Cover Page

Title of Design: Web-Based Smartphone Application for Pavement Analysis: A Geographic Information System Approach

Design Challenge Addressed: Airport Operations and Maintenance Challenge

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Web-Based Smartphone Application for Pavement Analysis: A Geographic Information System Approach

Airport Operations and Maintenance Challenge

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I. Executive Summary

Title: Web-based Smartphone Application for Pavement Analysis: A Geographic Information System Approach

Pavement maintenance is one of many daily tasks that must be undertaken in order for an airport to run smoothly and safely. Furthermore, because pavement maintenance is a daily task, even minor improvements can have a significant impact on both cost and quality.

One way that can significantly improve day-to-day pavement maintenance is increased automation. Airport personnel drive out daily onto each runway, manually inspect each problem area, and manually organize the information gathered. Automating even a fraction of these tasks would greatly reduce error, and save a significant amount of time. Not only will the gathered information be more reliable, but also airport personnel will be able to focus on those parts of runway evaluation that are not easily automated. In addition, at many airports, the people in charge of runway maintenance also have other responsibilities. By minimizing the amount of time spent on pavement maintenance, these individuals can spend more of their time fulfilling these other responsibilities.

To this end, a team of 25 students from the Department of Computer Science, Thomas J. Watson School of Engineering and Applied Science, Binghamton University, State University of New York, with the aid of industry experts, has developed and submitted this proposal for a smartphone application to aid in pavement maintenance. The application will record photographs of damaged pavement, and leverage current technologies in automated image analysis and data organization to efficiently record, track, and analyze pavement deterioration on a day-to-day basis.

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II. Problem Statement and Background

i. Pavement Maintenance and Ratings

Airport safety relies heavily on appropriate pavement maintenance in order to avoid accidents and high repair costs, and the core of pavement maintenance is properly handling pavement distress. Pavement distresses can be caused by loading, constructional defects, environmental factors, or any combination of the three. The Federal Aviation Administration (FAA) classifies each pavement distress as either a functional or a structural failure. Functional failures are inexpensive to repair, while repairs of structural failures are significantly more expensive. If an area classified as a functional failure is left untreated, it can very well turn into a structural failure. [1]

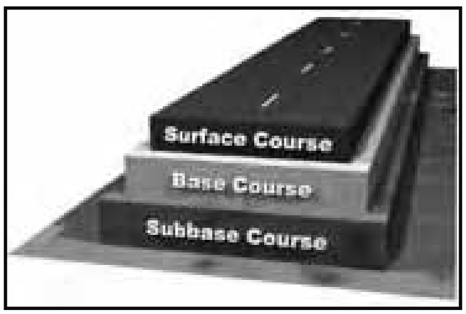

Figure 1: Pavement Layers [2]

The types and severity of pavement failures are impacted significantly by the type of pavement affected. Types of pavement include rigid, flexible, hot mix asphalt overlays, and rigid overlays. A mix of these pavement types make up the different layers of airport pavement. The three layers consist of the surface course, base, and subbase, as seen in Figure 1. The surface courses contain Portland Cement Concrete (PCC), Hot Mix Asphalt (HMA), sand-bituminous mixture, and sprayed bituminous surface treatments. The base courses consist of a mixture of different materials, which are either treated or untreated. Finally, the subbase consists of granular material, stabilized granular material, or stabilized soil. [3]

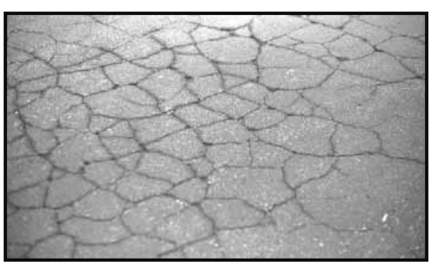

Figure 2: Alligator Cracking. [1]

HMA pavements often experience alligator cracking, shown in Figure 2. Alligator cracking is a structural failure that consists of several interconnecting cracks. Meanwhile, depression is an example of a functional failure in HMA.

Two types of failures that occur often in PCC pavement are pop outs and corner breaks. A pop out is a functional distress that is caused by a freeze-thaw action, as depicted in Figure 3. A corner break is a structural distress that is caused by load repetitions and loss of support and curling stresses.

Figure 3: Pop Out [4]

ii. The Pavement Condition Index

The FAA utilizes a rating system known as Pavement Condition Index (PCI), to measure pavement's structural integrity and surface operational condition. [5] The index ranges from 0 to 100, where 100 indicates pavement in good condition, as shown in Figure 4. The process of calculating PCI involves several steps. Firstly, the different paved areas must be identified by purpose such as runways, aprons, or taxiways. Then, each of those areas is divided into sections, which are then divided into several units.

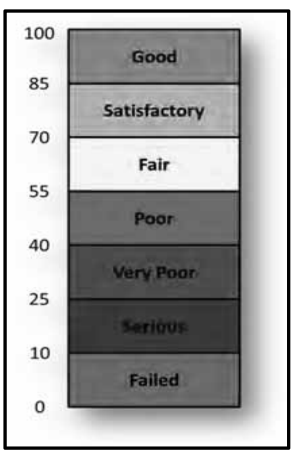

Figure 4: PCI Measurements [6]

The PCI is calculated using: $n = \frac{2Ns}{e/_{2}(N-1)+s2}$ where *e* is the acceptable error when calculating PCI, *s* is the standard deviation of the PCI from one sample unit to another within the section, and *N* is the total number of sample units in the section, as outlined in ASTM Standard D 5340. [7]

The collected data is then used as an aid when scheduling maintenance and rehabilitation for airport pavements.

iii. The Problem

The FAA requires that all airports conduct daily inspections on their pavement and that they provide reports on any problem areas. [8] However, most of the work associated with daily pavement inspections, is done manually. This makes the process time consuming, error prone and increases the chances of inconsistencies between different pavement inspectors.

The lack of uniformity and relatively high chance of error are particularly detrimental. The variations in day-to-day pavement analysis could obscure the actual rate of pavement deterioration, making it difficult to analyze pavement deterioration in any meaningful manner. Meanwhile, if a pavement inspector fails to notice the true extent to which a section of pavement has deteriorated, or the deterioration is not brought the attention of the proper authorities quickly enough, then sudden, rapid deterioration later may force expensive and time-consuming repairs that could have been averted.

iv. Background on Smartphone Applications

A Smartphone is a mobile phone offering advanced computing capabilities. A variety of applications has been written specifically to harness the computing capabilities of these sophisticated cell phones. There are applications related to different professional fields such as healthy living, day-to-day reminders, education, and entertainment purposes. [9]

There is also a variety of applications related to flight, such as Airport Maps, iFly Pro, and FlightUpdate; on the iPhone. All of these applications give users the information about their flights, airports, and real time access to information on airport services. [10]

v. Background on Geographic Information Systems

Geographic Information Systems (GIS) are computer systems with the ability to store, capture, analyze, and display data associated to a specific coordinate on a map. [11] In addition, a GIS will generally incorporate maps, aerial photos, or satellites to show where this data comes from. Unlike other computer systems that use addresses or zip codes as locations, GIS will always use geographical references as to store and access information. [12]

Figure 5: A GIS generated airport map [13]

The FAA currently relies on GIS to collect, manage, and analyze airport data that is essential for developing, planning, and protecting airports throughout the country. All of this is incorporated in the Airports GIS (AGIS) program, recently initiated by the FAA. The main goal of the AGIS program is to standardize and simplify the data collection process at airports, and to organize this data in one centralized web-based system. The AGIS program also strives to improve how geographically referenced information for airports is represented and displayed by transforming this information into detailed maps as seen in Figure 5. [13]

A particularly powerful aspect of GIS is its ability to link data together. An example includes linking satellite data with runway data, and making traffic patterns observable. [11] Other features of GIS include mapping objects, mapping quantities, and mapping changes. GIS can also visualize and interpret data in the forms of maps, globes, reports, and charts. In these new forms, it is much easier to find relationships, patterns, or trends within the data. [14]

The company Esri has a mobile GIS application called ArcGIS for both smartphones and tablets running Windows Mobile, which can be seen in Figure 6. This application can be used to view and navigate mobile maps, as well as update and share GIS data. Additionally, ArcGIS for Windows Mobile includes a Software Development Kit for creating custom Windows application, and is able to synchronize GIS information between server, desktop, and mobile clients. [15] Even day-to-day tasks such as managing inventory or tracking pavement maintenance can be greatly assisted using the combination of these two technologies.

Figure 6: ArcGIS running on Windows Mobile [16]

vi. Pavement Inspection Cameras

Many airports use VideoLogging to collect a series of pictures of the pavement, which are captured by multiple cameras mounted on a Video Van, shown in Figure 7. The cameras used on these Video Vans provide a panoramic view of the pavement, which is collected by an outside contractor biennially. [17] The Bureau of Planning and Research, GIS Division is responsible for the VideoLogging software that goes on the Internet. [18] Since the essential data is online, inspectors can evaluate the pavement condition anywhere there is access to the Internet.

Figure 7: Three cameras mounted on a Video Van [17]

Because evaluating pavement conditions are subjective to human observations, this assessment is arguably unreliable, inaccurate, and requires trained personnel to perform.[19] A Smartphone application for monitoring and assessing pavement conditions can help eliminate natural, human error.

vii. Background on Gyroscopes

A gyroscope is an apparatus that is used to measure or maintain orientation by using the principles of angular momentum shown in Figure 8. [21] When a gyroscope is tipped, the gimbals attempt to reorient in order to maintain the rotor's spin axis.

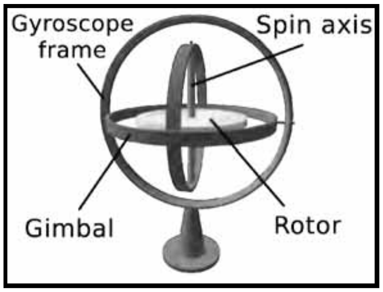

Figure 8: Labeled gyroscope [20]

Smartphones have incorporated gyroscope technology. For example, the iPhone 4 includes an electronic version of a vibrational gyroscope called a microelectromechanical system (MEMS). It is possible to use the gyroscope feature with a camera in order to help ensure that different pictures are taken at the same angle. For example, there currently exists an iPhone application called "You Gotta See This!," shown in Figure 9, that uses the iPhone's gyroscope in order to determine the camera's orientation. It then uses this information to build a collage of multiple photos taken while moving. [22]

Figure 9: iPhone application using the built-in gyroscope [22]

A uniform, partially automated means of daily pavement inspections can be developed by combining smartphones with gyroscope capabilities, with an understanding of PCI and GIS technology.

III. Summary of Literature Review

i. Pavement Testing and Analysis

Early pavement maintenance significantly reduces the cost of pavement repairs, according to an FAA document outlining the benefits and legal requirements of pavement maintenance. Early detection of problematic pavement areas may result in savings of $3 to $4 per $1 spent on maintenance. [23]

Airport maintenance staff must follow strict guidelines when inspecting their pavement, as outlined in the Advisory Circular 150/5380-6B. Experienced personnel must schedule periodic inspections that will ensure that each area is thoroughly examined; any problems found are to be properly recorded. [24] Although the airport staff do daily drive by inspections, it is a requirement that all paved areas are thoroughly inspected at least twice a year and caution be given during potentially problematic weather.

PCI rankings are used to quantify pavement condition. The PCI ranges from 0-100, with zero being the worst rating, and 100 the best. If the PCI is below 10 then it is considered failed. Typically, however, airports take measures to repair pavement before the PCI falls below 10. [1]

Nondestructive Testing (NDT) is one method of collecting and analyzing data relating to airport pavements. A standard NDT test will only take a couple of minutes, and will not disrupt the operation of the airport. Unfortunately, some of the data gathered by NDT equipment may be affected by the climate or time of day. Additionally, the data gathered may not be enough for the engineers to make a proper analysis of the pavement. [25]

When it comes to the site inspection, the FAA has a set of minimum rules to which airports must adhere. Airports must keep inventory on their entire paved surfaces that describes location of pavement as well as its type and dimensions. A detailed inspection must be performed at least once a year and can be extended to every three years as long as history of recorded pavement deterioration is available. In addition, the airport must perform a monthly drive-by inspection to account for unexpected changes in pavement condition. The FAA requires that the results of these inspections be kept on file for a minimum of five years. These records must contain inspections date, location, distress types, and maintenance scheduled or preformed. When it comes to information retrieval, the FAA does not enforce any method as long as the information can be retrieved to provide a report to the FAA.[24]

The Innovative Pavement Research Foundation lists some distresses as well as their method for repair. For example, plastic shrinkage cracks are shallow cracks and can only be repaired by applying methacrylate inside the cracks. Also, edge slump is a depression that occurs when something is wrong in the paving process (mixture, equipment, etc.). If the edge slump is found before the concrete is set, a plastic repair can be performed, however if it has hardened, the edge must be removed and replaced. [26]

The FAA AC 5320-6E document outlines the methods for investigating soil foundation and climatic conditions, as well as pavement evaluation, overlays, and reconstruction. Both of these first two factors affect the pavement design procedures, because there needs to be protection from the harmful effects of frost. [3] Engineers are required to use the computer program FAA Rigid and Flexible Iterative Elastic Layered Design for to design pavement. This program is used to design pavement thickness for airports. [27]

The FAA has a recommended five-step process when it comes to evaluating pavement, regardless of the pavement type. The steps are records research, site inspection, sampling and testing, pavement condition index, and evaluation report. The most important step concerning this proposal is the site inspection step. When there is a site in question, the site must be visually inspected and the condition of the pavement must be noted. In addition to the pavement condition, the inspector is required to examine the existing drainage conditions as well as the site's drainage structure. Based on the condition of the pavement the inspector will decide if the later steps need to be followed. [28]

The U.S. Army Construction Engineering Research Laboratory developed software to handle pavement inspection called MicroPAVER 4.2. The software allows pavement inventory, condition and maintenance history to be stored and accessed easily. In 1996, the Albany International Airport used this program to handle their pavement inspection under C.T. Male Associates. They divided the runway into 1,219 units, with each unit being approximately 6,000 square feet. The units were inspected and reported regularly. Over time, the inspection history data became consistent and valid predictions could be made concerning the degradation of the pavement. This project won a 2002 Platinum Award for Engineering Excellence.[29]

ii. Safety and Risk Management

According to the Safety Management System (SMS) Manual, safety does not just involve the lack of accidents in the present, but also involves putting measures in place to ensure safe conditions in the future. All proposed changes to the National Air Space (NAS), from the reorganization of air traffic routes, to the basics like introduction of new equipment, require Safety Risk Management (SRM) evaluation. [30]

In the Air Traffic Organization Safety National Runway Safety Plan, runway safety is measured by monitoring the frequency, severity, and type of runway recursion. Each risk is later reviewed and a severity category, between category A (for more serious) and category D (for less serious) is then applied. The Runway Safety Action Team has the responsibility of identifying surface risks and developing processes for mitigating these risks. [31]

The order 8040.4 introduced the basic principles of the safety risk management system and defined the policy of safety risk management. The approach to safety risk management is composed of five steps: plan, hazard identification, analysis, assessment, and decision.[32]

The Risk Management Handbook describes six primary types of risk that can be encountered: Total Risk, Identified risk, unidentified risk, Unacceptable risk, Acceptable risk, and Residual risk.[33]

In the past, the approach to safety was not as methodical as recent technologies have allowed. This is why, according to the FAA Flight Plan 2009-2013, the focus will be shifting to more of a data analysis based model to prevent accidents before they happen. [33]

iii. Goals of the FAA

In its Portfolio of Goals for the Fiscal Year of 2011, the FAA outlined its goals for improved safety in all airports under the jurisdiction of the FAA. [34]

First, the FAA measures risk in a number of ways. General Aviation is the practice of aviation by civilians other than commercial air carriers or military flights. The risk for air carrier flight is given a unit of measurement as number of fatalities per 100 million persons. The risk for General Aviation is given a unit of measure as number of fatal accidents per 100,000 flight hours. Any unnecessary risk, or any risk with no returns in terms of benefits or opportunities, is unacceptable.[34]

iv. Geographical Information System

GIS is defined by Environmental System Research, Inc. as a system that “integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information." Many international organizations, businesses, and governments use this system to gather and maintain important geographical data. [35] Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium with a Computer-Aided Design program, and geo-referencing capabilities. [1]

The FAA uses the Airports Geographic Information System to collect airport data. Geographic information of the facility, including runways, are be readily available and can be used to track pavement conditions and help determine when a section of pavement needs to be repaired or replaced.[36]

v. Smartphone Applications

Among the applications that involve airports, applications such as "Airport Maps" can be found that provide the user with a detailed view of an airport's layout.[37] This allows passengers to navigate to the desired gate with minimal delays. Another incarnation of this idea is provided by an application titled "WingX," which is meant for professionals. It provides the user with a variety of features, including to but not limited to the ability to view safety threats, VFR Sectionals, and Geo-Referenced Approach Charts.[38]

Phone applications dealing with asphalt conditions are very rare. Among the very few apps offered dealing with this subject, FixMyStreet most closely resemble the idea presented in this project. FixMyStreet is meant to help government agencies identify street areas that require repair in the United Kingdom.[39]

IV. Problem Solving Approach

The project started when Professor Ziegler appointed Andrew Cholewa as the project leader. They started the project by meeting at McFarland Johnson Inc. with Vice President of McFarland Johnson Chad G. Nixon and the Commissioner of Aviation Carl Beardsley. There it was decided to develop an idea based around using a smartphone to record data gleaned from daily pavement inspections.

When the team gathered for the first time, Professor Ziegler split the students into four smaller teams: the Design Team, the Engineering and Graphics Team, the Risk Assessment and Research Team, and the Strategies and Ethics Team. The Design Team handled the engineering, scientific, and technical design. The Engineering and Graphics Team covered the problem statement, as well as the graphics and photography. The Risk Assessment and Research Team conducted research and reviewed the potential risk and safety issues. The Strategies and Ethics Team described the team's approach to the problem and ethical considerations regarding the project. Joseph Nocco and Katherine Espana were selected as Technical Leaders of the project. Joe led the Design Team while Katherine led the Engineering and Graphics Team.

Figure 10 Commissioner Beardsley discussing the specifics of each runway

The first proposal for the project called for a smartphone application that would use a photo of a section of pavement to calculate the level of pavement degradation displayed in the photo. The application would then notify inspectors if the section required further attention. The team had the initial idea of utilizing GIS for the project, but the details of the GIS system were still unknown.

To find out more about the use of GIS in airports, and to discuss different aspects and features the smart phone application should contain, the team went to the Greater Binghamton Airport and met with Commissioner Beardsley and Vice President Nixon. When the team brought up questions involving GIS, Vice President Nixon demonstrated how the airport's existing GIS software functioned.

The team also suggested a speech detection feature that would assist workers in recording information to an audio file. Commissioner Beardsley, pictured in Figure 10, liked the idea because not all signs of pavement degradation can be perfectly captured using a camera.

The team also toured the runway and apron, to understand some of the difficulties involved in the inspection process and to inspect actual pavement degradation. Overall, the team walked away from the meeting with the idea that the smart phone GIS application would enhance and assist the workers in accomplishing their job faster, more precisely, and with greater efficiency.

In the first meeting after the airport visit, the suggestions and feedback from Commissioner Beardsley and Vice President Nixon were reviewed and discussed. The team proposed a couple areas of focus, particularly the speech to text feature, auto detection of pavement condition, and integration into existing GIS software.

Figure 11 Mock-up of the application on a smart phone

The next issue the team encountered was the consistency of photographs of damaged pavement. If the smartphone application was to perform auto evaluation, it needed consistent photographs of the same troubled areas. The engineering and graphics team came up with a solution utilizing the gyroscope functionality built into most smartphones. The application would use the gyroscopes in the phone to assist inspectors in taking photographs from a predefined angle.

Next, the Engineering and Graphics created a graphical user interface (GUI) for the application. The GUI, displayed in Figure 11, was presented and was critiqued by the whole team.

The group also invited Chad Nixon to Binghamton University to learn his opinion about the current progress of the program. During this visit, it became clear that the use of PCI in the program did not make much sense. Chad Nixon explained that the PCI was actually something that was only calculated overall once every year or more, and was used for large segments of pavement. Therefore, calculating PCI from small sections of pavement would not be practical. The group decided that if the PCI was not the answer, perhaps another type of index was. As a result, the group developed the Crack Condition Index to handle individual cracks.

Finally, it was decided that the smartphone application would serve as an integrated data gathering and analysis tool. Pavement inspectors would take pictures of any problem areas encountered using the smartphone’s integrated camera. The inspector would then record notes about the problem using either the voice recording functionality of the smartphone, or the onscreen keyboard. The application would store the information in a database, and calculate the CCI rating for the photographed crack, storing that information in the database as well.

V: Safety & Risk Assessment

When introducing a new system to an existing operation, there are always concerns about its reliability. These concerns are weighted against the potential positive effects, and then a decision is made whether or not this system is worth implementing. This is done primarily with the assistance from the FAA's Safety Management System (SMS), which defines safety as the freedom from unacceptable risks. [33] While the incorporation of this application would make day-to-day pavement inspections more reliable, there are a few concerns that have been identified and need to be addressed.

The first area of potential concern is the set of third party hardware that the proposed project relies on. If the smartphone on which the application runs is either damaged, unable to operate, or unavailable, the application will be either be unavailable or may not work as intended. However, even if the application were to become unavailable for a time, airport personnel would simply have to follow the system they use currently, and then manually upload the collected data to the GIS system later.

If the GIS connection becomes unstable, data transmission could be corrupted or lost. If the phone is unable to communicate correctly with the GIS, a time sensitive operation like pavement analysis could be delayed.

There could also be anomalies in the data analysis. By allowing the image analysis of a crack to identify and assess the degradation automatically, a concern arises about special cases and incorrectly formatted data being incorrectly analyzed. Although most of the automatically calculated data can be viewed and manually altered, falsely represented data can lead to misjudged situations.

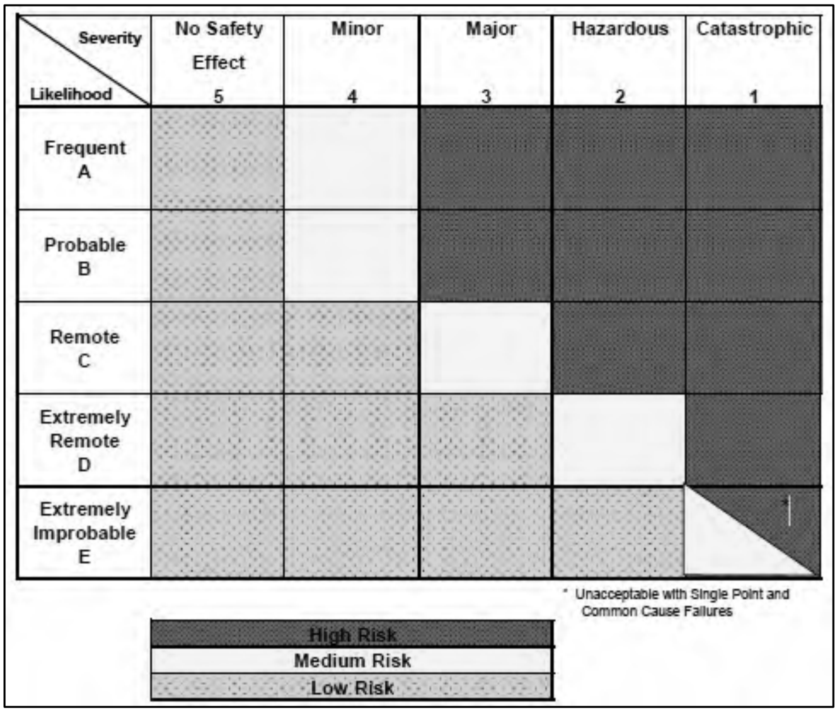

Figure 12 Risk Matrix [33]

Although the aforementioned risks are certainly possible, it is important to differentiate between all possible faults in a system, and probable faults in a system. These risks can be evaluated with the Risk Matrix from the SMS Manual, displayed in Figure 12.

The first potential risk that was identified was potential hardware malfunctions. Applying the Risk Matrix to this event would result in an Extremely Improbable Situation due to the dependability of modern hardware. Furthermore, the hazard would be of Minimal Severity due to the potential backup mechanisms and flexibility of the task. Therefore, this fault would have the lowest possible risk.

The next risk identified was failure of the GIS system in terms of connectivity and data maintainability. First, the likelihood would be classified as Remote because the average up time of a connection that does not change position is often very high. In addition, relatively little data (just the pavement analysis currently being conducted) would be lost, giving the event a Minor severity level. Furthermore, routine data management practices, such as backing up data and temporarily saving the data in the smartphone's memory, would be effective mitigation techniques. Therefore, this would be a Low Risk hazard.

The last risk to be considered here is the automated image-processing portion of the application. This event, depending on the efficiency and reliability of the developer's implementation, could have at worst case a Remote Likelihood. Furthermore, the severity of this event is Minimal, because manual data manipulation that is done in current practices can still be used to verify the results of the automated analysis should its accuracy come into question. It should be noted that thorough testing processes would ensure the maximum possible stability, further reducing the risk of an unreliable software system.

In general, most of the risks associated with this system are no different from the risks associated with any software system. In this situation, not only do the risks pose little danger to airport personnel and aircraft passengers, but also they can be mitigated using good data management practices.

VI. Technical Aspects Addressed

i. Overview

A smartphone with an integrated gyroscope, camera, and GPS will be used to gather the necessary information about pavement deterioration during pavement inspections. Using the GPS the location of each troubled area examined will be mapped onto the Airport GIS. An image of the troubled area will be stored along with the location and a voice recording by the inspector, if desired. The image will be analyzed by a computer and given a score out of 100. Depending on the score, a remediation action will be recommended.

ii. Crack Condition Index

At the heart of this project is a new scale for measuring the condition of specific cracks. This new scale, referred to as the Crack Condition Index (CCI) is heavily based on PCI. However, while the PCI is geared towards measuring large sections of pavement over a long period, the CCI is geared towards measuring very small segments of pavement on a daily or as-needed basis. The CCI determines the severity of the deterioration, and the possible actions that might be taken, and is determined by a computer analysis of the image taken.

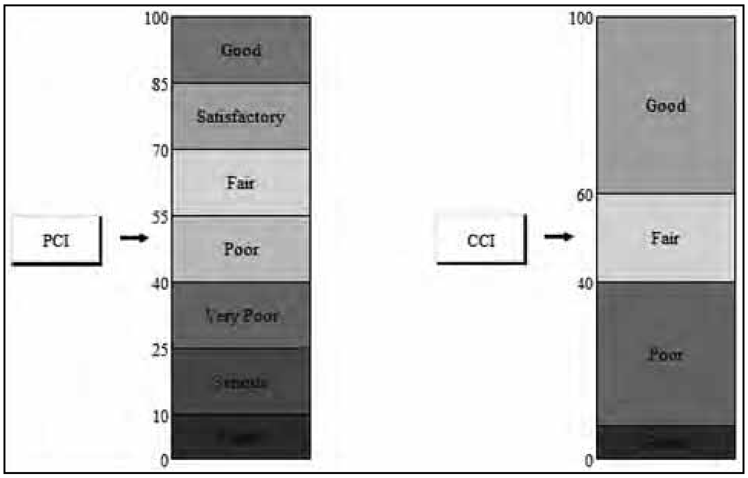

Figure 13: Comparison between PCI (on left) and CCI (on right).

Figure 14 displays the breakdown of both the PCI and CCI. Essentially, pavement that does not display any signs of cracking will have a CCI value of 100, indicating there are currently no visible problems. The CCI rating will then decline as cracks form and further plummet as conditions worsen. Once the CCI number reaches a poor rating, the section of pavement will

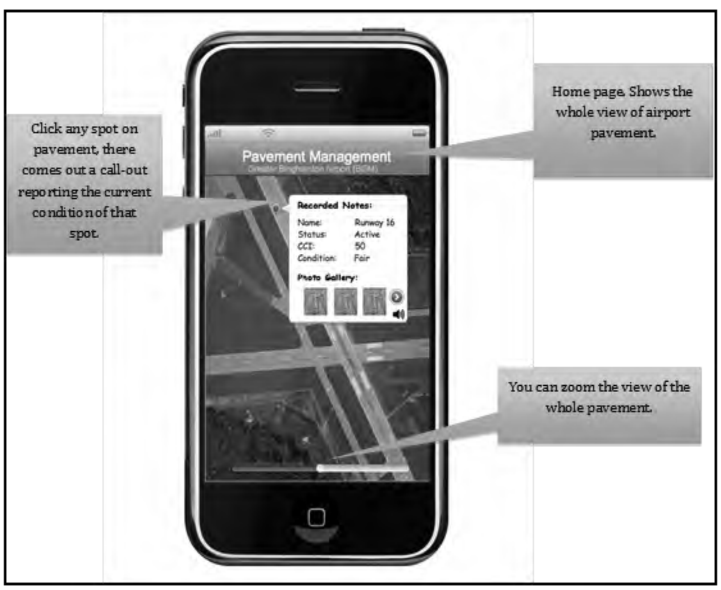

Figure 14: Image of what the screen will look like to the user.

need to undergo significant reconstruction, potentially causing a section of pavement to become unusable. The goal of this proposal is to help ensure that the CCI never reaches zero.

iii. Displaying the Crack Information

Figure 15: Enlarged image of a crack callout.

To display previously collected data, the proposed application will utilize the Airport GIS. When a problem area has been documented by an inspector, a point of interest will be created on the airport's GIS. A user can then select a point of interest to view the information associated with a given problem area.

Information displayed will be the crack's location, the latest calculated CCI number, and the three most recent images. Figure 15 shows how information will be displayed on the smartphone. In addition to images of the crack, the user will be able to view descriptions and explanations created by the inspector who originally documented the point of interest. The user will be able to view the comments in text, or listen to the original recording.

A page of thumbnails containing the images captured at the specified location will be displayed. The screen will contain a maximum of nine images, displayed in a grid. If more than nine images are associated with the location, the user will have the ability to scroll down to view less recent photographs. The user can get a close up view of any of the images by selecting it. There will also be an option button that when clicked, displays the calculated CCI for the image as well as any comments left at the time of documentation.

When the user logs into the application, the airport's GIS will be displayed. As can be seen in Figure 14, the GIS will have points of interest that are associated with problem areas on the pavement, displayed as red dots on the runway map. Upon selecting a particular point, a window will appear containing information about the problem area. The information includes the status of the pavement, the calculated CCI, the condition, and the photos associated with it. If the user wants to see more information about the point of interest, the user can do so by clicking the blue arrow, shown in the lower right corner of Figure 15.

Once the point of interest is selected, the user will have the ability to view the photograph history of the area. The collection will begin with the most recent image of the crack and progress towards the oldest. Figure 16 consists of two different pictures of the same crack. The phone on the left is displaying a picture taken on November 30, 2012. As the one of five heading indicates, this image is the most recent of five photographs. The photograph on the right was taken six months later, on May 6, 2012. In that time, the crack had degraded drastically as shown by the significant increase in crack width. Where the CCI rating of the original image was at a good level, the CCI of the image on the right would be at a poor level. As both the CCI and the photograph indicate, repairs need to be made.

Figure 16: The screen on the left displays a picture of a crack. The screen on the right is another picture of the same crack, only months later.

The use of a voice recording will allow pavement inspectors to record additional information about a given problem area. This becomes very beneficial for locations with concavity or heaving defects as opposed to cracking. Concavity and heaving are currently very difficult to determine through image processing.

After the photograph has been taken and analyzed, a CCI rating will be determined. The CCI will be displayed to the user, and automatically uploaded into the GIS database. The image in Figure 17 shows the CCI number for a picture just analyzed. At this time, the inspector may record a comment by pressing the microphone button located in the middle of the screen. Also, on the screen is a recommendation for repairing the crack. In this example, the crack requires a sealant. When the employee saves the information, an alert will be sent to the appropriate airport officials. From there, the manager can decide whether to take the recommended action or not. If the manager decides to go through with crack repair, a work order can be automatically generated using the gathered information and sent out.

Figure 17 CCI rating with recommended maintenance.

iv. Crack Analysis Algorithm

Based on the calculated CCI level, and the type of crack, the application would generate a suggested repair method. For example, light traverse cracking on rigid pavement would have a CCI rating fairly close to 100, and would not require any maintenance. As the crack's severity increases to medium or even high, the CCI rating would fall to fair. Once this crack enters the fair rating, a rotary-random saw and seal is recommended with either a hot or cold applied sealant. As the CCI ranking moves toward zero, the suggested repair methods will change, usually becoming more expensive and more thorough, until the only method possible is total rehabilitation.

Different types of pavement exhibit unique forms of cracking and require different methods of repair. For example, alligator cracking can occur in both rigid and flexible pavements, but have particular repair protocols depending on the pavement type. Therefore, the software program will need to consider the pavement type when determining recommended repair procedures. However, the CCI will still behave the same way and only give a fair rating once maintenance is required, regardless of the type of pavement.

v. Storing Crack Information

When a crack is documented and photographed, the data will need to be sent to a database. The database will contain several tables relating to the crack information and analysis. The main tables in the database will consist of those pertaining to current cracks, archived cracks, and various tables regarding the analysis of the photographs submitted. Figure 18 shows how every crack documented will be given a unique identification number that will be stored in an online table. This table will contain only the identification of the crack and the GIS coordinates of the crack. A sub-table will contain each record of a specific crack in the coming days or weeks. Each record in this sub-table will contain the location of the image that was taken, a timestamp, and the employee responsible for documenting the record. The most important table will be the one that stores the analysis information; it will store various numerical changes as well as the change in the Crack Condition Index value.

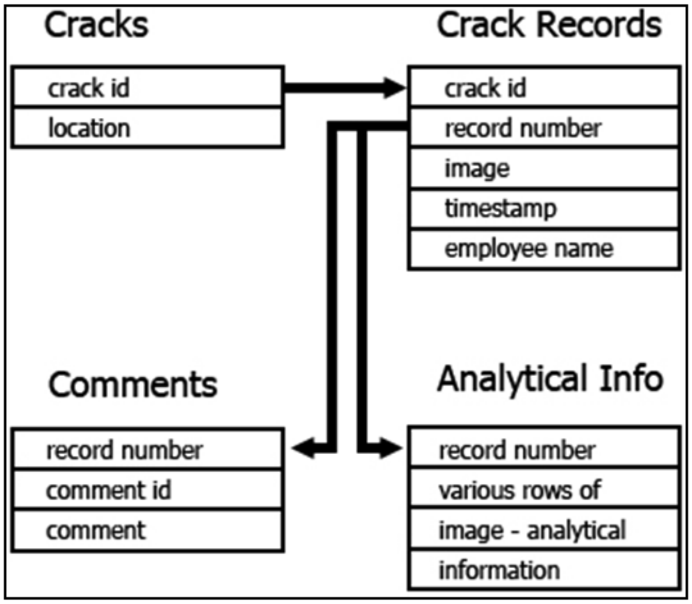

Figure 18: Database relations for the GIS.

A small subset of the tables pertaining to crack information storage will be responsible for storing comments and human input regarding crack conditions. Such comments include any recording made by the pavement inspector, text generated from this recording using speech-to-text software, and any text that the inspector chooses to type in directly. Since the system does not require employees to record comments, not every record number will appear in the Comments table. As seen in Figure 19,

Cracks

Crack Id	Latitude	Longitude
c0001	42°6'12"N	75°54'42"W
c0002	42°6'08"N	75°54'48"W
c0003	42°6'06"N	75°54'37"W
c0004	42°6'08"N	75°54'25"W

Crack Records

Crack Id	Record Number	Image	Timestamp	Employee Name
c0001	r0001	5d42153.jpg	12/28/2011	Smith
c0002	r0002	b552001.jpg	1/20/2012	Carey
c0003	r0003	43543d51.jpg	1/27/2012	Johnson
c0004	r0004	9101431.jpg	2/14/2012	Carey

Comments

Record Number	Comment Id	Comment
r0002	cmt0001	"Deep cracking to base"
r0003	cmt0002	"Swelling"
r0004	cmt0003	"Surface Crack"

Analytical Information

Record Number	Crack Type	Crack Severity	CCI
r0001	Alligator Cracking	L	96
r0002	Longitudinal Cracking	H	52
r0004	Longitudinal Cracking	L	90

Figure 19 Sample Database for Crack Information

record number ‘r0001’ (associated with Crack c0001 as shown in the Crack Records table) does not exist in the Comments table.

vi. Crack Analysis

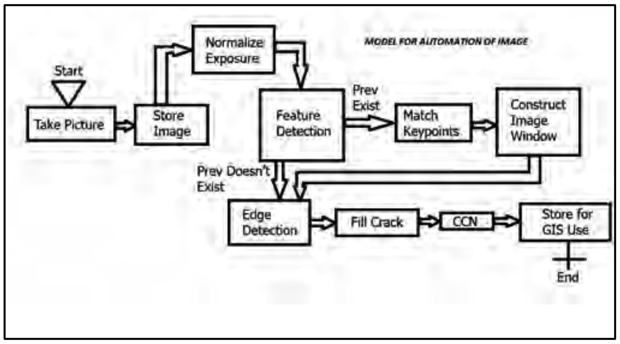

Figure 20: The process of analyzing an image

The analysis of crack information data is imperative to the process of assuring that runway conditions maintain high standards. Previously, most crack analysis was done by eye; a method that can be tedious and subjective. To counteract this flaw in the system, a new method using both computer vision and image processing algorithms would be used to analyze the images of the cracks. The full process is portrayed in Figure 20.

vii. Isolate Cracks

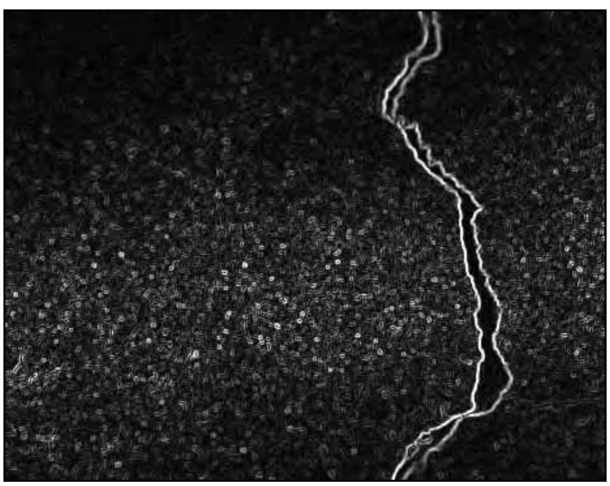

Figure 21 This image displays the corresponding points between two different crack images. Only good features were shown due to the removal of outliers.

Before a crack can be analyzed, it must first be detected in the image. A common recurrence when viewing pavement cracks is the evident change in light intensity within the cracks and the normal pavement. Using this information, a variety of algorithms exist that can be used to isolate this crack [40]. With the information of the crack confined to a single structure, aspects of the crack such as the direction, orientation, crack type, and thickness of crack can be addressed. This process of crack separation is displayed in Figure 21 [40].

viii. Image Overlaps using Feature Detection

Since not all photographs of the same area taken at different times will perfectly resemble previous photos, a method for making sure the new photographs stay consistent with the old is necessary. For this reason, an algorithm is needed that will recognize key similarities between the old and the new image (called key points) [41] [42]. In Figure 21 key points can be found with corresponding matches. Once key points between images have been found and properly compared, simple geometry can be used to compute the overlapping region of the new image taken.

VII. Interactions with Airport Operators

The team, in an effort to seek a knowledgeable understanding of the airport process and FAA standards pertaining to the project, engaged with several aviation and engineering professionals. The team's main collaboration was with Chad Nixon, Vice President of McFarland Johnson, Inc., and Carl Beardsley, Commissioner of Aviation at the Greater Binghamton Airport and President

Figure 22 First Full-Group Meeting with Beardsley and Nixon at the Greater Binghamton Airport

of the New York Aviation Management Association.

The team's first interaction with airport officials consisted of a meeting between Commissioner Carl Beardsley, Vice President Chad Nixon, Professor Ziegler, and project team leader Andrew Cholewa. The meeting was held at McFarland Johnson's corporate headquarters in Binghamton, New York. The objective was to reach an agreement on a project topic that was both viable and beneficial to airport operations. After a discussion of various potential topics, the group settled on a smartphone application that would improve the efficiency and accuracy of daily runway maintenance using the GIS that was already set up within the airport.

In order to formulate a design approach and learn more about the current inspection and maintenance procedures, a second meeting was held at the Greater Binghamton Airport, which is shown in Figure 22. This meeting involved Commissioner Beardsley, Vice President Nixon, Professor Ziegler, and various members of the team. Commissioner Beardsley described currently used methods of inspection and maintenance while the team members toured the runway and inspected cracks that had already been sealed. Commissioner Beardsley explained the categories of cracking and the precautions necessary to manage and record a discovered anomaly in the pavement. The grid system and the use of the PCI were of particular importance to design considerations.

Next, Chad Nixon detailed the use and application of the GIS. After seeing an example of the airport's implementation of GIS, the team suggested incorporating geo-tagged photographs from the smartphone application. The photographs would relate directly to their respective points of interest. These photos would then be used to examine the deterioration of the pavement.

Commissioner Beardsley also suggested that the smartphone not attempt to remove the human-element completely from the important process of pavement maintenance, by allowing a method of recording data on interest points. In response, the team proposed that the application have an additional speech-to-text feature that will keep the inspector as an important part of the process while still maintaining efficiency.

Figure 23 Second Meeting with Vice President Nixon

The team had a meeting with Vice President Chad Nixon at Binghamton University to discuss areas of the project that needed further consideration. This meeting is shown in Figure 23. At this meeting, the validity of basing the application's evaluation system solely on PCI was brought into question. Chad Nixon corrected the team's understanding of the PCI and the impracticability of using a large-scale measure for a small-scale application. As a result, the idea of creating a Crack Condition Index (CCI), which would evaluate the severity of individual cracks instead of large segments of pavement, was suggested.

VIII. Projected Impacts of Design

i. FAA Goals

There are five primary objectives in the FAA Portfolio of Goals for the Fiscal Year 2010:

1. Next Level of Safety – Achieve the lowest possible accident rate during all phases of flight by constantly improving safety, including cyber security, for both aircraft and commercial space launches.

2. Delivering Aviation Access through Innovation – Ensure full NextGen capabilities are implemented and utilized based on aviation needs in order to advance solutions to safety, funding, airport infrastructure, and environmental problems.
3. Sustaining our Future – Limit the number of people exposed to aircraft noise and increase NAS energy efficiency.
4. Improved Global Performance through Collaboration – Reduce the rate of aviation accidents worldwide to limit airport congestion and delays.
5. Workplace of Choice – Improve FAA ratings from both employees and patrons.

The design being proposed supports each one of these goals [43].

ii. Next Level of Safety

Neglected runway pavement causes damage to airframes, engines and landing gear, unnecessarily compromises safety and leads to higher rehabilitation costs [28]. With the consistent, accurate, and frequent pavement examinations facilitated by this software, preventative maintenance can be completed swiftly and efficiently. Pavement quality would therefore be maximized, and the threats posed by pavement degradation would therefore be minimized.

iii. Delivering Aviation Access through Innovation

Once a crack has been annotated, it will be placed on the GIS database and visible amongst airport personnel, allowing quick and easy access to current pavement conditions. This will improve operational decisions by making it easier to use, evaluate, and share pavement data, in accordance with the FAA’s NextGen plan [44].

iv. Sustaining our Future

Digitalizing crack documentation would offer several benefits over traditional paper methods. Transmitting electronic data can be performed nearly instantaneously, which is considerably faster than sending physical documents via mail or fax. In addition, the centralized data storage, would allow the appropriate personnel to track pavement degradation almost as quickly as it occurs. This will help officials monitor pavement distress and apply appropriate repair procedures. In addition, once enough data has been collected over an appropriate span of time, trends in crack development can be more easily determined. As a result, underlying problems in the pavement (if any) may be more quickly recognized and fixed, minimizing the resources spent on short-term repairs.

v. Improved Global Performance through Collaboration

By being the first to adopt an effective smartphone application for pavement maintenance using GIS, the US could be an example for other countries to automate airport pavement analysis. Furthermore, making this technology available to other air travel organizations, would allow the FAA to take a leadership role in introducing uniform, quantified, automated pavement analysis to day-to-day pavement maintenance [44].

vi. Workplace of Choice

This proposal will assist human resource management by permitting proper allocation of airport employees. For example, the application would handle crack identification and assist in any paperwork required, minimizing the time that employees would spend on such tasks, allowing the employees to spend more time fulfilling other responsibilities.

vii. Commercial Potential

Installation of this system would save airports time. First, analyzing crack conditions are as simple as photographing a troubled area, so data gathering would be quick and simple. Furthermore, since the system is automated, maintenance crews would no longer need to take the time to fill out the paperwork that was previously required, allowing time either for a more thorough analysis of a larger stretch of the runway, or more time to complete other tasks, or both. Airports would also save time when accessing and working with the information. With the information available in a centralized location, and in a digital format, it is in an excellent condition for any number of future data analyses. For example, it would become possible to automatically determining which regions of a given runway seem to have the greatest number of pavement-related issues, or to track automatically the expenditures related to pavement maintenance.

viii. Process of Implementation

The program would rely heavily on spatial information and would therefore require access to a GIS system to label and track cracks as they develop. However, the FAA already requires airports to have a GIS in place. Therefore, this step should already be satisfied by a majority, if not all, FAA-regulated and government-funded airports.

Once the GIS is created, the airport would need to purchase smartphones on which to run the application, a desktop for running the image processing algorithm, and a license to use the software. It would be up to the discretion of the airport commissioner how many smartphones the airport would need, depending on the frequency of pavement inspections, and the number of inspectors. A desktop computer is necessary because image-processing algorithms require more computing power than can currently be provided by a smartphone to complete in a timely manner.

ix. Affordability and Utility

The most outstanding cost would be the cost of the development of the system. Chad Nixon, Vice President of McFarland Johnson, estimates the software development phase would cost between $25,000 and $50,000. Figure 24 uses the high end of this estimation for cost calculations. It should be noted that this one-time development cost would not vary depending on the number of airports using the software. Each airport would however need to pay for several initial expenses. In particular, each airport would need to pay for the equipment, installation of the software, training, the ongoing software subscription, an adequate smartphone data plan, and smartphone insurance.

To help integrate the system into an airport, an expert technician would need to install the system and train employees in its use. Figure 24 estimates the set up fee to cost around $1,440, based on an hourly salary of $90 and two eight-hour workdays. The first day would consist of installing the software. In particular, the technician would test the application to ensure everything is functioning properly. The second day would be spent training airport employees on proper techniques and procedures for using the application.

Next, each $200 smartphone purchased by the airport would require a data plan. A 2-gigabyte (GB) per month data plan would provide sufficient space for the application to run. This would include analyzing photographs and interaction with the GIS. 2GB data plans cost around $30 for each month, according to most wireless providers. In conjunction with the monthly data plan fee, each phone should have an insurance plan. Insurance plans can start as low as $7.99 per month, or as seen in Figure 24, around $96 for the entire year. Insurance plans would cover the cost of replacing or repairing the associated smartphone in the case of damage or loss.

Costs	
Development Costs	
Expense	Amount
Software Development	$ 50,000.00
Initial Costs (per airport)	
Expense	Amount
Desktop Computer	$ 600.00
Smartphone	$ 200.00
Set Up Fee	$ 1,440.00
Yearly Costs (per airport)	
Expense	Amount
Software License (yearly)	$ 600.00
2GB Data Plan (yearly)	$ 360.00
Smartphone Insurance	$ 95.88
First Year Total	**$ 53,295.88**

Figure 24: Table displaying costs for creating and implementing the proposed system. The total cost after one year is displayed.

Like many other continual projects, the suggested system would also have a cost of ownership. The total cost of ownership (TCO) is calculated using three main components: the

Ongoing Costs					
Airport with 1 Phone		Airport with 2 Phones		Airport with 4 Phones	
Expense	Amount	Expense	Amount	Expense	Amount
Software License (yearly)	$ 600.00	Software License (yearly)	$ 600.00	Software License (yearly)	$ 600.00
2GB Data Plan (yearly)	$ 360.00	2GB Data Plan (yearly)	$ 720.00	2GB Data Plan (yearly)	$ 1,440.00
Smartphone Insurance	$ 95.88	Smartphone Insurance	$ 191.76	Smartphone Insurance	$ 383.52
Yearly Total	**$ 1,055.88**	**Yearly Total**	**$ 1,511.76**	**Yearly Total**	**$ 2,423.52**

Figure 25: Cost of Ownership for a year at a single airport, using a varying number of smartphones

airport's software license, the 2GB data plan, and the insurance plan for each smartphone. Each of these monthly fees would need to be paid for by each airport in order to use the system. Figure 25 provides a table with the projected yearly costs. Every year, airports using only one smartphone would need to pay roughly $1,056 to maintain the program. Owning two to four smartphones would cost $1,512 to $2,424. If an airport were to possess additional smartphones, the yearly cost for the data and insurance plan would increase accordingly.

However, the expected benefits of the program would offset the costs proposed above. According to Chad Nixon, the CCI metric, use of electronic storage, automated recommendations, and time-bound data points would cost less than existing methods while providing enhanced benefits. For example, consider the CCI. It provides a uniform metric across all paved surfaces and is spatially bound to a single pavement irregularity. Meanwhile, other existing metrics, such as PCI, are spatially bound to an entire section of runway, resulting in coarser granularity. By constraining CCI to a single pavement irregularity and combining GIS location-specific information with the irregularity, pavement repairs can be better targeted, resulting in more efficient, and therefore less expensive, repairs.

Furthermore, according to Commissioner Beardsley, many airports use paper forms to document pavement records. With the database provided by the proposed system, retrieving information for a specific area of the runway does not require sifting through piles of paperwork, but rather only several clicks of the mouse.

x. Future Potential

The proposed system has the potential to be extended to more than just basic day-to-day inspections. Currently, most airports periodically hire outside consultants to perform a total pavement analysis to access conditions. In Chad Nixon's professional opinion, the frequency of such pavement evaluations could be reduced once enough data has been gathered from an airport using the suggested design. By taking the data gathered each day by personnel using this application, and analyzing it in an appropriate manner, a reliable assessment of overall pavement condition can be assessed.

In addition, this program may also be extended to augment the outside inspections. Patterns in distress development may become readily apparent as the database created by this application grows. Such information would allow the outside consultants to focus their analysis on sections of the pavement that have a history of distress, while spending less time on sections that have a history of just normal wear and tear. Such targeted analysis may reduce both the time and cost associated with the more thorough analysis.

IX. Summary and Conclusion

i. *Summary of the Problem*

Adequate pavement management is crucial in maintaining airport safety, and avoiding high repair costs. In order to ensure proper pavement maintenance, the FAA requires that airports conduct daily inspections. In order to comply with this requirement, airports have trained personnel that inspect paved areas on a daily basis.

Currently, inspectors drive around the paved areas and when they see a problem area, they fill out a form by hand with the details of the problem. Unfortunately, natural human variation leads to inconsistent results, depending on who investigates a section of pavement when. However, uniformity is crucial when examining such a pivotal part of an airport.

ii. Aiding Pavement Management

The purpose of this project is to use smartphones to streamline and automate as much of the daily pavement maintenance process as reasonable. The algorithm within the application would quickly calculate uniform CCI ratings for every single documented crack. Once the CCI of a given crack falls below a certain threshold, the problem area will be flagged, and a suggested method of repair will be proposed. Therefore, this program would streamline current maintenance procedures, provide uniformity to pavement maintenance, and provide the data in a format that makes it open to future data analysis.

Appendix A: List of Complete Contact Information

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Appendix B: Description of Binghamton University

The State University of New York at Binghamton, also named Binghamton University, is a public research university located in upstate New York. Since its establishment in 1946, the University has grown from a small liberal arts college, then called Harpur College, to a large, doctoral-granting institution, presently consisting of six colleges and schools. Besides for the still present Harper College, the five other schools are as follows: the Thomas J. Watson School of Engineering and Applied Science, the Decker School of Nursing, the College of Community and Public Affairs, the School of Management, and the School of Education. Total, throughout all these schools, there are nearly 15,000 undergraduate and graduate students. [45] After many years, Binghamton is proud to be ranked among the elite public universities in the nation for challenging their students academically, not financially, which results in a unique, best-of-both-worlds college experience.

Figure 26, Binghamton University [46]

According to *USA Today's 100 Best Value Colleges,* Binghamton is ranked as the fourth best public university for its overall value. [47] The *Princeton Review* states that Binghamton is one of only sixteen colleges in the nation, and the only SUNY School, to receive the highest score on The Princeton Review's annual “green rating” for campus environmentally related policies, practices, and academic offerings. [48] *U.S. News & World Report* has ranked Binghamton University among the nation's elite universities for thirteen years in a row.

The 15,000 students that attend Binghamton University represent a variety of backgrounds, coming from all 50 states and from 100 different countries. Additionally, 85% of

Binghamton students were in the top 25% of their High School class. The average SAT and ACT score range is 1190-1340 and 26-31 respectively. [45]

Binghamton offers more than 80 academic undergraduate majors and more than 30 graduate majors. Binghamton employs close to 600 full-time faculty members where 93% of whom have PHDs or equivalent in their fields. [45]

Appendix C - Description of Non-University Partners

BGM (pictured in Figure 27) is the team's airport collaborator on this project. Located at 2534 Airport Road, Johnson City, NY, 13790, the Greater Binghamton Airport is a publicly owned regional airport serving the Southern Tier of New York [49]. BGM offers nonstop commercial air service to Philadelphia, Detroit, and Washington, D.C. At this time, three airlines offer service at the airport: US Airways Express, Delta Connection, and United Express [49]. The airport has two runways, one with a length of 7100 feet and another with a length of 5001 feet. There are, on average, 52 aircraft operations each day on the runways, the majority of which are air taxi operations [51].


Figure 27 Outside BGM[50]

Carl Beardsley, Commissioner of Aviation at the Greater Binghamton Airport, is the team's airport consultant on this project. On September 30, 2010, Beardsley was elected as President of the New York Aviation Management Association [52]. Beardsley has provided guidance into how runway maintenance is carried out at the Greater Binghamton Airport, helping the team understand the subject matter at hand.

McFarland Johnson, Inc. (MJ) is the team's design collaborator on this project. Founded in 1946, McFarland Johnson is an employee-owned engineering consulting firm and a recognized leader in infrastructure planning, design and construction management [53]. The firm's corporate headquarters are located in Binghamton, NY, with branch offices in Canandaigua, NY, Putnam, CT, Concord, NH, Saratoga Springs, NY, Hallstead, PA, South Burlington, VT, and Boston, MA [54]. The firm's primary services are in aviation, bridges, buildings and facilities, environmental services, highways, site/civil design, and sustainable services [55]. The firm recently received two Engineering Excellence awards by the American Council of Engineering Companies of New Hampshire (ACEC NH) and an Engineering Excellence award by the ACEC of Vermont (ACEC VT) [56].

Chad G. Nixon, Vice President and Business Development Officer at McFarland Johnson Inc., is one of the team's design consultant on this project. Nixon also serves as Special Projects Manager on statewide and airport specific aviation planning projects. Nixon's areas of aviation expertise include aviation forecasting, economic analysis, airport negotiations, business planning, and project management [57]. Nixon's insight into the design aspect of the project has been of invaluable help to the team.

Appendix E: Evaluation of the Educational Experiences Provided by the Project

1. **Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?**

Yes, it did by giving us the opportunity to experience the work environment. Unlike the school atmosphere, solving a problem in the work field is no longer as easy as just looking it up in the course textbook, it becomes a process or recognizing the problem, identifying possible solutions, setting up a solution plan, implementing it, putting measure in place to prevent it from happening again, all these while working as a team . Through this process, we got to work on not just our teamwork skills but also communication while exchanging ideas among ourselves and also with the employees in the industry who helped. We perfected our problem solving skills by coming up with a solution after being presented with a problem.

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

We had very little knowledge about airports and airport pavements. We had to do extensive research to get familiar with the field before we could actually start thinking of possible solutions to the problem. Soon enough we figured that the project was more about the process of getting from the problem to the solution and the steps in between.

Since most of the work in college is dependent on oneself, having to work as a team and depending on somebody else to finish their task so that you can do your own was also challenging. Obviously, bigger teams proved even more challenging because of factors like strained communication and different timetables. Discussions over regular meetings and compromises were always the solutions to this problem.

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

We developed the hypothesis using a series of steps. First, we discussed the problem and made sure that everyone was clear on what needed to be solved. After discussing the problem, we brainstormed to come up with potential solutions and we made sure every team member came up with at least one idea or more. After our group had a long list of ideas for each problem, we analyzed and looked at each potential solution in more depth to determine if it was feasible. We narrowed down our now shortened lists of ideas to what the group thought was most practical, realistic and effective.

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

Participation by the industry was quintessential to the completion of the project. We used the Greater Binghamton Airport as a case study for our project and met with airport experts on site. We learned firsthand of their current maintenance plan for the pavement After learning about their current plan, we told them about what our idea was and how they could use smartphones to save time and costs. After we told them about our broad idea, which was well received, we asked them about what requirements they had which enabled us to develop a plan. We studied the actual l pavement and maintenance procedures on location at the Greater Binghamton Airport. Getting to see how the maintenance actually takes place was extremely useful because despite careful planning and analysis we no longer needed to visualize it and it gave us insight into potential barriers and other minor adjustments we could make to our idea. We researched the project heavily and learned about the Pavement Condition Index and discussed this with industry professionals who visited Binghamton University. . We learned that the original plans we had made using the pavement condition index would not be effective because the pavement is broken into large chunks but smartphones cannot photograph a large area. We developed a better plan that included developing our own index that would suit the needs of the project. The assistance and compliance by industry was appropriate and very useful because without meeting with them we would not have developed an effective plan. Additionally without industry support we would not have seen the pavement firsthand in order to better understand the project needs and requirements.

5. **What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?**

This project provided a valuable learning experience. The technologies researched by our team were certainly not typical. There is an immense amount of thought that goes into the building and maintaining of airport runways, and it was fascinating to learn how it is done.

In addition to learning about technologies, the project gave an opportunity to refine other skills necessary to succeed in the working world. When we worked with the airport officials, we needed to use a certain level of professionalism in the way we communicated. Although we had never met the airport personnel before, we had to get valuable information from them while treating them with the respect they deserved.

Another valuable facet to this project was the degree of teamwork necessary to complete the project. Sometimes it is much harder to collaborate on a project than it is to work alone. Since many projects in the workforce are team based, getting some team experience was very beneficial.

For faculty members:

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

I believe that my students can solve just about any reasonable problem thrown at them, but where they are truly at a disadvantage is recognizing a problem that has not been placed in front of them. The FAA Design Competition helps fill that gap by letting students define the problem themselves and then formulate a solution to that problem. These students have never had to perform real research on a topic they began knowing nothing about while collaborating with so many individuals to create a solution. Additionally, the FAA Design Competition allows the students to gain experience in life-long learning, something that is not typically possible in the traditional classroom setting. This competition provides an educational experience that is simply immeasurable in value.

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

The students participating in this competition are stretched far beyond their comfort zone, but the learning experience presented by the FAA competition is exactly what should be expected of all students as they approach graduation.

When I describe the projects that my students develop for the FAA competition, people are quite surprised that the primary goals of the projects are to make my students better communicators and problem solvers. The competition is undertaken as a class project in a required senior level undergraduate course titled Professional Communication and Ethics. The course is intended to bridge academe and professional practice within the themes of communication, ethics and problem solving, The FAA competition provides an appropriate learning experience at a level that pushes students out of their comfort zone and provides the exact outcomes that I desire from my course and my students.

3. What challenges did the students face and overcome?

My students face many challenges by undertaking this competition and that is what makes the competition so good. Their challenges include lack of technical writing skills, lack of experience at open-ended problem solving, lack of knowledge regarding aviation, lack of experience collaborating and communicating on a large team, and *senioritis*.

When students begin handing in their drafts for this competition, it becomes quite apparent that they have never been taught how to write from a technical or scientific perspective. Therefore, I must insist that they write portions of their entry repeatedly, in many cases up to five times and usually at least three times. This is quite frustrating for both the students and for me, but this is proof that the challenge of writing well is exactly what they need.

All good students seem quite capable of solving well-defined reasonable problems related to their courses. However, my students become significantly challenged when they must define an open-ended problem themselves and then formulate a solution to that problem. This competition seems to be the first time these students have had to analyze something without first knowing the problem and they find that to be quite a challenge because they have never had to face that situation before.

My students are all undergraduate Computer Science seniors with no experience relating to air travel, airports, aviation, etc. Their lack of experience relating to the aviation industry takes them far from their comfort zone and that is quite a challenge for them. However, I tell them repeatedly throughout their preparation for the competition, that this is how the professional world works. No one is going to provide them a known problem with a known solution, as is typical in nearly every college course. In the real world, determining the problem is sometimes more difficult than determining the solution.

Another significant challenge is that of collaboration and communication when working on a team. The student team consists of 25 students, which is far too many for such a project. However, the FAA Competition has become the hallmark of one of our courses and due to limited resources, the only way it can be offered is with an enrollment of 25 students. This is far from ideal, but it provides yet another learning opportunity that sometime you have to seize opportunities when they arise, and the FAA competition is a tremendously worthwhile opportunity, regardless of the communication challenges that are presented by trying to collaborate with such a large team. Students will realize later that the collaboration and communication challenges they faced on the FAA project prepared them well for the future.

The sixth challenge is that of motivation, also known as senioritis, and the methods to deal with the students who fall into the category of the weakest links. "*I am no longer your professor; I am now your coach and you are the team. When I do not feel you are living up to* *your potential, I am going to have to let you know and you will have to do better*." Those words are used to let my students know that I will only accept work that is done to their highest potential. In a typical professor/student relationship, I have come to the realization that some students are quite satisfied with a grade of *C*, accompanied by a *C* level of commitment, and I have learned to live with that. However, in a competition, everyone must work at an *A* level of commitment because the weakest link can bring down the entire team and the *coach* cannot be content with students who might otherwise choose to work at a *C* level. The typical *professor/student* relationship becomes a *coach/team* relationship and that is a challenge for my students and for me. However, I have learned through participating in the FAA competition in past years how to tackle the new *coach/team* relationship with my students. There are times when I am sure that some of the students are not happy when I make them rise to their true abilities. In the end, I hope they have learned the true meaning of teamwork, responsibility, and to take pride in their work.

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

I am 100% behind this competition and love telling everyone I know about how my students compete each year. While at the Greater Binghamton Airport a few weeks ago, my students noticed a problem that has nothing to do with their topic, but from that problem came a great idea for next year's competition. Preparing for the FAA Competition has been a fabulous experience for not only the students, but also our aviation partners who assisted us in the competition, our local community, the university, and of course for me. I am anxious for the process to start all over again next year.

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

I worry that fresh ideas regarding the topics listed in the competition guidelines may get more difficult for those of us who are regular participants in the competition. I do not want my students to work on any projects that have been submitted to the FAA competition in the past, because I feel it will be too easy for them to use existing information rather than starting from scratch. I also do not want it to appear that we were copying ideas that had already been presented at some earlier time. I was happy to see that the FAA added several suggested topics to the competition this year and I think that will be very beneficial.

The FAA competition is by far the best-organized competition I have seen in my 34 years in higher education. The educational value and experiences presented by participating in the competition are simply unmatched anywhere else.

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Appendix G: Photo Gallery

Consulting with Commissioner Beardsley and McFarland Johnson Vice-President Nixon at the Greater Binghamton Airport

Examining the Greater Binghamton Airport pavement

Consulting with Commissioner Beardsley on the runway at the Greater Binghamton Airport

Consulting with McFarland Johnson Vice-President Nixon outside of the classroom

Appendix H: Ethical Considerations

In order to protect both personnel and passengers, airports must maintain high safety standards, including proper pavement maintenance. Pivotal to proper maintenance is early detection of pavement deterioration [58]. The smartphone application proposed here assists in the early detection of problem areas of pavement, and therefore helps prevent serious injury and potentially saves lives.

If airport pavement is not properly maintained, it quickly deteriorates to the point where it poses a threat to aircraft, airport infrastructure, airport personnel, flight crew, and passengers [59] . [59]. The auto evaluation of pavement condition by the smart phone application proposed here helps ensure proper pavement maintenance. By making accurate evaluations with greater consistency, the airports are better able to identify and repair pavement deterioration before it can become a safety liability. Inspectors may also use the GIS and record keeping features to assist in tracking early signs of deterioration. Doing so decreases the possibility that further pavement deterioration goes unnoticed [60].

In addition to safety concerns, airports must consider the cost of pavement maintenance. Early detection is one way airports can do this. [23] By more quickly locating early signs of wear, airports can usee less costly repair procedures.

As important as saving lives and reducing costs is, airports must also consider the privacy and security of data. Any sensitive data that may compromise the safety of travelers or employees must be protected. While the smartphone application does store data involved in the safety of persons, the data itself is not highly sensitive. Exploiting the pavement weaknesses noted in the application in a malicious manner would require access to the pavement itself. In addition, since the application works in conjunction with an airport's GIS, even if the data security was compromised, access to the GIS software would still be required. Regardless, the possibility of the aforementioned data leaks can be considerably reduced by limiting access to the smartphone, and installing security software on it [61].

In summary, few privacy and security concerns exist with the smart phone application and in fact, this product would be beneficial in terms of safety, and cost reducing perspectives.

Appendix I: Biographies

Joseph Barra is a senior at Binghamton University. He is pursuing a degree in computer science, with an expected graduation date of May 2012. He plans to work in distributed systems. In addition to programming, Joseph enjoys chess and racquetball.

Fangzhi Cai is a student at Thomas J. Watson School of Engineering and Applied Science of State University of New York at Binghamton. She is an international student originally from China. She will receive her Bachelors of Science degree in this spring. Fangzhi is a Computer Science major with a minor in Mathematics. Upon graduation, she will be pursuing a master's degree in Management of Information System at Carnegie Mellon University.

Michael Caruso is a senior at Binghamton University and will graduate with a Bachelor's Degree in Computer Science in May 2012. Upon graduation he will begin work full time as a Network Administrator/Software Developer at the offices of the International Union of Operating Engineers Local 15 in New York. Outside interests include sports and travelling, as Michael spent the Spring 2010 semester at the University of Nottingham in the United Kingdom and backpacked through Europe.

Andrew Cholewa is currently studying computer science and mathematics at Binghamton University, with an expected graduation date of May 2012. In August 2012, he will begin pursuing his PhD in computer science at the University of Illinois at Urbana-Champaign. His research interests include formal software verification, computational linguistics, and theoretical computer science. He is a member of the Binghamton University Scholars Program, the Upsilon Pi Epsilon Computer Science Honor Society, and the Pi Mu Epsilon Mathematics Honor Society. His favorite pastime is to engage in "leisure learning," which is to independently study something that he finds interesting without the stress associated with deadlines.

Hollyann Clift is a senior studying Computer Science at Binghamton University, expecting to graduate in August 2012. She was born and raised in Buffalo, NY. After graduation, she hopes to gain a career with a software engineering company, creating software people will use every day. Hollyann spends her free time reading science-fiction novels, playing video games, and writing fiction.

Raymond Conn is expected to graduate from Binghamton University, in May 2012, with a B.S. in Computer Science. He is a member of UPE. Raymond's main interests of study are in the areas of computer networks and distributed systems.

Nicholas Cox is a senior studying Computer Science at SUNY Binghamton. His hometown is O'Fallon, IL. He is currently enrolled in Cornell University's Air Force Reserve Officer Training Corps with an acceptance to Undergraduate Pilot Training at Columbus Air Force Base, Mississippi.

Renan Del Valle is a student at the State University of New York at Binghamton. He is a candidate for a B.S. in Computer Science in May 2012. His main interests lie in distributed systems and computer networks.

Katherine Espana is a senior at Binghamton University and is expected to graduate with a Bachelor’s of Science in Computer Science in May 2012. She is a member of Upsilon Pi Epsilon (UPE), the international computer science honor society.

Samuel J. Feher is an undergraduate at Binghamton University currently pursuing a degree in Computer Science. His interests in the field of computer science include image processing, 3d graphics, and data analysis. His future plans include graduating at the end of the current semester and beginning to work in his field of study.

Raanan Korinow is expected to receive his B.S. in Computer Science with a minor in Mathematics from Binghamton University in May 2012. Raanan has been a course assistant in the Computer Science department for three years. His academic interests include networking, agile development methodologies, and algorithm design.
Jin Kim is a senior pursuing a Computer Science BS degree at Binghamton University, expecting to graduate in May 2012. He plans on teaching abroad after graduation. Born and raised in Queens, New York, his personal interests include piano, sports, and being a rabid fan of the New York Mets, Jets and Knicks.

Ryan Latham is a senior at Binghamton University majoring in Computer Science. He previously attended Tompkins Cortland Community College for one year, before transferring to Binghamton University in 2008. After Ryan graduates, he plans to pursue a career in video game development. He spends his free time either inside working on video games, or outside hiking and swimming

Kenneth Louie is a senior at Binghamton University graduating in May 2012 with a Bachelors of Science in Computer Science. He is currently doing an internship at the SUNY ATTAIN lab in downtown Binghamton, where he works as a part time instructor and tutor. At his internship, Kenneth tries to help his students get back into the work force by teaching them relevant and essential computer skills. His interests outside of school include, watching sports, playing basketball, learning about technology, and playing PC games.

Joseph Nocco is a senior at the State University of New York at Binghamton. He is expected to graduate with a B.S. in Computer Science in May 2012. Joseph’s study interests include data mining and machine learning.

Prerak Parikh is an undergraduate student at Binghamton University. He is a senior, pursuing a Bachelors of Science degree in Computer Science, with an expected graduation date of May 2012. He has worked as an intern for Online Worlds and Department of Environmental Protection; with expertise in Web Programming. He plans to enter the Information Technology field upon graduation. He wants to open his own startup company in the future. His interests include web design, cricket and tennis.

Lionel Peña was raised in Bronx, NY by his beloved family. He is currently a junior in Binghamton University working to achieve a Bachelor’s degree in Computer Science by May

2013 but is now looking to intern in different fields of computer science to find the most suitable career for him. Lionel's current interests include website building, programming software, and drawing.

Donald Pu is a candidate for a Bachelor of Science in Computer Science. He is a recruiter for Summer Advantage USA. In his free time, Donald enjoys volunteering for icouldbe.org, practicing slack lining, watching movies, and playing video games.

Joshua Rosenkranz is expected to receive his B.S. in Computer Science and a minor in mathematics from Binghamton University in July 2012. His main software interests include graphics and image processing. He has completed research internships in the field of image processing and is currently working in the Graphics and Image Computing Laboratory of Binghamton University.

Nidhi Shah is a junior at Thomas J. Watson School of Engineering and Applied Science of State University of New York at Binghamton. She will receive her Bachelors of Science degree in Fall 2012. Nidhi is a Computer Science major and plans on pursuing a Master's degree in Finance for her graduate studies.

Collin Stowell is expected to receive his B.S. in Computer Science from Binghamton University in May 2012. His study interests include graphics design, web development, algorithms, and network security.

Marvin Vinluan is a senior Computer Science major at Binghamton University. He is active at the campus radio station and as president of the Animation Club. His hobbies include video gaming, collecting postmarks, and volunteering at anime conventions

Janette Wambere is a fourth year student at Binghamton University. She is currently pursuing her first bachelor's degree in Computer Science and is expected to graduate in May 2012. While at Binghamton, Janette took advantage of the study abroad program available and spent a year studying in Kenya - Africa, where she worked with a small group of IT professionals to bring basic computer information and skills to the local high school children. She hopes to go back to Africa later and volunteer with the same group when not busy pursuing her Master's degree.

David Yeager is an undergraduate Computer Science student at Binghamton University. He plans to work at BAE Systems after he graduates.

Appendix J: Milestones

Milestone 1: Professor William Ziegler and project leader, Binghamton University Senior Andrew Cholewa, met with the Vice President of McFarland Johnson Chad G. Nixon and the Commissioner of Aviation at the Greater Binghamton Airport, Carl Beardsley to discuss project ideas. Eventually they settled on the broad idea of a web based smartphone application that would streamline elements of day-to-day runway maintenance. Specifics of a viable problem statement, design, risk analysis and solution were left to be later determined by the entire team.

Milestone 2: Professor Ziegler and Andrew Cholewa introduced themselves and the project to the entire class. They proceeded to distribute the workload and responsibilities among four different teams. These include the Design, Strategies and Ethics, Risk Management, and Engineering and Graphics teams. Students were asked to fill out a forum highlighting their personal strengths and team preference.

Milestone 3: Andrew Cholewa reviewed the students submissions and assigned each student to a specific team. Andrew then discussed his decisions with Professor Ziegler, wherein team assignments were finalized.

Milestone 4: Team assignments were announced in a meeting with Professor Ziegler, Andrew Cholewa, and the class. Professor Ziegler reiterated the expectations of each team, including due dates.

Milestone 5: A discussion and overview of literature reviews was given by Professor Ziegler. The discussion focused on the importance of credible sources, and how to write a literature review. The use of FAA official sources was strongly suggested. Each team was also told what type of information they should focus on.

Milestone 6: Teams determined both team leader and team quality assurance leader positions. Teams also shared contact information and agreed upon a workflow system and a weekly meeting place.

Milestone 7: The entire team discussed the specific ways in which a smartphone application could improve the runway maintenance and inspection procedure. Eventually the team narrowed down the idea into a viable problem statement, design, risk analysis and solution.

Milestone 8: Professor Ziegler explained the writing and formatting requirements for each team’s technical writing assignments. Andrew Cholewa gave a demonstration on how to insert pictures and captions into each individual team’s submissions.

Milestone 9: The entire team, particularly the Design team, began to brainstorm and discuss the Projected Impacts. The team explained how the project will meet FAA goals, commercial potential, affordability and utility of the project, a financial analysis, and described the process of implementation.

Milestone 10: The entire team met with Professor Ziegler, Chad Nixon, and Commissioner Carl Beardsley at the Greater Binghamton Airport. A discussion on project difficulties and design direction was held, culminating in a decision to include a speech to text feature and integration of the proposed smart phone application into existing GIS implementations. The team also got a chance to inspect the runway and apron pavement, in order to further understand areas of potential improvement.

Milestone 11: The team discussed removing the human element completely from the inspection and evaluation process. Upon further consideration, the team decided that the smart phone application could increase pavement inspectors efficiency and accuracy, but would not be able to replace them.

Milestone 12: The entire team worked on developing a final problem statement. Professor Ziegler recapped some of the information learned at the team's visit to the Greater Binghamton Airport. Team members were asked to voice any suggestions or criticisms of project goals. Eventually the team narrowed the problem statement down to a focus on increasing the efficiency and accuracy of the pavement inspection process by improving the detection and chronicling of pavement deterioration. By doing so, the smart phone application would reduce the risk of damage to equipment and increase the safety of air travel.

Milestone 13: The engineering and graphics team compiled project visuals, including photos documenting the strategic process, into a cloud storage space. The cloud storage was designed to be a central repository to store and organize all future visuals as well. Access to the cloud was then provided to the team leads to be distributed to team members.

Milestone 14: Professor Ziegler discussed the importance of teamwork to the entire team and the importance of leadership to the individual team leaders. Best practices in team communication and coordination were also addressed by Professor Ziegler

Milestone 15: To address concerns over the consistency of photographs, the engineering and graphics team proposed the inclusion of gyroscope functionality, which was accepted into the design. The team also decided that the smart phone application must perform some method of auto evaluation of pavement, perhaps PCI based.

Milestone 16: Binghamton University's Professor and Director of the Graphics and Image Computing Laboratory, Dr. Lijun Yin, is asked for his professional opinion on the viability and ease

of computing pavement condition from smartphone pictures. Professor Yin commented that he not only believed it was possible, but that it should be relatively easy compared to other types of photograph recognition.

Milestone 17: Joeseph Nocco, design team lead, and Chad Nixon, Vice President of McFarland Johnson Inc. worked on the design issue of pavement cracks that were too large for a single photograph. After reviewing possible solutions, a system of allowing multiple photographs to evaluate one crack was chosen and introduced into the project design.

Milestone 18: Further discussions were held with Chad Nixon at Binghamton University. Concern arose over how the PCI, which evaluates large segments of pavement, would be used to evaluate much smaller segments. Heeding the advice of Mr. Nixon, the team created a Crack Condition Index (CCI), a smaller scale version of the PCI, which would be used to evaluate the photographs.

Milestone 19: Design of the smartphone application was finalized. The key design elements included auto evaluation of pavement through CCI, photograph consistency assistance with smart phone gyroscope functionality, procedurally generated GIS points of interest including all relevant information, photograph gallery - accessible from the smart phone and GIS software, and text to speech and voice log record keeping.

Milestone 20: The entire team discussed the relevance of the FAA project to computer science majors. Professor Ziegler offered several original examples illustrating the importance of teamwork and communication in the computer science industry. Being able to incorporate and translate a skill set into a broad project framework was shown to be one of the benefits of the FAA project. Professor Ziegler also talked about some of the difficulties involved in making this transition.

Milestone 21: Professor Ziegler gave a presentation about ethics in business and academia. Specific examples were offered and the team was asked to give their opinions on ethical dilemmas. Ziegler also discussed the importance of considering the ethical ramifications of the smartphone project.

Milestone 22: After a debate and several rounds of voting, the team decided on a formal name for the project.

Milestone 23: With a more complete understanding of the design and engineering aspects of the smart phone application, the team revisited the topic of economic viability. Katherine Espana, engineering and graphics team lead, who had met with Chad Nixon on several occasions to discuss cost and sources of funding, presented her findings to the team. The team also considered and debated possible adoption rates of the application by airports. The discussions cumulated in a finalizing of the projected impacts of the project.

Milestone 24: Professor Ziegler explained the practice and classroom presentations that each team will be required to give. The teams will present their contributions to the FAA project, and discuss some of the methods used to coordinate team communication and workflow.

Milestone 25: The teams completed the final edits and review of the assigned workload. Every section of the project document was sent to Andrew Cholewa and Professor Ziegler for grading and compilation.

Milestone 26: Project leader Andrew Cholewa, finished review and integration of the various parts of the written document.

Milestone 27: The team submitted the project to the FAA.

Appendix K: List of Acronyms

CCI: Crack Condition Index

FAA: Federal Aviation Administration

FOD: Foreign Object Debris

FRAT: Flight Risk Assessment Tool

GIS: Geographic Information Systems

GPS: Global Positioning System

HMA: Hot Mix Asphalt

MEMS: Microelectromechanical system

NDT: Nondestructive Testing

PCC: Portland Cement Concrete

PCI: Pavement Condition Index

SMS: Safety Management System