A Web GIS Application for Airport Pavement Management

by

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A Thesis Presented to the
Faculty of the USC Graduate School
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
Master of Science
(Geographic Information Science and Technology)

August 2017

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Acknowledgements

Thank you to my family and friends for their continued support throughout my graduate coursework and thesis writing. Their continued support has allowed me to pursue my dream of finishing my master's degree.

Thank you to all my professors at USC, but especially Dr. Karen Kemp my thesis chair, and my committee members Dr. Darren Ruddell and COL [R] Steven D. Fleming. You made this process a whole lot easier with your continued support and guidance.

List of Abbreviations

APMS   Airport Pavement Management System

FAA   Federal Aviation Administration

GIS   Geographic Information System

PMP   Pavement Management Program

PMMP   Pavement Maintenance Management Program

SaaS   Software as a Service

SSI   Spatial Sciences Institute

USC   University of Southern California

Abstract

One of the most important resources at a commercial service airport is the airport pavement. An airport has the responsibility of ensuring that aircraft are able to safely land, taxi, and takeoff by ensuring that the airport pavement is in a safe and serviceable condition and that the life of the pavement is maximized. With the continuous need to efficiently manage pavement at commercial service airports to extend the service life of pavement while reducing rehabilitation costs, more airports are turning to technology to assist with these tasks. However, the cost to implement an asset management system or a pavement management system can be extremely expensive and they often do not include GIS functionality as a standard feature. Though, with the recent growth of Web GIS technologies, commercial service airports can now implement a cost-effective solution to managing their airport pavement. This research demonstrates how to develop a Web GIS application for airport pavement management for use at a commercial service airport using a low-cost, Software as a Service (SaaS) based Web GIS platform. The development includes the design of an airport pavement GIS data model. Esri's ArcGIS Online SaaS-based platform was chosen for the development of the Web GIS application that is user-friendly and easily accessible via any web browser, tablet, or mobile device. With the Airport Pavement Management Web GIS application, airport staff have the ability to visualize existing pavement conditions that enable them to make more informed pavement maintenance and rehabilitation decisions, visually compare previous inspections and detect trends, and allow them to direct the timely repair of deteriorating pavement and extend the life of the pavement. The development of this application also provides the foundation for uses in other domains such as disaster response or emergency management operations, in addition to supporting future GIS integrations with Smart Infrastructure technologies.

Chapter 1 Introduction

One of the most important resources at a commercial service airport is the airport pavement. An airport has the responsibility of managing and maintaining their airport pavement, which includes the runways, taxiways, and parking aprons, to ensure that the pavement is in a safe and serviceable condition and that the life of the pavement is maximized. Without properly maintained airport pavement, aircraft are unable to safely land, takeoff or taxi. To assist with efficiently managing airport pavement, more airports are turning to technology to assist with these tasks. This thesis project focuses on the development of a Web GIS application, using a low-cost, Software as a Service (SaaS) based Web GIS platform, which allows airport staff to visualize their existing pavement conditions, visually compare previous inspections and detect trends, and allow them to repair deteriorating pavement and extend the life of the pavement.

The remainder of Chapter 1 introduces the project, motivation, application development, and organization of this thesis. Section 1.1 provides an overview of the project by specifying the need for the application. Then, Section 1.2 describes the motivation for this study and an overview of the application development is provided in Section 1.3. Finally, Section 1.4 provides an outline of the structure of this thesis.

1.1. Project Overview

While there are several commercial service airports that manage their pavement with commercially available asset management software solutions, such as IBM Maximo® or Cityworks, other airports have developed, through consulting firms, custom asset management applications that include GIS functionality. However, both options can be very expensive to purchase, require a great amount of time and effort maintain, and may not be the most user-friendly. This research demonstrates how to develop a Web GIS application for airport pavement

management at a commercial service airport using a low-cost, Software as a Service (SaaS) based Web GIS. The development of the Web GIS application also includes the design of an airport pavement GIS data model.

This thesis project shows that although a commercial service airport may lack the financial means or personnel to purchase an asset management software solution or an enterprise-level Web GIS, they can still use a SaaS-based Web GIS to manage their airport pavement. By using a SaaS-based Web GIS, an airport can manage their airport pavement using an inexpensive, user-friendly, and easily accessible web-based application via any web browser, tablet, or mobile device with minimal support from their Information Technology support staff.

For this project, Esri's ArcGIS Online SaaS-based Web GIS was chosen for the development of the Web GIS application that is user-friendly and easily accessible via any web browser, tablet, or mobile device while requiring minimal support from their Information Technology support staff. Using ArcGIS Online, a Web GIS application was created to allow airport staff have the ability to visualize existing pavement conditions that enabling them to make more informed pavement maintenance and rehabilitation decisions, visually compare previous inspections and detect trends, and allow them to repair deteriorating pavement and extend the life of the pavement.

1.2. Motivation

The motivation for developing an Airport Pavement Management Web GIS application originates from experience in conducting Pavement Condition Index (PCI) inspection and the establishment of a Pavement Management Program (PMP) at multiple commercial service airports. For a commercial service airport to receive federal grant monies through the Airport Improvement Program (AIP) or from the Passenger Facility Charges (PFC) Program, a PMP

must be established (Federal Aviation Administration 2014a). However, once PCI inspection is complete and a PMP established, an airport is typically only provided a written report establishing facility policies, setting priorities and schedules, allocating resources, and budgeting for pavement maintenance and rehabilitation. The report typically includes exhibits depicting the current pavement conditions and the airport may receive supporting files that include either CAD or GIS files of the inspected pavement. These files are often not accessible by airport staff due to their lack of possessing either CAD or GIS software. These files often do not contain additional pavement attribute data (e.g. section identifiers, pavement type, etc.). Also, the airport may receive Airport Pavement Management System (APMS) files that includes every inspected pavement distress; however, most airports do not possess the specialized APMS software required to open these files nor have the expertise to use such software. In the end this leaves the airport with only the exhibits from the report to visualize their pavement conditions that does not allow for any further analysis. However, with a Web GIS application, the airport staff can monitor the existing condition of airport pavement and make informed decisions related to their pavement.

Although many airports have a desire to have a GIS application that gives airport staff the ability to effectively manage their airport pavement, the cost of an asset management system is often too expensive. Not only is the software costly, it often does not include GIS functionality as a standard feature. If GIS functionality is available, it is typically sold as an additional feature and requires the airport to also have an enterprise-level GIS server. With the compounded cost of the system, to include hardware and software, most airports are unable to procure such a system that includes GIS functionally. However, with ArcGIS Online, an airport can start with just one

Web GIS application dedicated to pavement management and expand to managing other airport assets in the future.

1.3. Application Development Overview

The development of the Airport Pavement Management Web GIS application consisted of two major phases broken down into six stages, shown in Figure 1. Phase one, the data review and geodatabase phase, consisted of the following development stages: review of existing data, design of an airport pavement GIS data model, and creation of the airport pavement geodatabase. Next, phase two, the application development phase, consisted of the following development stages: uploading the geodatabase to ArcGIS Online, development of a web map for the Airport Pavement Management Web GIS application and development of the Airport Pavement Management Web GIS application. Additional detail pertaining to each stage is provided in Chapter 4.
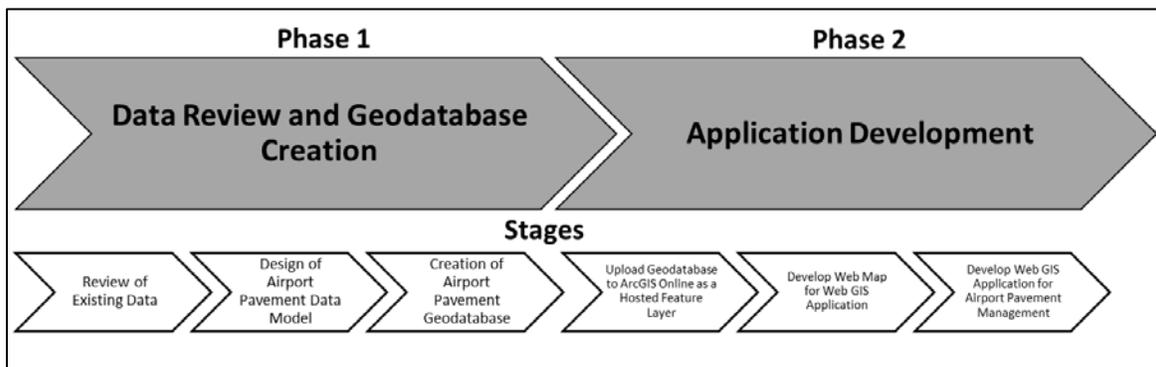
Figure 1. Application Development Overview

1.4. Thesis Organization

This remainder of this thesis is divided in five chapters. Chapter 2 assesses the use of GIS in both airport asset management and airport pavement management systems, and provides an overview of Web GIS and ArcGIS Online. Chapter 3 provides a detailed

overview of the application requirements including design principles and choices. Chapter 4 presents the detailed application development process of the Airport Pavement Management Web GIS Application. Chapter 5 analyses the results of the application evaluation from user surveys. Finally, Chapter 6 concludes with a discussion determining if the web application has fulfilled the application requirements while addressing opportunities for future work.

Chapter 2 Background

This chapter presents a literature review for this Airport Pavement Management Web GIS application. Section 2.1 assesses the use of GIS in airport asset management with commercially available asset management software. Next, Section 2.2 analyzes the use of GIS in airport pavement management systems with both commercially available pavement management software and custom web-based solutions. Lastly, Section 2.3 provides an overview of Web GIS and ArcGIS Online. This Airport Pavement Management Web GIS application incorporates aspects of each of the reviewed topics.

2.1. Airport Asset Management and GIS

The management of assets at commercial service airports is vital to an airport in operating, maintaining, upgrading, and disposing of assets cost-effectively. Assets, also commonly referred to as infrastructure, at an airport can include airfield signs, airport pavement, buildings and structures, and vehicles. An effective asset management program, typically managed through software, allows an airport to extend the life of an asset by identifying the most appropriate, economical time to perform maintenance and rehabilitation tasks. An asset management system also allows an airport to predict when an asset might fail or become obsolete and replace it only when necessary.

In 2012, the Transportation Research Board conducted a study that determined that with an asset management system in place at an airport, a 13.5 percent increase in pavement life was observed and pavement levels of service were maintained with a 30 percent cut in budget (Transportation Research Board 2012). In brief, an asset management system allows an airport to make decisions that result in the best economic, service level, and risk exposure outcomes.

GIS has been incorporated into airport asset management systems to allow airport operations and maintenance personnel to easily locate assets using GPS devices. While detailing a full-cost approach to airport pavement management, McNerney and Harrison (1995) concluded that one of the new practices in state-of-the-art airport infrastructure management is the combination of maintenance management with GPS and GIS technology for better management of airport resources and better coordination with operations.

In 2000, the American Association of Airport Executives conducted a survey that indicated that more that 60 percent of airports use GIS or intend to use GIS within the next three years for infrastructure management (McNerney 2000). Using GIS to locate assets is not only more efficient by saving time but also ensures that workers are locating the correct asset. Asset management systems that incorporate GIS also allow airport staff to visually monitor the status and condition of assets, and use spatial tools to analyze patterns based on the location of assets.

Many commercial service airports have invested in asset management software solutions to manage and maintain their facilities; however, GIS functionality is not always an included standard feature. Often, these asset management software solutions are already in use outside of the airport, in other parts of the local government (e.g. city or county), and are easy to implement at the airport. Personal experience indicates that typical asset management software solutions include implementations of either IBM Maximo® or Cityworks. However, with these solutions, to enable GIS functionality, an organization must purchase additional software components or extensions in addition to purchasing additional third-party hardware and software. For example, with IBM Maximo®, to add GIS functionality an airport must purchase the additional IBM Maximo® Spatial component that also requires an ArcGIS Enterprise server (IBM 2017).

Similarly, Cityworks also requires Esri ArcGIS Enterprise server to enable GIS functionality (Cityworks 2017).

At some other commercial service airports, the airports have developed, through consulting firms, custom asset management applications that include GIS functionality. For example, Atkins North America, an engineering consulting firm, has developed a GIS-based asset management system that optimizes the costs and logistics of regular maintenance (Atkins North America 2011). Although both off-the shelf solutions and custom developed solutions can be very effective, these solutions can often be very costly for an airport to implement and maintain over time. Also, with custom-developed, proprietary systems, support may be limited to the original developer since they are the only entity familiar with the system.

2.2. Airport Pavement Management Systems and GIS

The Federal Aviation Administration (FAA) requires that each commercial service airport have administrative oversight of their pavement by developing an Airport Pavement Management Program (PMP) that is designed to assist the airport in finding optimum strategies for maintaining pavements in a safe serviceable condition over a given period for the least cost (Federal Aviation Administration 2014a). A PMP is also referred to as a Pavement Maintenance-Management Program (PMMP) or a Pavement Management System (PMS). With a properly implemented PMP, an airport can make crucial pavement rehabilitation decisions at the most suitable time and reduce pavement maintenance costs significantly. Figure 2 illustrates the typically pavement condition life cycle and costs, dollar amount, associated with pavement rehabilitation.
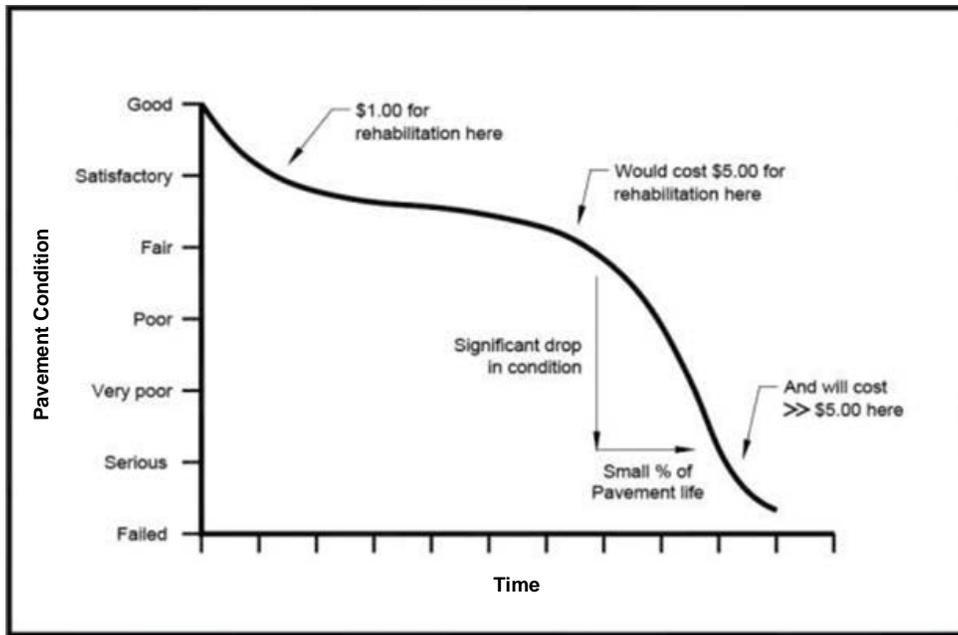
Figure 2. Typical Pavement Condition Life Cycle and Cost of Rehabilitation

At a minimum, the PMP must include a pavement inventory, pavement locations, pavement maintenance history, and pavement surface inspection results (Tighe and Covalt 2008.). The pavement surface inspection results of the PMP often include exhibits of the pavement sections and samples. Figure 3 shows an example of a pavement inspection results exhibit from a PMP. An airport typically has either a consultant develop a PMP on their behalf, manage their airport pavement through existing asset management software solutions, or manages their airport pavement though an APMS solution.
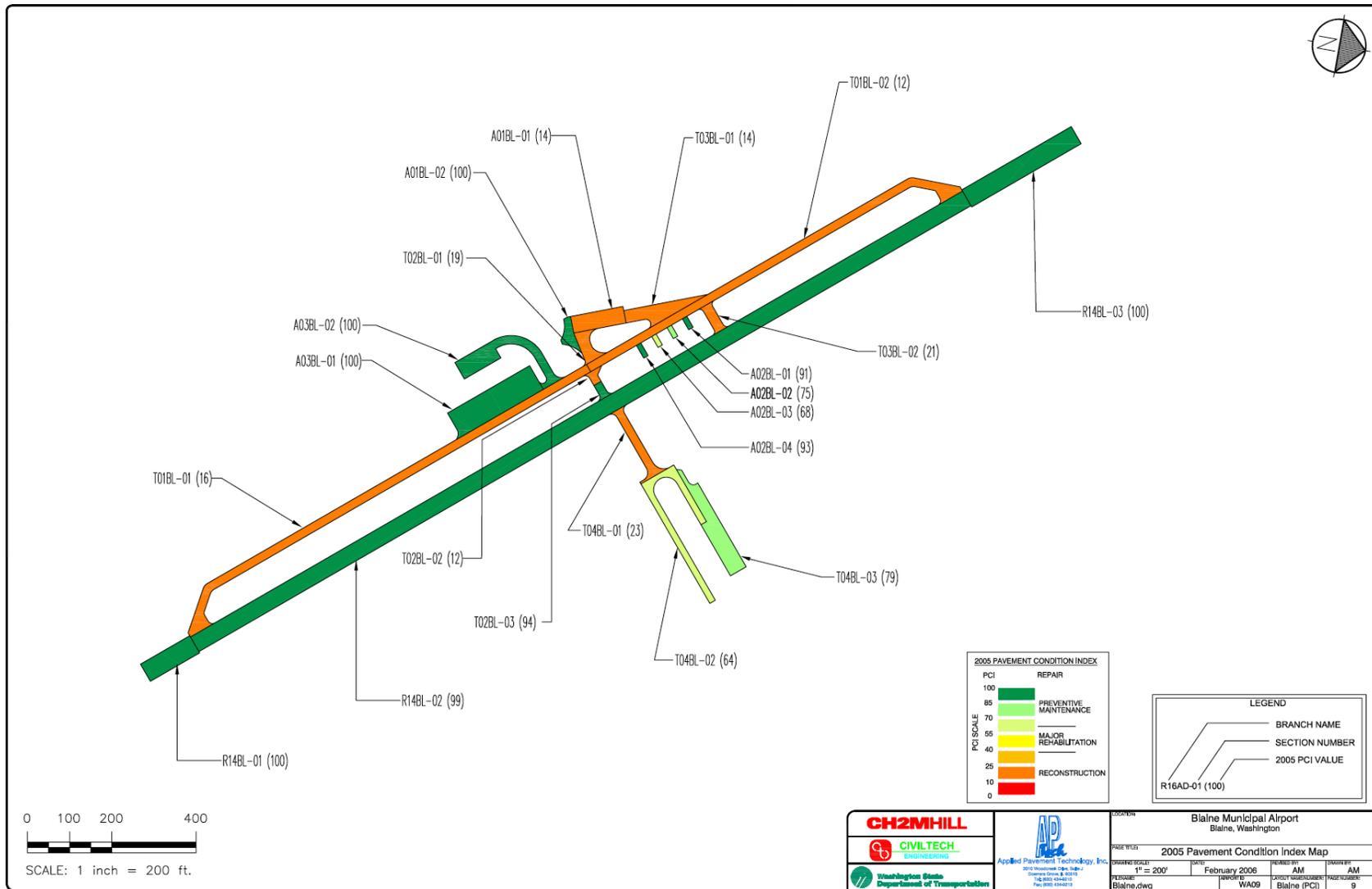
Figure 3. PMP Pavement Inspection Results Exhibit. Source: WSDOT 2005

One such APMS is the Microsoft Windows-based PAVER^{TM}, developed by the US Army

Corp of Engineers, which provides pavement inventory, field inspection, prediction modeling,

condition analysis, and maintenance and rehabilitation work planning (USACE 2009).

PAVER^{TM} includes GIS functionality, however, the functionality is limited to selecting

pavement sections from a map display and viewing basic airport pavement maps. Another

limitation is that the software is only accessible on a device running Microsoft Windows

operating system. Also, once the GIS data is imported into PAVER^{TM} from GIS software, it is

not editable and attribute data is not easily accessible.

While PAVER^{TM} and other APMS software solutions are useful for certain types of

pavement analyses, they are not very effective in the day-to-day operational environment at

commercial service airports. The primary purpose of an APMS software solution is for

prediction modeling, condition analysis, and maintenance and rehabilitation work planning.

However, the software does not provide the ability to track current pavement discrepancies and

schedule repairs. Also, PAVER^{TM} does not provide a way to record or track pavement distresses

outside of a formal inspection process.

With the widespread use of web-based systems, many commercial service airports began

to use web-based applications to manage their pavement. One such web-based pavement

management application was developed for the Oklahoma Aeronautics Commission to manage

airport pavement at 88 airports statewide (Mooney et al. 2005, 241-249). Although this web-

based system contains detailed pavement data and has been beneficial in making high-level

pavement management decisions, existing conditions cannot be easily updated by airport

personnel due to the technical expertise required to update the system.

More recently, between 2006 and 2009, Tampa and Denver International Airports have developed, through a consulting firm, a custom-designed Geospatial Airfield Pavement Evaluation and Management System (GAPEMS). The GAPEMS uses GIS for data collection, data integration, 100% pavement inspection, and geospatial analysis of remaining life. The GAPEMS incorporates georeferenced distress field mapping using ruggedized tablet PCs, Esri's ArcPad, WAAS assisted GPS, and GPS enabled cameras (McNerney and Keegan 2012, 255-270). The GAPEMS also includes georeferenced construction history, nondestructive deflection testing (NDT) results, and core samples. At Denver International, the GAPEMS data is accessible via a web-browser interface, allowing access from both office and field environments. However, at Tampa International, the data has only been published in map books and is not as accessible to airport staff through a web-browser interface.

While ahead of its time in 2009, the technology used in the GAPEMS, including the collection methods and devices, is now considered outdated. With advancements in both web and mobile technology which include the widespread introduction of web and cloud-based GIS, there are now more user-friendly solutions. For example, the technology built into Esri's ArcGIS Online and its mobile data collection applications simplify GIS data collection.

2.3. Web GIS and ArcGIS Online

A Geographic Information System (GIS) is designed to provide storage, retrieval analysis, visualization, and mapping capabilities for spatial information data (Zhang et al. 2007, 3968-3980). A Web GIS is a GIS system that uses web technologies to allow for access to GIS data through a web browser either on an internal network or the internet. Some Web GIS systems, commonly referred to as enterprise-level GIS systems, can include a GIS database server, a GIS Server, and a web server. While these systems provide Web GIS services they can

contain many different components that are expensive to purchase and maintain. However, there are also cloud-based Web GIS services, known as Software as a Service (SaaS) platform, that provide the same web GIS functionality and are hosted by third-party providers at a fraction of the cost.

There are both commercial, open-source, and publicly accessible Web GIS SaaS providers and solutions available. Open-source and publicly available solutions attract many Web GIS developers since there is typically no cost associated with using these solutions to a certain extent. For example, Mapbox is an open-source mapping platform that allows developers to create and host Web GIS maps and applications at no cost up to 50,000 map views per month and 250 megabytes (mb) dataset storage. The no cost plan does not provide customer or technical support aside from access to documentation and internet support forums. For additional data storage or technical support options, monthly plans begin at $499 per month as of May 2017 (Mapbox 2017). Google Maps offers a publicly accessible Web GIS solution at no cost through a JavaScript API for developers to incorporate into Web GIS maps and applications up to 25,000 map loads per day; however, no dataset storage is available and no additional support is available aside from access to documentation and internet support forums. A premium, paid service is available that includes technical support and pricing is based on the volume required (Google 2017).

While open-source and publicly accessible Web GIS solutions are available at no cost, they often require development experience and technical is support is often limited; however, there are commercial Web GIS SaaS providers that provide maps and applications that are ready for immediate use. Once such company providing commercial Web GIS SaaS services is Esri, a

major GIS software company, which provides both enterprise-level and SaaS Web GIS platforms.

Esri's enterprise-level web GIS, known as ArcGIS Enterprise, includes Portal for ArcGIS that provides a portal website with map and scene viewers, a content repository, and application templates. ArcGIS Enterprise is used to create, use, and share web maps and web GIS applications both internally and externally. However, ArcGIS Enterprise must be run on an organization's own infrastructure or infrastructure managed by a cloud provider, such as Amazon Web Services or Microsoft Azure.

ArcGIS Enterprise is typically chosen over the SaaS solution, known as ArcGIS Online, when an organization requires full control over their hardware to maintain a particular service-level agreement (SLA). Also, an organization may choose to use ArcGIS Enterprise when data is prohibited from being physically stored off-premises or computers within the organization are not connected to the internet.

The cost of ArcGIS Enterprise would include, at a minimum, both the server hardware and operating system software in addition to the ArcGIS Enterprise software. In addition to the hardware and software costs, an organization may have to hire additional information technology personnel to configure, manage, and maintain ArcGIS Enterprise. Lastly, an organization incurs recurring annual maintenance costs associated with ArcGIS Enterprise.

ArcGIS Online provides similar capabilities as ArcGIS Enterprise that allow ArcGIS Online users to create, use, and share both maps and Web GIS applications within their organization and the public. With ArcGIS Online, all components run in Esri-managed cloud infrastructure in a SaaS model. Every aspect of the system, including the computing and data storage resources, is hosted by Esri in a highly scalable environment.

By using ArcGIS Online, an organization is not required to purchase dedicated hardware or software in order to have a web GIS solution. ArcGIS Online is licensed on a subscription basis at significant reduction in cost compared to ArcGIS Enterprise. ArcGIS Online is available to an organization as an annual subscription that initially includes five users and 2,500 service credits for a cost of $2,500 as of May 2017 (Esri 2017a). Each organization receives their own unique ArcGIS Online Homepage (e.g. http://company.maps.arcgis.com) that can be secured or made publicly accessible. An organization can be configured to be only be accessed through a secure connection (i.e. Hyper Text Transfer Protocol Secure (HTTPS)) ensuring data security. Service credits are consumed when users host feature service layers, perform analytics, or use premium content available on ArcGIS Online (Esri 2017b). The amount of service credits used varies based on the type and file size of the stored GIS data or premium content accessed.

One of the many benefits of ArcGIS Online compared to ArcGIS Enterprise, is that it is designed to allow small organizations to start with a small GIS solution at a low initial cost of entry and grow as needed. Also, ArcGIS Online allows for additional user accounts and service credits to be purchased at any time. Additionally, in the event an organization downsizes, at the time of renewal, the number of users and service credits needed can be reduced.

Another benefit of ArcGIS Online compared to ArcGIS Enterprise is that Esri directly manages ArcGIS Online services that are both elastic and available on demand allowing for growth as needed. Esri uses commercially reasonable efforts to make their services available with a quarterly uptime percentage of 99.9% (Esri 2013). Esri also provides customer support that allows Information Technology staff and users to receive assistance if needed

With ArcGIS Online, there are numerous templates for creating web GIS applications that can be used. Additionally, a custom application template called Web AppBuilder for ArcGIS

allows for a user to customize the look, feel, and functionality of the application. With Web AppBuilder for ArcGIS, a user can create a custom user experience that allows a user to query spatial and related aspatial data and to perform advanced geospatial analyses through widgets.

In addition to having the ability to create and store GIS data, maps, and applications, users also have access to Collector for ArcGIS, ArcGIS Online mobile application, which allows for field data collection on mobile and tablet devices with built-in GPS that can be synced directly with features hosted on ArcGIS Online (Esri 2017c). Also included in an ArcGIS Online subscription is Workforce for ArcGIS that provides a built-in workforce management application allowing users to be directed to a feature in need of collection by Collector for ArcGIS. There is also Navigator for ArcGIS, which provides mobile routing directly to features on a map, available for $50 per user per year and sold in 5 user packs for $250 yearly as of May 2017 (Esri 2017d). These mobile applications bring additional capabilities and enhance the existing ArcGIS Online service capabilities.

Chapter 3 Requirements

This chapter presents the requirements for the Airport Pavement Management Web GIS application, hereafter called simply the Application. Section 3.1 identifies the goals of the Application, Section 3.2 describes the user requirements of the Application, Section 3.3 defines the functional requirements of the Application, and Section 3.4 details the Application design principles and choices.

3.1. Application Goals

The objective of the Application is to allow Airport staff, primarily personnel from the planning and engineering, maintenance, and operations departments, to visualize existing pavement conditions through an interactive, map-based user interface that is accessible via a computer, tablet, or mobile device through a web browser with an internet connection. The Application includes the ability to visually compare past inspection data and identify pavement areas that require maintenance and repair. Additionally, the Application should assist airport staff in making informed decisions regarding pavement maintenance that in turn extends the life of their airport pavement.

3.2. User Requirements

The users of the Application should be able to access the Application from any web browser by using either a computer, tablet, or mobile device. The Application should not require any specialized GIS training or additional GIS knowledge to in order to operate. The Application should have a simplified, easy-to-use interface that does not present a confusing user experience. Additionally, the Application should not have advanced functionality or user customization that could distract from the Applications primary functions. Lastly, the Application should be hosted

on a platform or service provider that is both reliable and has customer support available if additional support is required.

3.3. Functional Requirements

The primary function of the Application is to view existing pavement conditions (i.e. recent Pavement Condition Index (PCI) values) and view pavement distresses for each section and inspected samples. In addition to viewing the pavement data, the user must be able to print or export an image of the map based on current map extents. The Application should include map extent shortcuts, known as bookmarks, which allows the user to easily zoom to different areas of the airport. Additionally, the Application should include the ability for the user to draw or mark-up the map in order to highlight areas that are in need of repair. Furthermore, the Application should include the ability to perform both length and area measurements in order for the user to determine the dimensions of different pavement sections and samples.

3.4. Design Principles and Choices

This section provides an overview of the software chosen to develop the application, the platform chosen for users to access the application, and details regarding the design of the user interface.

3.4.1. Software Choice

The Application was developed using Esri's desktop GIS software and their online Software as a Service (SaaS) solution known as ArcGIS Online. The Esri software is proprietary software that requires an initial purchase for the desktop software and an annual subscription for ArcGIS Online. However, if an airport has a consultant perform the development of the application, only the ArcGIS Online subscription would be required. During the initial stages of

the project, open-source online GIS solutions were explored; however, Esri software was chosen due to its accessibility, functionality, reliability, and the customer support provided by Esri.

ArcGIS Online is accessible from any web browser by using either a computer, tablet, or mobile device. In regards to functionality, ArcGIS Online not only provides online GIS data storage but a user-friendly interface for creating and editing web maps that allow a customization of labeling, layer order, symbology, and visibility settings. Also, ArcGIS Online includes a variety of application templates that are easily customizable to the user's needs.

In terms of reliability, Esri directly manages ArcGIS Online services and uses commercially reasonable efforts to make their services available with a quarterly uptime percentage of 99.9% (Esri 2013). Esri also provides customer support for ArcGIS Online that allows Information Technology staff and users to receive assistance if needed.

3.4.2. Platform Choice

The Application, developed using ArcGIS Online, is a web-based application that is accessible through a web browser with an internet connection. By using a web-based application that allows a user to use it on practically any device, there are no accessibility limitations. If an operating system-specific application had been chosen, access may be limited. Also, ArcGIS Online is extendable to Esri mobile applications that allow for field data collection. Although this functionality is not part of the Application, it could easily integrated be in the future.

3.4.3. User Interface Design

The user interface of the Application was designed to meet the user requirements of a simplified, easy-to-use application interface that did not present a confusing user experience. This was achieved by using the ArcGIS Online built-in, customizable application template, Web

AppBuilder for ArcGIS. The template allowed for every aspect of the user interface to be

configured to provide the best user interface while ensuring required functionality was included.

Chapter 4 Development

This chapter presents the development of the Airport Pavement Management Web GIS

Application. Section 4.1 details the review of existing data, design of an airport pavement GIS

data model, and creation of the airport pavement geodatabase. Section 4.2 describes the

development of the Application and includes details regarding uploading the geodatabase to

ArcGIS Online, development of a web map for the Application and the development of the Web

GIS application.

4.1. Data Review and Geodatabase Creation

This section summarizes the review of existing data, describes the design of an airport

pavement GIS data model, and details the creation of the airport pavement geodatabase.

4.1.1. Review of Existing Data

A review of the existing airport pavement GIS data for a commercial-service

international airport was conducted in order to develop a conceptual GIS data model for the

project. The review was conducted using ArcGIS for Desktop (ArcMap) to examine the GIS data

that was formatted in the Shapefile file format (.shp). The Shapefiles consisted of polygon

features for pavement sections and samples and a polyline feature for the concrete Portland

Concrete Cement (PCC) joints. Prior to this project, the data had been originally formatted in an

AutoCAD file format (.dwg) that was converted to Shapefile file format.

The pavement section and sample Shapefiles were in the WGS 1984 Web Mercator

(Auxiliary Sphere) projected coordinate system and contained attribute data required for the GIS

data to be imported into PAVER^{TM}. The concrete (PCC) joints polyline Shapefile, also in the

Web Mercator projected coordinate system, contained no attribute data.

Since ArcGIS Online web maps use the same projected coordinate system, the Shapefiles did not need to be projected into another coordinate system. The Web Mercator projection, when used for measuring distances over large areas, is not accurate due to the substantial vertical and horizontal stretching at extreme latitudes (Quinn 2010); however, the use of the projection is not an issue in regards to measurements at the scale of an airport. This was verified by projecting the data back to its original projection, WGS 1984 UTM 16N, where the offset difference between the two datasets was 0.0004 feet.

In addition to reviewing the GIS data, the recent inspection results from 2015 and 2016, formatted in the Microsoft Excel spreadsheet file format were reviewed. The spreadsheets contained the 2015 Pavement Condition Index (PCI) values, 2016 Pavement Condition Index (PCI) values, 2016 Distresses by Section, and 2016 Distresses by Sample. These spreadsheet files, previously exported from PAVER^{TM}, required additional processing prior to being imported into the geodatabase. The additional processing included adding a unique key field for relationships since the PAVER^{TM} unique ID was not in an easily usable format. The sample airport data from these spreadsheets were imported as either feature class attribute data or independent tables with relationships to feature classes during the creation of the airport pavement geodatabase to demonstrate the capabilities of the Application.

4.1.2. Design of Airport Pavement Data Model

The first step in creating the airport pavement GIS data model was to review existing GIS requirements and standards for airport pavement. This included reviewing the ASTM pavement inspection standard (ASTM 2012), FAA data collection and GIS standard (Federal Aviation Administration 2014b), and the PAVER^{TM} user manual (USACE 2009) to determine GIS

requirements. The FAA data collection and GIS standards did not specify any standards related

directly to pavement management.

The ASTM pavement inspection standards did not contain any specific GIS standards;

however, the standards did contain information on how pavement should be classified. The

classification included a hierarchical decomposition of the pavement network into branches,

sections, and samples in order of largest to smallest. The inspection standard also specified that

when a pavement inspection is performed, the Pavement Condition Index (PCI) is only reported

at the section level, not at the sample level. This clarification was important when determining

appropriate attributes for the section and sample feature classes.

Lastly, the PAVER^{TM} user manual provided guidance on GIS attribute data required for

the GIS data to be imported into the software. The attribute requirements included required

fields, maximum character counts for each field, and the requirements for a unique identifier

field.

After reviewing the requirements, an airport pavement GIS data model was created using

an entity-relationship database model. The pavement GIS data model included feature classes

based on ASTM Pavement classification standards. The feature classes consisted of pavement

sections (polygon), pavement samples (polygon), and pavement PCC joints (polyline). Then,

attribute data was added to each of the feature classes based on PAVER^{TM} requirements.

Additional attribute fields were added to allow for relationships to be built between feature

classes and tables. For example, the pavement section feature class had an attribute field named

"SectionPID" that is a unique, calculated field and is a primary key used when creating

relationships. Lastly, related tables were added based on data that would typically be associated

with pavement inspections. The existing data tables, previously exported from PAVER™, were used as a reference in this design.

The last step in creating the GIS data model involved determining appropriate relationships between feature classes and tables. Appropriate relationships were created between feature classes and feature classes (e.g. pavement sections and pavement samples) and feature classes and tables (e.g. pavement sections and extrapolated pavement distresses by section). Without the relationships, users of the Application would be unable to query past inspection data when selecting a feature class. All of the relationships were one-to-many (e.g. one pavement section contained many pavement samples). Figure 4 shows the pavement GIS data model with relationships.
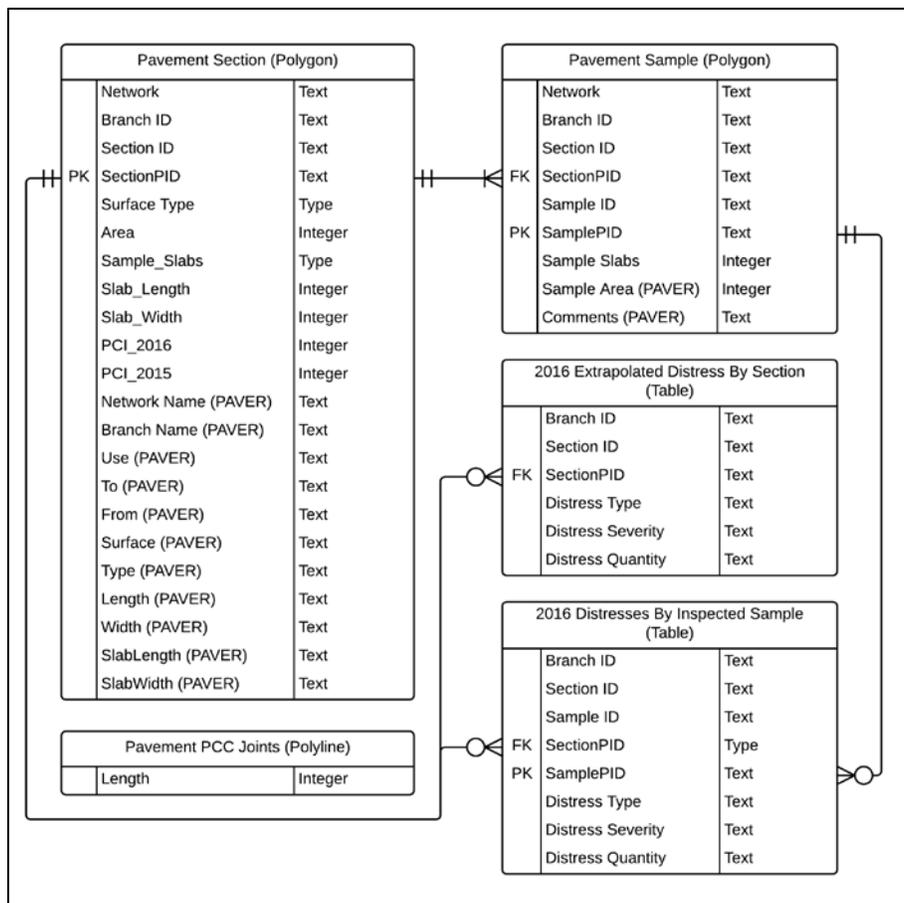

Figure 4. Airport Pavement GIS Data Model

4.1.3. Creation of Airport Pavement Geodatabase

An Esri file geodatabase was created using ArcGIS for Desktop (ArcMap) that contained feature classes based on the airport pavement GIS data model. The geodatabase contained polygon feature classes for pavement sections and pavement samples as well as a polyline feature class for pavement PCC joints. During the creation of the feature classes, attribute fields were added based on the pavement GIS data model. With the attribute fields, the GIS data can be exported and easily imported into PAVER™ if needed.

When creating the attribute fields, a field alias was configured so that each field had an easily readable name. Also, when the data was published to ArcGIS Online the field alias is also replicated in the published data in turn saving time when creating the Web Map.

Next, the previously reviewed sample airport pavement GIS data, in Shapefile format, along with the recent inspection results, in Microsoft Excel spreadsheet file format, were imported into the geodatabase. This data was imported to demonstrate the GIS data model functionality and provide sample data for testing in the Web GIS application. Upon importing each Shapefile, the GIS data was validated to ensure accuracy. Since the GIS data model was based on PAVER™ attribute data and the shapefiles already contained that attribute data, the data was retained. Using ArcMap, field calculations were performed on certain fields such as "SectionPID" and "SamplePID" to create unique records to be used as primary keys when creating relationships. For example, the "Section ID" field was calculated to combine the "Branch ID" and "Section ID" fields separated by a hyphen (e.g. TWY A-01).

The recent pavement inspection results spreadsheets were imported as either feature class attribute data or as independent tables. The 2015 Pavement Condition Index (PCI) values and the 2016 Pavement Condition Index (PCI) values spreadsheets were imported into the pavement sections feature class as attributes. The 2016 Distresses by Section and the 2016 Distresses by

Sample spreadsheets were imported as individual geodatabase tables. Lastly, geodatabase

relationships were created between feature classes and tables based on the previously determined

relationships in the pavement GIS data model. Figure 5 shows the final airport pavement
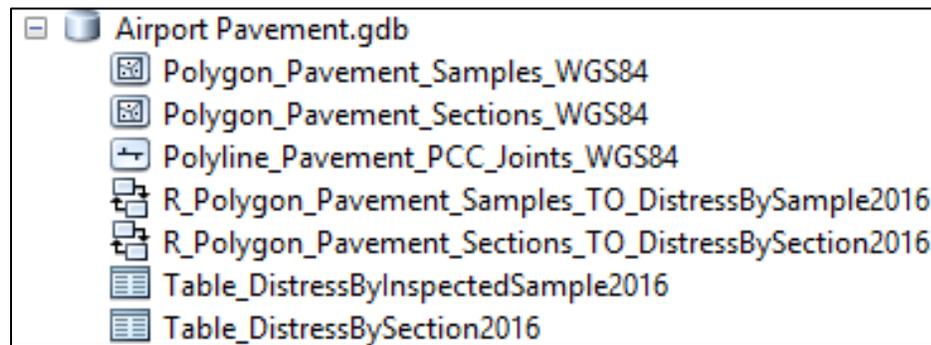
geodatabase.

Figure 5. Airport Pavement Geodatabase

4.2. Application Development

This section describes the development of the Application and includes details regarding

uploading the geodatabase to ArcGIS Online, development of a web map for the Application and

the development of the Web GIS application.

4.2.1. Upload Geodatabase to ArcGIS Online as a Hosted Feature layer

The first step in developing the Application was to upload the geodatabase as a hosted

feature layer to ArcGIS Online. A hosted feature layer is a GIS feature service that can contain

multiple feature classes, related tables, and relationships which are stored on ArcGIS Online and

are accessible via web maps. The hosted feature layer, which consumes service credits based on

the file size of the data, is the only option available to store this type of data on ArcGIS Online.

To upload the geodatabase to ArcGIS Online, ArcGIS for Desktop (ArcMap) was used to

create map a document file (.mxd) that contained the feature classes and tables previously

imported during the creation of the geodatabase. During the creation of the map document, the

layer order and layer symbology settings were applied. These settings are retained when the

feature layer is published to ArcGIS Online and saved time when creating a web map. Figure 6

shows the ArcMap map document prior to publishing.
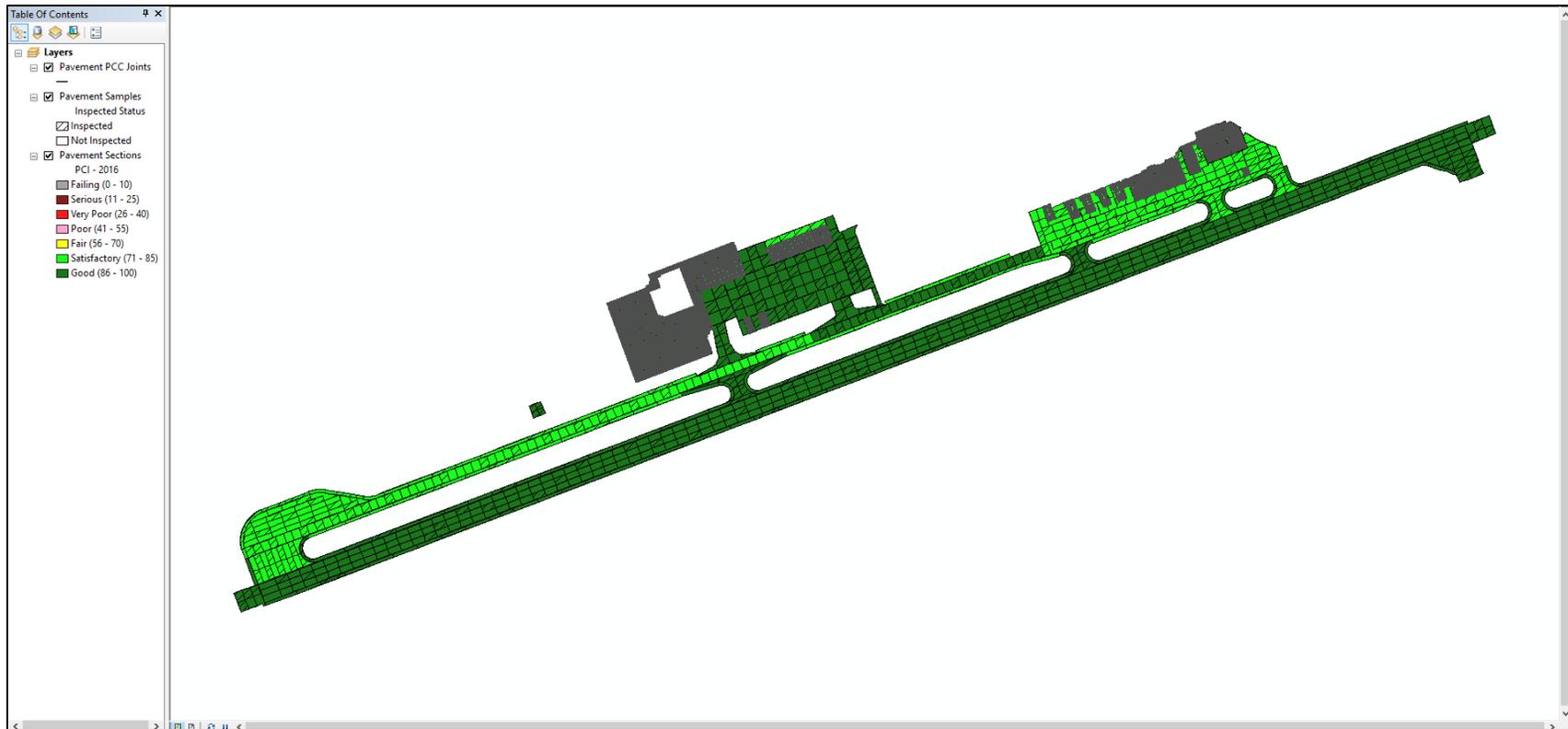
Figure 6. ArcMap Map Document Prior to Publishing

Once the map was created and settings were configured, the map was published as a service to ArcGIS Online as a hosted feature layer. During this step, the editing functionality of the feature service was disabled since the current purpose of the application was to only view the data. However, if needed in the future, the editing functionality can be enabled through the item details page of ArcGIS Online. Figure 7 shows the published *Pavement Features* ArcGIS Online hosted feature layer.
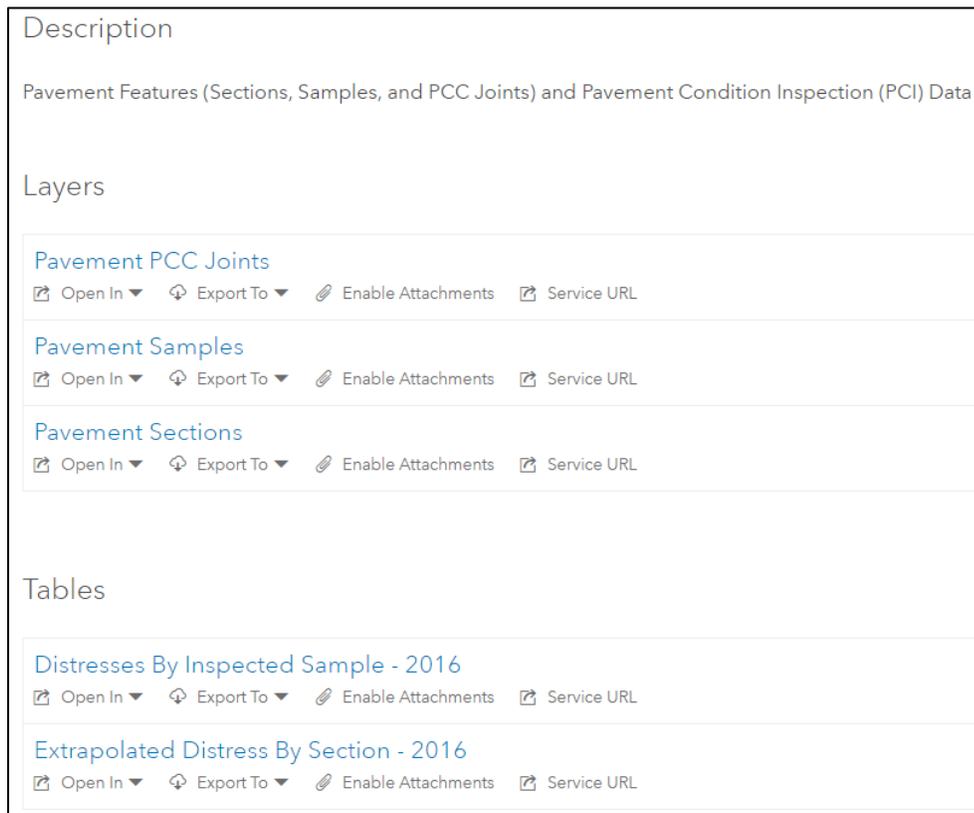

Figure 7. *Pavement Features* ArcGIS Online Hosted Feature Layer

4.2.2. Develop Web Map for Web GIS Application

With the GIS data successfully published as a hosted feature layer, the next step in the application development process was creating a Pavement Management web map that would be used in the Application. The first step in creating the web map was to choose a basemap to provide a background of geographical context for the pavement features displayed on the map.

ArcGIS Online has a selection of basemaps that include imagery, topographic, and street maps. For the Pavement Management web map, the imagery basemap was chosen as it provides the user with the ability to easily locate the general vicinity of pavement features using known visual references from the basemap.

Prior to selecting the imagery basemap, high-resolution, ortho-rectified imagery had initially been considered for upload to ArcGIS Online to use as a custom basemap. However, due to the extremely large file size and the increased consumption of ArcGIS Online service credits to store and host the imagery, the Esri imagery basemap was chosen for use instead. The Esri Imagery basemap needs to be periodically checked for accuracy against known features as the basemap's accuracy may shift when updated by Esri. The result of using the high-resolution imagery would have added little benefit to the overall use or functionality of the web map.

With the basemap selected, the *pavement features* hosted feature layer containing the pavement GIS data and related data tables, was added to the map. The previously configured layer order and symbology settings were verified and no changes were required. Since the web map is viewable at multiple scales, also known as zoom levels, the layer visible range settings were configured to specify the visibility of each feature (i.e. *Pavement Sections*, *pavement Samples*, and *Pavement PCC Joints*) at the different zoom levels. For example, the *Pavement Sample* features are not visible when viewing the entire airport; however, when the user zooms in they are able to view each sample. Then, upon zooming in further, the user is able to view the *Pavement PCC joints* on pavement areas that are constructed of concrete. In the map legend, when a layer is out of range, its name appears in a lighter gray color in the contents and legend than the layers that are in range. Figure 8 shows the Pavement Management web map legend showing the layer order, symbology, and visibility settings configured.
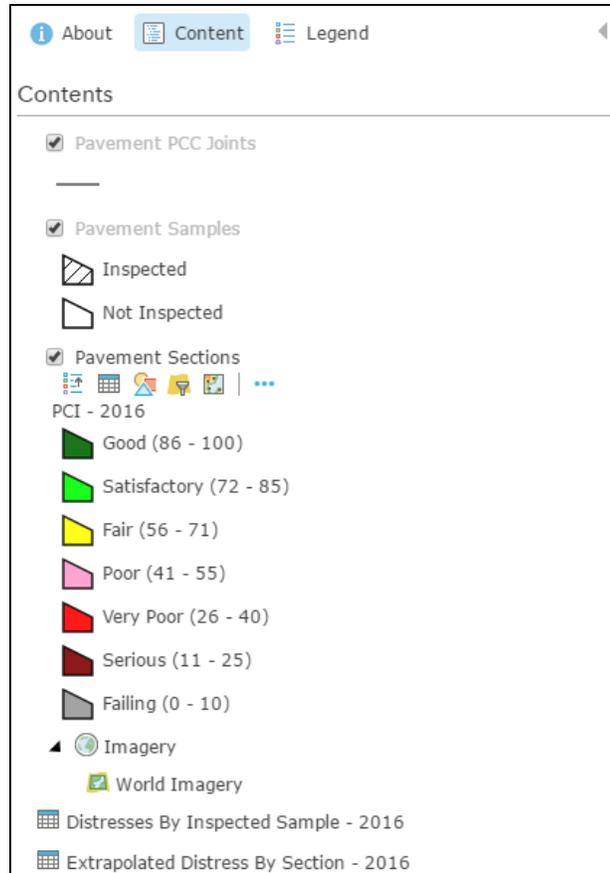
Figure 8. Pavement Management Web Map Legend

Next, the labeling settings were configured for the *Pavement Sections* and *Pavement Sample* layers to help the user easily understand each feature on the map. An appropriate text size and color were chosen for each layer based on each layer's visible range settings. The label text was derived from each features attribute data. For example, the *Pavement Sections* layer uses the "Section ID" attribute field as its label text. Additionally, the label visibility range was set to only display the text labels at appropriate zoom levels. Figure 9 shows an example of the web map labeling for the *Pavement Sections* layer.

Figure 9. Pavement Management Web Map Labeling Example

Following the configuration of the labeling, feature pop-ups were enabled and configured

for the *Pavement Sections* and *Pavement Sample* layers. The pop-ups allow the application user

to select an individual feature and view pertinent attribute data. This step was simplified by

previously configuring the attribute field alias for each field in the geodatabase, using ArcMap,

prior to publishing the data as a hosted feature layer. Figure 10 shows an example pop-up for a

Pavement Sample feature.
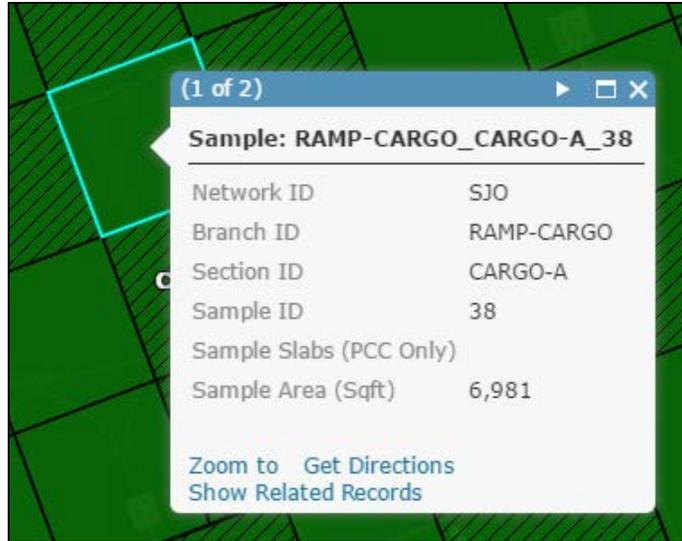
Figure 10. Pavement Management Feature Pop-up Example

The last step in creating the Pavement Management web map was to set the extent of the map. The extent of the map was set so that when the user opens the map, through the Application, the geographic location of the airport is displayed. Figure 11 shows the completed web map.

Figure 11. Pavement Management Web Map

4.2.3. Develop Web GIS Application for Airport Pavement Management

To develop the Airport Pavement Management Web GIS Application (Application), Web AppBuilder for ArcGIS, an ArcGIS Online built-in customizable application template was used to design an application to meet the user and functionality requirements of the application.

The Web AppBuilder for ArcGIS template, shown in Figure 12, has four tabs that allow for the customization of the application which include the Theme, Map, Widget, and Attribute tabs. The Theme tab allows the configuration of the applications theme, style, and layout. Although there are many different layouts available, the foldable theme was chosen for its professional look-and-feel while having no limitations on which widgets can be used. The style settings allowed seven predefined colors or a custom color to be chosen as the main color for the theme. For the Application, a custom color, grey, was chosen. Lastly, a layout representing the placement of user interface items was chosen.

After finalizing the theme settings, the map options were configured using the Map tab. The previously created Pavement Management web map, containing the *Pavement Features* hosted feature layer, was selected as the map for use in the application. All previously configured symbology, labeling, layer order, layer visibility, and pop-ups were retained when adding the web map to the application. Next, the initial extent of the web map was selected using the default extent of the web map. Lastly, the visible scales of the web map were configured to limit the scale levels to prevent a user from zooming too far in or out. This setting was configured to only allow map scales at or around the airport to be available to the user. This setting prevents the user from zooming out too far and having difficulty relocating the airport.

Figure 12. Web AppBuilder for ArcGIS Template

With the map settings configured, the functionality of the application was configured using the Widget tab. The Web GIS applications functionality is controlled through the settings contained within each widget. Widgets are considered either in-panel (i.e. visible to the user) or off-panel (i.e. behind the scenes) with some widgets being required while others are optional.

The required widgets for this template include Attribute Table, Coordinate, Extent Navigate, Home, My Location, Overview Map, Scalebar, Search, Splash, and Zoom Slider widgets located in the main Widget tab. There are additional required Widgets located in the Header Controller accessible via the Widgets tab and include the Legend and Layer List widgets. Although these widgets are considered required, some can be disabled through the Widget tab if needed.

The Attribute Table widget settings were configured to display a tabular view of *Pavement Sections* and *Pavement Samples* layers. The *Pavement PCC Joints* layer did not have any attributes so the attribute table was disabled. The specific fields displayed are based on the previously configured pop-up settings configured while creating the web map and no modifications were required. The related distress tables were configured to be accessible through the feature pop-ups but do not appear in the default attribute table view.

The Coordinate widget allowed for the coordinate system display output to be selected for the Application. The default coordinate system was based on the current map coordinate system (WGS 1984 Web Mercator (Auxiliary Sphere)) and was retained. However, the display units were changed from "decimal degrees" to "degrees minutes seconds" format for easy user identification.

The Extent Navigate widget was enabled to allow the user to navigate the map to its previous extent. Next, the Home widget was enabled to allow the user to easily navigate to the web map's initial extents. Then, the My Location widget was enabled to allow for users to detect their location and zoom to it on the map. This functionality allows the user to easily locate and identify pavement sections and samples when using the Application on a mobile device while on the airfield.

The Overview Map setting allows a small map, in a corner of the Application, to be configured to show the current spatial extent of the map display relative to the entire spatial extent of the basemap service. The Overview Map was configured to appear minimized in the lower right-hand corner of the map. After configuring the Overview Map, the Scalebar widget was enabled to display a scalebar in the lower left-hand corner of the map.

Next, the Search widget was configured to allow a user to search for a *Pavement Section* by "Section ID" instead of using the built-in world geocoder. Then, the Splash widget which displays content on the splash screen of the application when started was configured to inform the user of basic application details and provide a link to the application's quick-start guide. Lastly, the Zoom Slider widget was enabled to provide interactive zoom controls in the map display.

After configuring the required widgets on the application configuration Widget tab, the Legend and Layer List widgets were configured by selecting the Header Controller. The Legend widget, similar to the legend in the web map, displays labels and symbols for layers in the map. The widget was configured to automatically update when the visibility of the layers or sublayers change (i.e. the user zooms in or out).

The Layer List widget was enabled and configured to provide a list of operational layers and their symbols, and allow the user to turn individual layers on and off. The widget allowed for many layer settings to be enabled that include zoom to, transparency, enable / disable pop-up, move up / move down, open attribute table, and description/show item details/download; however, for the application, only the zoom to and open attribute table functionality were enabled to meet the application requirement goal of providing a simplified, easy-to-use interface that did not present a confusing user experience.

After configuring the required widgets, the optional widgets available were evaluated to determine if applicable to the application. The Web AppBuilder for ArcGIS template includes many optional widgets including: About widget, Add Data widget, Basemap Gallery widget, Bookmark widget, Draw widget, Measurement widget, Print widget, Query widget, Share widget, and Time Slider widget. With one of the application requirements being to provide a simplified, easy-to-use interface that did not present a confusing user experience, the amount of optional widgets was constrained. Only the following widgets were selected for use: About widget, Bookmarks widget, Draw widget, Measurement widget, and Print widget.

The About widget allows content to be created and displayed for the user. This widget was configured to appear in the header controller adjacent to the Legend and Layer List widgets. The About widget has a single hyperlink to the Quick Start guide that was created once the application was developed to provide a brief overview of the application for users.

The Bookmark widget stores a collection of map view extents, also known as spatial bookmarks, displayed in the app. The widget was added to the application and configured to contain bookmarks for main airport features and includes the commercial apron, cargo apron, and the runway ends.

The Draw widget enables the application users to draw basic graphics and text onto the map by providing basic sketching and redlining functionality within the application. The widget was added to the application and configured to display measurements for drawn features, such as lengths for lines, and areas and/or perimeters for polygons.

The Measurements widget allows the user to measure the area of a polygon, length of a line, or find the coordinates of a point. The widget was added to the application and the area, distance and location measurement functionalities were enabled. The default area unit was set to square feet and the default length unit was set to feet.

The Print widget enables printing of the map from within the application. The widget as added to the application and configured to allow the map to be printed to a portable document file format (.pdf) that could easily be shared via e-mail or printed.

With the required and optional widgets configured, basic customization of the Application's title and logo settings were configured using the Attribute tab. A basic airplane graphic was added as an application logo and the application title set so that users could easily identify the application. Additionally, the "app state" setting was enabled to maintain the map extent and layer visibility when a user leaves and returns to the Application.

With the application settings configured, the development of the Application was complete. The final step was to create a Quick Start Guide that explained the purpose of the application and a brief overview of each of the application features. The Quick Start Guide, in the Portable Document Format (PDF) file format was uploaded to ArcGIS Online. A direct link to the guide was added to the About and Splash widgets. Figure 13 shows the completed Airport Pavement Management Web GIS Application as it appears when first opened by a user.

Figure 13. Airport Pavement Management Web GIS Application

Chapter 5 Application Evaluation

An evaluation of the Application was conducted to inform fine-tuning needs and future development plans. Chapter 5 presents this evaluation process and its results. Section 5.1 provides an overview of the application evaluation process. This section describes how the individuals were identified to be evaluators of the Application and how the Application evaluation survey was developed. Section 5.2 presents the results of the evaluation and summarizes the evaluators' answers.

5.1. Evaluation Process

With the development of the Airport Pavement Management Web GIS Application completed, it was important to have the Application evaluated by experienced airport engineering and operations professionals with knowledge of airport pavement management. The evaluation process allowed for these industry professionals to evaluate the usefulness, ease of use, and their overall satisfaction with the Application.

Five industry professionals were invited to evaluate the Application. They were selected based on their previous professional experience with airport pavement management. None of the evaluators had any previous knowledge of the Application and had not been involved in the development process. During the week of April 23, 2017, each evaluator was individually contacted via e-mail and given a basic description and background of the Application along with instructions on how to access the Application via their web browser. The instructions also included the Quick Start Guide, included in Appendix A, which provided more details related to the Application's functionality. The instructions also informed the evaluator that the Quick Start Guide was incorporated into the Application in multiple locations (e.g. Splash and About Widgets).

The e-mail also included a hyperlink to a web-based electronic survey that was created on SurveyMonkey, an online survey development website, to allow the evaluator to provide feedback focused on the usefulness of the Application, including its effectiveness, ability to save time, if it met their needs, and if it did everything that they expected it to do. With the survey being electronic, the results were easily retrievable. Appendix B includes a printed version of the Application Evaluation Survey. The Evaluators were given ten days to complete the evaluation and by May 2, 2017, all evaluations were completed.

5.2. Evaluation Survey Results

After the evaluators completed the evaluation survey, the results were reviewed and analyzed to determine the usefulness, ease of use, and overall satisfaction with the Application. The first evaluation survey question, Question 1, consisted of a set of questions focused on the usefulness of the Application, including its effectiveness, ability to save the time, if it met their needs, and if it did everything that they expected it to do. The evaluators rated each question in the set as either strongly disagree, disagree, neutral, agree, or strongly agree. These answers were given a numerical value on a Likert scale from 1 to 5 with the following correlation: 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree. Figure 14 shows Question 1 and its responses.
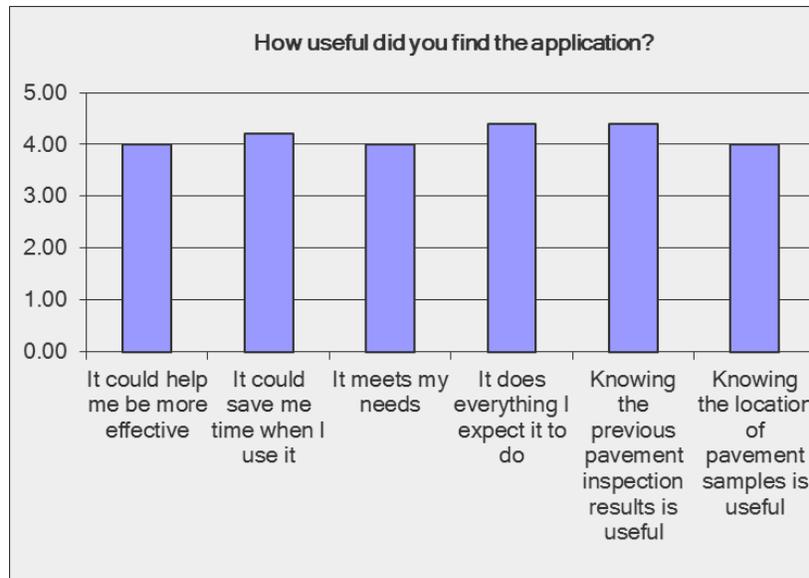
Figure 14. Evaluation Form Question 1 and Responses

If the evaluator answered "disagree" or "strongly disagree" to any of the Question 1 set of questions, Question 2 requested additional information. Next, Question 3 asked the evaluators if there was other functionality they would like to use in the Application. Figure 15 shows Questions 2 and 3. These questions were designed to solicit more specific feedback from the users, as well as allow feedback for suggestions on other potential functionality.

Figure 15. Evaluation Form Questions 2 and 3

No evaluators answered any of the questions in Question 1 with either "disagree" or "strongly disagree", so Question 2 had no responses. One evaluator responded to Question 3 and

suggested adding the ability to add new pavement distresses while accessing the Application on a tablet or mobile device while out on the airfield.

The next evaluation survey question, Question 4, consisted of a set of questions focused on the Application's ease of use, including the ease of navigating around the Application, viewing information about a specific pavement section and sample, and performing a search for a pavement section. The evaluators rated each question in the set as either not at all easy, moderately easy, or easily. These answers were given a numerical value on a Likert scale from 1 to 3 with the following correlation: 1-not at all easy, 2- moderately easy, and 3-easily. Figure 16 shows Question 4 and its responses.
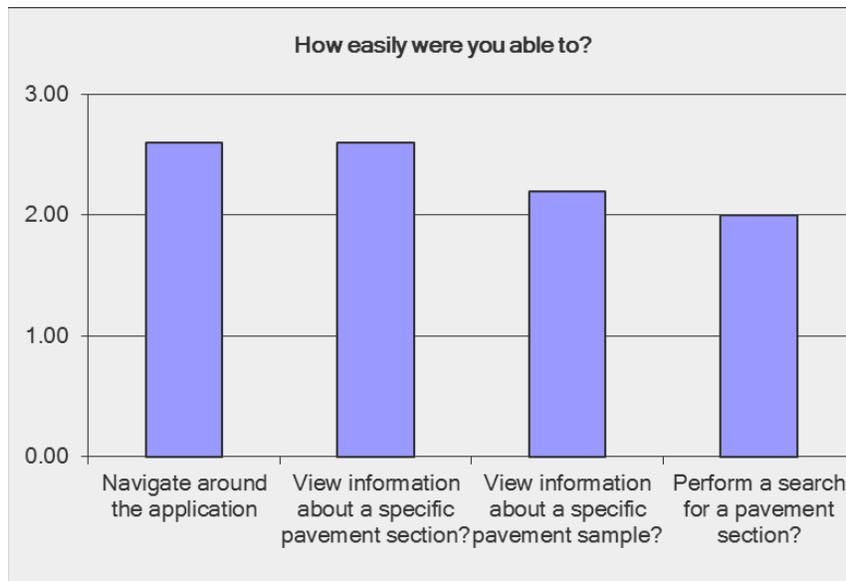

Figure 16. Evaluation Form Question 4 and Responses

The next evaluation survey question, Question 5, consisted of a set of questions focused on the evaluators' overall satisfaction with the Application, including their satisfaction with the Application, if they would recommend it to a coworker, if it works the way they want it to work, and if they were able to find the information they were looking for. The evaluators rated each question in the set as either strongly disagree, disagree, neutral,

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agree, or strongly agree. These answers were given a numerical value on a Likert scale from 1 to 5 with the following correlation: 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree. Figure 16 shows Question 5 and its responses.
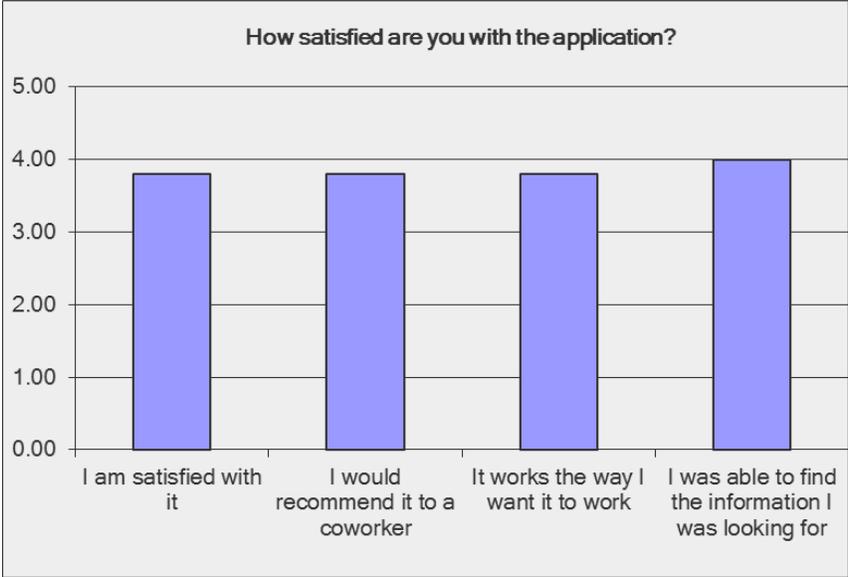
Figure 17. Evaluation Form Question 5 and Responses

If the evaluator answered "disagree" or "strongly disagree" to any of the Question 5 set of questions, Question 6 requested additional information. Next, Question 7 asked the evaluator there was any data or functions for their specific job that would benefit from this type of application. Lastly, Question 8 asked the evaluator if they had any other comments or suggestions. Figure 18 shows Questions 6, 7 and 8.

Figure 18. Evaluation Form Questions 6, 7, and 8

No evaluators answered any of the questions in Question 5 with either "disagree" or "strongly disagree", so Question 6 had no responses. One evaluator responded to Question 7 and stated that the viewing of previous pavement inspection data would be beneficial to easily identify areas of pavement in need of repair. Question 8 included multiple responses that both links to the Quick Start guide did not function properly. When the evaluators clicked the link, they received an error message. Also, one evaluator identified that the My Location widget was greyed out and did not allow it to be selected. Lastly, multiple evaluators identified that although the Application was developed for airport pavement management, it could easily be adapted for managing other airport assets such as signage or lighting.

5.3. Evaluation Summary

The feedback provided by the evaluators validated that the main objective of this project was met: developing an easy-to-use web application which allows airport staff the ability to visualize their existing pavement conditions, compare previous inspections to detect trends, and

allow them to make informed decisions regarding pavement maintenance, rehabilitation, and end of life determinations The evaluation process also generated a greater interest in GIS and how it could be applied to other aspects of effectively managing other airport assets.

The responses received relating to the Quick Start guide being inaccessible led to further investigation as to why the direct link was not properly functioning. It was determined that when a PDF file is uploaded to ArcGIS Online, ArcGIS Online stores the PDF using Amazon Web Services Storage (AWS). When the PDF is accessed through ArcGIS Online, a temporary, time-based access token is generated. Since the token is temporary, a direct link containing the temporary token does not work once the token expires. The solution to the problem was to change the direct link to the PDF's ArcGIS Online Item Page. This link allows each user to click the PDF link and generate their own access token.

The response received regarding the My Location widget being greyed out and not being selectable was also further investigated. It was determined that for the My Location widget to be enabled, the Application must be accessed through a secure connection (i.e. HTTPS). When the link to the application was sent to each evaluator, the hyperlink provided was not secure. Since future application users might not be aware of the need to access the Application through a secure connection, ArcGIS Online allows for an Administrator to change their ArcGIS Online organization's security setting to allow access to their organization through HTTPS only. This would be the recommended solution to prevent certain functions of an application from being disabled by a user's web browser.

Lastly, the response from Question # 8 suggesting adding the ability to add new pavement distresses while accessing the Application on a tablet or mobile device while out on the airfield is further discussed in Section 6.4, Future Improvements.

Chapter 6 Conclusion and Future Work

This chapter summarizes the development of the Airport Pavement Management Web GIS Application and details challenges encountered during the development of the Application, limitations of Application, and potential future work related to this project. Section 6.1 provides a summary of the Airport Pavement Management Web GIS Application. Section 6.2 presents the challenges encountered during the development of the Application. Section 6.3 discusses existing limitations of the Application. Lastly, Section 6.4 discusses future improvements that can be made to the application as well as future implementations.

6.1. Summary of Application

The Airport Pavement Management Web GIS Application allows for airport staff to view existing pavement conditions (i.e. recent PCI values) and pavement distresses for each section and inspected samples. In addition to viewing pavement data, the Application includes functionality that allows a user to either print or export an image of the map based on current map extents. Additionally, the Application includes functionality that allows a user to draw on or mark-up the map in order to highlight areas that are in need of repair. Furthermore, the Application includes functionality that allows a user to perform both length and area measurements in order for the user to determine the dimensions of different pavement sections and samples.

6.2. Challenges in Development

During the development of the Airport Pavement Management Web GIS Application, there were very few challenges encountered. This was mainly due to having previously published data to ArcGIS Online and developing other applications using Web AppBuilder for ArcGIS.

Previous lessons learned were incorporated into the development of the Application and detailed in Chapter 4. One example of a lesson learned was that when previously publishing data to ArcGIS Online, it was identified that if a field alias, layer order, and layer symbology had been configured prior to publishing, the settings would be retained when the data was added to a Web Map.

6.3. Limitations of the Project

The Airport Pavement Management Web GIS Application was designed for commercial service airports with paved runways, taxiways, and aprons. The Application could also be used at a general aviation public-use airport with paved runways if the airport has pavement inspection data; however, general aviation airports are not required have a PMP or PMMP as required by the FAA. The Application and GIS data model would not be able to be used for unpaved (e.g. grass, dirt, or ice) runways, taxiways or aprons as the classification and inspection criteria for these surfaces varies from paved surfaces.

For Airport staff to access the Airport Pavement Management Web GIS Application, they must have an active internet connection. This is due to ArcGIS Online being a web-based SaaS solution that requires internet access. In the event that an airport requires their data to be only accessible either offline or secured behind a firewall, an enterprise-level GIS solution, such as ArcGIS Enterprise with Portal for ArcGIS, would have to be implemented.

The Application was designed as a pavement data viewer and does not include the ability to modify any of the existing pavement data. The ability to edit existing pavement data or add new pavement data could be added to the Application and is discussed in the Future Improvements and Adaptations section of this chapter.

6.4. Future Improvements and Usages

This section details the many ways that the Airport Pavement Management Web GIS Application can be either further improved or used in a different manner. The future improvements discussed include the addition of field collection capabilities, migration to an enterprise-level GIS, management of other airport assets, and future integrations with Smart Infrastructure technologies. The Application can also be adapted to be used in natural disaster or emergency response operations along with real-time field collection capabilities post natural disaster.

During the evaluation of the Application, feedback was received relating to the addition of the ability to add new pavement distresses while accessing the Application on a tablet or mobile device while out on the airfield. This functionality could be easily implemented by creating a new, separate editable hosted feature layer on ArcGIS Online and adding it to a new Web Map that allows for editing. By creating a separate hosted feature layer, the original hosted feature layer is safeguarded from being accidently edited Then, airport staff can install Collector for ArcGIS on either a tablet or mobile device enabling field data collection while either directly connected to ArcGIS Online or offline and later synced. Lastly, the new hosted feature layer can be added to the Airport Pavement Management Web GIS Application for either viewing or editing.

In the event that the needs of an airport change and the airport decides to expand their GIS infrastructure due to either the need for additional data storage, implementation of a Relational Database Management System (RDBMS), or the need for either an offline or secure (i.e. behind a firewall) solution then the Application and GIS data could easily be migrated. Although the Application and GIS data were developed and stored using ArcGIS Online, the

Application and GIS data could easily be migrated to ArcGIS Enterprise which includes both

ArcGIS Server which allows for RDBMS access and Portal for ArcGIS which is similar to

ArcGIS online except it is independently hosted.

Although the purpose of the Web GIS application was to manage airport pavement, this

thesis provides the foundation for developing a Web GIS application that could be easily adapted

for managing other airport assets such as airfield lighting, signage, and utilities. The Airport

Pavement Management Web GIS Application could also be adapted to include these additional

hosted feature layers containing other airport assets leading to a complex Web GIS airport asset

management application.

The development of the Airport Pavement Management Web GIS Application also

creates a GIS infrastructure that could eventually include future integrations with Smart

Infrastructure technologies. Smart Infrastructure is infrastructure with embedded sensing

technologies that are connected to a communication backbone which allows real-time data

acquisition and analysis. For example, pavement constructed in the future could include sensors

that would record pavement strength or aircraft passes over pavement. This data could be

integrated in real time to appear in the Web GIS Application. This would allow airport staff to

make better-informed decisions about the structural health and maintenance of their assets.

In the event of a natural disaster or an emergency situation, an airport could use the

Airport Pavement Management Web GIS Application to view the existing pavement conditions

based on previous inspections and determine if pavement conditions are adequate to allow

disaster response aircraft to operate at the airport. Additionally, if an airport has previously

chosen to add the field collection capabilities discussed above, then airport staff could collect

real-time pavement conditions (i.e. distresses) during disaster response or emergency

management operations. This would allow the airport to use the Application for real-time pavement condition analysis and to direct the repair of damaged pavement areas.

In addition to disaster response or emergency management operations, the Airport Pavement Management Web GIS Application could also be adapted and used by military personnel to view and document pavement conditions at both permanent military airfields along with airfields located in austere, remote environments. By using such an application, military leaders and airfield operations personnel could monitor airfield pavement conditions and identify areas in need of repair. The application could also be utilized by civil engineering personnel to locate discrepancies previously identified by airfield operations personnel. The increased accessibility to current pavement conditions could lead to discrepancies being identified and corrected in an expedient manner and prevent potential aircraft mishaps. It is important to note, that due to potential network and data security policies, the Web GIS application and GIS data would need to be stored in a secure environment and require Esri's enterprise-level web GIS, ArcGIS Enterprise, for successful implementation.

This thesis successfully designed a GIS data model for airport pavement data and developed a Web GIS application for managing their airport pavement using a SaaS based Web GIS platform. With this research, a commercial service airport can replicate the steps outlined and implement a cost-effective solution to managing their airport pavement to enable informed pavement maintenance and rehabilitation decisions.

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Appendix A Airport Pavement Management Quick Start Guide

Airport Pavement Management
Web GIS Application

Quick Start Guide

Table of Contents

1. Overview

1.1. Purpose of Quick Start Guide

This Quick Start Guide provides a brief overview of the Airport Pavement Management Application and its functionality.

1.2. System Requirements

The Airport Pavement Management Application is developed using ArcGIS Online. For the best performance with the ArcGIS Online website, use the latest version of a browser listed below:

> IE 9 and higher (See IE 9 limitations below). Compatibility View is not supported.
> Edge
> Firefox
> Chrome
> Safari
> iOS Safari
> Chrome for Android

Limitations of using IE 9

- Internet Explorer 9 is supported but has the following limitations. Additional browser limitations are also noted below.
- You cannot view streaming feature layers in the map viewer.
- You cannot open metadata XML files or save local copies of your current metadata document in the built-in metadata editor.
- You cannot add CSV items (in My Content) as web layers in the map. This limitation applies to IE 9 and Safari.
- You cannot use the scene viewer or open apps created from scenes. This limitation applies to IE 9 and 10.
- If the map contains feature layers, labels on the following basemaps may appear hidden: Imagery with Labels, Dark Gray Canvas, Light Gray Canvas, World Oceans, and Terrain with Labels. This limitation applies to IE 9 and 10.
- The Visualization tab is not available on the item pages on IE 9.

1.3. Application Overview

The *Airport Pavement Management* Web GIS Application is an interactive, map-based user application that is accessible via computer, tablet, and mobile devices through a web browser with an internet connection.

The Application provides you with many important capabilities, including:

- Visual comparison of past inspection data
- Identification of pavement areas that require maintenance and repair.
- Printing and exporting an image of the map, based on set extents
- Creation of drawing or mark-ups in order to highlight areas that are need of repair.
- Measurements of length and area in order for the user to determine the dimensions of different pavement sections and samples.

2.   User Interface

2.1. General Layout

When opening the application, you will first see the application splash-screen window, shown in Figure 1, which informs you of basic application details and provides a link to this application overview guide. These details currently include the title of the application; however, in future application updates, the splash screen may include details regarding the update. The splash screen can be disabled by checking the box to not show again.

Figure 1. Application Splash Screen

The Application user interface, shown in Figure 2, has many functions and features, known as widgets, that include the following: attribute table, bookmarks, coordinate view, draw, extent navigate, home, layer list, legend, measure, my location, overview map, print, scale bar, search, and zoom slider. Each of the widgets specified above is detailed in the section below
.
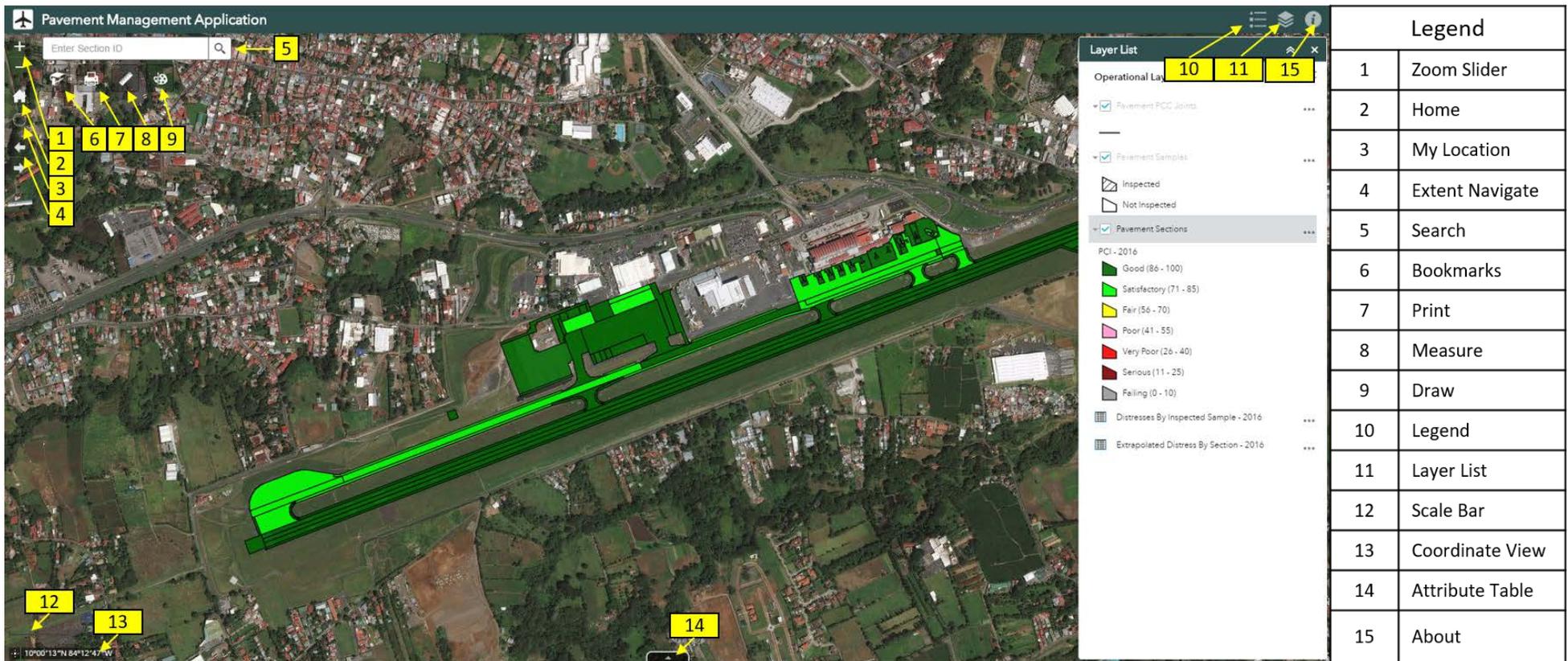
Figure 2. Airport Pavement Management Web GIS Application Overview

Legend	
1	Zoom Slider
2	Home
3	My Location
4	Extent Navigate
5	Search
6	Bookmarks
7	Print
8	Measure
9	Draw
10	Legend
11	Layer List
12	Scale Bar
13	Coordinate View
14	Attribute Table
15	About

2.2. Widget Overview

About

The About Widget, shown in Figure 2 item 15, displays a link to information about the application that includes a link to this quick-start guide.

Attribute Table

The Attribute Table Widget, shown in Figure 2 item 13, displays a tabular view of *Pavement Sections* and *Pavement Samples* layers. Also, when viewing related data (i.e. Extrapolated Distresses by Section) the table will appear in the attribute table tab.

Bookmarks

The Bookmarks Widget, shown in Figure 2 item 6, displays a collection of map view extents also known as spatial bookmarks. The bookmarks contains links to main airport features and includes the commercial apron, cargo apron, and the runway ends. Figure 3 shows the bookmarks widget in detail.
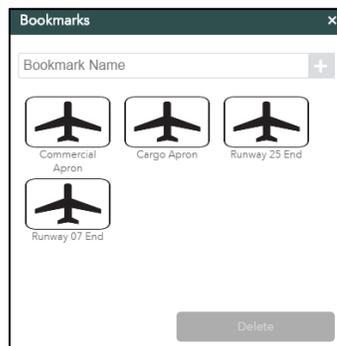
Figure 3. Application Bookmark Widget

Coordinate view

The Coordinate View display, shown in Figure 2 item 13, feature displays the coordinate output based on where your mouse is positioned on the map. The coordinate view displays the maps default coordinate system, WGS 1984 Web Mercator (Auxiliary Sphere), with the display units shown in degrees minutes seconds format.

Draw

The Draw widget, shown in Figure 2 item 9, allows you to draw basic graphics and text onto the map by providing basic sketching and redlining functionality within the application. The widget was added to the application and configured to display measurements for drawn features, such as lengths for lines, and areas and/or perimeters for polygons. Figure 4 shows the Draw widget in detail.
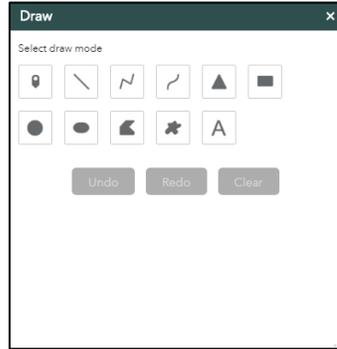

Figure 4. Application Draw Widget

Extent navigate

The Extent Navigate widget, shown in Figure 2 item 4, allows you to navigate the map to its previous or next extent.

Home

The Home widget, shown in Figure 2 item 2, allows you to easily navigate to the map's initial extent.

Layer List

The Layer List widget, shown in Figure 2 item 11, provides a list of operational map layers and their symbols, and allows you to turn individual layers on and off. The widget allows you to zoom to and open the attribute table for each map layer. Figure 5 shows the Layer List in detail.
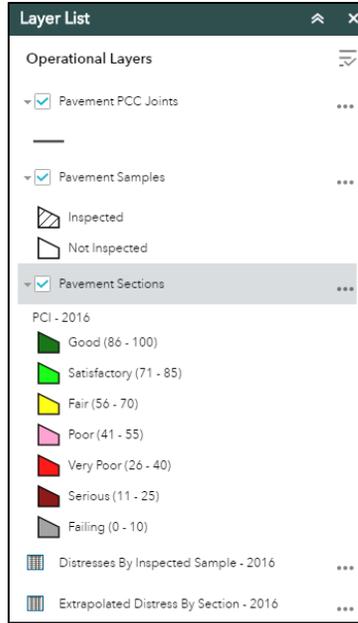
Figure 5. Application Layer List

Legend

The Legend widget, shown in Figure 2 item 12, displays labels and symbols for layers in the map. The widget automatically updates when the visibility of the layers or sublayers (i.e. you zoom in or out on the map) change. Figure 6 shows the Legend in detail.
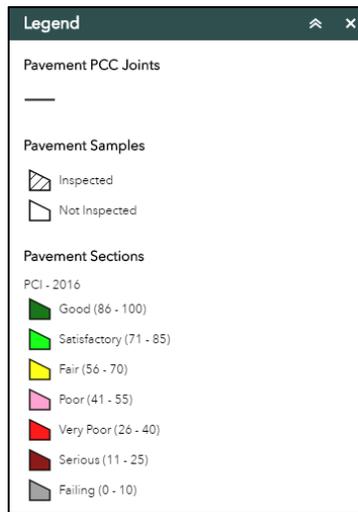

Figure 6. Application Legend

Measure

The Measurements widget, shown in Figure 2 item 8, allows you to measure the area of a polygon, length of a line, or find the coordinates of a point. Figure 7 shows the Measurement widget in detail.
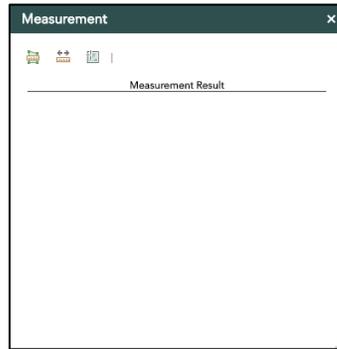
Figure 7. Application Measurement widget

My location

The My Location widget, shown in Figure 2 item 3, allows you to detect your current location and zoom to it on the map. This will allow you to easily locate and identify pavement sections and samples.

Overview map

The Overview Map widget, not shown in Figure 2, displays a small map, in a lower right-hand corner of the application, which shows the current spatial extent of the map display relative to the entire spatial extent of the basemap service when zoomed in.

Print

The Print widget, shown in Figure 2 item 7, enables printing of the map from within the application. The widget allows the map to be printed to portable document file format (.pdf) that could easily be shared via e-mail or printed to a local printer. Figure 8 shows the Print widget. In detail.
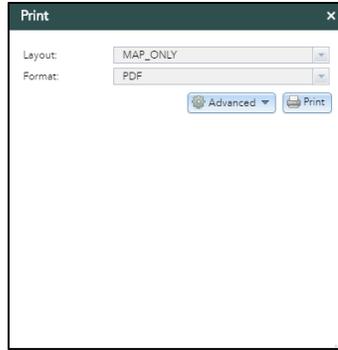
Figure 8. Application Print Widget

Scale bar

The Scalebar widget, shown in Figure 2 item 12, allows you to view the current scale of the map.

Search

The Search widget, shown in Figure 2 item 5, allows you to search for a *Pavement Section* by "Section ID".

Zoom slider

The Zoom Slider widget, shown in Figure 2 item 1, provides interactive zoom controls in the map display

Appendix B Application Evaluation Survey

Pavement Management Application - User Survey

1. How useful did you find the application?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It could help me be more effective	○	○	○	○	○
It could save me time when I use it	○	○	○	○	○
It meets my needs	○	○	○	○	○
It does everything I expect it to do	○	○	○	○	○
Knowing the previous pavement inspection results is useful	○	○	○	○	○
Knowing the location of pavement samples is useful	○	○	○	○	○

2. If you answered any question above with "disagree" or "strongly disagree", please let us know why you feel that way.

3. Is there other functionality you would like to use in the application? If so, please tell us and be specific.

4. How easily were you able to?

	Not at all easy	Moderately easy	Easily
Navigate around the application	○	○	○
View information about a specific pavement section?	○	○	○
View information about a specific pavement sample?	○	○	○
Perform a search for a pavement section?	○	○	○

5. How satisfied are you with the application?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am satisfied with it	○	○	○	○	○
I would recommend it to a coworker	○	○	○	○	○
it works the way I want it to work	○	○	○	○	○
I was able to find the information I was looking for	○	○	○	○	○

6. If you answered any question above with "disagree" or "strongly disagree", please let us know why you feel that way.

7. Can you think of any data or functions in your specific job that would benefit from this type of application?

8. Do you have any other comments and/or suggestions?