# GIS-BASED APPLICATIONS IN AIRFIELD INFRASTRUCTURE SYSTEM MANAGEMENT AND MAINTENANCE

**PAPER 08-0902**

By

Chun-Hsing Ho, Ph. D. Candidate
Department of Civil and Environmental Engineering
The University of Utah
104 CME, 122 South Central Campus Drive
Salt Lake City, Utah, 84112
(801) 581-6931
Email: chunhsing.ho@utah.edu

Pedro Romero, Ph.D., P.E.
Department of Civil and Environmental Engineering
The University of Utah
104 CME, 122 South Central Campus Drive
Salt Lake City, Utah, 84112
(801) 587-7725
Email: romero@civil.utah.edu

Submitted for presentation and publication to the
2008 Transportation Research Board Annual Meeting
Washington, D.C.
Original: July 15, 2007
Revised: October 15, 2007

Abstract: 320
Text: 5,348
Figures: 6@250=1,500
Tables: 0
Total: 7,168

## ABSTRACT

This paper discusses some new GIS applications in airfield infrastructure system management and maintenance. Aviation activities have been steadily increasing and U.S. airport facilities must provide higher service quality and increase capacities to accommodate the projected aviation growth. In response to the increasing requirements from passengers and airliners, efficiency is the most important factor in airport operations and airfield facilities maintenance. More and more airport authorities, particularly at large commercial airports, have understood the benefits in using GIS-based programs to plan and manage their airport facilities. An integrated GIS system combining with GPS and PDA provides a very powerful tool that helps airport operators and engineers improve regular airfield inspection, management, and reporting processes, resulting in a more efficient airport operation system. This paper introduces the GIS applications associated with other tools and aims to provide airport personnel with several GIS approaches and techniques in an easy-to-learn manner. It is intended to help airports improve current airfield facilities inspection processes and maintenance mechanisms. An implementation plan achieved at Kaohsung International Airport (KHH), Taiwan was used to demonstrate how an integrated GIS system can help airport operators and engineers receive real-time facilities data, evaluate deterioration degrees, and make policy decisions of maintenance and rehabilitation within a short time. This implementation plan is designed in a step-by-step basis that allows airport personnel to easily follow and apply them to airport practice. Another example carried out at the Salt Lake City International Airport (SLC) was used to show GIS applications in facilitating skid resistance evaluation of runway surfaces. By adding projection data to the airport image, SLC airport maintenance crews can graphically evaluate friction capacities of runway 16L-34R and investigate potential factors that result in a reduction of skid resistance. The objective of this paper is to show up-to-date GIS application approaches for airport personnel to develop a suitable GIS system that enables airports to improve their airport operation systems and increase aviation safety.

## INTRODUCTION

Geographic information system (GIS) has been widely applied in numerous areas across the world. More and more airport authorities, particularly at large commercial airports, have understood the benefits in using GIS-based programs to plan and manage their airport facilities. For example, the Orlando International Airport (MCO) authority initially developed a single GIS application to assist its staff in managing airport operations and has integrated original applications with other CAD programs resulting in an airport-wide GIS integration system [1]. Dallas-Fort Worth (DFW) International Airport has also developed GIS applications for the mapping and management of all underground utilities and for planning, managing, and integrating its airfield pavement system with other GIS applications [2] [3]. The recent advances in using GIS-based computer programs associated with Personal Digital Assistants (PDAs) and Global Positioning System (GPS) receivers at airports have been studied and resulted in several new applications for improving airport pavement management, airport operations, as well as aviation safety [4][5]. In the past years, airport authorities have been recognizing the need to perform faster and comprehensive pavement evaluations by using an integrated GIS system. Denver International Airport (DEN), for instance, has embarked on a comprehensive pavement evaluation program using GIS applications associated with portable personal computers (TabletPC) to update and inspect the existing pavement system [6]. These approaches provide airport authorities with opportunities for developing/utilizing practical GIS-based computer systems that allow airport operators/airfield inspectors to connect airfield inspection input with their GIS databases. Ideally, a GIS-based system not only applies in airfield pavement systems, but it also effectively facilitates enhancements of airport facilities on airfield pavements such as lights, markings, signs, navigation equipment, etc. An integrated GIS-based program associated with GPS and PDA (or TabletPC) can be a very powerful tool for airport personnel to develop their individually workable GIS systems, manage airfield inspection input, and effectively maintain airport facilities and equipment. Existing GIS-based computer systems can be useful in facilitating improvements of airfield pavement/facilities management and construction/maintenance estimates, which help turn daily airfield inspections into a simple, rapid and efficient task.

The national forecast for FAA towered airports reflected in "*FAA Aerospace Forecasts, Fiscal Years 2007-2020*" [7] shows aircraft operations growing at an average annual rate of 2.0 percent over the 14-year forecast period. Without a doubt, airport operation mechanisms including airfield pavement management, airport facilities inspections, and maintenance will become more important in order to provide proper service capabilities for aircraft operations and meeting public expectations as well as aviation standards. Keeping and maintaining airport infrastructure systems in an adequate condition for safely serving passengers and aircraft becomes a crucial element that airport authorities have been dealing with. Airlines are looking for airports where their airplane fleets can maneuver fast and safely so that airlines can accommodate an increase in their scheduled flights. At the same time, airports must make efforts to compete with nearby regional/international airports by providing aircraft and passengers with efficient operational services and a safety environment in order to recruit airliners to increase/establish their scheduled flights. In doing so, both airport and airlines can mutually benefit by increased profits. Under such aviation competing trends, the key point to maintain an airport's competitiveness is its service efficiency provided for passengers and aircraft. This is accomplished by rapidly and accurately evaluating airport facilities and repair deteriorations as soon as possible. As a result, airlines and passengers are satisfied with airport services leading aviation activities to significant progress.

## GIS APPLICATION APPROACHES

This paper, based from the point of view of airport operators, aims to present several GIS application approaches using a GIS computer program to provide airport authorities with practical guidelines that airport operators/engineers can follow. The GIS applications presented in this paper are demonstrated in a step-by-step approach that airport personnel can easily access and use. It is expected that, through GIS applications, airport operator/engineers will reduce processes of their daily airfield inspections and maintenance actions, resulting in a more efficient and safer airport. An implementation plan is provided in this paper to demonstrate how an integrated GIS system can facilitate improvements of airfield inspection, management, and maintenance processes. Followed by this implementation plan, a GIS example applied at an airport is presented to show airport authorities how GIS applications can help in skid resistance evaluations of runway pavements.

Airfield inspection and reporting processes have been seen as time-consuming due to the large number of manpower and time needed. Figure 1 explains the entire processes of daily airfield inspection that most airports have been using. It is clear that airfield inspection processes must be coordinated with the operation of air traffic control (ATC) which makes regular airfield inspection difficult to be achieved due to time limitations. Under air traffic security considerations, it is not easy to require airfield inspectors to bring accurate and detailed inspection input/information (specific locations and photos of identified problems, deterioration degrees and evaluations, distress descriptions, etc.) back to the office within the limited time available for the advanced evaluations and problem identification. Furthermore, if one inspection input is found incomplete or lacked, additional inspection task may be required. Thus, the traditional airfield inspection process is time-consuming and often inefficient. This difficulty might lead some airfield-related inspection/maintenance issues to be neglected putting an airport at risk of reducing its service quality. The following GIS application approaches could be used to help airports address current airport operation issues and to help airport operators/engineers improve airfield inspection processes, increase inspection input accuracy, and ensure aviation safety:

i. GIS-GPS applications in providing accurate locations (horizontal and lateral coordinates): The existing airfield inspection records are performed using handwritten formats. For example, when any deterioration is identified and the location on an runway is needed, inspectors need to measure the distance from the reference point and the perpendicular distance from the runway's center line or runway edge to determine the precise location; this process is time-consuming. A differential GPS receiver can access signals from several satellites and provide the location with a coordinate system that can be used to obtain the specific locations of the facilities' deteriorations making inspection processes easier and specific. Particularly, the GPS-aid method is very helpful and useful under dim/vague weather conditions or during the night. Because most maintenance work is performed at night (low-visibility conditions), by having GPS data, airport engineers can provide contractors with precise project locations; thus contractors will be able to reach to construction sites quickly based on the GPS coordinates given by airport engineers.

ii. GIS-PDA (or TabletPC) applications in recording deteriorations data and displaying digital photos during an airfield inspection: PDAs have been used in a variety of ways to assist pavement management systems in recording pavement input/data. The same PDA functions can be applied during the airfield inspection process. GIS systems support PDA's (or TabletPC) data to capture, analyze and digitize them into GIS software. Airport operators/engineers can examine/evaluate inspection information or facilities databases including deterioration descriptions, distressed degrees, problems photos, and other information by simply touching anywhere on a map of a GIS software.

iii. GIS Applications in mapping and digitizing airport facilities input and inspection data: GIS provides numerous attribute tables that show data information and inspection input through which airport operator/engineers can review deterioration rates and determine maintenance policies. Advanced applications provided by GIS systems can assist users in developing the calculation algorithms for maintenance/ project estimates using Visual Basic programming in the attribute tables of the GIS software. Development of such algorithms can be used to further establish databases in terms of facilities characteristics and project estimates (e.g. pavement marking areas, unit estimates, and potential maintenance costs, etc.). By establishing databases of maintenance estimates in GIS systems, airport engineers could reduce the process of providing and calculating project/maintenance estimates needed for facilities repairs so that required costs and budgets could be prepared as soon as possible. Airport engineers or maintenance crews are responsible for airfield facilities management and maintenance actions including pavements, lights, signs, etc. GIS applications not only have been applied in pavement management, but it could be also widely used in other airport-related infrastructure systems (e.g. lights, markings, signs, drainage channels, etc.) so contributing to form a better and integrated management system of airfield infrastructure.

As discussed earlier, the traditional airfield inspection process is normally a paper-based system. It takes time and manpower to inspect and report. Sometimes, inspection input may not meet the requirements of airport managers. The recommended GIS applications could provide airport authorities with "updated" approaches for the enhancements of airport operations. They are normally electronic-based instead of traditional paper-oriented processes. Not only airport operators, maintenance crews, engineers, and managers can "graphically" access the newest inspection input/facilities data through their computer screens, but they also can link inspection reports, submit work orders, track maintenance processes, and supervise construction quality with their finger tips. Furthermore, GIS databases could also be used to help airport operators update the latest airfield conditions and, if needed, issue "Notice To Airmen" (NOTAM) documents and Aeronautical Information Publication (AIP) for navigation assistance and notifications. As a result, GIS-aid applications can reduce airport operation processes, save time, require less human resource, and increase aviation safety.

# IMPLEMENTATION PLAN AND GIS APPLICATION EXAMPLE

## OVERVIEW OF INPLEMENTATION PLAN

The scenario of the implementation plan was chosen at Kaohsiung International Airport (KHH). KHH is the second biggest airport in Taiwan accommodating 7.1 million annual passenger enplanements in 2006 [8]. During peak hours, busy aircraft maneuverings at KHH operate only on one runway, 09-27, making airfield inspections more difficult than in other airports with 2 or more runways. That is the critical reason that GIS applications can demonstrate their useful aspects and features to help airport authorities reduce general inspection/maintenance processes and improve aviation safety.

In this demonstration, KHH facilities (lights, pavement markings, navigation equipment, etc.) were categorized into different layers (shape-files) depending on their characteristics. These layers or shape-files can be defined by users as follows:

i. Points: Points are created to represent the approaching lights, centerline lights and edge lights located on runway 09-27.
ii. Polylines: Centerline and edge markings of runway, taxiways, and aprons together with service roads were referred to polylines. In addition, airport boundaries are categorized into the polyline pattern with different color.
iii. Polygons: Polygons were created to stand for runway markings such as thresholds, aiming points, and touchdown zone markings. From the airfield maintenance side, creating polygons to represent such runway markings are meaningful and helpful for the purposes of airfield maintenance and management. Due to aircraft landings on touchdown areas, these runway markings are often covered by rubber deposits. Periodically re-painting of these runway markings is required to provide pilots with adequate visualized markings during aircraft operations. Hence, GIS software contains the useful function of calculations that can be applied to airfield maintenance in establishing maintenance quantity databases. This advanced application was further discussed later.

Figure 2 illustrates the configurations of each point, polyline, and polygon at KHH. Each point, polyline, and polygon was assigned an ID number that could be identified in the GIS map.

## DATA COLLECTION

The map used to demonstrate this implementation plan was obtained from KHH’s CAD files. Those CAD files consist of geometry features of KHH with coordinate systems converted to several shape files using GIS-related software as described previously. Through these shape files pavement edges, pavement markings, signs, and lights were edited and modified. Figure 3 illustrates the entire process of airfield inspection showing the applications of GIS associated with the GPS, PDA, and digital camera.

Pavement inspectors bring a GPS receiver, digital camera/video and PDA with them when inspecting airfield facilities and pavement conditions. The primary role of GPS is to obtain accurate spatial coordinate systems for the ground crews. This form of data collection is more convenient and accurate as compared to traditional paper-based inspection methods. Pavement inspectors only need to stand at the required locations where pavement distresses are observed and needs to be determined the coordinates. Collected coordinates are, in turn, recorded into a PDA and brief descriptions corresponding to each of distress are documented as well. For further investigation of damage degrees of deteriorations, inspectors can take images/video using a digital camera to assist engineers in reviewing and evaluating the distressed levels of each location. After the inspections, GIS-related computer programs are used for converting collected data, linking coordinates, creating shape files, and digitizing them into maps and tables.

## DATA DIGITIZING AND MAPPING

Data accessed from GPS and PDA was connected to the personal computer using GIS-related software in which inspection input was shown with text files. Those inspection data and images can be transferred, merged, and graphically shown on a GIS map from which airport operators/engineers can clearly see the specific locations of deteriorated facilities and recognize their geometry relations on taxiways and runways. The function of hyperlink offered by GIS software enables users to assess distress information and see images simultaneously on the map. Hyperlinks can add images, documents, and web pages to points, polylines, and polygons to facilitate dissemination of distress information. By indicating a direct path of distress photos to a user's computer, airport operators/engineers can easily have immediate access and visualized distress images, leading to better and more cost-effective airfield infrastructure management. This integrated GIS application helps airport operators/engineers effectively evaluate the distressed levels of pavements/facilities, efficiently interpret inspection results, and quickly determine proper maintenance activities. Furthermore, the FAA 150/5320 standard, "*Airfield Pavement Surface Evaluation and Rating Manuals*" was associated with airfield inspections. PDA or TabletPC can be formatted for airfield pavement inventories in accordance with the FAA's 150/5320 document and record rating pavement surface conditions into 5 levels [9]:

Rating 5: Excellent
Rating 4: Good
Rating 3: Fair
Rating 2: Poor
Rating 1: Failed

This rating system applies into both airfield asphalt and Portland cement pavements. Traditionally, pavement condition ratings were documented by airfield inspectors in written formats and subsequently submitted to the maintenance division for review. By using GIS applications, pavement condition rating input can be integrated into the attribute table associated with hyperlink and other GIS output. Rating data together with inspection input are interpreted and merged into GIS software for the process of digitizing, editing, and mapping. Thus, each identified distress can be graphically evaluated and associated with a rating level. These GIS digitizing and mapping processes for exhibiting airfield distress information are briefly illustrated as follows:

i. Convert GPS data to GIS software and show distress locations in a GIS map.
ii. Display specific distress locations together with attribute tables using the functions of digitizing, mapping, and hyperlink.

iii. Evaluate the damage degree of each distress in conjunction with rating data and linked images by clicking on the desired distress point.

On the airport operation side, this process provides airport operations with numerous benefits. For example, under low-visibility conditions, GPS data can enhance navigation when airport operators/engineers are moving and searching specific distress locations on airfield pavements. Furthermore, with GIS applications and specific coordinate systems, airport engineers can provide contractors with detailed distress information and accurate locations so contractors can easily reach the construction sites by previewing deterioration information. This is particularly critical since most airport maintenance activities are performed at night. GIS applications can be very helpful and useful for airport maintenance actions in reducing repair time and avoiding destruction or damage of airfield facilities (e.g. lights and signs); thus increasing aviation safety.

It is estimated that the traditional process of an airfield inspection illustrated in Figure 1 might be carried out within a week at many airports. Subsequently, airport maintenance crews and engineers obtain the inspection data/information or work orders couple days after inspection. Extra or further airfield visits may be required if distress data transferred to the maintenance division is not complete or clearly stated. However, by using GIS applications, the entire process of airfield inspection could be achieved within one or two days depending on an airport's reporting system. Thus, this approach is significantly time-saving, convenient and efficient as compared to traditional paper-based formats. Because newly pavement information is kept updated immediately after any inspection or examination, airport operators and engineers have the latest facilities information so that further activities such as submitting work orders or asking contractors to repair can be shortly achieved. As a result, airfield facilities and pavements are kept in a good condition and maintain an adequate and safety environment for aircraft landing and takeoff.

## GIS APPLICATIONS IN MAINTENANCE QUANTITY ESTIMATES OF AIRFIELD FACILITIES

Maintenance quantity analysis is an advanced tool in GIS applications using Visual Basic programming language (VB). VB has been widely used in sciences and engineering areas to develop desired models using programming codes. Applying the same functions of VB to GIS applications, GIS software provides users with useful application of data management and Macro design. A database in GIS software can consist of one or more tables. A table contains cells that can be filled with text (pavement damage levels, for example) or numerical data (spatial coordinate systems, etc.). When airport operator/engineers established a database, tables can be designed depending on what type of data they will contain (e.g. GPS coordinates, facilities evaluation results). Even new fields (hyperlinks) can be created by users. Each point, polyline, and polygon consists of a table that allows users to develop a simple macro routine using Visual Basic for: 1) advanced applications, 2) doing calculations on data sets in text formats, 3) adding reformatted text data sets, 4) running queries, and 5) creating buffer maps. This paper does not intend to introduce complex macro design sets using complicated Visual Basic codes to confuse airport operator and engineers. Instead, this paper developed Visual Basic codes in a simple and easy-to-learn manner that airport operator/engineers can easily follow and quickly apply macro design applications into their practices.

Maintenance quantity analysis implemented at KHH was an example of using digitizing data and macro design under the datasets of the tables of polygons. As previously stated, once distresses are identified, airport operators can submit work orders and maintenance crews can perform maintenance actions by either themselves or by contractors. Yet, maintenance quantities and corresponding costs need to be determined in advance to repairs or improvements. Macro design can establish datasets for the area calculations of each polygon (pavement marking, for example) and for estimating required project budgets or maintenance costs. Through these datasets, maintenance activities and related budgets/maintenance costs can be established in GIS databases and prepared already for maintenance. The following shows the macro design codes used at KHH to calculate areas of runway makings and subsequently determine the maintenance costs and re-panting estimates.

| PreLogic VBA Code (for area calculation) | PreLogic VBA Code (for maintenance estimates) |
|---|---|
| Dim dblArea as double<br>Dim pArea as IArea<br>Set pArea = [shape]<br>dblArea=pArea.area | Dim dblArea as double<br>Dim pArea as IArea<br>Set pArea = [shape]<br>dblArea=pArea.area |
| Area=<br>dblArea | Area=<br>dblArea* unit price ( in this example $ 3 was applied) |

Calculations are shown in Figure 4. This calculation algorithm is very useful and meaningful for airfield maintenance activities. In the area of airfield maintenance, re-painting markings are the most frequent maintenance actions on runways. The potential factors contributed to re-paint runway markings can be expressed as follows:

i. Rubber deposits due to aircraft landing and rolling actions.
ii. Runway maintenance activities: rubber built-up removal using high pressure water jets or other treatments, removing markings.
iii. Nature factors: weathering, flood flushing, etc.
iv. Navigation equipment adjustments: Precision Approach Path Indicator (PAPI) re-installation, for example, would require aiming point markings along with other touchdown stripe markings to be relocated in order to keep aiming point markings aligned with PAPI.

It can be seen that runway marking re-paintings are performed bi-weekly, monthly, or quarterly depending on the operations of aircraft at large commercial airports. Advanced GIS applications in maintenance quantity analysis using shape-file data and macro design can help airport engineers and maintenance crews effectively create airfield facilities databases and further apply quantity analysis data (figure 4) to conduct maintenance and construction estimates. This approach makes GIS applications the more convenient tool in airfield infrastructure system management. The job for airport operator/engineers is only to keep data management and macro design updated and reformatted, if needed, using a set of simple macro codes. When determining maintenance needs, specific locations and required maintenance costs of deteriorations will be effectively provided through GIS databases. Definitions of polygons are dependent on functions of facilities, resulting in different shapefiles and corresponding unit prices of maintenance. Applying the same theories to other points and polylines, airport operations and engineers can create tables, datasets, and macro design codes as demonstrated in runway markings calculations. For example, the maintenance costs of light facilities on pavements vary. Create multiple points to represent different light facilities will be essential for better data management and macro design. Figure 5 shows an overall layout of KHH using GIS software.

Materials aging problems have been challenging to airport maintenance mechanisms and may compromise aviation safety. Regardless of lights, markings, signs, pavements, or other facilities located in airport, effective management of aging airfield infrastructure and efficient maintenance activities is the key element to keep airfield infrastructure systems in a proper condition, ensure aviation safety, and provide passengers and aircraft with good ride quality and great travel experience. Given the increasing complexity of the airfield infrastructure behaviors, GIS applications associated with other programs (GPS, PDA, TabletPC, CAD, etc.) can make daily airport operations and maintenance actions easier and facilitate enhancements of airport service and aviation safety.

## GIS APPLICATIONS IN FRICTION EVALUATION OF RUNWAY PAVEMENTS

This section uses GIS applications in facilitating friction evaluation of runway pavements. An example implemented at Salt Lake City International Airport (SLC) was used to demonstrate how GIS applications could help evaluate pavement friction and determine areas where friction values are below the FAA standards. The FAA AC 150/5320-12 standard [10], "*Measurement, Construction, and Maintenance of Skid-Resistance Airport Pavement Surfaces*", requires airports to maintain friction values no less than 0.5 (for Airport Surface Friction Tester at a speed of 40 mph) to ensure aircraft safety operation during landing or take-off. Friction survey frequency is dependent on the number of daily minimum turbojet aircraft landings per runway end. At larger commercial airports, friction values are measured once a week or once every two weeks. The primary concern regarding the friction measurements is the specific areas where friction values are being affected and are below the standards. Showing accurate geometric locations between friction values and corresponding distances on runways is an important element for skid-resistant evaluation of runway surfaces. Therefore, an immediate and proper maintenance activity can be initiated to restore friction capacities of runway surfaces. This desired goal brings GIS applications to a useful and practical approach to provide airport maintenance crews with adequate pavement friction information together with visualized friction input.

Traditional friction evaluation is based on friction measurement input from a runway friction tester. Measurement input could be obtained as an electronic file or a paper report. Sometimes, electronic data is stored as an Excel file, but in many cases, paper-based reports are prepared for airport personnel to read and evaluate friction aspects of runway surfaces. Under such situations, a runway map should be provided along with friction data so that related geometric locations (e.g. friction values versus runway distances) could be determined. GIS applications can integrate friction values with airport maps or images. An example taken in the runway 16L-34R at the Salt Lake City International Airport (SLC) is used to demonstrate how GIS applications can help display skid resistance data and provide immediate and adequate geometric relations between friction values and runway distances. The operation division of SLC performs friction measurements using a SAAB Surface Friction Tester and submits friction input to the maintenance division for skid-resistance evaluation. As observed, friction input at SLC is presented in a paper-based report. Experienced airport personnel may understand the locations of friction affected areas on runways but, when the information is shared with others, the areas might not be so clear. New airport personnel need time to realize the geometric relations of friction values versus runway distances. By applying GIS-aid systems, airport crews can access an advanced layout showing the specific locations of friction affecting areas. This GIS application integrates friction values (particularly paper-based input) with an airport map by adding projection data (friction paper report) to an image (airport runway) so they both have related geographic location information and become an integrated digital file that can be used with other GIS files. That is how airport personnel would take advantage of this GIS integration system.

Figure 6 illustrates an integrated digital file resulting from adding friction input (projection data) to an airport image. As shown in Figure 6, it is easy to identify specific areas that have lower skid resistances along runway 16L-34R. This geographic information helps SLC personnel evaluate friction issues along with specific locations (e.g. rapid exits to taxiways, touchdown zones, etc.) so that potential factors caused to lower friction capacities can be further investigated. In many cases, poor skid resistance of runway surfaces might not directly be related to rubber deposits. Rather, some other contributors can result in lower pavement friction. For example, as shown in Figure 6, results of friction measurement indicate that three major areas of runway 16L-34R exhibit a reduction of friction capacity ranging from 0.6 to 0.4. Particularly, friction numbers around rapid exits from Taxiway H7 to Taxiway H10 exhibit the lowest values yet few rubber deposits were built on this area of the runway surface. The combination of friction data with airport images helps determine a specific location where a detailed inspection should be performed. Through Figure 6 (b) and based on in-situ observations, it can be determined that aircraft decelerations result in plastic movements of pavement surfaces. Thus, adequate maintenance strategies can be applied between Taxiways H7 and H10 to improve poor skid resistance. SLC maintenance crews evaluate surface characteristics of runway 16L-34R and assess future maintenance activities to improve surface deteriorations and restore friction capacities.

Friction capacities requirements documented in the FAA standard enable airport personnel to evaluate skid resistance characteristics. In many cases, friction data and its related skid resistant reports were formatted in a paper basis. As previously mentioned, an airport map or layout needs to be shown along with friction reports to help airport crews determine potential friction affecting areas on runways. However, by using GIS applications, friction data could be projected into an airport map, resulting in an integrated digital image as shown in Figure 6. In addition, the FAA friction capacity requirements can also be added to the map showing a specific geometry relation between friction values and runway distances. This map helped SLC personnel identify the friction loss areas and determine potential factors caused to lower friction capacities so further maintenance policies or activities can be performed.

## CONCLUSION

GIS-related applications presented in this paper provide evaluation techniques of airfield infrastructure system that are easy to learn. Throughout the demonstrations implemented at KHH and SLC, this paper intends to provide airport personnel with hands-on GIS applications so that they can develop their individual GIS programs. GIS software provides airport personnel with a basic set of spatial query and digitalized analysis tools where users can edit spatial data, add projection input, and create their individual attribute tables as illustrated previously. Airport crews could perform this individually by developing their suitable GIS-based systems, creating datasets, designing macro VB codes, and integrating digital files into a powerful tool. This paper introduces GIS applications techniques associated with other aid tools highlights the following features:

1. Electronic-based airfield data management: Traditional paper-based inspection reports require intensive time and labor involvements. By replacing paper work with digital files, airport personnel can simultaneously evaluate results from airfield inspection and input with images on their computer screens. This changes existing processes of airfield inspections and results in more efficient airport operation systems.
2. Easy-to-manage databases: spatial information (infrastructure data and images) obtained from daily airfield inspections or pavement examinations could be merged and stored in databases. The structure of GIS software allows airport personnel to easily manage, update, and integrate existing or future databases according to inspection results.
3. More effective airfield infrastructure management and efficient airport operations: Specific coordinates are accessible through GPS signals. Distress evaluation and images could be documented using PDAs (TabletPC) and digital cameras. The accurate spatial data provides airport personnel with the first-hand airfield infrastructure information. By digitizing and mapping spatial data, distress evaluation, work order submission, and determination of maintenance activities could be associated with GIS-based programs within a short time. This integrated GIS system facilitates enhancements of airport operations and results in more effective airfield infrastructure system management.

Implementation experiences of GIS applications in airport operation management and pavement maintenance have been positively received at large commercial airports. In response to increasing air travel demands from passengers and airliners, GIS-based applications are very helpful and useful tools that significantly improve traditional inspection processes and maintenance management of airfield infrastructure system and increase the airport service quality and aviation safety.

## ACKNOWLEDGEMENT

The authors would like to thank the Director of Kaohsiung International Airport, Mr. Peter Tsao, for his full assistance and advice while worked for KHH. Many thanks are given to Mr. Michael Widdison, Civil Engineering manager at SLC, and Mr. James Barron, Civil Engineer at SLC, for their kind assistance during the site visit and meetings.

## REFERENCES

1. Tamir, D., Draper, G. and Osborne, R. "*Airport Configuration Management Using a Technical Information Mapping System (TIMS)*." Airport Facilities: Innovations for the Next Century, 25th International Air Transportation Conference Proceedings, pp.303-318, ASCE, June 1998.
2. McNerney, Michael T. and McCullough, B. Frank. "*Fatigue Cracking in Rigid Airfield Pavements at Large Commercial-Service Airports*". The Journal of Transportation Research Record, No. 1703, pp65-71, TRB, Washington D.C. 2000.
3. McNerney, Michael T. "*Airport Infrastructure Management with Geographic Information Systems.*" The Journal of Transportation Research Record, No. 1703, pp58-64, TRB, Washington D.C. 2000.
4. Huang, Bo. Fwa, Tien Fang and Chan, Weng Tat. "*Pavement-Distress Data Collection System based on Mobile Geographic Information System.*" The Journal of the Transportation Research Board, No. 1889, 2004.
5. Cudmore, Paul. "*GPS/GIS Solutions for Improving Airfield Inspections, Reporting, Maintenance and Safety*." The 2007 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey, April, 2007.
6. McNerney, Michael T. and Kelley, Mark. "*The Use of TabletPCs and Geospatial Technologies for Pavement Evaluation and Management at Denver International Airport*" 2007 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey, April, 2007.
7. Federal Aviation Administration (FAA). "*FAA Aerospace Forecast Fiscal Years 2007-2020*." 2007.
8. Data can be found at KHH's web site: http://www.kia.gov.tw/content/airport/introduce-4.asp
9. Federal Aviation Administration (FAA), "*Airfield Pavement Surface Evaluation and Rating Manuals*", AC No: 150/5320-17, July, 2004.
10. Federal Aviation Administration (FAA), "*Measurement, Construction, and Maintenance of Skid-Resistance Airport Pavement Surfaces*", AC No: 150/5320-12C, March, 1997.

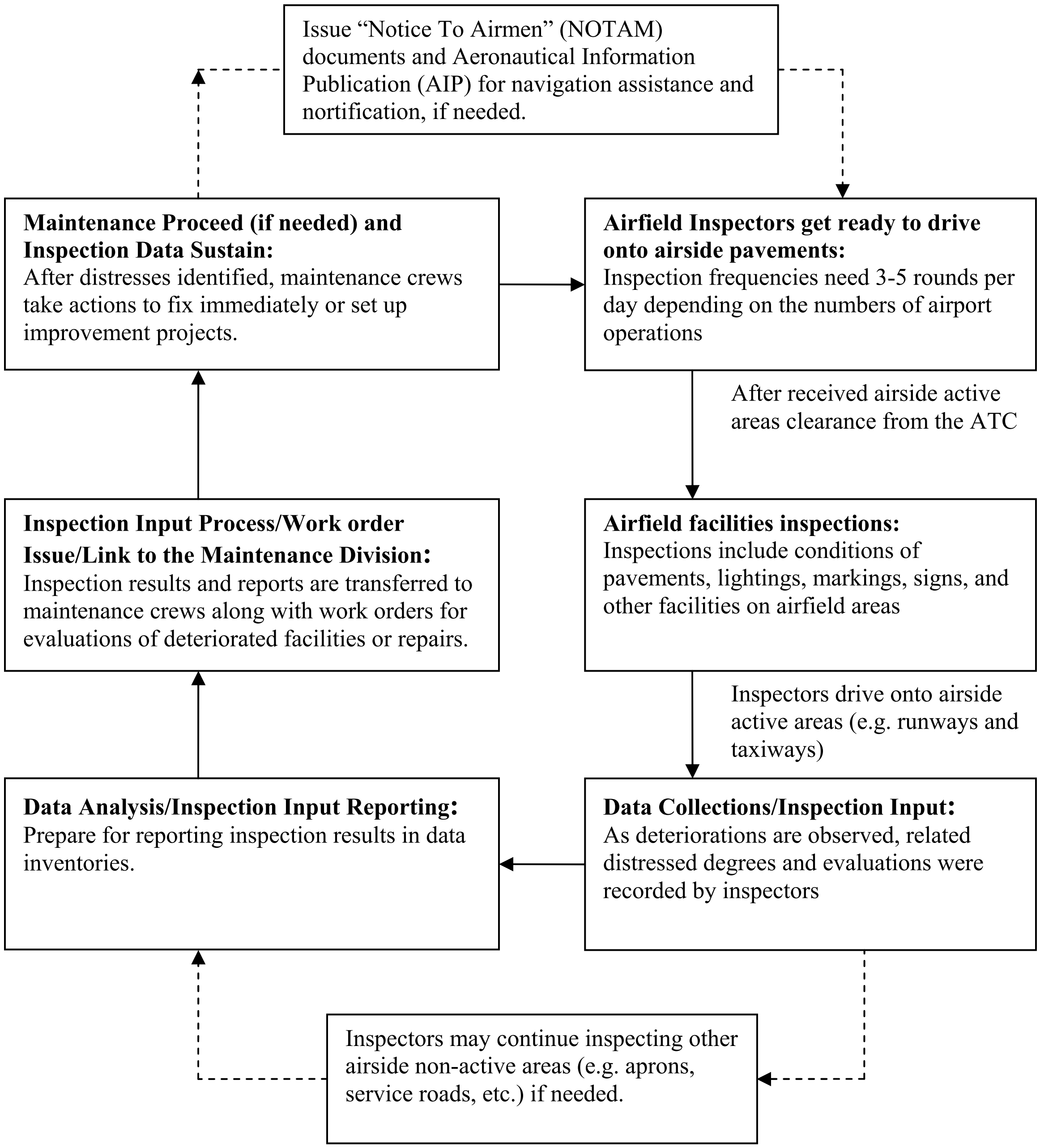



**Figure 1: Airfield Inspection and Reporting Processes**

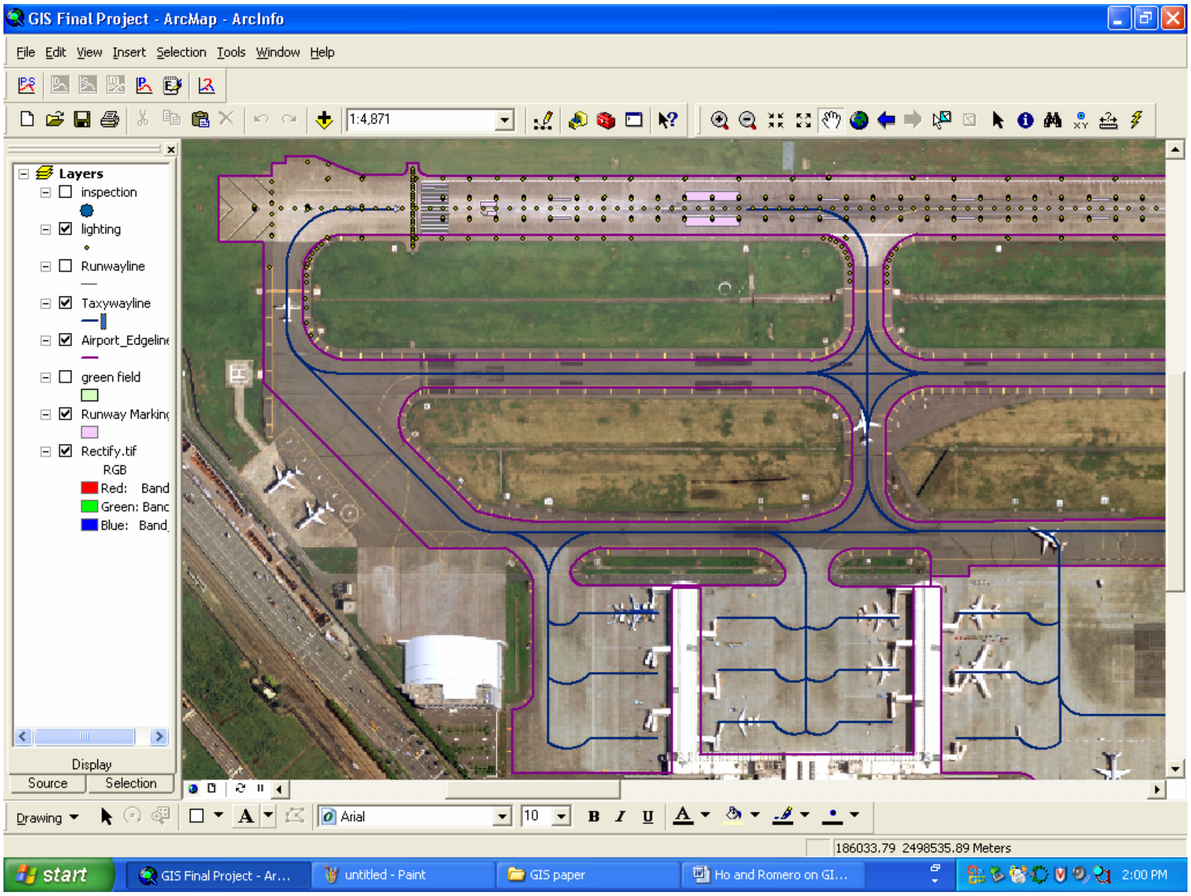
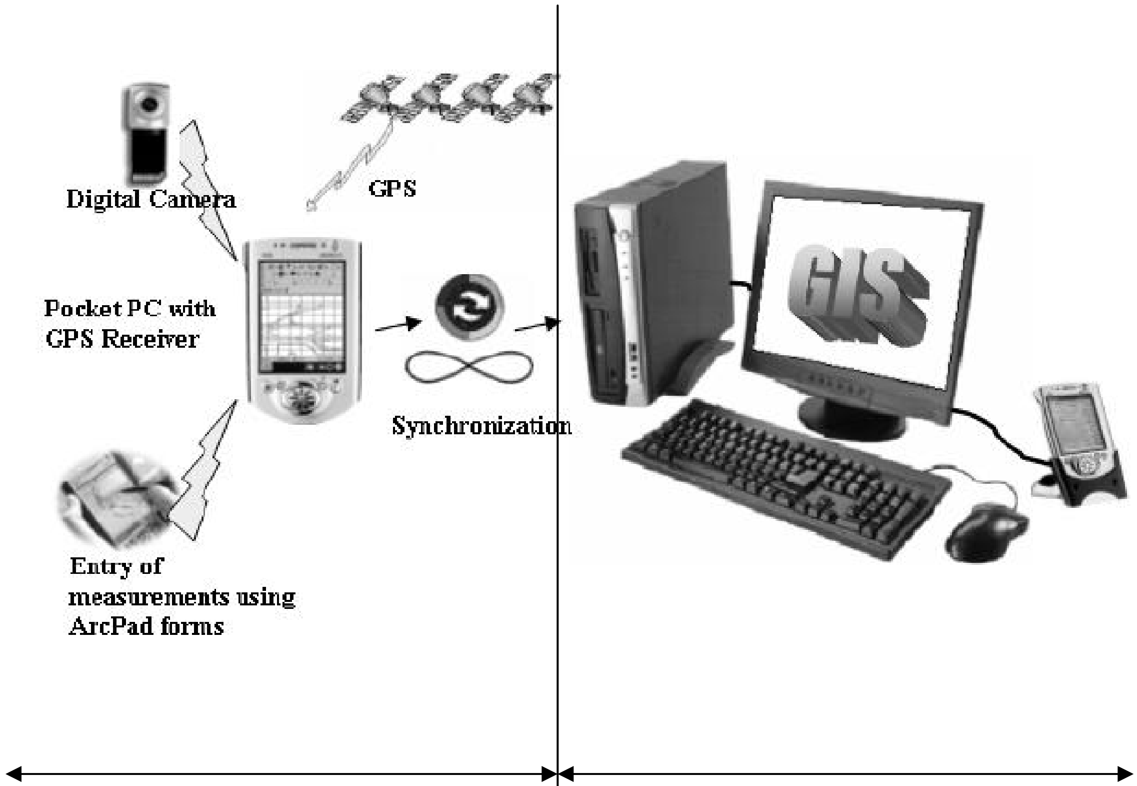



**Figure 2: Points, Polylines, and Polygons Are Created to Represent Light Facilities, Centerlines, Edge lines, and Runway Markings, Respectively**




Air Field Inspection:

1. Inspectors bring PDA, GPS receiver and digital camera to airfield.
2. Once any facility distress is noticed, inspectors measure location coordinates from the GPS receiver, take photos, and record brief distress evaluations into PDA.

Inspection Data Analysis and Reporting

1. Inspectors bring inspection input back to the office.
2. Inspection data and information are transferred to GIS software to go on a process of analyzing, digitizing, and mapping.
3. ArcGIS software is used to integrate inspection input into a database.

**Figure 3: Data Collection Processes**

Photo Resource: Huang et al. Journal of Transportation Research Board, 2004

Attributes of Runway Markings

| FID | Shape * | Id | Area | Estimates |
|---|---|---|---|---|
| 0 | Polygon | 0 | 34.97493 | 104.92479 |
| 1 | Polygon | 0 | 89.985462 | 269.956385 |
| 2 | Polygon | 0 | 25.759909 | 77.279726 |
| 3 | Polygon | 0 | 25.64022 | 76.920659 |
| 4 | Polygon | 0 | 17.422149 | 52.266446 |
| 5 | Polygon | 0 | 17.445667 | 52.337001 |
| 6 | Polygon | 0 | 17.323174 | 51.969522 |
| 7 | Polygon | 0 | 182.585553 | 547.756659 |
| 8 | Polygon | 0 | 54.429293 | 163.287879 |
| 9 | Polygon | 0 | 54.945509 | 164.836527 |
| 10 | Polygon | 0 | 54.733756 | 164.201268 |
| 11 | Polygon | 0 | 54.807724 | 164.423173 |
| 12 | Polygon | 0 | 54.834875 | 164.504626 |
| 13 | Polygon | 0 | 55.254931 | 165.764793 |
| 14 | Polygon | 0 | 55.658655 | 166.975965 |
| 15 | Polygon | 0 | 55.463523 | 166.390568 |
| 16 | Polygon | 0 | 55.580271 | 166.740812 |
| 17 | Polygon | 0 | 55.997296 | 167.991888 |
| 18 | Polygon | 0 | 55.381186 | 166.143558 |
| 19 | Polygon | 0 | 54.891584 | 164.674751 |
| 20 | Polygon | 0 | 55.482868 | 166.448603 |
| 21 | Polygon | 0 | 54.852789 | 164.558367 |
| 22 | Polygon | 0 | 54.933499 | 164.800496 |
| 23 | Polygon | 0 | 54.692211 | 164.076633 |
| 24 | Polygon | 0 | 109.062768 | 327.188304 |
| 25 | Polygon | 0 | 81.613548 | 244.840645 |
| 26 | Polygon | 0 | 67.095606 | 201.286818 |
| 27 | Polygon | 0 | 67.921017 | 203.763052 |
| 28 | Polygon | 0 | 600.872621 | 1802.617863 |
| 29 | Polygon | 0 | 602.82381 | 1808.471429 |
| 30 | Polygon | 0 | 67.7498 | 203.249399 |
| 31 | Polygon | 0 | 67.471979 | 202.415936 |
| 32 | Polygon | 0 | 65.414773 | 196.244319 |
| 33 | Polygon | 0 | 66.897896 | 200.693688 |
| 34 | Polygon | 0 | 68.593042 | 205.779126 |
| 35 | Polygon | 0 | 68.858629 | 206.575886 |
| 36 | Polygon | 0 | 65.820624 | 197.461873 |
| 37 | Polygon | 0 | 68.205782 | 204.617346 |
| 38 | Polygon | 0 | 68.921507 | 206.764521 |
| 39 | Polygon | 0 | 68.131068 | 204.393204 |
| 40 | Polygon | 0 | 68.247194 | 204.741582 |

Record: 0 Show: All

Note:

1. Calculations of Area and Estimates were generated from macro design codes as illustrated in previous statements.
2. FID refers to an "ID" number of each polygon (e.g. runway marking).
3. When maintenance polices are decided, desired markings can be identified in the GIS map and determined the required areas along with corresponding maintenance estimates in the attribute table of GIS.

Figure 4: Maintenance Quantity Analysis Example at KHH using Macro Design

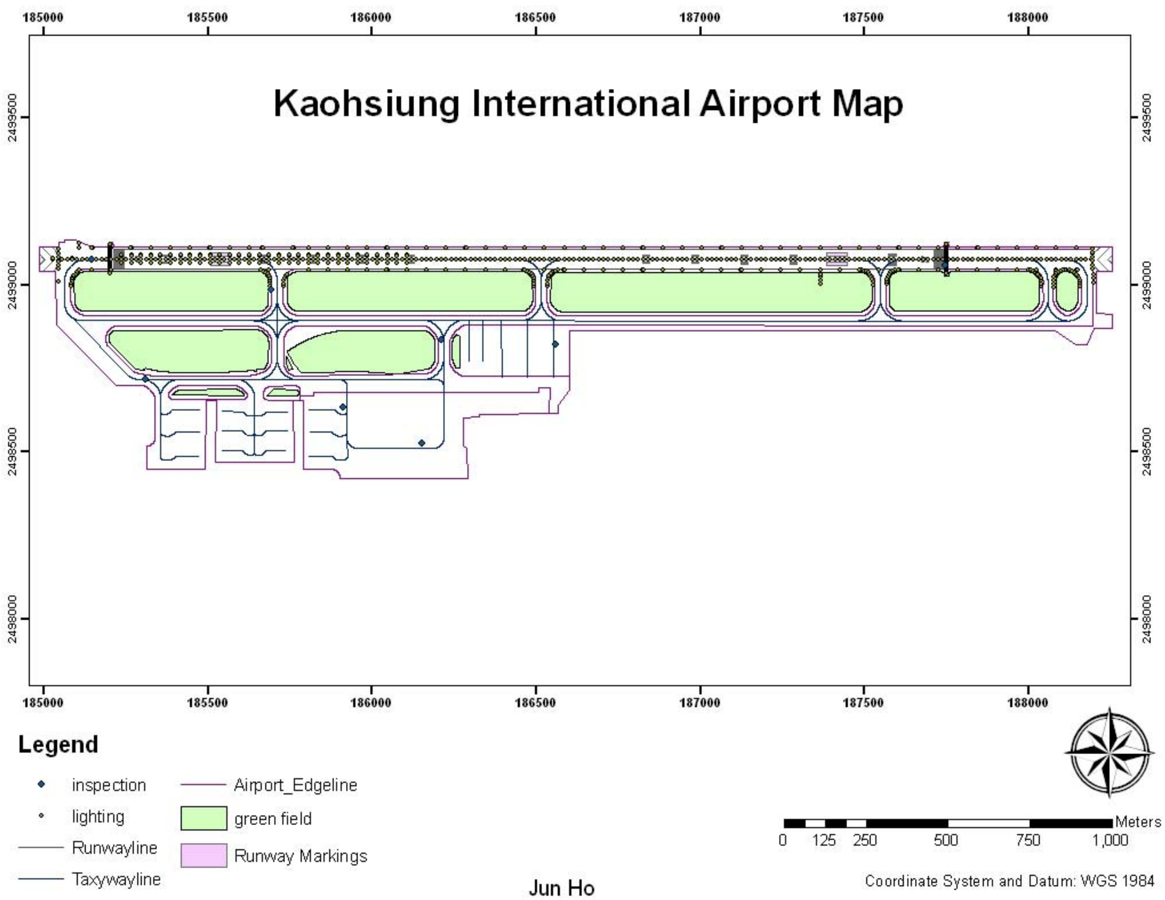
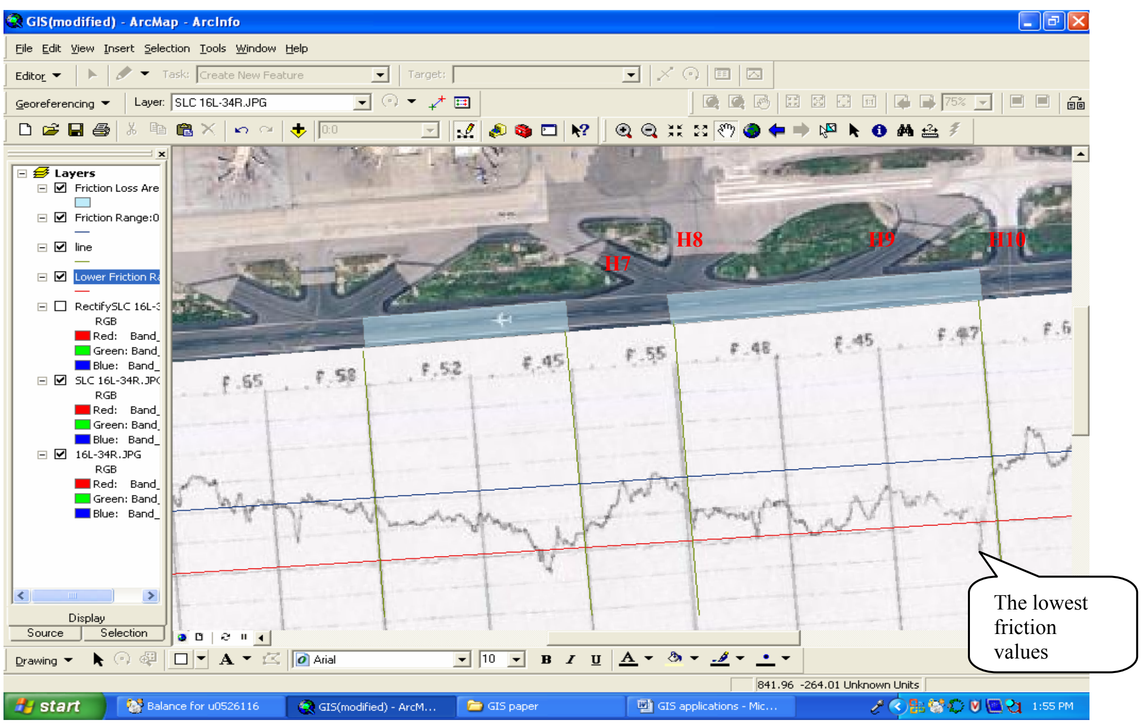



Figure 5: KHH Layout Using GIS Applications


(a) Skid Resistance Layout of Runway 16L-34R at SLC




(b) Friction Loss Area between Taxiway H7 to H10 at SLC

Figure 6: GIS Applications in Skid Resistance Evaluation of Runway 16L-34R at SLC