Final Report

Mobile Geographic Information System (GIS) Solution for Pavement Condition Surveys

*Florida Department of Transportation contract **BDR76***

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Unit Conversions

While this document does not spend very much time discussing data with units of measure, the following units are used either when describing stationing, hardware accuracy, or distress measurements.

US Customary	Multiply By	Metric
inch	25.4	millimeters
feet	0.305	meters
miles	1.61	kilometers
square feet	0.093	square meters
inches per mile (International Roughness Index)	0.0158	meters per kilometer (International Roughness Index)

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16. Abstract

This report discusses the design and implementation of a software-based solution that will improve the data collection processes during the Pavement Condition Surveys (PCS) conducted by the State Materials Office (SMO) of the Florida Department of Transportation. This software replaces the prior method of Microsoft Excel spreadsheets with macro programming and integrates data from both the Department's Geographic Information System (GIS) and their legacy test section database. The software, known as the XPCS system, contains three components: a database of pavement condition, an office application used for planning and reporting, and a mobile application used for data collection and navigation.

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Executive Summary

The State Materials Office (SMO) of the Florida Department of Transportation performs annual Pavement Condition Surveys (PCS) of the Department's pavement network. This work is performed by single person crews in a vehicle capable of measuring rutting, faulting, and ride quality (i.e., roughness) while traveling at prevailing traffic speeds. Information from these measurements along with visual evaluations and notations of pavement distresses are currently entered into a Microsoft Excel spreadsheet located in an onboard computer. The template for this spreadsheet (a separate file is used for each county) contains macros to perform basic error checking and integration of the automated and visual data.

There are several issues with the current approach. Among them are:

- A single operator is tasked with driving, navigating, data collection, and initial data verification
- A need to better plan and optimize routing and testing within a county
- Lack of geographic data available to the surveyor (e.g., cross streets, landmarks)
- Absence of progress reporting on a more regular basis (i.e., counties are recorded as either surveyed or not surveyed instead of tracking progress on a test section basis)
- Difficult to load resultant data into the Department's GIS for viewing or analysis

To address these issues, the Department, through the SMO, issued a Request for Proposals (RFP) titled "Mobile Geographic Information System (GIS) Solution for Pavement Condition Surveys". The intent of this RFP was to develop a computer-based solution that would both address the shortcomings of the current system while allowing better integration to the Enterprise GIS under development at the Department. The resultant software, XPCS, addresses many of these issues.

XPCS contains three components:

- Database – An independent database that is designed to contain all inspection data for the Department's test sections across multiple years. As this database uses existing test sections for its primary identification scheme, it is easily integrated back into the GIS.
- Office – A desktop application used for viewing and reporting designed to work with a live connection to the XPCS Database component of the system. This provides overall data, allows the user to explore specific data (e.g., inspections for a particular test section), and determine progress and overall network health through a reporting system. The office component also includes software that takes data from the mobile component and uploads that data to the Database.
- Mobile – An application used in the survey vehicles and designed so that a live connection to the XPCS Database component is not required.

This report discusses the methodology used to design and develop the software components of the XPCS system, the current state of those components, and suggestions for enhancement of the system in the future.

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Introduction

The Pavement Condition Survey (PCS) process is a well-established practice at the Florida Department of Transportation (FDOT) used to determine the overall condition of the FDOT pavement network and decide where to allocate resources (money, equipment, and personnel) related to the maintenance and rehabilitation of the pavement assets that belong to the agency. There are two different PCS surveys performed by the Department: project-level and network-level. Project-level surveys are used to measure specific pavement performance for rehabilitation design, project acceptance, warranty compliance, and research evaluation. These data tend to have significant detail to answer questions such as "What techniques will reduce wet weather accidents in this section?", "Does FDOT need to approach the contractor regarding warranty repair?" and "Should FDOT continue to use this specific rehabilitation technique?" Network-level surveys focus more on evaluating pavement performance for project prioritization and resource allocation across the entire State Highway System. Network-level surveys also tend to have less detail but cover a much greater surface area of pavement.

The focus of this project was to improve the network-level PCS process by incorporating software and GIS-based tools to improve the productivity of the surveyors, increase the accuracy of their surveys, reduce the amount of transit time between survey areas (*test sections*, in FDOT terminology), provide tools to supervisors to track progress and quality, and create reporting tools for supervisors to support the decision-makers at the Department.

To that end, the FDOT State Materials Office (SMO) selected Applied Research Associates (ARA) to assist them with the development and implementation of a new software system for the collection of network-level PCS data. This report discusses the process used to define the Department's needs, design the system, create the software components of the system, and implement the system at the SMO.

The result of this project is the Extended PCS (XPCS) software package. It consists of three main components:

- XPCS Database – This is the element of the system where all data is centrally stored and the data source upon which all reporting is performed.
- XPCS Office – This element of the system provides the in-office functions required of the software including the dashboard, supervisor review, data synchronization, routing, and reporting.
- XPCS Mobile – This element of the system is placed in the survey vehicles and is used by the field technical staff. It is designed to work in a disconnected environment where data is collected, verified, and stored locally. Upon returning to the office at the end of a work week, the field staff synchronizes the data collected and stored in their vehicle with the XPCS Database hosted in the office.

Methodology

Per ARA's proposal, the approach to this project has been in four phases as shown in Figure 1.

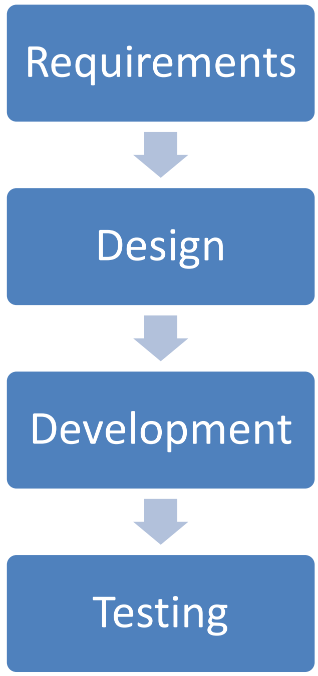

Figure 1. Project Approach

The first task was to examine the existing processes at the SMO related to the network-level PCS process. This task included interviews with SMO staff and ride-alongs with the SMO technicians responsible for the daily data collection. The ARA team also looked at existing data, process flow charts, and hardware involved in these efforts. ARA immediately followed up with the SMO and determined the desired improvements to the system such as status reporting, improved validation, and GIS integration. Based on these efforts, ARA began to draft and share versions of a pair of *Software Requirements Documents* (SRDs) with the SMO that discussed functional requirements (e.g., "Provide GIS Layer showing testing progress"), system configuration (the eventual three component system), and interface requirements (providing a visual representation of the initial versions of the final product for better understanding of the process). These drafts were reviewed and modified by the SMO and ARA based on feasibility, budget, existing FDOT systems, and required needs. The result was a pair of documents that could be checked to ensure that the final product met the requirements of the SMO and Department. The SRDs for both the office and mobile component of the system are attached to this report. The functions of the database component of the project are developed within these requirement documents as the visible components of this system are the office and mobile applications supported by the database.

Upon agreement of a final SRD for the project, the next task was to design the specific software that would meet the requirements set forth in the Requirements. This design would establish the technical specifics of the software such as database schema, internal object design, specific user interfaces, required libraries, and interfaces with other systems such as the Roadway Characteristics Inventory (RCI) Database and GIS. The results of this process, a pair of *Software Design Documents* (SDDs) would provide the guidelines our developers would follow when writing the software. The SDD for both the office component and mobile component are also attached to this document.

The next phase of the work was the actual coding and integration of the various components of the new system. It was developed on a component-by-component basis. The first component developed was the XPCS Database. The database framework was created based on the SDD and then populated with data from the existing PCS dataset. This database was placed in the SMO offices where SMO staff could begin testing their own reporting. ARA also created some example reports to demonstrate the capabilities of the component.

The primary challenge with the data within the XPCS system is the creation and maintenance of location references. While FDOT maintains a canonical list of roadway segments in their RCI database, the inspection crews often break these areas up into smaller segments based on actual on-the-ground features (such as construction history). Furthermore, the boundaries of the entered inspection values were previously matched based on physical and geographical landmarks which could lead to errors depending on the description provided. Unfortunately, this precluded a database structure of natural keys (unique identifying fields that could describe a specific location) whereby segments (and their related historical inspection records) could be explicitly referenced by section id, roadway code, and beginning and ending mileposts. Additionally, new segment limits might be introduced in the field by the creation of breakpoints (possibly leading to conflicts during synchronization). The system was also complicated by the possibility of the roadway code changing from one year to the next because of a change from composite to divided roads.

To manage this issue, a system of segment IDs, tagged by the unique ID of the computer from which they were generated and a flag for travel direction (upstation or downstation) was introduced to address these synchronization issues. Also, a “5% rule” was developed to allow nearly, but not strictly, matching stretches of roadway to be associated with one another in the same manner as a person might, looking at the data. For example, if the data indicated that a segment existed on test section 26050000 between mileposts 8.05 and 9.20 but the surveyor observed a segment between mileposts 8.00 and 9.20, the program should treat that as the same segment and assign the new condition data to the original segment.

From here, a layer of business objects (XPCSData) was developed to represent the actual inspection data (and its relationship in the county->section->segment->inspection hierarchy) as shown in Figure 2.

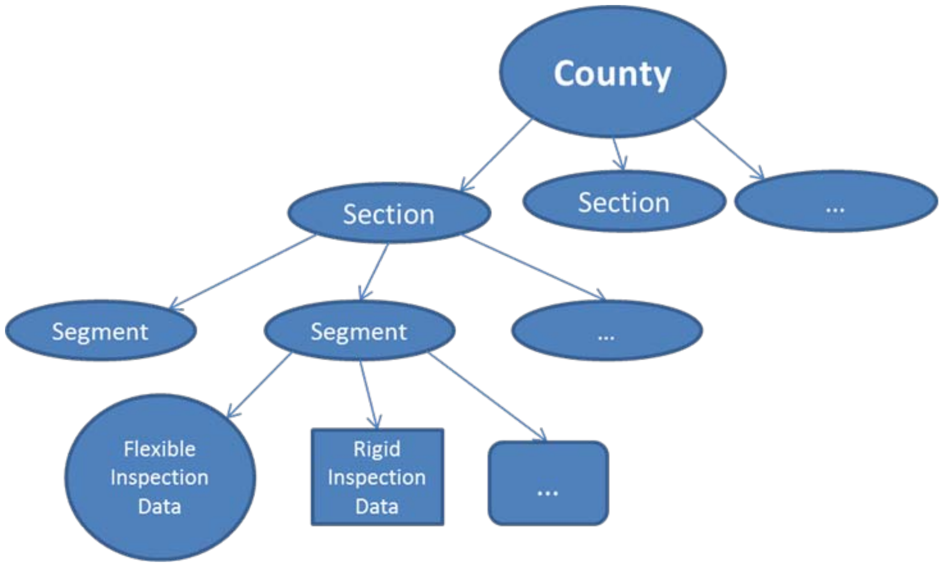

Figure 2. Layer of Business Objects

While in practical usage, rigid and flexible pavements are treated separately in the current PCS survey processes, there were many similarities that the developers were able to exploit. Most of the program operates on the more generic InspectionData object which could contain data regarding either flexible or rigid pavements. For those few operations that differ between the two pavement types and their condition data, two child classes were created: FlexibleInspectionData and RigidInspectionData. The advantage of this approach is that the code is more maintainable; most modifications simply need to be made to the InspectionData object. Only that code which performs operation unique to flexible or rigid pavement needs to be changed in the child objects.

The next component to be developed was XPCS Office. This component takes data from the XPCS Mobile component and transfers it to the XPCS Database. It also provides GIS services through the onboard SharpMap tools (an open-source GIS package) and the various functions defined in the SRD and SDD. The GIS system was designed with an eye for ease of use and simplicity. This design goal influenced everything from the function of the query tool (which avoids ambiguity when multiple sections may have been selected by zooming into the selection area) to the choice to invert the palette of colors (using a black background instead of the typical white). Additionally, the Office component was designed to provide flexible access to data by the linking of the GIS and Data Management tools. Selection of a section in either screen easily and quickly leads to its selection in the other.

Inspection data in the Data Management screen is automatically color coded to show the age of that data (current rows of data are white while previous data has a grey background which becomes darker depending on the age of the data) and is automatically grouped to let the user process the results in an intuitive manner. Other changes, such as the move from a “baked-in” dashboard (an interface that would need to be changed at the code level) to a window displaying one or more reports made the software easier to customize to a specific user or role (i.e., engineer, supervisor, and surveyor).

Finally, the XPCS Mobile component was developed and tested against the other two components. This software was tested by ARA developers and staff in the Champaign area (it was moved from the originally planned area in Pennsylvania to enable better debugging by the main development staff). Of course, the ARA IT environment and vehicle setup is not the same as that used by the SMO, so additional testing at the SMO was required.

The Mobile component was designed with flexibility in mind. Inspection crews are often forced to operate in sub-optimal traffic and construction environments and the ability to override the automatic section ordering provided by ArcGIS Network Analyst, the automatic screen flipping upon reaching the start and end of the test section, and the automatic adjustment of the zoom level of the MapPoint maps was deemed critical. While taking that need for flexibility into consideration, the Mobile component was designed to fully supplant the old Excel spreadsheet method of recording data while also providing an interactive map (updated in real-time) and direction to get the inspectors to the right place. The overall progress through the testing plan is shepherded by a constantly active Navigator object which manages the internal ordering of sections, the marking of sections as tested, and the automated management of the interface mode (navigation, testing, and verification).

Both components were designed with code-reuse in mind. The Office and Mobile applications use the same libraries to address data representation, form control (and even the same forms in some cases), validation, security, etc. In spite of a quite different look and feel, at every stage the underlying design principle was to treat the two components as two different ways of accessing and manipulating the same underlying system. In addition to the business logic layer (the code that handles activities such as validation), both applications use the same database structure. This simplifies the task of synchronization between the collection databases and the central database and eliminates the need to develop methods to convert information from a mobile format into an office format.

Deliverables

XPCS Database

The database is the core of the system and stores the data collected from the XPCS Mobile application for analysis and reporting by the XPCS Office application. It also stores FDOT-related data pulled from other systems within the Department such as the RCI database and the FDOT GIS basemap. This data is stored in a set of tables known as the Business Tables; the basic relationship of these tables is shown in Figure 3.

The database also stores all the security level data used to maintain data integrity and prevent data loss from non-administrative users. The basic relationships of these tables are shown in Figure 4.

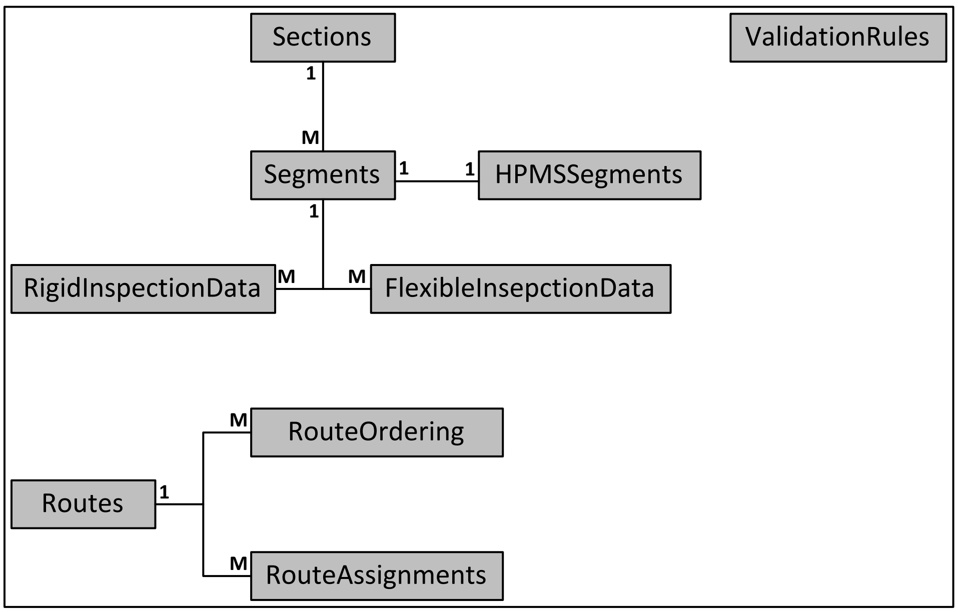

Figure 3. Business Tables

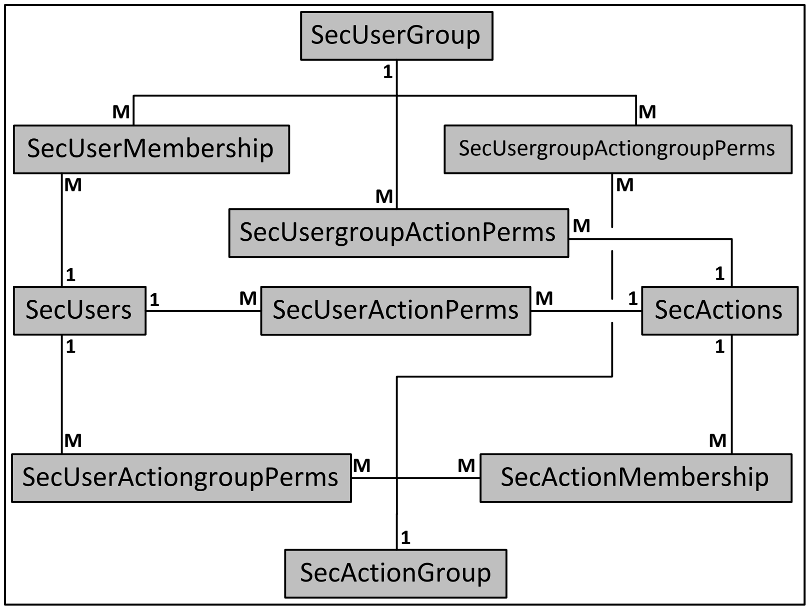

Figure 4. Security Tables

XPCS Office

The office component of the XPCS system is used for setup of data collection (i.e., route optimization), synchronization between the XPCS Database hosted within the FDOT IT infrastructure and the individual, disconnected XPCS Mobile field computers, validation, and reporting. It consists of the interfaces shown in Figure 5 through Figure 7. The layout is simple with the various functions represented by buttons on the left hand side and a large window on the right hand side storing GIS or various report results. Figure 5 shows the initial dashboard view that is displayed upon starting the software. The report that is generated may be specified by the user to match their needs and use case. In this example, a supervisor calls up a report on current progress across the statewide network when the software starts. Figure 6 shows the integrated GIS and data viewer elements of the system. This example shows in individual segment that has been selected in the GIS window and the condition data collected below. Darker rows in the grid represent older data. Finally, Figure 7 shows a sample report used for verification of data. This component can run any report on the database component of the software that the user has available. Reports are created with Crystal Reports 11.

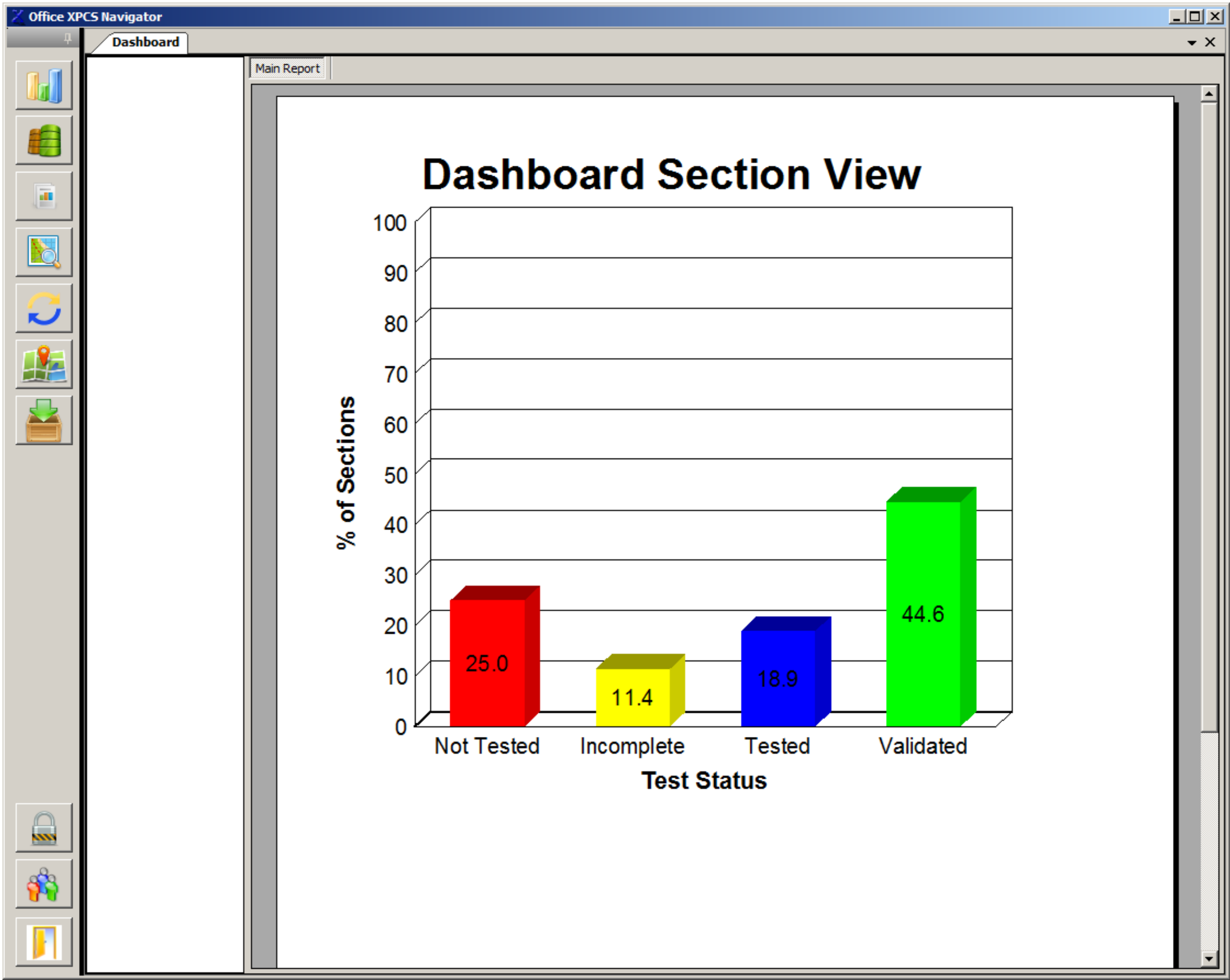

Figure 5. Dashboard Section View

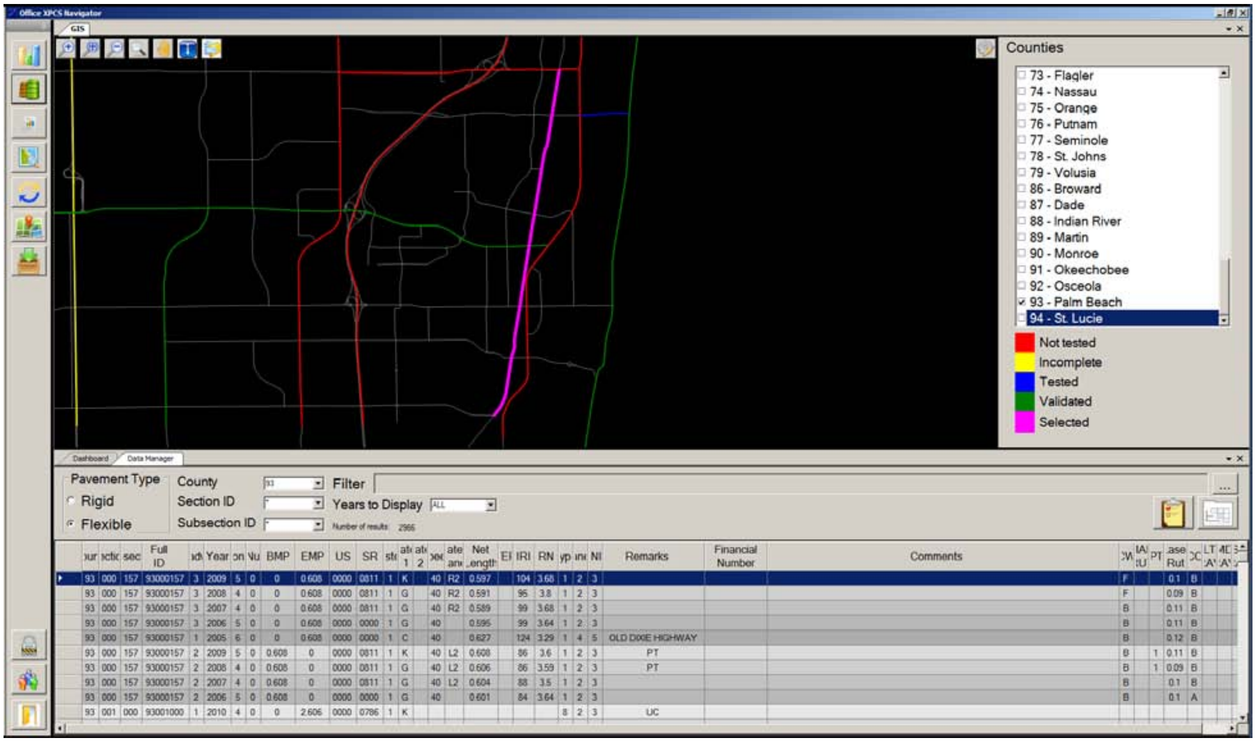

Figure 6. XPCS data viewing and integrated GIS

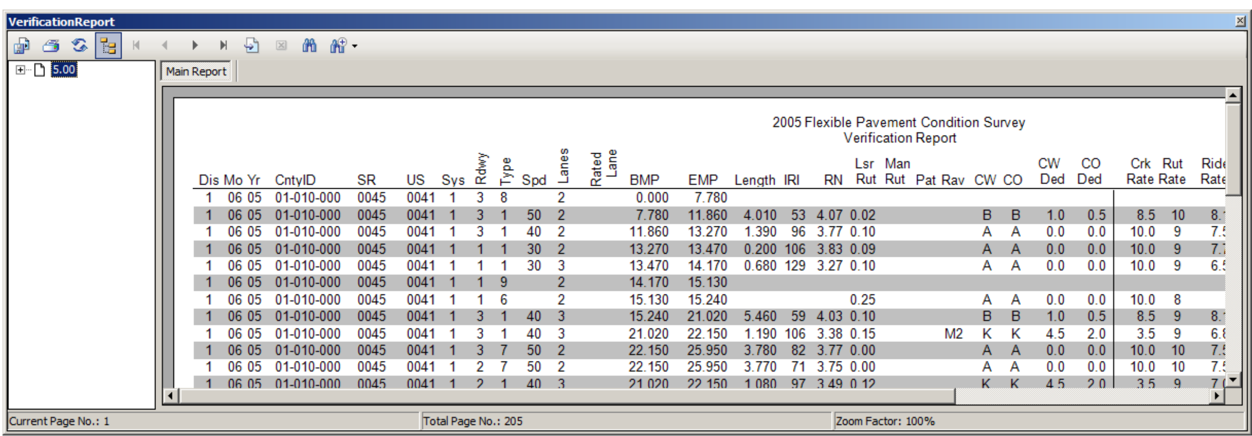

Figure 7. XPCS verification report

XPCS Mobile

The mobile component of the XPCS system is used in the field to collect data and perform immediate data validation. It operates in a disconnected environment; that is, data must be taken from the field computers and uploaded to the XPCS Database (the main data repository for this system) explicitly through the XPCS Office software.

The mobile component is broken up into three main sections.

The Section Navigator, shown in Figure 8, allows the operator to alter the order of sections to be visited as required and provides directions to the beginning of the test section. The surveyor may reorder the testing by dragging the individual elements of the route list. Route recalculation can also be invoked manually by clicking the Recalculate button in the lower right corner.

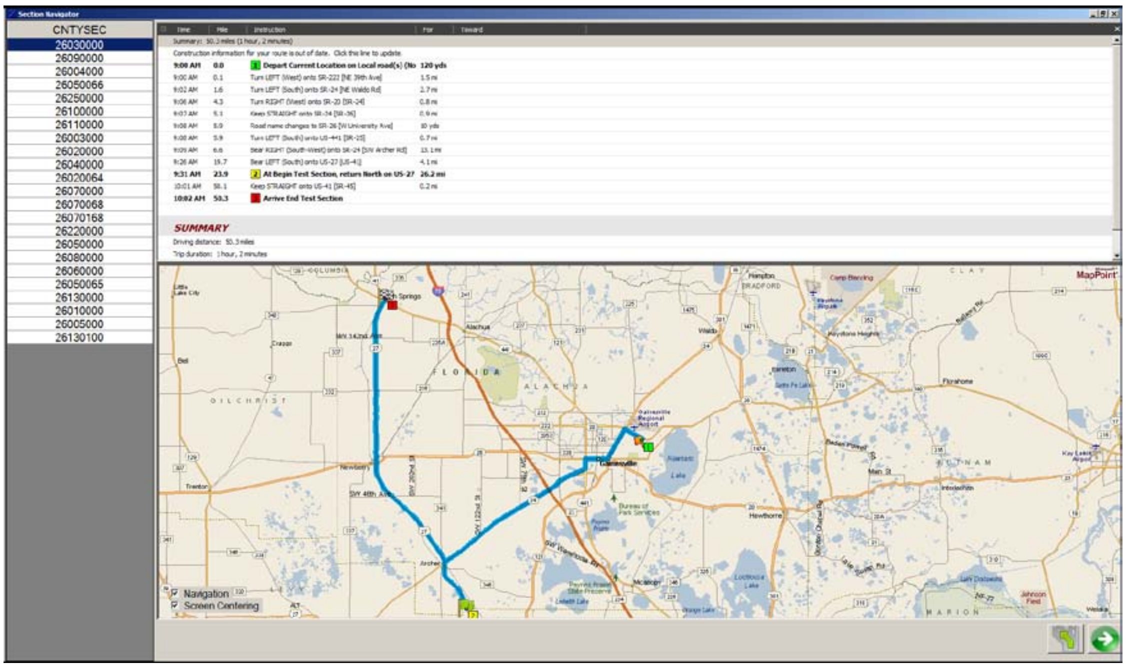

Figure 8. XPCS Mobile Section Navigator Screen

The Test Section interface, shown in Figure 9, guides the operator down the test section (or to the beginning of it, if they haven't yet reached it) and allows them to enter preliminary data while displaying the results of either last year's run or the previous run in the current testing cycle if a rerun is being performed. The surveyor can add breakpoints to create new segments within the test section through the boken chain button on the lower left of the interface.

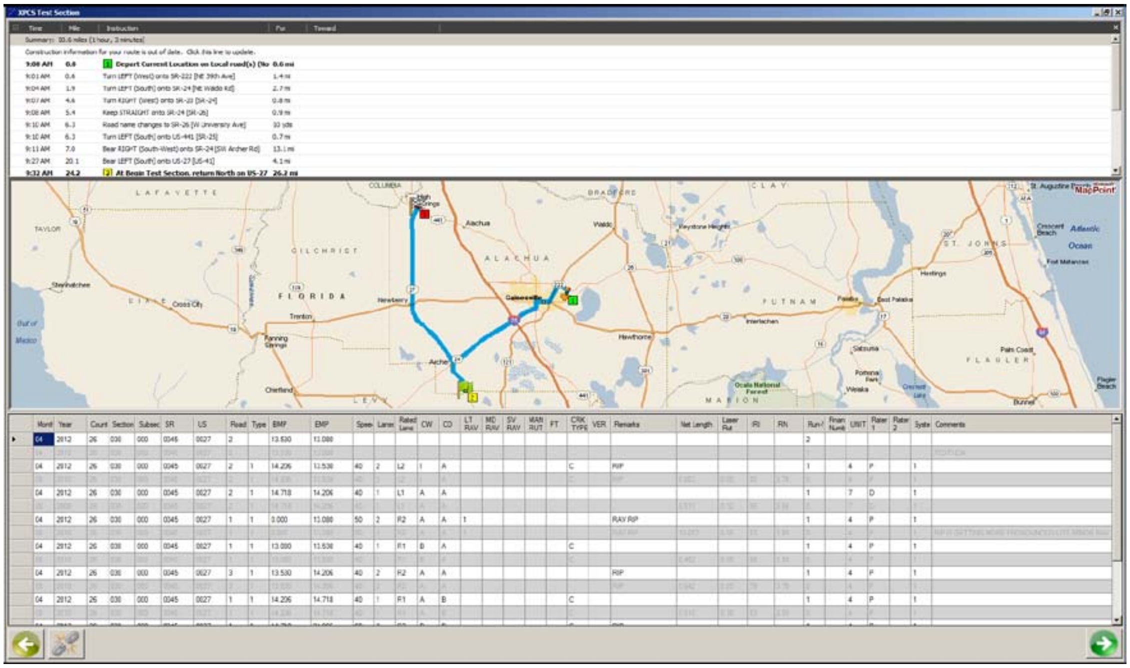

Figure 9. XPCS Mobile Field Test Screen

At the conclusion of a run, the vehicle operator will use the Data Validation screen (Figure 10). This interface is used to load data collected by WinRP as well as validate the collected/entered data. Prior year data is displayed in the grey rows between the active survey rows; the user can control the number of prior surveys shown through the drop-down box on the left.

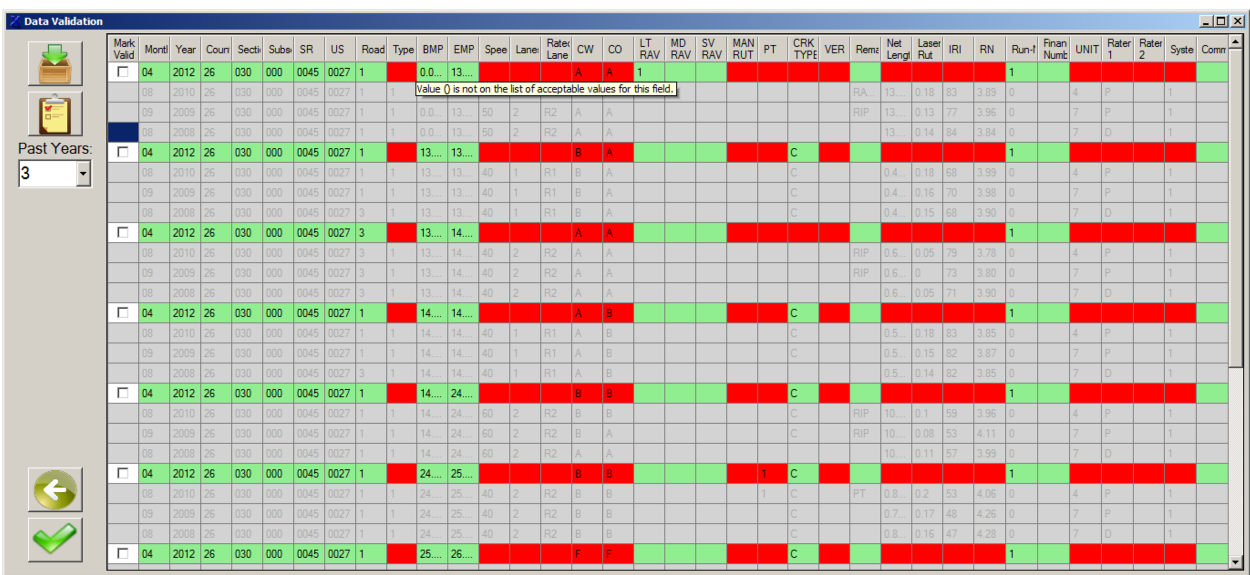

Figure 10. XPCS Mobile Data Validation Screen

Support & Improvement

Per the requirements of the RFP, ARA will provide support of the existing product for a one year period starting at the conclusion of the project. In addition to the support of the existing software, further steps could be taken to improve the overall system.

Improved Enterprise GIS Integration

The XPCS system was developed in parallel with the FDOT Enterprise GIS. While the current system makes extensive use of FDOT GIS data, better integration with the Enterprise GIS system is possible. ARA and FDOT have discussed these needs, and the Department has decided to perform this work within the existing Enterprise GIS integration effort. ARA will continue to assist FDOT with this work through the provision of software and documentation to meet the Department's needs.

Pavement Data Integration

Along with network-level PCS data, there are many other data sources that contain information about a given length of road (i.e., test section). A significant improvement to the system would be providing the ability to display these other data along with the network-level data collected through the XPCS system. Currently, ARA is working with the Department to determine how best to address this need.