8,000
Feet
N
Safety Record
Airport Boundary
Buildings
By: Shane Ingolia

Scenario 5

One of the biggest components of SMS is trend analysis. Trend analysis identifies changes in safety levels over specific periods of time in order to gauge safety performance at the airport (Ayres et al., 2009). This tool provides a snapshot of the safety levels at the airport and identifies if the SMS needs to be audited to determine if action is required for improving safety. After the specific safety objectives of the airport are determined, the safety team can create charts that depict safety levels based on identified indicators like total safety records or more specific indicators like safety incursions or surface incidents. Figure 10 and 11 shows a trend analysis report for the total number of identified hazards by year and total number by record type.

Figure 10

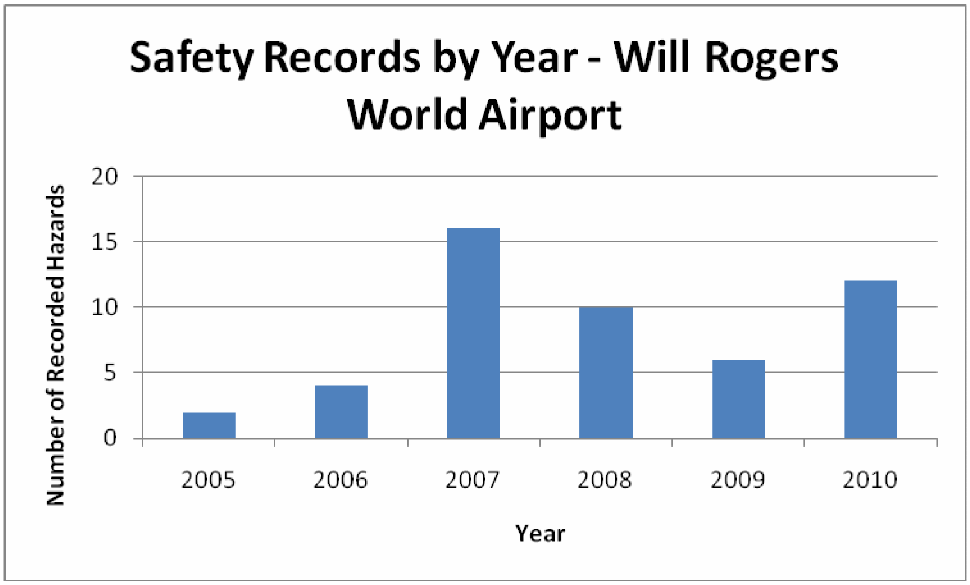
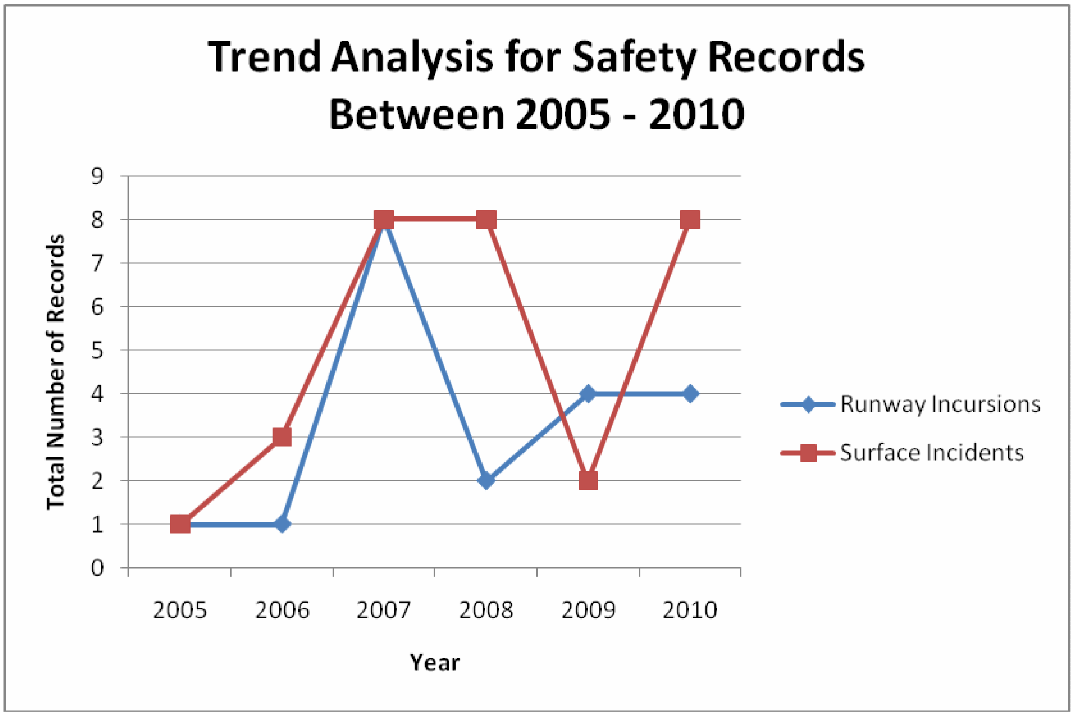


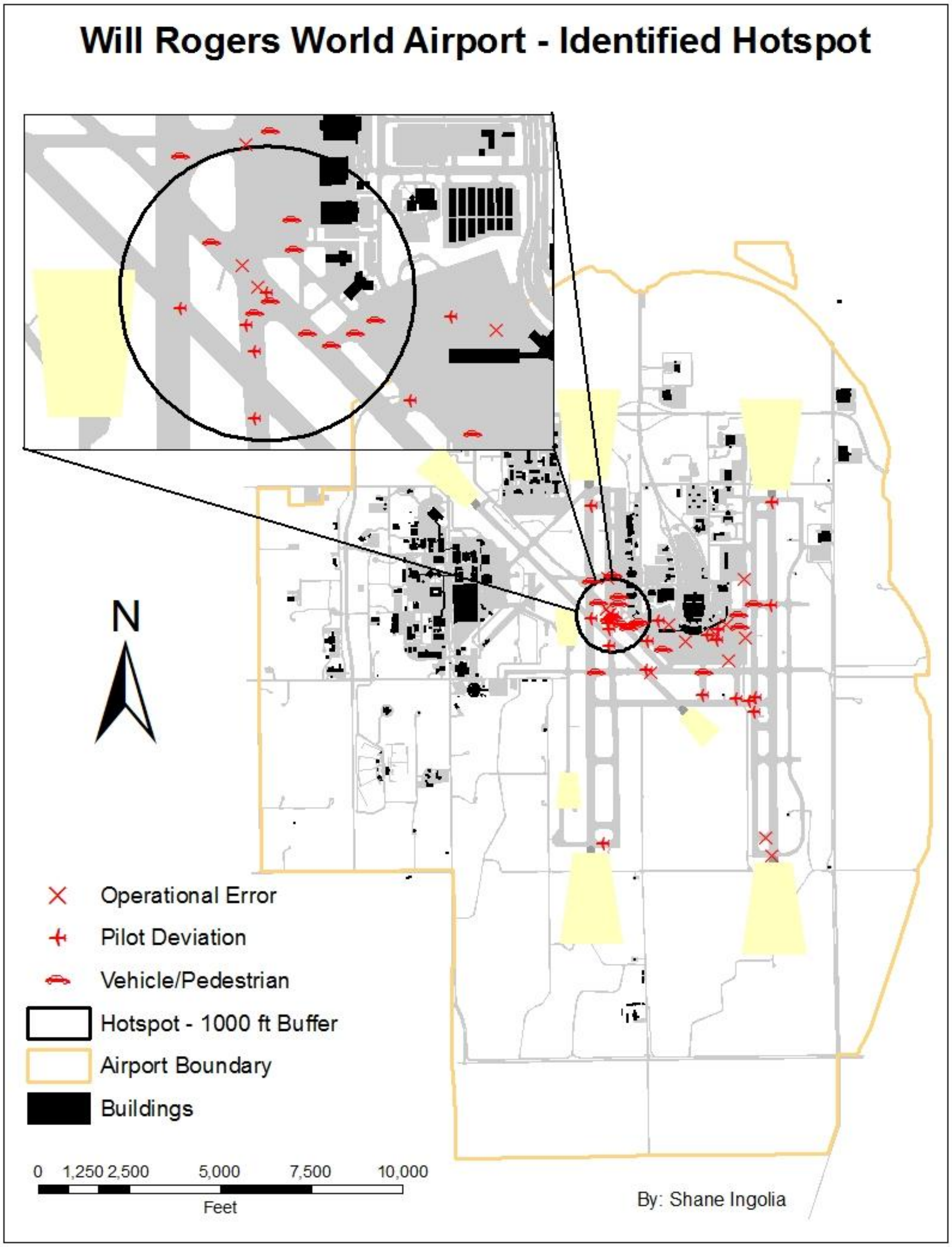
Figure 11


Trend Analysis for Safety Records Between 2005 - 2010
Total Number of Records
0
1
2
3
4
5
6
7
8
9
2005
2006
2007
2008
2009
2010
Year
Runway Incursions
Surface Incidents

Scenario 6

The last scenario is a hot spot analysis. Hot spots are concentrations of incidents within a limited geographic area that appear over time. The FAA has adopted the ICAO definition of a hotspot as "a location on an aerodrome movement area with a history or potential risk of collision or runway incursion, and where heightened attention by pilots and drivers is necessary," (FAA, 2010, p. 1). There are particular environments at airports that may attract specific hazards or concentrations of risks that need to be identified and analyzed. Indentifying these areas makes it easier for management to plan the safest path of movement for aircraft, operations vehicles and personnel (FAA, 2010). Understanding how to implement this tool within the SMS/A-GIS environment gives airport operators another layer of safety for daily operations in the movement area. Figure 12 depicts identified hotspots on the Will Rogers airfield that may be submitted airport management, commercial service providers and the FAA for further publication to increase safety awareness in high risk areas at the airport.

Figure 12


Will Rogers World Airport - Identified Hotspot
N
Operational Error
Pilot Deviation
Vehicle/Pedestrian
Hotspot - 1000 ft Buffer
Airport Boundary
Buildings
0
1,250
2,500
5,000
7,500
10,000
Feet
By: Shane Ingolia

CONCLUSION

The current FAA initiatives for both SMS and A-GIS are truly leading edge. The ability of both programs to be customized to fit the needs of each airport, have limitless applications for reducing hazards found at airports and increase safety. With proper investment from upper management, airports across the country can realize the benefits presented through this work. The preliminary findings presented here merely scratch the surface of the potential that combining SMS into the framework of A-GIS has. Giving airport operators the ability to query large safety databases and flag safety records that need mitigation is a specification that needs to be adopted by every airport implementing SMS at their facility.

The production of multi-layered maps enabling airport management to prioritize mitigation strategies is essential for the next generation of aviation safety. By adopting SMS/A-GIS principles, stakeholders can access data, from the convenience of any computer on the enterprise network that is centrally located and maintained with accurate, consistent and current in real time. This gives safety personnel the ability to consume system-wide information while analyzing and assessing safety records at the airport.

Consuming spatially oriented SMS data across the entire airport allows safety coordinators to extrapolate trends and anomalies over time that may otherwise not be "seen". Using GIS analysis, these trends may answer questions such as, (1) is there a history of similar occurrences or is this an isolated incident, (2) what other equipment of the same type has been involved in incidents before, (3) is it a specific area of the airfield that presents hazards that management need to investigate, and (4) is there a specific correlation with airport assets, like signage, that are causing similar incursions over time. Being able to recognize a root cause for identified hazards at airports that may span months increases the safety of airport operations.

Future directions of this research include expanding the database to include attributes such as equipment involved, personnel ID number, cost data, weather data, pilot information, environmental impact information and more. Another major direction for future work is the inclusion of the ArcGIS tracking analyst. With this extension, airports would be able to visualize and analyze temporal data based on position and attributes for real-time analysis (ESRI, 2003). Being able to record, play back and review spatio-temporal safety data is another potential layer in the safety matrix with major implications for NextGen. This ability will give the entire industry the chance to review the real-time historical event as long as it is stored within the database.

Additionally, airport management may also decide to use spatial statistical tools within their GIS software to test the significance of spatial clusters. A prime example would be to extend the hotspot analysis further by utilizing spatial statistics to determine the Getis-Ord Gi* statistic. This analysis creates a Z score and P-value for the safety feature class that will represent the significance of the spatial clustering values. A high Z score and small p-value indicates a spatial clustering of high values (hotspot) while a low negative Z score and small p-value indicates a spatial clustering of low values (coldspot) (ESRI, 2010). Airport sponsors can use these outputs of hotspots and coldspots to show the significance of hazardous clusters at their airport. Statistical significance of incident clustering may prove extremely beneficial when airports begin submitting requests for SMS related capital improvements.

As mentioned before, the potential is limitless for combining SMS within A-GIS initiatives. Many key features of SMS can be enhanced through the tools provided by A-GIS. Efficiency and effectiveness benefits will be explicit for airport management as soon as the system goes online. Giving airports the ability to do more with less is essential in today's economic environment and utilizing A-GIS for SMS oversight provides that.

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