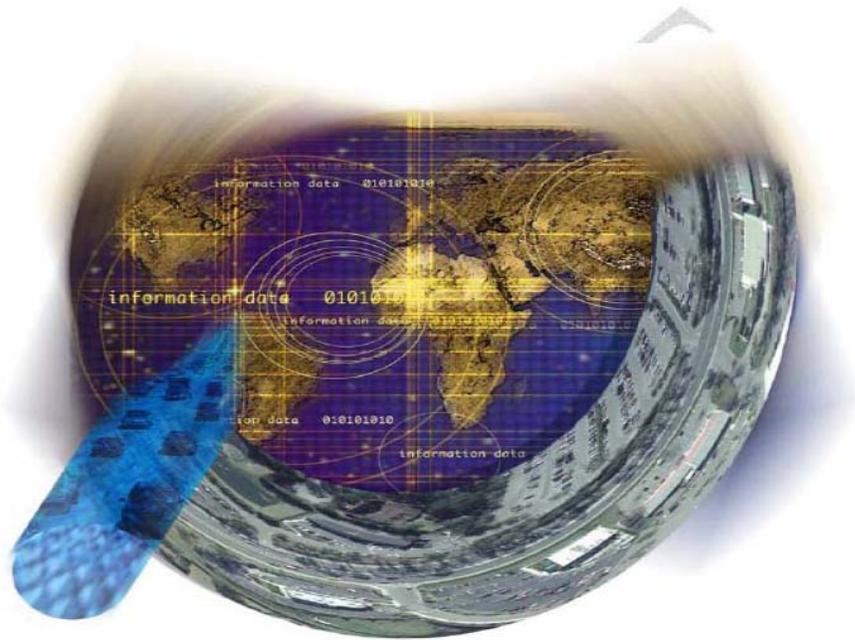# Highway Feature and Characteristics Database Development Using Commercial Remote Sensing Technologies, Combined with Mobile Mapping, GIS and GPS

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Executive Summary

Today, high-resolution images are made commercially available from different platforms including satellites, aircraft, and ground-based vehicles. These images have been utilized in transportation applications ranging from traffic management, roadway inventory, to transportation planning. The major objective of this project is to evaluate the feasibility of multiplatform commercial remote sensing technologies for the development of roadway features and characteristics databases. The goal is to provide demonstration and technical information on the use of commercial remote sensing in focused application areas for Florida Department of Transportation (FDOT) and other state and local government agencies. The project took an integrated approach that makes combined use of images from different remote sensing sources to derive accurate and comprehensive information for roadway features and characteristics, such as roadway centerlines, highway signs, traffic signals, road shoulders, medians, traffic lanes, intersections, etc. The project selected different types of road sections that cover interstate highways, state roads, and local connectors to conduct data extraction and evaluation tasks with imagery from the satellite, aerial photography, and the vehicle-based mobile mapping system.

In order to effectively determine the scope of the project activities and reconfirm the proposed technical approach, the project began with a state-of-practice review which helped to establish a basic understanding of the general trends of the technology and its applications in transportation. The review also closely examined approaches that had been demonstrated or implemented for roadway inventory in Florida and elsewhere. To effectively tie the project objectives with FDOT's data collection requirements, the project also conducted a quick data requirements analysis for FDOT's Roadway Characteristics Inventory (RCI). In this analysis, the project:

- Reviewed existing procedures and data elements that are specified by the Road Characteristics Inventory Handbook.
- Assessed candidate technologies, including imaging systems, image processing and desktop data acquisition software, and specific image and data products.
- Evaluated the proposed features, attributes, and accuracy levels for required data collection.
- Provided ranking on suitability of technologies including remote sensing, GIS, and mobile mapping on data collection for different data elements.

After the state-of-practice review and data requirements, the project proceeded to select the project sites and to collect the data for the project sites. For project purpose, different types of images and GIS data were acquired for the project sites, which include:

- High-resolution digital aerial photography (3 inch resolution) for Jacksonville I-10 and Arlington Expressway sites (data acquired from ACA).

- High-resolution panchromatic (1-m resolution) and multispectral (4-m resolution) imagery of Jacksonville I-10 and Arlington Expressway sites (data acquired from SpaceImaging).
- High-resolution digital aerial photography for Tallahassee sites (data provided by FDOT's Survey and Mapping Office).
- Mobile mapping image data for Jacksonville and for Tallahassee project sites (data acquired from GeoSpan).
- Photo logs and GIS road networks (data provided by FDOT).

After checking, validating and preprocessing the acquired data, images were utilized to extract roadway features and characteristics for the project areas. For demonstration purposes, satellite imagery was primarily used for land use classification, and aerial photographs were used for the extraction of planimetric features such as road centerline, shoulders, median and guardrail, while mobile mapping was used for signage inventory. The reason for this decision was to use each individual technology to its best advantage.

Land Use Classification with Satellite Imagery: The imagery acquired from SpaceImaging's IKONOS satellite was utilized for land use/land cover classification. This imagery contains both the 1-meter resolution panchromatic band and the 4-meter multispectral bands. The multispectral bands were first sharpened to one meter resolution and then were used as input for LULC classification. The LULC classification was based on a supervised classification method that uses training samples to learn about the characteristics of each LULC types first and then through the comparison of the learned LULC characteristics and the given characteristics of an image cell, the LULC type of the image cell will be identified. Information from both the satellite images and existing GIS data, the USGS land use map and the land use map from the Geographic Analysis Program (GAP) was combined to generate the LULC classifications for the project sites along I-10 and Arlington Expressway in Jacksonville. The LULC classification was based on the USGS LULC classification system, but a re-classification procedure was followed to generate RCI land use categories. The reason for this choice is that the LULC classification results will not only be useful for RCI, but also can be provided for other applications such as environmental analysis or transportation planning.

Data Extraction with Aerial Photographs: Several approaches were investigated for data extraction with aerial photography, which include the use of ERDAS Stereo Analyst, HSA's TransDat, and ESRI's ArcGIS. ERDAS Stereo Analyst is commercial-off-the-shelf software that can provide a standalone solution or can be utilized along with other software modules such as OrthoBase and IMAGINE to provide interactive feature extraction in a 3D environment. TransDat was used for extracting the required RCI features and characteristics by HSA. The advantage of the software is that it was customized to extract the specific data contents for FDOT's RCI. The production work of data extraction from aerial photography was mainly performed using ESRI's ArcGIS software. As required RCI planning features are mainly represented in a 2D environment, data extraction can be conducted on ortho-rectified or geo-rectified imagery, which can significantly improve the data extraction efficiency. The RCI data were extracted from

the aerial imagery cover project sites along I-10 and Arlington Expressway in Jacksonville and some sample areas along Magnolia Drive in Tallahassee. The extracted features and characteristics include roadway centerlines, through lanes, auxiliary lanes, outside shoulders, highway median, inside shoulders, intersections, structures, and so on. Some of the features required by RCI such as mile marker signs and traffic monitoring sites are indiscernible on aerial imagery and were not extracted. Road name and type road were assigned to the roadway segments; but the actual information about the road names and type road were not extracted from imagery. Extracted feature attributes such as guardrail length, mile-post, or shoulder length between measured locations were calculated automatically or interpolated implicitly.

Signage Inventory with Data from the Mobile Mapping System (MMS): The MMS imagery for the project was collected by GEOSPAN. The extraction for the roadway features was also performed by the company using its GEOVISTA 360º Visual Surveyor software. The vehicle-based MMS is built on basic photogrammetric principles. Compared with overhead remote sensing, it provides different vantage point of view. Once the imagery is spatially referenced, features in the imagery can be accurately located, measured, and extracted through triangulation by using two or more images that are obtained from different viewing angles. As many of the features and characteristics required for RCI can be extracted at different detailed levels with MMS imagery, the extraction process preceded with two phases. At the first phase, roadway features as identified in the RCI Features and Characteristics Handbook were individually extracted. At the second phase, features were counted along the roadways to obtain an aggregate number. The two phase approach provides some advantages for RCI data collection. It allows most detailed representations of the locations and attributes of the roadway features. At the same time, when verification and validation have to be done, extracted features and attributes can be checked individually to identify their positional and attribute accuracies. The extracted features with MMS imagery cover all the project sites in Jacksonville and Tallahassee. The extracted results include a shapefile on the account of features and characteristics for each of the road segments and a shapefile of the signs for the project sites.

Data Integration and Linear Referencing: The strategy of extracting different roadway features and characteristics with different technologies simplified the task of data fusion and data integration. Primarily, there were limited overlaps with features that were extracted from different technologies. Therefore integrating or combining data from different sources became more effective and there was no need for additional processing in order to select features from different sources or for combining information for the same feature that came from different sources. Nevertheless, data derived from different data sources had different formats, and they were not uniformly referenced to the roadway centerlines. The data integration task converted the extracted data into the same format and referenced the extraction information to the road centerlines uniformly. For instance, the LULC classification was first presented in a raster data format, which was then converted into vector-based polygon representation, which consequently was overlaid on the road centerlines to identify land use types along different road segments. The RCI data extracted from the aerial imagery include roadway centerlines, through

lanes, auxiliary lanes, outside shoulders, highway median, inside shoulders, intersections, structures, and so on. These features were also linearly referenced to road centerlines. The same process was followed for extracted signage from MMS.

Validation and Verification: A major advantage of the remotely sensed data is that they are provided in a graphical format and can be easily interpreted visually. Usually what you see is what you get. Given the multi-platform approach, features on the ground are captured multiple times from different points of views, with different resolutions, and from different sensors. Potential errors can be easily captured during data extraction process. Nevertheless, field surveys were conducted to acquire ground truth data in order to validate the spatial and attribute accuracy of the extracted data. In addition, cross-referencing and in-house validation were conducted to check and compare data from different sources. One observation is that aerial photographs generated using photogrammetry principles produced high positional accuracy. Features extracted from MMS coincided consistently with their corresponding locations on the aerial photography. GPS field surveys provided valuable information to confirm and validate location and attribute accuracies of extracted features, but it also revealed concerns on safety and efficiency. The data reliability from GPS also became questionable in urban and heavily wooded areas where GPS signals can be potentially blocked by trees or buildings.

In conclusion, the project demonstrated that the combined use of commercial remote sensing technologies of satellite remote sensing, aerial photography, and vehicle-based mobile mapping system offers an appealing solution to transportation data acquisition. Its effectiveness and advantages may not be easily achieved with individual technologies.

In particular, each technology can be used to its best advantage: satellite images cover large geographic areas and can be updated more frequently, which is important for data acquisition not only on highways, but for transportation corridors. Aerial photographs are particularly suitable for acquiring planimetric features for roadway inventory. These features can be extracted either in a 2D or in a 3D environment. Vehicle-based Mobile Mapping System (MMS) proved to be an effective technology for sign inventory and has the potential for many other types of roadway features and characteristics. Features such as signs or traffic signals that are usually represented as points on a map are difficult to identify from overhead imagery. But these features can be very effectively captured with MMS images.

The use of multiple data sources also overcomes shortcomings of single source solutions. Data collected from different sources can be cross-referenced that will significantly reduce the uncertainty on data quality and eliminate inconsistency when data are collected from uncoordinated data acquisition activities. The multi-technology solution can also reduce the need for field surveys, which has safety benefits not only to data collection agencies, but to the traveling public. Different vantage points using multi-platform remote sensing, particularly the combination of overhead views and terrestrial views, can address data collection problems associated with limitations of a single view point. That is, satellite imagery and aerial photography can provide images from

overhead that cover areas far beyond roads, while vehicle-based mobile mapping systems can bring out images behind trees or under bridges.

The project also highlighted some important issues that need to be addressed in the future. To a great extent, remote sensing continues to be an under-utilized technology in transportation applications. The lack of data sharing, the difficulty in determining costs and benefits, and the inherent complexity of geo-spatial solutions are major barriers. The project recommends attentions for future activities in areas of data interoperability, requirement analysis and matching, cost-benefit analysis, and continued application demonstrations.

1. Introduction

The major objective of this project was to study the feasibility of the state-of-the-art commercial remote sensing technologies to develop comprehensive databases of roadway features and characteristics. The project assessed a combination of remote sensing technologies, including commercial satellite imagery, aerial photography, and mobile mapping systems to extract features on highways and along highway corridors, features such as road centerlines, edges and medians, shoulders, traffic lanes, land use, etc. Existing databases from GIS were also utilized to facilitate land use classifications and supplement information such as roadway names or administrative characteristics that were difficult or impossible to be extracted from imagery. Field GPS surveys were performed to acquire ground truth data for comparative analysis and for verification and validation.

1.1. General Background

Remote sensing technologies have been increasingly used in transportation applications in recent years. The key driving forces include the increasing data acquisition speed and decreasing cost, the rapid advancement of softcopy image processing technology, and the ever growing demands for more accurate, comprehensive, and updated data. Digital cameras and various types of digital scanning devices play a key role in reducing the cost and the time for data acquisition. The use of these digital sensors streamlines many of the image processing procedures that otherwise must be performed manually (e.g., image orientation, rectification, and transformation). Technologies for rapid geo-referencing for remote sensors also contribute significantly to cost reduction and speed increases. In particular, the combined use of Global Position Systems (GPS) and Inertial Navigation Systems (INS) makes automatic image orientation possible, a task that is traditionally realized through the use of extensive field control points. To acquire these field control points, however, is time-consuming and can cost up to 40 percent of the data collection cost (Wolf, 1983).

Today, a variety of image processing software tools are made commercially available. These tools range from image visualization to image rectification, enhancement, classification, and automated and semi-automated feature extractions. Once images are presented in a digital format, these tools can be utilized individually or in combination to perform specific functions or derive necessary information to meet application requirements. With the right computer equipment and software, users will be able to be directly involved in the data processing, analysis, and decision making process, which will transform the ways images are to be utilized and applied in transportation and many other applications.

More importantly, transportation agencies face growing challenges when many transportation issues such as traffic congestion, safety, and environmental impact must be

addressed adequately with limited budget and resources. Information, particularly geo-spatial information acquired through various geo-spatial technologies including remote sensing, becomes a critical resource to transportation planners, engineers, and decision makers. To effectively support planning and operation decisions, transportation agencies must collect not only a large amount of data about transportation infrastructure itself, but also background information that is relevant to transportation systems, e.g., land use and regional socio-economic characteristics. These data must be first collected, and then constantly updated and maintained. Given the range of applications involved, remote sensing technologies can provide various alternatives to meet data requirements for different applications that require different data acquisition frequency, accuracy, and coverage.

To comprehensively study, implement and advance the use of remote sensing technologies in transportation, U.S. Department of Transportation (USDOT) and National Aeronautics and Space Administration (NASA) jointly sponsored the National Consortia of Remote Sensing for Transportation (NCRST), which consists of four consortia, each focusing on a specific transportation application area. The Environmental Application Consortium or NCRST-E, led by Mississippi State University, focuses on streamlining multi-modal corridor planning and environmental data services. The Infrastructure Management or NCRST-I, led by University of California, Santa Barbara, focuses on solutions for critical infrastructure management and for improving maintenance service efficiency. The Hazards and Disaster Management Consortium or NCRST-H, led by University of New Mexico, focuses on applications for improving the preparedness and response of communities for unplanned disasters and security of critical transportation lifelines. The Multimodal Transportation Flows Consortium or NCRST-F, led by the Ohio State University, focuses on technologies facilitating regional traffic and freight flow monitoring and management.

The current project was also part of the NCRST program under the umbrella of NCRST-I. The project was jointly funded by Florida Department of Transportation (FDOT) and USDOT. The application focus of the project is on roadway inventory data collection using remote sensing technologies.

1.2. Specific Objectives

The specific objectives of the project:

(1) Implement integrated remote sensing solutions to develop accurate and comprehensive Roadway Characteristics Inventory for selected study road sections that meets Florida DOT's production requirements.

(2) Assess the practical applicability of the proposed technologies with respect to their effectiveness, accuracy, fitness, and ease of implementation.

(3) Document the commercial remote sensing products, implementation procedures, and technical approaches used in the project.

(4) Recommend on future project activities and feedback to the research and industry communities for technological enhancement.

Although remote sensing, mobile mapping and GPS have been separately utilized for transportation data collection, an integrated approach applied to a detailed roadway and roadway feature database development, as proposed by the current approach, has not been fully investigated. The project will provide an operational test of such an integrated approach. This test will allow us: (a) to draw some basic conclusions about the feasibility of the integrated use of remote sensing, mobile mapping, GIS and GPS technologies for the purpose of infrastructure database development, and (b) to assess and compare the functionality of these technologies and their applicability in real world applications.

1.3. Relevancy

Florida DOT's Transportation Statistics Office, under the State Transportation Planner, coordinates transportation data collection, storage, and reporting activities throughout the Department. The Office is responsible for data collection, update and maintenance of the Roadway Characteristics Inventory (RCI) system, which is a critical component of the Department's infrastructure management process. Unique to Florida is the investment decision rule that preservation of the system is "taken off the top." This means existing infrastructure must be maintained before more funds are spent for new capacity on the system. Preservation is divided into three categories: pavement, bridge, and routine maintenance. Each of these has an extensive inventory-driven, performance-based management system that allows investment decisions to be based on needs and priorities.

The Pavement Management System requires an annual pavement condition survey to evaluate ride quality, crack severity, and average depth of wheel-path ruts. The Bridge Management System inspects each of the state owned bridges as well as additional bridges that are not owned by the state every two years to identify which need preventive maintenance, minor or major repair work, or replacement. The maintenance-rating program is a process that rates five primary categories of highways environment three times a year. The items rated are roadway (potholes etc.), roadside (shoulders), vegetation and aesthetics (mowing, litter removal), traffic services (signs, lighting), and drainage (ditches). Each category is rated and the overall maintenance condition is calculated.

To ensure success of the Department's infrastructure management process, the Transportation Statistics Office has a responsibility for collecting, updating and maintaining a comprehensive, accurate feature database for highway infrastructure. The infrastructure includes traffic lanes, pavement, shoulders, road signs, guardrails, bridges, and so on. Currently, the data used to support the Department's management process are based upon data collected from different sources such as engineering designs, field surveys, and existing databases. Collecting and maintaining the data have proved to be a major challenge. Because data come from different sources, inconsistency is frequently encountered. Maintaining data accuracy and keeping them current become especially

difficult and expensive when some data items have to be collected or maintained separately.

To address this challenge, the approach as proposed by the project utilizing commercial remote sensing technologies, combined with mobile mapping and GPS technologies, becomes very attractive. The potential benefits of this approach include the elimination of redundant data collection efforts, improvements in data consistency and accuracy, and a reduction in data production time and costs, and improvement in safety for data collection activities and for the driving public. Other benefits are also implied such as cost reduction and production improvement in maintenance activities, that is, a comprehensive and integrated procedure for data collection and maintenance will allow more coordinated access to resources for maintenance activities ranging from planning to coordination, to field maintenance tracking.

1.4. Document Organization

This document is a technical report of the conduct of the project, which describes project technical decisions, approaches, activities, results, and conclusions and recommendations. The report is organized as follows: Section 2 provides a description of the project decisions and overall approaches taken by the projects. Section 3 presents the study on the use of satellite imagery for land use and land cover classification. Section 4 describes the project work on aerial photography for planimetric feature extraction. Section 5 describes the use of mobile mapping for sign inventory. Section 6 presents the results on data validation and verification. Section 7 provides project conclusions, discussions of issues, and recommendations to address these issues.

2. Project Decisions and Overall Approaches

The project proposed an integrated solution that would make combined use of remote sensing technologies, GIS, Mobile Mapping, and GPS to develop comprehensive, detailed and accurate databases of roadway features and characteristics for infrastructure management. Nevertheless, the overarching project approach must be tailored to address the specific application requirements. It became obvious that FDOT has very focused priorities to address its inventory data collection. These priorities are largely reflected in its handbooks on Roadway Characteristics Inventory (RCI) (FDOT, 2004). Also several on-going data collection pilot projects using remote sensing and other geospatial technologies were under way, which must be considered for the current project. A revised and more practical approach was taken for the implementation of the project.

2.1. State of Practice Review

At the very beginning of the project, a state-of-practice review was conducted to provide an overview of recent technological developments and their applications in transportation in general and in roadway inventory specifically. The review on the general trends of remote sensing technologies demonstrated that:

- Sensor systems, e.g., high-resolution commercial satellite sensors, multispectral and hyper-spectral, and mobile mapping imaging systems, advance rapidly, which provide diversified data sources that transportation decision makes, planners, and engineers can choose from.
- Multi-sensor data fusion and data integration, e.g., the coupling of sensor systems with Global Positioning Systems (GPS) and Inertial Navigation Systems (INS), become a more standard practice, which continue to increase the accuracy, frequency, and efficiency for image data acquisition and decrease data acquisition costs.
- Image processing and data extraction technologies evolve rapidly. Software tools to interactively and semi-automatically extract information from imagery become more reliable and diversified. Many are commercially available. Automated data extraction has been a major research subject for sometime, but usually incorporated into a semi-automatic environment to improve accuracy and reliability.
- Transportation applications, such as roadway inventory, facility management, transportation planning, traffic management, and environmental assessment, using remotely sensed data have been studied and demonstrated extensively. Some technologies, e.g., aerial photography and MMS have been practically implemented. Nevertheless, gaps between technology demonstration and practical applications continue to exist.

For roadway inventory, especially in FDOT, major efforts were made to evaluate and implement remote sensing technologies for RCI purposes.

- The accuracy of aerial photography was vigorously investigated by FDOT's Transportation Statistics Office along with Marlin Engineering, Weidener Surveying and Mapping, P.A., and HSA Consulting Group (FDOT, 2003). It was confirmed that the accuracy of the use of aerial photography and photogrammetry far exceeds the RCI planning data requirements.
- FDOT's Turnpike District piloted a RCI data collection solution that made use of existing aerial photography, videolog images, and existing GIS data (Dove et al, 2001). The method was built on existing GIS software and allowed not only the update of exiting RCI data records, but also the creation of new data elements. Calculations such as the length of a guardrail or the size and cost of a mowing area could be done automatically.
- FDOT's District Three since 2001 has implemented an aerial photography and photogrammetry solution to collect all RCI features using aerial remote sensing. The district considers the method has a number of benefits including cost savings and value added to the RCI inventory.
- In Florida and elsewhere, Mobile Mapping Systems were evaluated and implemented to create complete vector maps and layers of roadway features and characteristics information (El-Sheimy, 1996; He, 2002; Novak and Nimz, 1997). The technology has been used not only for inventory, but also for safety, road maintenance, and many other applications.

Nevertheless, the state of practice revealed that many of the existing efforts focused more on the use of individual technologies. An integrated solution that combines a set of technologies was not extensively studied and demonstrated, which confirmed the need for an investigation on an integrated remote sensing solution.

2.2. Project Site Selection

The selection of the project sites was an important consideration of the project. On one hand, it would be ideal for the project to cover as diverse geographic settings and roadway segments as possible. Different geographic settings and different types of roadway segments will allow the project to capture different features and to demonstrate comparative advantages of different technologies. In general, Interstate highways are associated with a special set of roadway characteristics. They usually contain fewer traffic signs, but with complex interchanges and wider median. In contrast, state highways and local roads have a different set of features. In some cases, features found in state or local roads will not be found on Interstates, e.g., stop signs and traffic signals. The differences of geographic settings have influences not only on the occurrence of the types of features, but also on the usefulness of the types of technologies. In urban areas, the distribution of traffic signs will be denser, requiring more efforts to collect these features compared to the same length of roadways in rural areas. For areas that have dense forest coverage, data collection from aerial photography would be more difficult because of poorer visibility from the overhead. In heavily built-up urban areas, due to

blockage of GPS signatures, GPS field surveys can be difficult as well. In summary, three factors were considered in the selection of the project sites:

(1) The selected sites must include major road categories: Interstates, arterials, and local streets.
(2) The selected sites must include areas that have some comparison for open sky, tree coverage, and heavily built-up areas.
(3) Road segments in both urban and rural areas should be selected for the project.

Based on these considerations, the project selected four road segments as the project testing sites:

(1) I-10 near Jacksonville
(2) Arlington Expressway in Jacksonville
(3) Magnolia Drive in Tallahassee
(4) US-90 near Tallahassee.

The selected road segment of I-10 stretches from Jacksonville to its outskirt, which provides a representative environment for Interstate highways in both urban and rural settings. The road section chosen for Arlington Expressways is a major corridor in the east-west direction through downtown Jacksonville. It represents a typical signalized arterials or state road in an urban environment. US-90 is also a major arterial in the state, but the selected section is situated in a rural or suburban environment. Magnolia Drive in Tallahassee is a local road, which contains most of the roadway features that can be found in a typical local street. Also extensive tree coverage can be found along Magnolia Drive, which is an additional interest to the project to select the site.

2.3. Review for Data Collection Requirements

FDOT's Transportation Statistics Office (TSO) has a major responsibility for Roadway Characteristics Inventory (RCI) activities. Features and characteristics in RCI (FDOT-TSO, 2004) are those that are of general interest to FDOT. Therefore it is critical for the project to pay special attention to the data requirements for the RCI. At the same time, requirements from other offices such as Planning, Environmental Management, Traffic Operations, Safety, Survey and Mapping were also considered.

To come up with the features and characteristics that would be evaluated for the project, three lists were developed for three application areas: Planning, Maintenance, and Traffic Operations. Parts of the lists are illustrated in Tables 2.1., 2.2, and 2.3. The development of these lists was mainly based on the existing RCI Handbooks (FDOT-TSO, 2004). Additional discussions were conducted with different offices within the Department to establish an understanding of the nature of the requirements. These discussions focused on the following aspects concerning with the data collection:

(1) Feature Dimension (e.g., if a physical characteristic, how is it measured: length, width, height, slope, etc.)

(2)   Condition (e.g., reflectivity, cracking, rotting, straightness, etc.)
(3)   Location (e.g., how is location identified? latitude/longitude, county, road milepoint, etc.)
(4)   Locational accuracy (e.g., if using milepoint, plus or minus how many feet?)
(5)   Resolvability (whether the required features or characteristics can be easily or economically acquired or identified, e.g., easy, or average, or difficult?)
(6)   Tolerance (e.g., how far off can a measurement be?)
(7)   Precision (e.g., the fractions of a unit used for the measurement? 10ths, 100ths, etc.)
(8)   Units (feet, miles, ID, code, etc.)
(9)   Frequency of data collection (e.g., monthly, yearly, or biannually?)
(10) Contents (information contents about the item)
(11) Metadata (what type of descriptive information will be necessary for the collected data)
(12) Index (is there an ID or number that should be used as an index)
(13) Degree of importance (how badly the data is needed)
(14) Data format (e.g., organization of the data such as record length or number of items comprising a single record).

It was understood that data requirements analysis could potentially go through a formal database design procedure, but it was also necessary to make quick decisions on the inclusion of the features and attributes that could be practically evaluated with the current project. For this reason, a preliminary assessment was given to the list of features and characteristics with considerations of the importance of those features. The assessment was also served as a basis for selecting specific technologies for data acquisition. The data requirements review resulted in following decisions:

(1) Most features and characteristics for traffic operations and maintenance (e.g., traffic signs, signals, posts, message boards, etc) to be collected with Mobile Mapping Systems.
(2) Most planning features, mainly planimetric features (e.g., road centerlines, shoulders, medians, etc.) to be collected with aerial photography.
(3) Land use characteristics to be collected with satellite imagery.

These decisions were based on consideration that each of the technologies would be utilized at their best advantages given all the data to be collected. At the same time, several technologies such as aerial photography, mobile mapping and satellite imagery had been extensively utilized on an individual basis in the state. A combined use of these technologies would provide a unique perspective on roadway data collection.

Table 2.1. Partial list of planning features and characteristics.

Feature ID	Characteristics Code	Description
111	STROADNO	State Road Number
	STRDNUM2	State Road Number
112	FAHWYSYS	Type of Federal Aid: NHS, STP, or None
	OLDFASYS	Old Federal-Aid Highway System Code
	SPECSYS	Special Systems
	STGHWNWK	Strategic Highway Network
	TRAVLWAY	Travel Way Along Roadway
113	USROUTE	Lowest Numerical Posted U.S. Route No.
	USROUTE2	Second Lowest Numerical Posted U.S. Route No.
114	LOCALNAM	Posted or Known Local Street Name
118	ATGROTHR	Other / No Control At-Grade Intersections
	ATGRSIG	Number of At-Grade Intersections w/Signal
	ATGRSTOP	Number of At-Grade Intersections w/Stop Signs
	CURCLASx	Curves by Class (x=A-F)
	GRACLASx	Grade by Class (x=A-F)
	HORALADQ	Horizontal Alignment Adequacy
	HPMSIDNO	HPMS ID Number
	LOADTDEV	HPMS Sample Type
	PEAKLANE	Number of Lanes in Peak Direction in Peak Hour
	SIGPREV	Prevailing Type of Signalizations
	SIT1500	percent of Passing Sight Distance >=1500 feet
	TERRAIN	Type of Land Terrain
	TURNLANL	Turn Lanes Left
	TURNLANR	Turn Lanes Right
	TYPEOP	Type of Operation
	VRTALADQ	Vertical Alignment Adequacy
	WIDEFEAS	Is Widening Feasible?
	YRIMPT	Year of Last Improvement

Table 2.2. Partial list of maintenance features and characteristics.

Feature ID	Characteristics Code	Description
217	BOXCULHT	Box Culvert Height
241	BOXCULLT	Box Culvert Width
	BXCULGTH	Box Culvert Length
	NOBXCULV	Number of Box Culverts
	CRSDRLGH	Length of Crossdrain
	NOCRDRAN	Number of Crossdrain Pipes
	PIPEDIAM	Pipe Diameter
	PIPEHIGH	Non-Circular Pipe Height
	PIPEWDTH	Non-Circular Pipe Width
	PIPETYPE	Type of Pipe
242	INLETS	Number of Curb Inlet
	MANHOLES	Number of Manholes
	MDITCBAS	Number of Catch Basins
243	BORRPITS	Number of Borrow Pits
	RETAREAS	Number of Retention Areas
	SED BASIN	Number of Sediment Basins
	MITARACR	Mitigation Area in Hectares
245	PAVDTLEN	Paved Roadside Ditch Length
	STMSWLEN	Storm Sewer Roadside Ditch Length
	FRDRNLEN	French Drain Roadside Ditch Length
	TRKLNLEN	Trunk Line Roadside Ditch Length
248	ODITHAND	Outfall Ditch by Hand Length
	ODITHAUL	Outfall Ditch by Hauled Length
	ODITPAVE	Outfall Ditch by Length Paved
	ODITPIPE	Outfall Ditch Length Piped
	ODITSPR	Outfall Ditch Spread Length

Table 2.3. List of features and characteristics for traffic operations.

Feature ID	Feature Code	Description
311	DTESZAPP	Date speed zone approved by Transp. Sec.
	DTESZIMP	Date speed zone implemented
	MAXSPEED	Maximum posted speed limit
	MINSPEED	Minimum posted speed limit
312	TURNMOVE	Turn movement restriction
	DTETMAPP	Date turning movement approved by Sec.
	DTETMIMP	Date turning movement implemented
	LMTRSTRC	Limited restriction
313	DTEPKAPP	Date parking restriction approved by Sec
322	PKRSTIME	Parking restriction time
	SIGNALTY	Traffic signal type
	SIGNALNC	Non-counted signal type
323	SDESTRET	Sidestreet Name
	SCHLSPED	School zone speed limit

2.4. Technical Approaches

To evaluate the combined use of different remote sensing technologies for roadway data collection, the project focused on three major technologies: satellite remote sensing, aerial photography, and mobile mapping systems. Field GPS surveys were also conducted to compare with the results from remote sensing, and existing GIS databases were also utilized to extract information that was difficult or impossible to acquire from remote sensing sources.

2.4.1. Satellite Remote Sensing

Various types of satellite remote sensing technologies can be potentially useful for roadway data acquisition (e.g., roadway centerline, land use characteristics along transportation corridors, or transportation-related impervious surfaces). The advantage of using images from satellites is obvious. These images usually cover large geographic areas, which provide rich geographic background information about transportation systems and transportation corridors. For many applications, e.g., transportation planning, not only are data about features and characteristics that are along or near roadways important, but also data about features and characteristics that are far away from the roads are required when decisions are to be made (e.g., whether an area is urban, rural, or whether an urban area belongs to residential or commercial districts).

Satellite images can be also collected more frequently due to their lower operational costs. This is important to transportation applications because transportation agencies must constantly evaluate changes on the ground so that transportation services can be provided to accommodate evolving demands and in many cases to anticipate potential impact of new development. The use of multiple spectral bands and the availability of commercialized image processing software also make the information process more effective and efficient. Many of the satellite images contain the infrared band in addition to the red, green, and blue bands. Some have much more. For instance, the Landsat Enhanced Thematic Mapper Plus (ETM+) has seven bands. The Hyperion has 220 spectral bands that can establish precise signatures of many terrestrial features. Using multiple or hyper spectral information, computer programs can be utilized to extract information from images automatically.

Nevertheless, when specific features and characteristics are considered for RCI, the choices became very limited. Many types of satellite images have a resolution that is unsuitable for detailed roadway feature extraction purposes. The project focused on two types of major commercial technologies: the IKONOS satellite from SpaceImaging and the QuickBird satellite from Digital Global. The IKONOS satellite provides images at a one-meter resolution for the panchromatic band and images at a four meter resolution for multiple spectral bands. Figure 2.1 is an illustration of an IKONOS image in Jacksonville. The QuickBird satellite provides images at a 0.6 meter resolution for the panchromatic band and images at a 2.4 meter resolution for multiple spectral bands.

Image resolutions at these ranges as given by IKONO and QuickBird are suitable, not only for land use classifications and impervious surface estimations, but also for road network extractions and for building identification that would support many transportation applications (e.g., transportation planning, Intelligent Transportation Systems, evacuation, etc).

With the presence of aerial photography and mobile mapping imagery, the strategy of the project was to use satellite imagery to acquire land use information, which is part of the roadway characteristics required in the RCI. It was possible that land use information could have been extracted through aerial photography for RCI, but the solution we explored was not purely for RCI purposes, but can be potentially applied for applications such as environmental analysis, traffic demand modeling, or daytime population estimation, etc.

2.4.2. Aerial Photography

The use of high-resolution airborne images was an important component of the overall approaches. There were several reasons. First, airborne digital imaging technologies, including analog-capture-digital-publishing, deliver a variety of products that can meet transportation data needs at a fine detail and with high accuracy. Previous studies conducted by FDOT demonstrated that the aerial photography and photogrammetry can provide an accuracy that far exceeds the requirements for RCI. Figure 2.2 is a digital aerial photograph for part of Magnolia Drive in Tallahassee. Clearly, road centerlines, edge lines, road wide, segment length, and other related data can be extracted accurately from this image. Second, the flying altitude, time schedule and sensor types are highly flexible, which allows images to be acquired to meet very specific requirements including cost targets, resolution constraints, or schedule constraints. Third, off-the-shelf commercial software is available and can be utilized to perform image processing tasks conveniently such as the tasks of ortho-rectifying images and creation of digital elevation models (DEM) or image classification. These three factors are critical for many state and local government agencies in their consideration on the use of the technology.

In the project, aerial photographs were utilized to extract planimetric features for RCI in both 2D and 3D environments. Due to the high resolution (e.g., 3 inches) and high precision, aerial photographs were actually used not only for feature extraction, but for position referencing and validation for mobile mapping imagery. A Digital Elevation Model (DEM) was also obtained for part of the project areas, which when overlaying with 2D planimetric features can potentially provide an additional way of generating three-dimensional representations of the roadway features without directly extracting these features in the 3D environment.

Figure 2.1. Satellite imagery is useful for data acquisition in large geographic areas for features such as transportation networks, land use and land cover, and vegetation.

Figure 2.2. Aerial photographs are useful for the extraction of detailed planimetic information of transportation infrastructure such as traffic lanes, intersections, bridges, and shoulders.
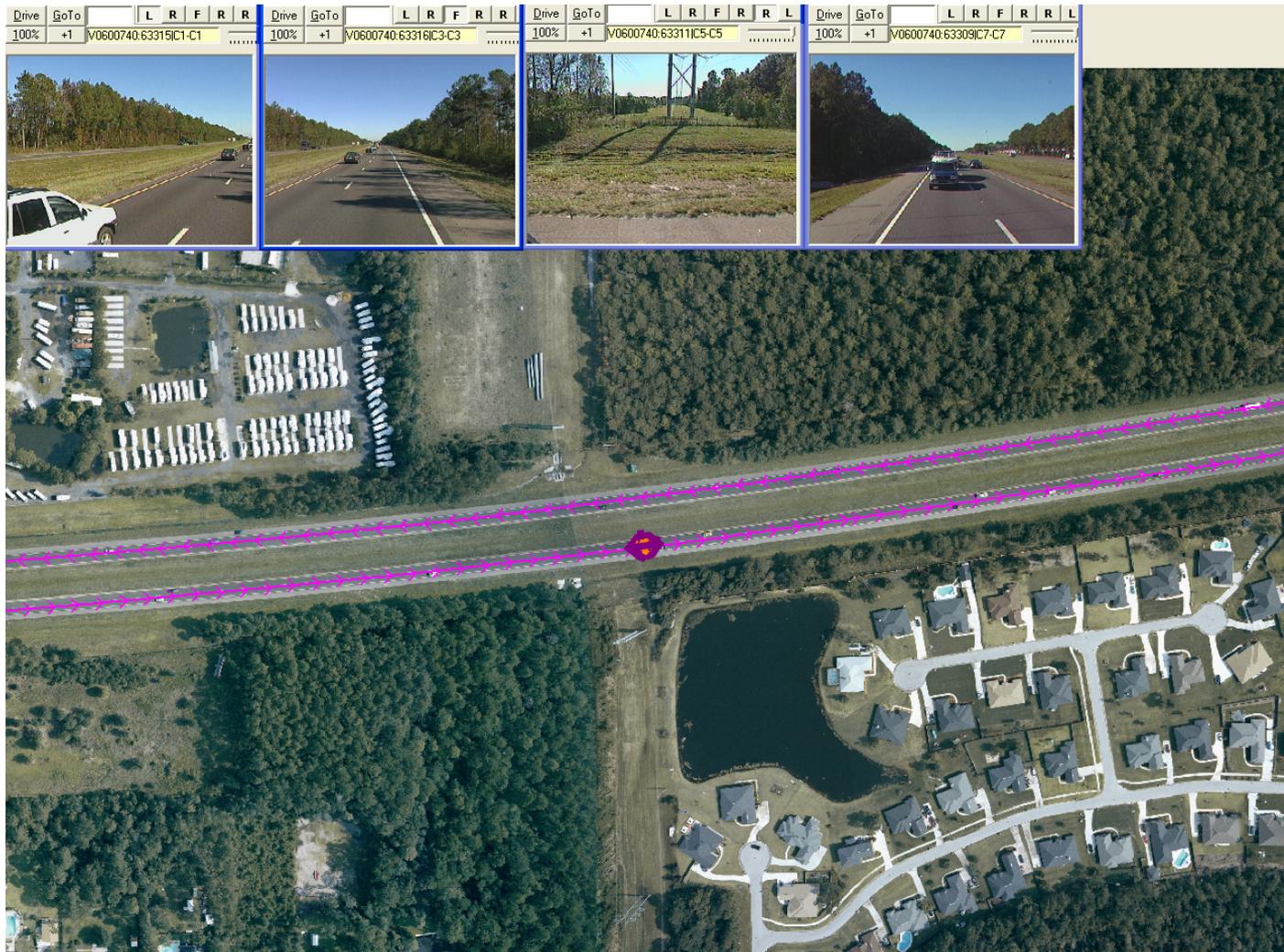
Figure 2.3. Images acquired from Vehicle-Based Mobile Mapping System can be used not only to identify features and attributes at refined detail, but also to pinpoint their precise locations and measure their dimensions, features such as traffic signs, bridge structures, telephone poles, manholes, fire hydrant, etc.

2.4.3. Mobile Mapping

Features such as road signs, traffic devices, or telephone poles that are usually represented as points on a map are difficult to identify in imagery obtained from overhead remote sensing. These features can be more effectively captured using vehicle-based Mobile Mapping Systems (MMS), especially those that incorporate digital video imaging, coupled with GPS and inertial systems. Basically, MMS are capable of capturing many features and attributes of highway infrastructure at refined details with high accuracy (El-Sheimy, 1996; Novak and Nimz, 1997). The integrated use of GPS and inertial navigation systems provides continuous, automated positioning and orientation capabilities for the remote sensors. Multi-camera systems are commonly used in MMS to collect images that can provide multiple viewing angles of the same scenes instantaneously or provide panoramic views of the navigational environment. With the exterior orientation provided by GPS/INS, images acquired with MMS can be effectively geo-referenced in real-time or through automated post-processing procedures.

The major difference between images acquired from MMS and images from videologs is that images acquired from MMS are not only tagged with precise camera positions, but also attached with information about camera orientation and calibration. Therefore MMS images can be processed and analyzed based on photogrammetric principles. In contrast, videolog images are referenced with proximate locations and more frequently intended for visual analysis instead of high precision measurement or positioning. Many commercial MMS are available at the market place (e.g., TRANSMAP systems from TransMap Inc, GPSVision Mobile Mapping Systems by Lambda Tech International, Inc., and VISAT Mobile Mapping Systems by the Sanborn Map Company, Inc). The current project took advantage of an existing commercial system, the GEOVAN by GEOSPAN Corporation. GEOSPAN using its GEOVAN and its desktop survey software supported both imaging data collection and major data extraction tasks for this project. Figure 2.3 provides a combined view of MMS imagery and aerial photography.

2.4.4. GIS and GPS

Existing GIS data are an important information resource that was to be exploited in this project. For many data collection projects, not all the data need to be collected from the fields. Some of the data cannot and will not be collected from the field, e.g., road functional classes or administrative status. Some of the information such as the mileage of a road segment can not be changed with a single road measurement, instead the mileage numbers must be extracted from official records and passed to databases that are to be maintained and updated. In this project, the road network basemap provided by FDOT was utilized to establish official identifications of the extracted roadway segments as well as to build a linear referencing scheme to integrate the data from different remote sensing sources. Along with satellite images, existing GIS data layers (e.g., land use and land cover maps from USGS and the Geographic Analysis Program) were also utilized to facilitate the land use/land cover classification.

The project also explored the use of field GPS data collection in order to compare, validate and verify information that was acquired from remote sensing and mobile mapping. Commercially available GPS equipment can provide centimeter accuracy in location positioning, which theoretically are suitable for accurate ground control. Field GPS survey is also a simple and easy way to collect roadway feature and attribute data. Although the project experience suggested that field GPS surveys should be conducted as infrequently as possible for safety reasons, it was realized that the use of field GPS surveys can be justified in some cases where remote sensing solutions are out of reach.

3. Land Use Classification with Satellite Imagery

3.1. Background

Different types of satellite images can be utilized to acquire information on roadways or along transportation corridors. Most frequently used satellite images for transportation come from Landsat Enhanced Thematic Mapper Plus or ETM+, the DigitalGlobe's Quickbird, and the SpaceImaging's IKONOS. ETM+ imagery has a resolution of 30 meters for multispectral bands and 15 meters for the panchromatic band. In contrast, Quickbird has a resolution of 2.44 meters for multispectral bands and 0.61 meter for the panchromatic band, while IKONOS images have a 4 meter and 1 meter resolutions for its spectral and panchromatic bands. Because of the coarse resolution of ETM+, the selection was focused on Quickbird and IKONOS. While searching through the image databases from both of the SpaceImaging and Digital Global, it was found out that IKONOS imagery was the only data that could be quickly made available to the project. The satellite imagery data covered both the Arlington Expressway and I-10 in the Jacksonville area.

3.2. Technical Approaches

Several technical strategies were considered in formulating approaches for LULC classification. These strategies include: (1) a good land use classification system, (2) the use of a supervised classification method, and (3) the integration of existing GIS data with remotely sensed data to enhance the classification results. Each of these strategies is briefly described below.

3.2.1. Land Use Classification System

Different LULC classification systems have been developed to facilitate the documentation of LULC information (Xiong et al, 2003). The USGS LULC classification by Anderson et al. (1976) is one of the systems that has been widely adopted in the remote sensing and GIS communities, because it was designed in consideration of the use of remotely sensed data. The Anderson classification is a hierarchical system (see Table 3.1). Usually only the top two levels of classification (i.e., level I and level II) are needed for a given application. The top classification (level I) consists of nine categories: 1-Urban or built-up land, 2-Agricultural land, 3-Rangeland, 4-Forest land, 5-Water, 6-Wetland, 7-Barren Land, 8-Tundra, and 9-Perennial snow or ice. Each category at the top level is further divided into subcategories (e.g., Urban or built-up land has seven subcategories, including: 11-Residential, 12-Commercial or services, 13-Industrial, 14-Transportation, communication, utilities, 16-Mixed urban or built-up land, and 17-Other urban or built-up land).

To facilitate LULC classification, the USGS LULC classification system was utilized. There are several reasons for this choice. First, the USGS classification system was particularly designed for use with the remotely sensed, which means classes identified by the USGS LULC classification are more likely discernable on remote sensing images. Second, this classification system is well recognized and accepted in the community of LULC studies. Also the classification system is generic enough so that LULC classes can be more flexibly adapted for different applications. By using the system, the classification results will not be restricted for specific application purposes. Notably, there are differences between USGS LULC classes and the land use classes required by RCI. Nevertheless, these differences can be bridged through a post-processing which allows the USGS LULC classes to be mapped to RCI land use classes.

Table 3.1. USGS Anderson Land Use/Land Cover (LCLU) classification system.

Level I	Level II
1 Urban or Built-up Land	11 Residential.
	12 Commercial and Services.
	13 Industrial.
	14 Transportation, Communications, and Utilities.
	15 Industrial and Commercial Complexes.
	16 Mixed Urban or Built-up Land.
	17 Other Urban or Built-up Land.
2 Agricultural Land	21 Cropland and Pasture.
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas.
	23 Confined Feeding Operations.
	24 Other Agricultural Land.
3 Rangeland	31 Herbaceous Rangeland.
	32 Shrub and Brush Rangeland.
	33 Mixed Rangeland.
4 Forest Land	41 Deciduous Forest Land.
	42 Evergreen Forest Land.
	43 Mixed Forest Land.
5 Water	51 Streams and Canals.
	52 Lakes.
	53 Reservoirs.
	54 Bays and Estuaries.
6 Wetland	61 Forested Wetland.
	62 Nonforested Wetland.

7 Barren Land	71	Dry Salt Flats.
	72	Beaches.
	73	Sandy Areas other than Beaches.
	74	Bare Exposed Rock.
	75	Strip Mines, Quarries, and Grave Pits.
	76	Transitional Areas.
	77	Mixed Barren Land.
8 Tundra	81	Shrub and Brush Tundra.
	82	Herbaceous Tundra.
	83	Bare Ground Tundra.
	84	Wet Tundra.
	85	Mixed Tundra.
9 Perennial Snow or Ice	91	Perennial Snowfields.
	92	Glaciers.

3.2.2. Supervised Classification Method

A supervised classification method was utilized for LULC classification in this project. The main idea of this method is that a computer program is first trained with known characteristics of various LULC classes and then the program will use these characteristics as a reference to automatically classify other samples in the area. The major advantage of this method is that known LULC classification in some areas can be utilized to derive LULC information in places where LULC classification is unknown. Image processing with a supervised classification method usually starts with the selection of training samples. After these training samples are selected, image characteristics, such as spectral intensity statistics, and shapes and patterns of given LULC classes, are extracted. The extracted image characteristics are also called image signatures because they uniquely identify different types of classes on the ground. By using these signatures, LULC classes can be identified throughout the entire study area.

A critical step in supervised classification is to identify training samples. Different approaches can be utilized for this identification process. Usually, samples can be quickly identified on an image through manual interpretation. That is, a human operation analyzes the study area and then picks out sample areas that can be assigned with specific classes. Sample identification can also use information provided by related maps or from ground truth data. In general, this is an iterative process, because selected samples may have the correct classes on the ground, but not necessarily representative. Therefore, trying classifications can be performed so that samples that are not representative or cause classification errors can be removed while good samples will be kept or introduced.

3.2.3. Use of Existing GIS Data

Information captured by imagery is usually limited by its spatial, temporal, spectral and radiometric resolutions. Also not all the information that is required for specific applications can be acquired from remote sensing. The use of existing GIS data can effectively address this kind of problem. In many cases, existing GIS data are a kind of "ground truth" and contains attributes that may come from sources other than remote sensing sources (e.g., the name of a river). More importantly, some of the existing data can be directly utilized in situations where ground characteristics can not be effectively identified with the imagery. For instance, it is usually difficult to differentiate between forestland and recreational park facilities. Park boundaries in a GIS layer can be referenced to determine whether a wooded area is classified as a park or as forestland.

Many types of GIS layers can be utilized to enhance LULC classifications or directly provide information for this purpose (e.g., transportation networks, hydrology, digital elevation models, population density, etc). For practical reasons, two existing GIS data layers were utilized to assist land use classification for this project: The USGS LULC Map and the Florida Land Cover Map.

The USGS LULC map was developed in the 1970's and early 1980's using NASA High-Altitude Photography (NHAP) and USGS 1:250,000 Topographic Base Maps. Although information contained in this map is somewhat outdated and it is a small scale map, the map can be a valuable reference when new LULC maps are generated. In general, regularity exists when LULC changes. For instance, the forestland in the fringe of a city is more likely to be converted into urban land. In contrast, the likelihood of conversion of built-up areas to agriculture land is small. Based on this type of regularity, a preference for classification can be prescribed when the LULC category on the USGS LULC map is known. That is, if a wetland is identified on the USGS map and forestland is identified for the corresponding area, the prescribed rule would classify this area as wetlands. Similarly, if a residential area is identified on the USGS map and a built-up urban category is identified on an image, then residential land use would be assigned to this area.

The Florida Land Cover Map was developed by the Florida Fish and Wildlife Cooperative Unit through the Florida GAP Project. Information for this map was derived from the classification of Landsat TM satellite imagery collected in May 2000, along with Florida water management district land use/land cover maps Videography ground truth information; third party ground truth information, National Wetlands Inventory (NWI); and soil conservation service soils maps. As the Florida Land Cover Map was developed with multi-date imagery, spectral differences due to seasonal changes improve the discerning ability of imagery for different types of vegetations. This map is particularly useful for the classification of vegetation-related land use/land cover types (e.g., deciduous versus evergreen, agriculture versus grass land, and forest versus wetlands), which was just utilized for that purpose in this project.

3.3. Technical Implementation

3.3.1. Data Preprocessing and Preparation

Three types of data were selected as input for the LULC task, which include:

(1) SpaceImaging's IKONOS imagery: four spectral bands at a four-meter resolution and one panchromatic band at one-meter resolution.
(2) The USGS 1:250,000 LULC Map
(3) The Florida GAP Land Cover Map.

When these data were gathered, each data set had different formats, different projection, and different spatial resolutions, which make the use of the data difficult. Format conversion and data preprocessing were conducted subsequently. Data format conversion was to bring all different types of data into a single uniformed format. In the present case, The ERDAS IMAGINE .img file format was used as standard format for land use classification therefore. All the input data were first converted into the IMAGINE format. For instance, IKONOS imagery came with a TIFF format, while USGS LULC map came with an ARC/INFO vector file.

After data are converted into the standard file formats, projection conversion is also necessary to reference these data in the same spatial coordinate system. As the imagery used the UTM coordinate system, all other data layers were also projected to the UTM coordinate. For IKONOS data, the panchromatic images and the multispectral images come in different resolutions. In this case, the image sharpening procedure in IMAGINE software were utilized to interpolate lower resolution multi-spectral imagery onto a panchromatic band of a higher resolution. This literally converted a 4 meter resolution image into a one-meter resolution image. The comparison for images before sharpening and after sharpening is illustrated in Figure 3.1 and Figure 3.2.

3.3.2. Supervised LULC Classification

The objective of LULC classification is to establish the LULC classes for the study area. After image sharpening, the IKONODS multi-spectral imagery represents a four-layer overlay with each layer representing a spectral band. The LULC classification was then based on the spectral intensity values of the four bands on each image pixel, which is a 1 X 1 meter square on the ground. In order to assign a LULC category for each of the pixels, the supervised classification procedure was utilized. Using this procedure, the computer program was first trained with selected LULC samples, and then image pixels were classified into different LULC categories using the supervised classification rules.

In the IMAGINE environment, a training sample is simply defined as a polygon that delineates an area that represents a unique LULC category. Once the area of a training sample is determined, the spectral value on each band of each pixel in this area is analyzed by the IMAGINE software to generate a set of statistics, such as the mean, median, deviation, maximum and minimum spectral values on each band for this sample.

Figure 3.1. Original 4 meter IKONOS spectral image.

Figure 3.2. IKONOS image sharpened to 1 meter resolution.

Sample statistics are also called signatures because we can instruct the computer software to utilize these signatures to identify the LULC classes or features they represent. Usually it takes an iterative process to get accurate signatures for a set of LULC classes. During this iterative process, training samples are first identified; then signatures are extracted and applied back to recognize the categories from which the signatures are extracted. The recognition results then are analyzed so that the training samples can be modified or purified. This process continues until the samples can be classified accurately by the extracted signatures. This whole process is called supervised training.

Depending on the decision rules, the methods used for supervised classification can be divided into two categories: parametric classification methods and non-parametric classification methods. The parametric classification methods use parametric signatures that are defined by mean vectors of spectral bands and the covariance matrix. The non-parametric classification methods are based on minimum and maximum values of the training sample, which determine whether given pixel values are within the defined signature boundary. Parametric classification methods operate in a continuous decision space, while non-parametric classification methods use finite decision boundaries. For this reason, parametric classification usually classifies all the pixels while non-parametric classification may leave the classes of some pixels unidentified due to overlapped decision boundaries or uncharted classification space.

In this study, the Maximum Likelihood method was used to implement the supervised classification. Maximum Likelihood is a parametric classification method that has the advantage of allowing complete classification of an image when proper samples are specified. The real strength of the Maximum Likelihood method lies in the mathematical principles used to derive the parameters of the mean vector and the covariance matrix. Theoretically, the parameters derived with Maximum Likelihood method maximize the probability of obtaining the samples as actually observed. By doing so, the best classification results can be achieved.

As six image scenes were used for this study and each was acquired in a different date, their spectral intensities are slightly different and cannot match exactly at the edges. For this reason, the LULC classification was conducted for each image separately, but the classification results were merged at the end. This process alleviated the problem of incompatible samples for different images, but for each image, separate class samples must be provided and independently applied.

3.3.3. Classification Post-Processing

The complexity of LULC on the ground makes it impossible to derive all the LULC types correctly from the imagery using the spectral information. For instance, the same vegetation can occur in the forest land or in the residential neighborhood, but the land use classes can be quite different. Also the same type of rooftop may be found for both commercial and industrial buildings and there is no way to differentiate whether these buildings should be classified as commercial or industrial land use by using the spectral information alone. The post-processing procedure was employed to resolve some of this

type of problems through the use of ancillary data: the USGS LULC map and the Florida Land Cover Map.

To make effective use of the USGS map, the project built a post-processing reasoning procedure which assumed that LULC conversions followed some generalized rules. For instance, the forestland in the study area is more likely to be converted into urban land. In contrast, the likelihood of conversion of built-up areas to agriculture land is small. Based upon these assumptions, a preference for classification was prescribed when the LULC category on the USGS LULC map was known. For instance, if a wetland was identified on the USGS map and forestland was identified for the corresponding area based on the ETM+ imagery's spectral characteristics, the prescribed rule classified this area as wetlands. Similarly, if a residential area was identified on the USGS map and a built-up urban category was identified on the imagery, residential land use would be assigned to this area.

Similarly, the Florida Land Cover map was utilized to refine the classification of LULC types. This refinement was mainly for LULC types that require more precise characterization of vegetation types or environment. For instance, when an area was identified as forest land, the Florida Land Cover map was then used to determine whether this area belongs to evergreen, deciduous, or mix forest land. By doing so, the updated imagery will exclude areas that were previously identified as forest land on the Florida Land Cover Map, but now used for other purposes (e.g., residential or commercial). At the same time, when the forest land in an area has not been converted into other land use types, its vegetation type more likely stays the same. Similar rules were applied to agriculture land and to wetlands.

3.4. LULC Classification Results

The LULC classification procedure generated a LULC map for the Jacksonville area that covered both the Arlington Expressway and I10 project sites. This map is illustrated in Figure 3.3. Table 3.2 provides the LULC categories contained in the map, which is a shortened list of the USGS LULC classes because some of the classes were not found in the project area (e.g., perennial snowfields).

Table 3.2. LULC categories identified for the project area.

1 Urban or Built-up Land	11 Residential.
	12 Commercial and Services.
	13 Industrial.
	14 Transportation, Communications, and Utilities.
	16 Mixed Urban or Built-up Land.
	17 Other Urban or Built-up Land.
2 Agricultural Land	21 Cropland and Pasture.
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas.

| | | 23 | Confined Feeding Operations. |
| | | 24 | Other Agricultural Land. |

| 3 | Rangeland | 31 | Herbaceous Rangeland. |

4	Forest Land	41	Deciduous Forest Land.
		42	Evergreen Forest Land.
		43	Mixed Forest Land.

5	Water	51	Streams and Canals.
		52	Lakes.
		50	Unclassified

| 6 | Wetland | 61 | Forested Wetland. |
| | | 62 | Nonforested Wetland. |

| 7 | Barren Land | 72 | Beaches. |
| | | 76 | Transitional Areas. |

The LULC map derived for this project using the USGS classification system has many potential applications, e.g., land use-transportation planning, transportation-related environmental analysis, or urban development analysis. Nevertheless, to meet the specific need of roadway characteristics inventory, the initial LULC categories must be re-classified into six RCI prevailing land use types:

1. Central Business District (CBD)
2. High Density Business/Commercial Center
3. Low Density Commercial
4. High Density Residential
5. Low Density Residential
6. Other

In order to do so, land use classes were processed with raster spatial data processing techniques, primarily with cell size re-sampling and the focal majority operator, to identify prevailing land use types using Arc/Info's Grid. The cell size re-sampling changed the resolution of the land use map to allow better identification of the prevailing land use types. The focal majority operator removed small changes of land use for a given neighborhood. It also removed the footprints of road networks so that a simple overlay of road centerlines and the land use map could be used to identify land use types for any given road segment. Figure 3.4 illustrates the prevailing RCI land use types as a result of this reclassification process.

The raster land use map was then converted into a vector map with polygons representing different types of land use. Intersecting the vector land use map with the road centerlines provides land use types for road segments. That is, through the vector map intersection, each road segment was then labeled with a land use type. Finally, a linear reference

algorithm was applied to generate the from-mile-post and the end-mile-post for each of the road segments. With this procedure, land use types obtained from a raster image were effectively registered to the road centerlines.
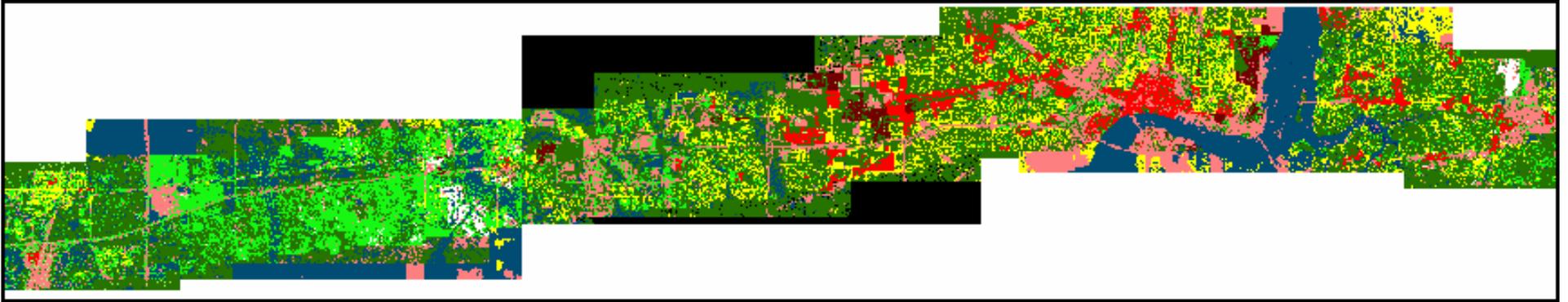
Figure 3.3. Land use/land cover map using the USGS LULC classification system.
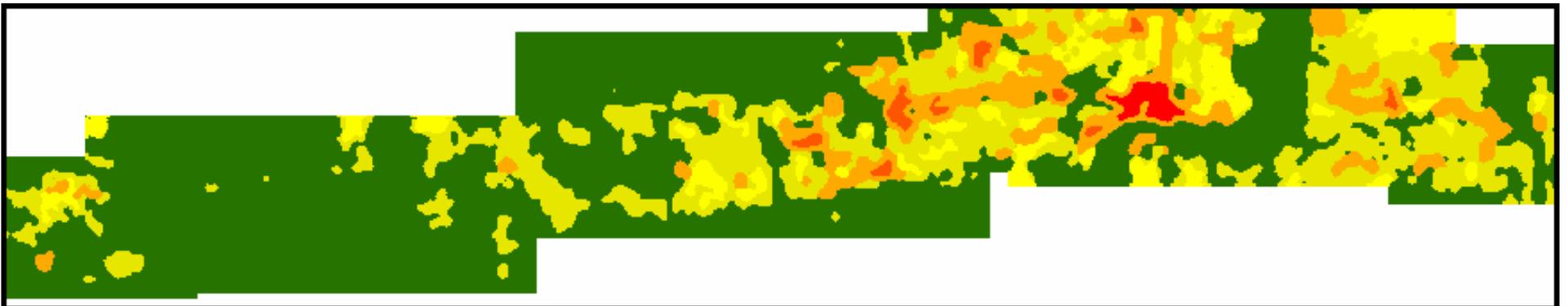

Figure 3.4. Land use map using the RCI land use categories.

4. Aerial Photography for Roadway Inventory

4.1. Background

The use of photographs for photographic interpretation from aerial platforms dated from 1858 when Gaspard Felix Tournachon took the first-known aerial photograph from a hot air balloon, while photogrammetric techniques started to be developed during the same period of time (Slama, 1980; Jensen, 2000). Aerial photography has been traditionally used by state DOTs as a major means for highway data collection, but with the rapid advancement of digital photogrammetry, the technology is not only used by photogrammetry professionals, but also by application specialists. In recent years, different types of airborne sensors have been demonstrated and implemented for many transportation applications, such as roadway inventory, environmental impact assessment, corridor planning, engineering design, and traffic flow monitoring and management.

The current project was particularly interested in how to practically utilize aerial photography to extract roadway features and characteristics, assuming other technologies, satellite imagery and vehicle-based mobile mapping system (MMS) are available. Based on the principles that each technology should be used to their best advantages, it was determined that the use of aerial photography for this project would focus on the extraction of planimetric highway features such as centerlines, traffic lanes, shoulders, medians, etc.

4.2. Technical Approaches

The project was intended to assess different types of aerial photography and different types of data extraction techniques. Both traditional analog cameras and a digital multispectral camera were planned for imagery acquisition. Although there is an advantage of using the images acquired directly from the digital camera, to meet project schedule constraints, a decision had to be made to focus on the imagery that acquired from analog cameras. From an application point of view, particularly from a data user's point of view, the differences between the use of digital cameras and the use of analog cameras are limited as long as the data are provided in a digital format, at the right price, and with the right quality.

To assess different types of data extraction techniques, the project focused on two different approaches for feature extraction: feature extraction in a 2D environment and feature extraction in a 3D environment. The key difference between 2D and 3D data extraction is the extracted results. Usually the coordinates for features extracted in a 2D environment are two-dimensional, e.g. forming the coordinate pairs of {x, y}, while the coordinates for features extracted in a 3D environment are three-dimensional, e.g. forming the coordinate triplets of {x, y, z}. Of course, we assume the existence of stereoscopic images for both cases.

4.2.1. 2D Feature Extraction

To correctly prepare images for 2D feature extraction, the processing procedures required is very much the same for 3D feature extraction. For images that acquired with analog cameras, an immediate follow-up procedure is to convert the hard copy photographs into digital images. (It must be noted that analog solutions such as the use of stereoscopic plotting instruments can provide similarly results or even better results for roadway feature extraction, but can be more labor-intensive or time-consuming, which will not be discussed in this report.) If the images are already in a digital form, then there is no need for analog-digital conversion.

The follow-up process falls into traditional photogrammetry procedures for image processing, but in a digital environment. That is, parameters of exterior orientation will be derived using aerial triangulation techniques. These parameters include the position of the exposure stations and the camera attitude or orientation when images were taken. Exterior orientation usually requires ground control, or airborne GIS/INS, or a combination of them. Subsequently stereoscopic models can be established using image pairs, and ortho-rectification can be conducted to remove image distortions caused by relief and the camera. An important property of ortho-rectified images is that they show the correct orthographic positions they contain, which means ortho-rectified images are equivalent to maps that represent true planimetirc locations of objects in the space (Wolf, 1983).

The advantage of using the ortho-rectified imagery for feature extraction is obvious. Images can be displayed the same way as other map layers. Extracted features will have correct planimetric positions and data extraction can be conducted using many existing GIS or image processing software packages. Usually no additional constraints will be imposed on computer hardware for the use of orthoimages. Nevertheless, ortho-images have some drawbacks. These images are not always the true "ortho" photographs. That is, in places where elevation changes drastically, the images cannot be correctly bridged to reflect those drastic elevation changes. Also when features are blocked by other features, bringing these features out with single rectified images is difficult.

4.2.1. 3D Feature Extraction

The ability to view and extract information in a 3D environment is ultimately attractive for roadway inventory. To some extent, the procedures required to process images for 3D feature extraction is no more difficult than the procedures for 2D feature extraction. When correct exterior orientation parameters are derived, the stereoscopic models can be subsequently established to allow 3D extraction. Nevertheless, in order to conduct 3D feature extraction, complete sensor model information must be provided, which includes: the sensor exterior orientation parameters for each image (position and orientation) and camera interior orientation parameters (focal length, distortion characteristics, and image coordinates).

Software components that are able to establish a stereoscopic model and conduct measurement and data extraction on this model are the key to 3D feature extraction. In that

case, various software tools have been made commercially available, such as ERDAS Stereo Analyst. In addition to the software, proper hardware components such as graphic cards or viewing devices are required to render stereoscopic images and facilitate stereoscopic viewing. To evaluate the 3D feature extraction solutions, image processing and data extraction procedures were implemented with HSA TransDat software. Some experiments were also conducted with the ERDAS Stereo Analyst.

4.3. Implementation

4.3.1. Data Acquisition

For project purposes, aerial photographs were obtained from three sites: I-10 near Jacksonville, Arlington Expressway in Jacksonville, and Magnolia Drive in Tallahassee.

For Arlington Expressway in Jacksonville, imagery was also provided by ACA in a similar arrangement. The files provided by ACA include:

♦ Scanned images. Scanned images were originally captured with an analog camera, but then were scanned at a 3-inch resolution and were put into a TIFF image file format.
♦ Ortho-rectified images. Image ortho-rectification procedures were followed to generate ortho-rectified images. There images were also provided in a TIFF image file format.
♦ Interior and exterior orientation information for the scanned images.
♦ Aerial triangulation and ground control files.
♦ Digital Elevation Model (DEM). A DEM was generated with the stereoscopic images and were provided in ArcInfo TIN format for the project use.

For I-10 near Jacksonville, Florida DOT had an existing project where high-resolution color aerial photographs were acquired by ACA. A set of files were then provided by ACA for the project use, which include:

♦ Scanned images. Scanned images were originally captured with an analog camera, but then were scanned at a 3-inch resolution and were put into a TIFF image file format.
♦ Geo-referenced images. The study area is flat and has very limited evaluation changes. Because of that, geo-rectified imagery was used as a replacement of the ortho-rectified imagery.
♦ Interior and exterior orientation information for scanned images.
♦ Aerial triangulation and ground control files.

For Magnolia Drive in Tallahassee, images were provided by FDOT's Survey and Mapping Office (SMO). Those images were acquired using its newly purchased digital camera. The images contain four spectral bands: red, green, blue, and near infrared. In addition to the original digital images, FDOT-SMO also provided ortho-rectified images and interior and exterior orientation information and ground control files for these images.

4.3.2. 2D Feature Extraction Implementation

The images provided for I-10 and Arlington Expressway were used for 2D feature extraction, particularly for planimetric features. For Arlington Expressway, in addition to the scanned unprocessed imagery, ortho-rectified images ware also provided. These images were already projected to Florida State Plane (East) coordinate system. Similarly, geo-referenced images for I-10 were provided for the project. As the project site on I-10 is flat, geo-referenced images have the necessary position accuracy for the planimetric extraction. These images were also projected to the State Plane.

The 2D feature extraction was implemented using ESRI's GIS ArcView software. Linear features such as guardrail, auxiliary lanes, and centerlines are extracted through head-on digitization. However, when their shapes are extracted, their attributes such as their length, starting milepost, and ending mile post were calculated automatically through a post-processing program (see Figure 4.1 for an illustration with the extraction of auxiliary lanes).
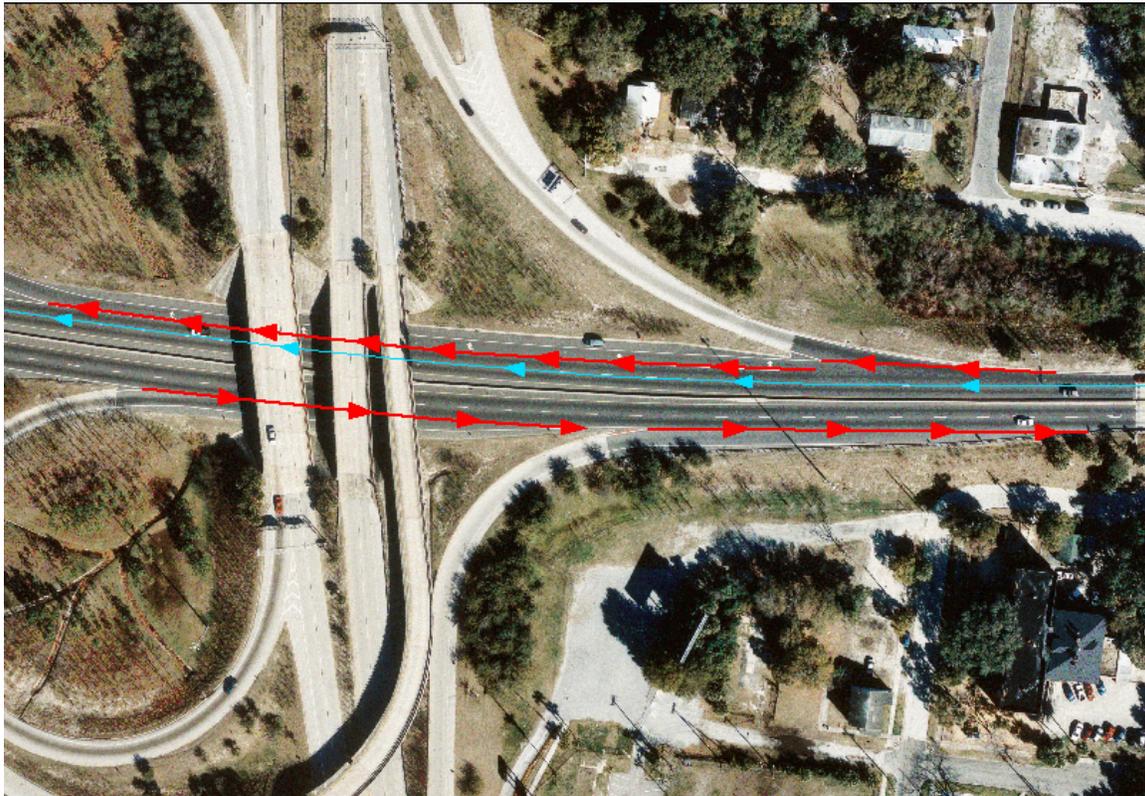
Figure 4.1. An illustration for extraction of auxiliary lanes (red line represents the extracted auxiliary lane, while the line of light blue shows the direction of the road in its linear referencing system).

Features such as shoulders and medians were digitized with a line segment representing the width of the shoulders or the medians at discrete locations (see Figure 4.2 for an illustration with the extraction of inside shoulders). Then post processing was applied to

pair these line segments to interpolate feature width for all other locations. This extraction process was straightforward, but it was also found that interactive extraction is a time consuming process. The follow-up post-processing, e.g., the automated calculation of the feature length, width, and width interpretation, did provide time saving for the extraction process. Still more improvements can be made to allow a more effective data extraction process such as higher level of automation in linear feature recognition or following, which, of course, will be a continued research topic in this area.
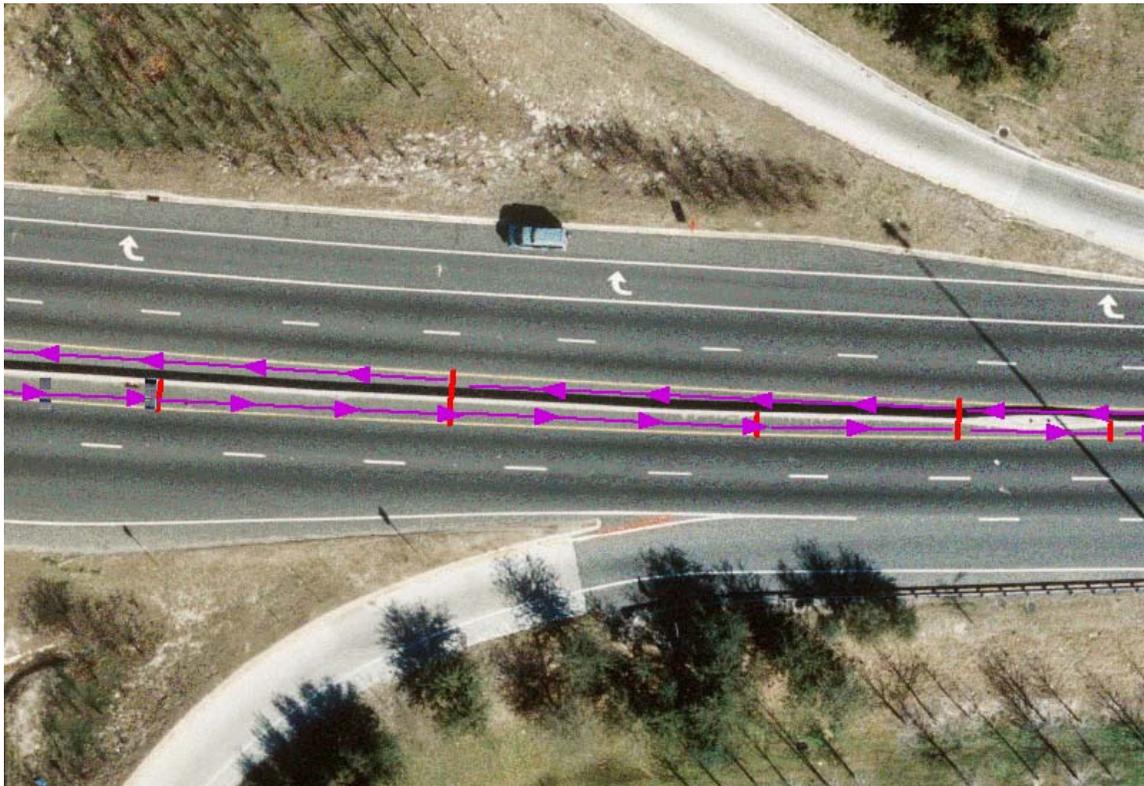
Figure 4.2. An illustration for extraction of inside shoulders (short red lines indicating extracted shoulder widths, arrowed purple lines represent the underlining procedures to interpolate the shoulder widths to locations that are between measured locations).

4.3.3. 3D Feature Extraction Implementation and Experiment

In order to support 3D feature extraction, the project also collected scanned unprocessed images along with exterior and interior orientation information as well as ground control points (GCPs). All this information can be directly utilized to establish image stereo-models for the study sites. Experiment was conducted using ERDAS Stereo Analyst at ORNL on 3D feature extraction. Most of the 3D extraction task was implemented by HSA using its 3D extraction software, TransDat, which is a customized software package for RCI data extraction.

For the ERDAS Stereo Analyst, as the exterior and interior information was provided external to the system. Significant effort was made to import this information to the

system. Although file transfer was assumedly possible for importing the exterior and interior orientation information, the required orientation data were eventually manually keyed in. Once the data were into the system, the software offered various functions for image manipulation, 3D viewing, and feature extraction in the 3D environment. The HSA implementation was a more smooth process. The images and camera model information were effectively imported to the TransDat software by HSA. HSA subsequently conducted the 3D feature extraction for sampled RCI features and attributes for all the study sites.

4.4. Extraction Results

The extracted features in 2D covered project sites along I-10 and Arlington Expressway in Jacksonville. The following layers were included in this extraction:

♦ Roadway centerlines
♦ Through lanes, auxiliary lanes
♦ Outside shoulders
♦ Highway median
♦ Inside shoulders
♦ Intersections
♦ Interchanges
♦ Structures
♦ Sidewalks

Some of the features required by RCI such as mile marker signs or traffic-monitoring sites are indiscernible on aerial imagery and were not extracted. Road name and type road were assigned to the roadway segments, but the actual information about the road names and type road was not extracted from imagery. It came directly from the FDOT base map.

When these features are extracted, they are represented with points and lines. Although all the features extracted from the imagery have their own spatial coordinates and can be mapped or displayed geographically, they are not yet referenced to or integrated with the roadway centerlines directly. Aligning the extracted features with the road centerlines was the key part of the data integration task. To align or integrate data for extracted features, road centerlines were utilized to establish a linear referencing system for each of the point or line feature layers. For point layers, the geographic coordinates of each feature point were used to calculate the exact mile point position of the feature on the referenced centerline. For line layers, the geographic coordinates of both the beginning and the end of the features were used to calculate their mile-point positions. The procedure was applied to all the layers that were extracted from aerial photos, which include: RCI Feature 212 – Through Lane; 213 – Auxiliary Lanes; 214 – Outside Shoulders; 215 – Highway Median; 216 – Bike Lanes and Sidewalks; 219 – Inside Shoulders; 251 – Intersections; 252 – Interchanges; 258 – Structures; and 271 – Guardrail.

The implementation with 3D feature extraction by HSA generated both 3D lines and points which were provided in an MS Access Database. These extractions covered all the project

areas. Nevertheless, because features extracted with in 2D met the project requirements and because features extracted in 3D were sparse and incomplete, the extraction results were not further processed.

5. Mobile Mapping

5.1. Background

The use of the Mobile Mapping Systems is a key component of the overall strategies to collect roadway information. MMS integrating digital sensors, Global Positioning Systems (GPS) and Inertial Navigation Systems (INS), particularly when mounted on vehicles, forms an ideal data collection platform for RCI. Image sensors, such as digital cameras, multi/hyper-spectral scanners, and Light Detecting and Ranging, are capable of providing various types of high-resolution and close-range imagery. These systems can also operate effectively under bridges, in urban canyons, and under dense tree coverage. Although each MMS has its unique advantages, the essential hardware configuration is about the same: a GPS receiver, an INS, imaging cameras, and a central processing unit. The most critical component for any of the MMS systems is the ability to effectively provide the six parameters for camera exterior orientation, which can be best achieved with a combination of a GPS receiver and an INS. The differential GPS can provide sub-meter accuracy to determine precise vehicle locations and locations of cameras in the 3D space. Nevertheless, blockage of GPS signals, when operated in rugged terrain, under bridges, in urban canyons, or in dense forest, make continuous measurement of vehicle trajectory extremely difficult. The use of inertial measurement unit (IMU) or INS can compensate the temporal blockage of the GPS signals and provide redundant information necessary for vehicle trajectory determination. IMU is able to sense angular velocity and acceleration of the vehicle movement, which when stamped with time, can provide accurate measurement of the orientation and position changes of the vehicle in the 3D space.

Today, many MMS are commercially available (e.g., TRANSMAP systems from TransMap Inc, GPSVision Mobile Mapping Systems by Lambda Tech International, Inc., and VISAT Mobile Mapping Systems by the Sanborn Map Company, Inc.). Commercial services may range from image data collection, to data extraction, to equipment rental, to assembly and delivery of the entire hardware and software system. For demonstration purposes, the current project took advantage of an existing commercial system, the GEOVAN by GEOSPAN Corporation. GEOSPAN using its GEOVAN and its desktop survey software supported both imaging data collection and major data extraction tasks for this project.

5.2. Technical Approach

Mobile Mapping is a relatively new technology. The key feature of the Mobile Mapping System (MMS) is that it couples Global Position Systems (GPS) and Inertial Measure Units (IMU), which make the acquired images suitable for accurate orientation and measurement. Using photogrammetric principles, spatial relationships found in the real world can be recovered in the image space. The potential of extracting roadway data such

signage, intersections, roadway conditions may be extensive because images acquired with MMS are in close range, and there are fewer obstructions compared with other data acquisition approaches.

Despite of the choices in commercial services for MMS, many of the MMS solutions are usually customized to make the data acquisition, processing, and extraction an integrated process, which is operationally efficient from the point of vendors, but can limit the choices of the users. The MMS imagery for the project was collected by GeoSpan, Inc. Although GeoSpan also provided all necessary data that can be utilized along with another software package, for efficiency concerns, it was also decided that the extraction for the roadway features was also performed by the company using its GEOVISTA 360º Visual Surveyor software.

The main idea of the MMS data extraction is similar to aerial photography, but utilizes a different vantage point of view. Once the imagery is spatially referenced, features in the imagery can be accurately located, measured, and extracted through triangulation by using two or more images that are obtained from different viewing angles. As many of the features and characteristics required for RCI can be extracted at different detail levels with MMS imagery, the extraction process proceeded with two phases. At the first phase, each of the roadway features as identified in the RCI Features and Characteristics Handbook was individually extracted. At the second phase, features were counted along the roadways to obtain an aggregate number. The two-phase approach provides some advantages for RCI data collection. It allows most detailed representations of the locations and attributes of the roadway features. At the same time, when verification and validation have to be done, extracted features and attributes can be checked individually to identify their accuracy, completeness or commissions and omissions.

5.3. Implementation

5.3.1. Image Acquisition

The image data were collected with the GEOVAN MMS that uses cameras to collect images from eight different angles. The system uses a high grade INS, (e.g., the ring laser gyroscopes) to provide information on camera orientation and a dual frequency GPS receiver for update of the camera positions. The combined use of the INS and GPS system makes it possible to provide accurate georeferencing of the images acquired. With the INS/GPS on board, each of the images is provided with the six parameters of exterior orientation which include latitude, longitude, and altitude of the camera position, and roll, pitch, and yaw of the camera orientation. In addition, interior orientation information is also provided for each camera. This information includes the focus length, the number of rows and columns of an image, the size of a pixel, coordinates of the principle point, and lens distortion information. Both real-time and post differential corrections are utilized to achieve high precision for vehicle positioning. During the post processing phase, real-time corrections are replaced with base station GPS corrections. As a result, points surveyed within 100 feet can achieve an accuracy of one meter 95 percent of the time and a tenth of a degree of accuracy can be achieved for camera orientation.

The MMS data collection covered all the road sections selected for the project, which include:

♦ I-10 near Jacksonville
♦ Arlington Expressway in Jacksonville
♦ US-90 near Tallahassee
♦ Magnolia Drive in Tallahassee.

The image data were collected with following specifications:

♦ Images to be collected for each-traffic direction for the selected sections
♦ Multiple cameras to be used to capture overlapping 360° views of the roadway
♦ Images to be captured sequentially from each camera to provide a complete set of images within every 20 feet
♦ Images to have a resolution that would enable visual identification of road signs, speed limit, direction information, etc.
♦ Image data collected from the field to be post-processed to ensure positional accuracy.

To ensure the compatibility of the delivered data, the project also specified the data formats and data contents for the delivery:

♦ Each image to be in a separate file using a standard image format, either in TIFF or JPEG. If compressed, lossless compression or compression with information loss rate less than 95 percent is used.
♦ A separate text file to be used to provide following information:

   (1) For each camera used, provide the internal orientation and calibration information, e.g., camera identification, focal length, principal point coordinates, etc.
   (2) For each image, provide exposure position and exterior orientation information.

5.3.2. Information Extraction

Once images were acquired along with information of exterior and interior orientations, these images will be ready for information extraction. The list of features that can be measured and attributed from MMS images is almost endless. It is possible to extract almost all the objects that can be found on the MMS images. Given the fact that planemetric features such as road centerlines, road shoulders, and side walks, or land use were to be extracted from aerial photography, the extraction task from MMS imagery focused on following features:

♦ All traffic signs
♦ Milemarkers
♦ Traffic signal type and location
♦ Guardrail type and location

♦ Turn Lanes Left
♦ Turn Lanes Right

As images and exterior and interior orientation data were all provided in open file formats (images are in JPEG and exterior and interior orientations are in ASCII and in MS ACCESS database), any of the photogrammetry software packages can be used to facilitate the extraction of the information from the acquired images. The actual extraction task was performed by GEOSPAN for this project. For illustration purposes, the procedure of using GEOSPAN's GeoVista software to information extraction is described below.

Critical to any of the information extraction functions are the browsing and viewing functions for collected images. The GEOSPSN Software provides several such functions, e.g.:

(1) Select and view images acquired from up to four cameras simultaneously.
(2) Identify a location to view a image or images.
(3) Step forward and backward along vehicle navigation tracks.

In addition, vehicle navigation tracks can be overlaid with aerial photographs to provide overhead views of the navigation environment that can provide additional clues or information to identify features for extraction.

The procedure of extracting feature locations is straight forward. By selecting two or more than two images that contain the same feature, the exact location of the feature can be calculated using photogrammetric principles. This is done with an interactive process in GEOSPAN software. As shown in Figure 5.1, when the traffic sign is identified in one of the images, an additional image that contains the same traffic sign is brought up. By clicking on the same location where the traffic sign is to be positioned on both of these images, the coordinates of the clicked location will be calculated automatically. Additional refinement of the surveyed location is possible through adding additional images, or by adjusting the clicked location. At this point, the user will also be informed of the estimated accuracy of the measured position, and will be provided the opportunity to input the attributes, e.g., identify the type of the surveyed object.

The extracted results can also be overlaid with overhead imagery for immediate validation and verification as shown Figure 5.2.

(a)

(b)

Figure 5.1. Illustration of traffic sign extraction.
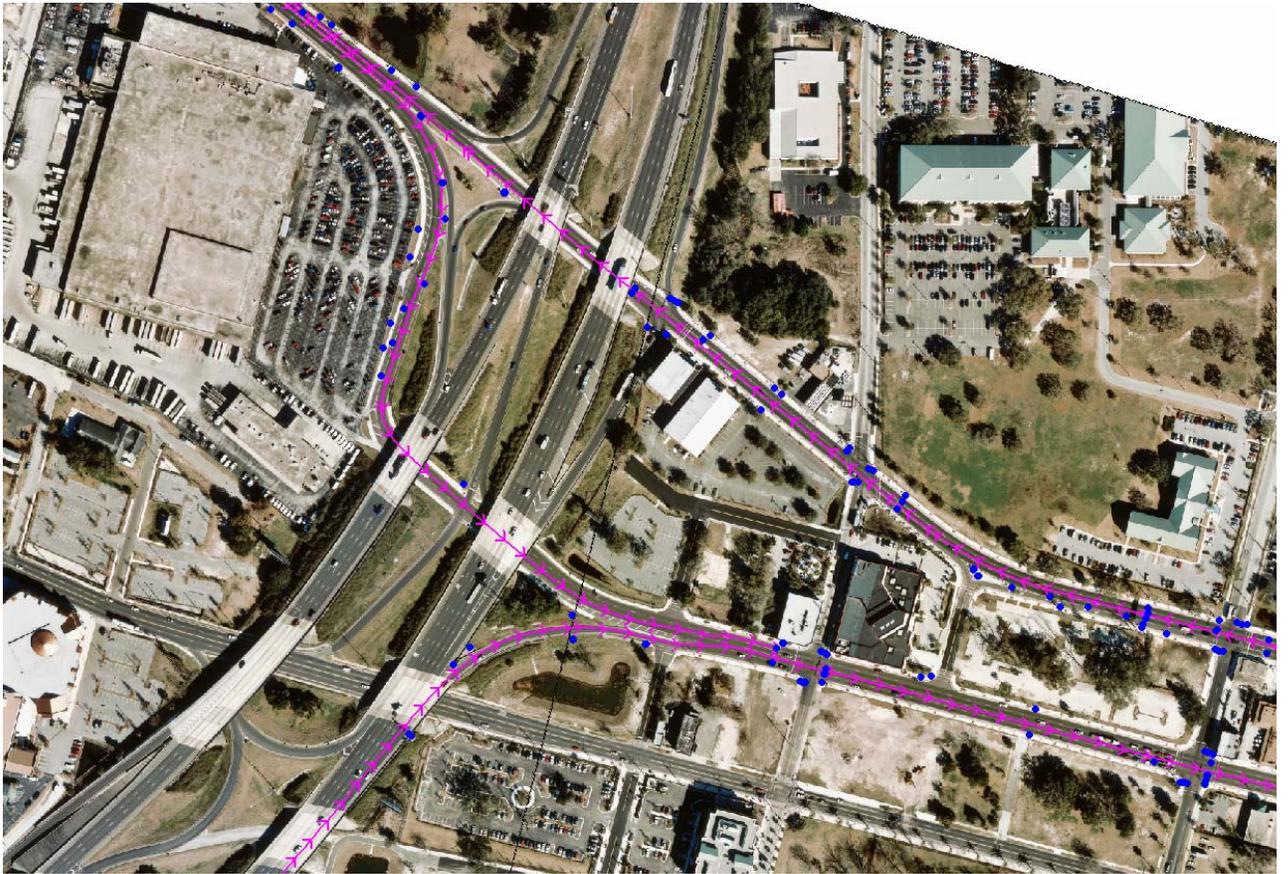
Figure 5.2. Illustration of extracted feature locations mapped to aerial imagery.

5.4. Extraction Results

The extracted features were provided both in an MS Access database and in a shapefile format. The deliverables include both the signage point file and the aggregated signage account. For the signage point file, each sign is recorded and identified separately. The aggregated signage layer provides the aggregated counting of features along each roadway segment. After the signage layer was generated, each feature was subsequently associated to a roadway segment, and then referenced to the road network through the linear referencing system established for the Florida roadway networks.

To notice that auxiliary lanes were also extracted from the mobile mapping imagery, mainly based on the painted marks on the pavement and represented with points. Because data for auxiliary lanes were also extracted from aerial photographs, data extracted for auxiliary lanes from mobile mapping imagery were dropped from the data integration process with the consideration that extraction of auxiliary lanes from aerial photographs may represent a more effective process. To integrate the sign features with the road centerlines, the geographic coordinates of the sign features were utilized to calculate their mile point positions along the road centerlines, which is a similar process to linear referencing for point features extracted from aerial photographs.

6. Data Validation and Verification

A major advantage of the remotely sensed data is that these data are provided in a graphical format and can be easily interpreted visually. Usually what you see is what you get. Given the multi-platform approaches, features on the ground are captured multiple times from different points of views, with different resolutions, and from different sensors. The chances for errors are low. Nevertheless, field data collection was conducted to acquire ground truth data to verify and validate the spatial and attribute accuracy of the extracted data. That is, data acquired from field surveys for selected features were compared with the corresponding data that were obtained from imagery to provide a reality check. In terms of data verification and validation, the project mainly focused on location and attribute accuracy for data extracted from aerial photography and mobile mapping imagery. As land use classification with satellite imagery was already correlated with land use maps from USGS and from the land use map of the Geographic Analysis Program (GAP), the classification accuracy far exceed the requirements for RCI purposes. This is the same for its positional accuracy as RCI mainly concerns with prevailing land use types.

6.1. Positional Accuracy for Aerial Photography

Aerial photographs used for feature and attribute extraction were provided by ACA. These photographs were taken at a 3600 ft height and had been ortho-rectified or geo-rectified before delivered. The images for Arlington Expressway were ortho-rectified because of some elevation changes found in the study area. While for I-10, the flat terrain allowed the omission of the ortho-rectification procedure, but images are geo-referenced. Based on the aerial triangulation reports, the root mean square error of residuals at the control points for Arlington Expressway in the x direction is 0.167 ft, in the y-direction 0.140 ft, and in the z-direction 0.047 ft; the root mean square error of residuals at the control points for I-10 in the x direction is 0.106 ft, in the y-direction 0.097 ft, and in the z-direction 0.095 ft.

The positional accuracy for aerial photographs obtained for this project is consistent with previous FDOT's findings. For instance, Transportation Statistics Office along with Marlin Engineering, Weidener Surveying and Mapping, P.A., and HSA Consulting Group conducted a study on the accuracy of the use of aerial photography for RCI data collection. In this study, it was found that the position accuracy from aerial photography far exceeds that required by planning roadway inventory data. Based on the study, 100 percent of the points collected were within 4.2 inches in the horizontal direction while 97.6 percent with in 4 inches and 73.l3 percent within 2 inches. Actually, FDOT's District Three Planning Office has been collecting all RCI field features by aerial remote sensing (aerial photography and photogrammetry), which uses a specification that requires that the maximum RMSE be 12 centimeters (4.72 inches) in each of the horizontal x and y dimensions, and a maximum RMSE of 15 centimeters (5.91 inches) in the vertical z dimension (Jones, 2003, email message). Observations from this project

and previous studies allow us to conclude that the positional accuracy from given aerial photography is sufficient for RCI planning features and characteristics.

6.2. Positional Accuracy for Features Extracted from MMS Images

Both field surveys and in-house observations were made to check the accuracy of the positional accuracy for features extracted from MMS imagery. To assure the fairness and efficiency of the data quality assessment, features identified from imagery were randomly selected through a random selection program. The randomly selected features were then surveyed in the field. Data validation and verification took place in two phases: in-house validation and verification and field validation and verification. Each of two phases is described below.

6.2.1. Field Validation and Verification

Field surveys were conducted for the project by Marlin Engineering. The effort was organized separately between sites in Jacksonville and the sites in Tallahassee. Table 6.1 provided the information about the field surveys for Jacksonville. Table 6.2 provides the comparison of the coordinates derived from the signage inventory and coordinates measured in the field with GPS.

Table 6.1. Information on field surveys for Jacksonville I-10 and Arlington Expressway.

Information Items	Values
Data Collector(s)	Marlin Engineering Personnel
Data Collection Equipment	Measurement Wheel, Measurement, Tape, GPS (WAAS)
Mode of Travel	Truck and Walking
Expected Level of Accuracy (Measurement Tape)	1 inch
Expected Level of Accuracy (Wheel)	0.5 to 1.0 feet
Expected Level of Accuracy (GPS)	1-3 meters
Date	10/08/2004 to 10/09/2004
Coordinate Datum	NAD 83
Coordinate Projection	Transverse Mercator

As shown in Table 6.2, 90 percent of the coordinates are within 10 feet when these coordinates are checked against each other. In-house validation as reported later indicates that several outliers identified in the table are due to external errors (e.g., ID mismatches or differences in measured locations). Given accuracy of GPS surveys (1-3 meters), this table shows a reason correspondence between signage locations and their corresponding locations determined by GPS surveys.

Table 6.2. Comparison of coordinates derived from the signage inventory and coordinates measured in the field with GPS (measurement unit: feet).

FID	X_GPS	Y_GPS	ID_MAP	X_MAP	Y_MAP	DX	DY
0	445126.12	2182301.00	1498	445127.24711	2182300.90918	-1.13	0.09
1	445283.51	2182286.25	22	445283.04043	2182290.89803	0.47	-4.65
2	445663.33	2182229.23	19	445668.25488	2182237.34700	-4.92	-8.12
3	446484.88	2182013.37	1286	446482.47507	2182011.43136	2.40	1.94
4	446852.31	2181924.72	838	446861.16742	2181920.83308	-8.86	3.89
5	447581.16	2181740.82	839	447572.43759	2181729.73354	8.72	11.09
6	449559.02	2181222.89	1021	449556.34323	2181250.85916	2.68	-27.97
10	453998.93	2179733.58	1297	453996.28663	2179731.75511	2.64	1.82
11	454659.63	2179558.83	60	454662.50227	2179538.14326	-2.87	20.69
14	455093.62	2179474.19	1626	455091.54364	2179472.08194	2.08	2.11
15	455246.82	2179438.51	1192	455244.36867	2179436.67163	2.45	1.84
16	455470.06	2179429.60	786	455472.08660	2179421.93708	-2.03	7.66
17	464426.72	2179420.42	1125	464424.38815	2179413.96658	2.33	6.45
18	464777.97	2179416.51	855	464770.96316	2179440.84469	7.01	-24.33
19	464855.65	2179418.36	1676	464852.88287	2179419.67558	2.77	-1.32
21	466112.28	2179414.80	1748	466107.60934	2179408.26389	4.67	6.54
22	466441.08	2179442.90	883	466437.80177	2179439.97325	3.28	2.93
24	475368.25	2179464.33	1057	475366.53105	2179464.68722	1.72	-0.36
25	476602.18	2179255.60	1459	476567.59828	2179387.35550	34.58	-131.76
26	478977.44	2178178.48	50	478976.86109	2178184.22341	0.58	-5.74
27	480201.94	2177503.76	1310	480204.96011	2177498.40718	-3.02	5.35
28	480661.51	2177417.74	1292	480695.56230	2177426.16876	-34.05	-8.43
30	482104.08	2177215.81	1366	482104.57396	2177206.16226	-0.49	9.65
31	480284.43	2177636.03	1377	480287.36324	2177637.30024	-2.93	-1.27
32	479933.79	2177785.91	988	479938.17587	2177785.22549	-4.39	0.68
34	478591.09	2178520.60	256	478600.48235	2178509.41970	-9.39	11.18
36	478141.83	2178733.94	1480	478147.87010	2178730.61642	-6.04	3.32
37	470547.80	2179554.99	211	470547.88967	2179549.72327	-0.09	5.27
38	469812.33	2179541.41	528	469815.57205	2179545.52648	-3.24	-4.12
39	469468.67	2179546.71	713	469472.88560	2179537.12829	-4.22	9.58
40	467362.43	2179523.99	53	467357.10845	2179542.40578	5.32	-18.42
41	467325.79	2179535.50	1169	467327.37465	2179528.01442	-1.58	7.49

Similar GPS surveys were conducted for Tallahassee. Table 6.3 provides details. Noticeably the GPS receiver used for these surveys has higher position accuracy, 5-10 centimeters. However the field surveys for Tallahassee sites were conducted without directly knowing corresponding features extracted from the signage inventory. For this reason, points surveyed in the field were manually examined to match both the locations and the types of signage for features that are extracted from the imagery. The field GPS points for Tallahassee area were provided in the state plane coordinates or coordinates projected to Lambert Conformal projection in the unit of feet. Similarly, the coordinates for the extracted features were projected to the same projection, and then their coordinates were compared in both directions (x direction and y direction). The differences between GPS surveys and image extraction are shown in Table 6.4. It is observed that positions obtained with GPS surveys and image extraction show more consistency for the Tallahassee area than the Jacksonville area. This is largely due to the use of a higher precision GPS receiver for the Tallahassee sites.

Table 6.3. Information on field surveys for Magnolia Drive in Tallahassee and US 90 near Tallassee.

Information Items	Values
Data Collector(s)	Marlin Engineering Personnel
Data Collection Equipment	Measurement Wheel, Measurement, Tape, GPS (RTK)
Mode of Travel	Truck and Walking
Expected Level of Accuracy (Measurement Tape)	1 inch
Expected Level of Accuracy (Wheel)	0.5 to 1.0 feet
Expected Level of Accuracy (GPS)	5-10 cm
Date	08/30/2004 to 09/03/2004
Coordinate Datum	NAD 83
Coordinate Projection	Lambert Conformal

6.2.2. In-House Validation and Verification

The use of field GPS surveys to validate positional accuracy for features extracted from signage inventory provided one type of check to the signage features, but due to potential GPS errors in urban and wooded environments, additional validation from another source would be helpful. Observations were made to check the consistency between the locations of features extracted from MMS imagery and their corresponding locations on the aerial photography. Visual checking revealed close correlation between locations from the two types of images. Those signage points checked with GPS along Arlington Expressway were re-examined in house on the aerial photographs and on imagery from MMS. Those points that could be positively identified on MMS images and on aerial photographs were listed in Table 6.5.

Table 6.4. Comparison of locations determined by GPS surveys and image extraction (measurement unit: feet).

ID	X_GPS	Y_GPS	SIGNID	X_MAP	Y_MAP	DX	DY
32	2043194.09	526884.51	398	2043198.27576	526873.50974	-4.19	11.00
58	2043562.68	525999.85	1266	2043567.23647	525984.66954	-4.56	15.18
59	2043522.17	525973.23	1289	2043522.52026	525970.02816	-0.35	3.20
88	2043457.51	526009.52	606	2043456.59025	526003.71460	0.92	5.81
130	2043343.68	528601.90	1307	2043345.02230	528582.84100	-1.34	19.06
131	2043522.16	524196.96	1042	2043516.15350	524189.70691	6.01	7.25
154	2043523.85	522493.07	327	2043522.54583	522486.51847	1.30	6.55
156	2043527.05	522292.68	194	2043525.80134	522285.76362	1.25	6.92
175	2043575.29	523150.03	932	2043576.64695	523139.83441	-1.36	10.20
186	2043575.05	523731.00	95	2043574.16975	523722.11115	0.88	8.89
193	2043574.23	524468.38	1593	2043574.19896	524462.23877	0.03	6.14
206	2043611.62	522115.02	1375	2043615.36873	522104.10145	-3.75	10.92
210	2043541.46	521989.50	318	2043539.98621	521982.46862	1.47	7.03
212	2043540.25	521747.15	876	2043539.54660	521740.24449	0.70	6.91
215	2043542.55	521080.60	1088	2043542.50930	521076.13738	0.04	4.46
222	2037955.77	516461.18	1365	2037956.68656	516461.94825	-0.92	-0.77
225	2039870.00	516486.25	1389	2039869.59179	516488.60914	0.41	-2.36
231	2043304.83	526791.87	1203	2043309.08955	526772.63180	-4.26	19.24
235	2043238.52	527047.82	473	2043240.18107	527027.07817	-1.66	20.74
259	2074814.94	539707.13	1570	2074818.87285	539702.74414	-3.93	4.39
260	2075302.20	539910.79	313	2075306.19887	539907.13673	-4.00	3.65
263	2074963.39	539902.82	1611	2074963.80933	539902.84679	-0.42	-0.03
264	2071167.80	538183.34	77	2071171.43993	538180.21703	-3.64	3.12
265	2071083.98	538193.06	1631	2071081.92831	538197.05531	2.05	-4.00
267	2069024.05	537341.64	217	2069024.45859	537341.26393	-0.41	0.38
268	2068544.01	537146.17	951	2068543.33520	537146.79438	0.67	-0.62
269	2068367.57	536983.67	962	2068371.17104	536978.64827	-3.60	5.02

Table 6.5. Comparison of locations determined by aerial photography and MMS extraction (measurement unit: feet).

ID	X_IMAGE	Y_IMAGE	X_MMS	Y_MMS	DX	DY	Comments
1	482104.89882	2177209.31614	482104.57396	2177206.16226	-0.3249	-3.1539	
3	480665.99112	2177407.52130	480695.56230	2177426.16876	29.5712	18.6475	Mismatched ID
4	480208.07834	2177499.00062	480204.96011	2177498.40718	-3.1182	-0.5934	
5	479934.98555	2177788.94002	479938.17587	2177785.22549	3.1903	-3.7145	
6	478598.39114	2178511.26307	478600.48235	2178509.41970	2.0912	-1.8434	
8	478145.20022	2178733.14951	478147.87010	2178730.61642	2.6699	-2.5331	
9	476605.36973	2179250.79724	476567.59828	2179387.35550	-37.7715	136.5583	Mismatched ID
10	475369.84858	2179464.98901	475366.53105	2179464.68722	-3.3175	-0.3018	
11	470548.65251	2179550.70862	470547.88967	2179549.72327	-0.7628	-0.9854	
12	469815.78195	2179546.27434	469815.57205	2179545.52648	-0.2099	-0.7479	
13	467356.45897	2179543.04824	467357.10845	2179542.40578	0.6495	-0.6425	
14	466109.45484	2179410.96687	466107.60934	2179408.26389	-1.8455	-2.7030	
15	464859.40490	2179419.69619	464852.88287	2179419.67558	-6.5220	-0.0206	
16	464777.21886	2179413.08178	464770.96316	2179440.84469	-6.2557	27.7629	Positioing differently
17	464428.49831	2179418.25944	464424.38815	2179413.96658	-4.1102	-4.2929	
18	455476.45894	2179422.82908	455472.08660	2179421.93708	-4.3723	-0.8920	
19	455248.22885	2179438.42486	455244.36867	2179436.67163	-3.8602	-1.7532	
20	455095.31985	2179472.40366	455091.54364	2179472.08194	-3.7762	-0.3217	
22	453999.51274	2179731.36324	453996.28663	2179731.75511	-3.2261	0.3919	
23	445286.36945	2182291.31423	445283.04043	2182290.89803	-3.3290	-0.4162	
24	445128.21182	2182303.12870	445127.24711	2182300.90918	-0.9647	-2.2195	

As indicated in Table 6.5, in most cases, differences between coordinates extracted from aerial photographs and MMS images in the x and y directions are less than 7 feet. For the three points where differences are larger than 10 feet, two were due to mismatched ID and one was caused by differences in measured locations. Each should be considered as a human error. If these three points are dropped and the locations measured with the aerial photographs are assumed correct, the RMSE for those locations extracted from MMS is 3.23 feet or 0.98 meter in the x direction and 2.04 feet or 0.62 meter in the y direction.

6.3. Attribute Validation and Verification

Field surveys conducted for I-10 and Arlington Expressway in Jacksonville and for Magnolia Drive and US 90 in Tallahassee all are useful to validate the attribute information that was extracted from imagery. Attribute validation was implicit for sign inventory acquired from MMS because the types of signs must be first matched correctly before their positions were validated. A separate field trip was made to validate the attribute accuracy of features extracted from aerial photographs. Detailed information about this effort is provided in Table 6.6. The field survey information was matched with the information extracted from the imagery to identify correspondences or discrepancies. Table 6.7 shows a comparison of through lane information obtained in the field and derived from aerial photography.

Table 6.6. Information on field surveys for Jacksonville I-10 and Arlington Expressway.

Information Items	Values
Data Collector(s)	Marlin Engineering Personnel
Data Collection Equipment	Measurement Wheel, Measurement, and Tape
Mode of Travel	Truck and Walking
Expected Level of Accuracy (Measurement Tape)	1 inch
Expected Level of Accuracy (Wheel)	0.5 to 1.0 feet
Expected Level of Accuracy (GPS)	N/A
Date	10/22/2004
Coordinate Datum	N/A
Coordinate Projection	A/A

As shown in Table 6.7, the numbers of lanes obtained from imagery and from the field are mostly consistent. When we checked the places where attributes are recorded differently, these differences are artificial instead. For instance, in the case for ID1_MAP 26, as shown in Figure 6.1, when we look at the traffic lanes in the down stream, two through lanes can be counted for the pointed location (blue dot). In contrast, if we look at the traffic lanes in the upper stream, three through lanes can be counted for the pointed location. As the in-house lane counting and the field lane counting were performed

independently, different judgment calls resulted in different counts. However, this should not be considered a problem of the use of a specific type of technology.

Table 6.7. Comparison of the number of through lanes (NoLanes_Field: number of lanes observed in the field; NoLanes_MAP: number of lanes observed on imagery).

ID_FIELD	ID1_MAP	ID2_MAP	NoLanes_Field	NoLanes_MAP	Difference
64	37	6	2	2	N
137	28	27	3	2	Y
20	23	18	2	2	N
19	38	7	2	2	N
18	22	5	2	2	N
65	5	22	1	1	N
134	36	2	2	2	N
135	26	25	3	2	Y
21	39	20	2	2	N
136	27	26	3	3	N

Figure 6.1 Illustration of the count of the through lane.

Field surveys were also conducted for auxiliary lanes. The comparison between the field data and image-based extraction illustrated that the number of lanes shown for the field surveys (LAN_F) is consistent with the number of lanes shown for the image-based extraction, see Table 6.8. Nevertheless, it also reveals that there are differences between field results and results from imagery on the coding of the turning types. A double check with the imagery confirmed that the results from imagery were correctly coded.

Table 6.8. Check of auxiliary lanes (CODE_F: RCI Code from the field; LAN_F: number of lanes counted in the field; CODE_M: RCI Code from images; LAN_M: number of lanes counted with images; DCODE: Code difference between the field and in-house; DLAN: difference of lane numbers)

ID_FLD	ID2_M	CODE_F	LAN_F	CODE_M	LAN_M	DCODE	DLAN
5	23	7	1	7	1	N	N
90	110	4	1	7	1	Y	N
6	24	3	1	4	1	Y	N
113	91	4	1	4	1	N	N
114	92	3	1	3	1	N	N
7	66	3	1	4	1	Y	N
88	82	3	1	4	1	Y	N
157	10	4	1	7	1	Y	N
158	14	3	1	7	1	Y	N
2	15	4	1	4	1	N	N
3	16	3	2	3	2	N	N
89	83	3	1	4	1	Y	N
112	88	4	1	3	1	Y	N
111	7	3	1	3	1	N	N
4	17	7	1	7	1	N	N

Measurements were also made in field surveys to compare the measurements made on images. In general, these measurements are consistent on images and in the field, see Table 6.9. Discrepancies mainly arise from different measurement locations or human errors. For instance, as shown in Figure 6.2, the blue line was the line where the median width was measured on the image, but this line can not be measured in the field because of dense bushes and trees. Instead, the median width had to be measured along the red line in the field, producing a length of 111 feet (the corresponding length on the image is 111 feet). When the width of 111 feet is used to compare the width measured along the blue line, as shown in Table 6.9, the reported difference between the two measurements is 3 feet because the width along the blue line is 114 feet, but such a difference is superficial.

Several lessons were learned from the experience of field surveys. First, GPS surveys can provide useful information for image data validation and verification. However, it is generally difficult to establish precise identities for features measured in the field. Instead, additional information such as the types of the features or some other descriptive

information about the features will be necessary in order to tie the feature to the real world. This is different from features that are extracted from imagery. In the imagery case, extracted features can always be re-projected to images so that not only the information about features themselves, but also the contextual information (e.g., the surrounding environment) can be utilized to tie the extracted features to the real world. The inability to effectively establish identities of the measured features in the field may reduce the reliability of the use of GPS surveys for validation and verification.

Table 6.9. Comparison of median widths between image measurements and filed surveys (measurement unit: feet).

ID_Median	Width_Field	Width_Image	Diff
34	74	75	1
97	128	133	5
98	117	119	2
19	20	24	4
20	36	34	-2
21	45	44	-1
107	216	201	-15
111	32	30	-2
132	14	14	0
11	111	114	3
93	64	64	0

Second, safety is another major concern for field data collection. To position features in the field, and acquire attributes for them, field personnel constantly need to stay or walk along or across a road, which can be a major safety hazard. In some cases, the field crew has to stop the traffic in order to get precise measures such as lane width or shoulder width. Environmental (e.g., weather) conditions are other safety factors that need to be accounted for during the process of field data collection. For instance, the occurrence of the recent hurricanes in Florida had impacts on the scheduling of the field data collection.

Third, cost and data quality are still important factors when GPS field surveys are considered. Perhaps, GPS can be used to survey sparsely locations, but collecting accurate GPS position data for a large number of features in the field, especially for roadway features of high density, can be very expensive. The field survey experience also confirms that the quality of GPS data is not necessarily consistent. It can be highly accurate in some locations, but not accurate or totally unavailable in other locations. Also it is difficult to replicate the same survey results using GPS when environmental conditions change. After all, GPS field surveys can be a useful alternative and can provide direct location references for features collected from the field, but the number of features, the type of characteristics, and the locations to be surveyed must be planned carefully in order to assure quality, efficiency, and safety.

Figure 6.2. Illustration of differences in measurement positions.

7. Conclusions and Recommendations

The combined use of commercial remote sensing technologies of satellite remote sensing, aerial photography, and vehicle-based mobile mapping system offers an appealing solution to transportation data acquisition. The effectiveness and advantages of an integrated approach are obvious. Most importantly, different technologies can be utilized to their best advantages:

(1) Satellite images, when combined with existing GIS layers, can provide valuable land use information that will meet purposes not only for RCI, but potentially for transportation planning, land use studies, and for transportation-related environmental assessment. With their multispectral bands and large geographic coverage, satellite images can be utilized more frequently and cost-effectively for transportation corridors to support short term and long term planning applications.

(2) Aerial photographs prove to be important data sources for both data extraction and for location referencing. Features such as traffic lanes, bridges, guardrail, and so on are best extracted from aerial photographs and these features can be extracted either in a 2D or in a 3D environment. In addition, because of the maturity of the technology, especially photogrammetry, aerial photographs can be reliably utilized to provide spatial referencing and to validate positional accuracies for images from other data sources.

(3) The Vehicle-based Mobile Mapping System (MMS) proves to be an effective technology for sign inventory and are suitable for the extraction of many other types of roadway features and characteristics. Features such as signs or traffic signals that are usually represented as points on a map are difficult to identify from overhead imagery. But these features can be very effectively captured using MMS. In-house and field observations indicated that MMS can achieve good positional accuracy to meet planning and maintenance feature extraction. Positions identified with MMS imagery are highly consistent with those identified on aerial photography. Feature attributes such as the type of sign can be accurately identified with MMS. Many other attributes such as the text of message can be potentially extracted as well using MMS imagery.

(4) Field GPS survey is a useful alternative for RCI. Nevertheless, when remote sensing imagery is available, efforts required for field GPS survey can be reduced and should be reduced for safety, efficiency, and data quality.

(5) Existing GIS data are important information resources for RCI. These data can provide information that continues to be accurate and useful. The use of these data can improve efficiency, confirm and refine information from remotely sensed sources, and speed up the data collection process.

The use of multiple data sources also overcomes many shortcomings of single source solutions:

(1) Data collected from different sources can be cross-referenced that will significantly reduce the uncertainty on data quality and eliminate inconsistency when data are collected from uncoordinated data acquisition activities. The multi-technology solution can also reduce the needs for field surveys and field data validation, which have tremendous safety benefits not only to data collection agencies, but to the traveling public.

(2) Different vantage points of views of using multi-platform remote sensing, particularly the combination of overhead views and terrestrial views, can address data collection problems associated with limitations of a single view point. That is, satellite imagery and aerial photography can provide images from overhead that cover areas far beyond roads, while vehicle-based mobile mapping systems can provide a terrestrial view of the features and bring out images behind trees or under bridges.

(3) Although a combined approach puts emphasis on the integrated use of multiple technologies, images can be acquired independently with individual technologies. In such a way, data collection activities can be conducted in different frequency for different types of features to accommodate the practical application needs. The essence of the proposed approach, however, is when images are acquired with different technologies, these images should be utilized in a coordinated fashion to achieve synergistic advantages.

The exact safety benefits offered by the combined use of multiple remote sensing technologies are difficult to estimate, but such an approach represents an ultimate solution for addressing risk concerns. For transportation applications, many of the data collection activities take place on heavily traveled highways. Reduction of activities on or along these highways will be highly desirable from a policy point of view and from an operations point of view because reducing field activities ultimately will improve safety, minimize risks, and reduce related uncertainties for roadway data collection.

The project also highlighted some very important issues that need to be addressed in the future. In the discussion of these issues, recommendations for potential solutions or for future project activities are also presented:

Remote sensing continues to be an under-utilized technology in transportation. Many transportation applications can potentially benefit from the data extracted from remote sensing sources, but have not done so. If more applications will start to use the technology, the cost will go down, the overall benefit/cost ratio will increase. In this case, a combined approach of using remotely sensed data will become even more beneficial. In the past, natural resources departments and environmental protection agencies have played a leading role in image data acquisition. Transportation agencies usually have more stringent data requirements that can be only met through their own data collection efforts. In future, transportation agencies will need to not only coordinate internally among different functional entities, but also to work across institutional boundaries so as to share data, costs, and experiences.

Data processing, analysis, management, and feature extraction for multiple image sources are still technically challenging. Images acquired with different remote sensing platforms or from different companies are usually provided in different formats, contain different types of metadata, and can not be handled effectively with a single software package. Data processing or visualization, in some cases, requires specialized hardware (e.g., stereoscopic image viewing and processing) that must be purchased with special orders and installed with extensive technical support. Also massive amounts of data can be generated with the current high-throughput remote sensing capabilities. Effectively storing, managing, processing, and utilizing those data are practical issues that transportation departments must address.

Data and software interoperability is yet another major concern. Frequently data generated with one software system can not be effectively imported into another software system. With the massive amount of data and different types of data involved, the cost to bridge data and software incompatibility can be extremely high. This can also increase risks in data investment, e.g., data collected from one format can not be cost-effectively moved to another format. There is no simple solution to it. Transportation agencies, industry and academia must work jointly to promote the use of open data formats and the interoperability of GIS and remote sensing software.

Lack of information on costs and benefits on the implementation of remote sensing technology and the difficulty to collect such information are major barriers in order for transportation agencies to justify investment decisions on the use of the technology. Assessment of value and usefulness of remote sensing technology in general and for individual technologies specifically has been considered as an important issue for many remote sensing demonstration projects (Laymon et al, 2001; Xiong et al, 2003). Laymon et al pointed out that there is not only a need to demonstrate the use of the technology, but also a need to engage stakeholders to assess the benefits and costs of remote sensing products. Cost/benefit information can be invaluable for planners and decision makers when they have to make informed investment decision for future data collection activities.

In addition to the cost and benefit analysis, there is also a continued need for reviewing data requirements for transportation applications and matching these requirements with potential remote sensing technologies. Because of constant changes in applications and in budget, these requirements may also need to be continuously updated and prioritized in terms of data contents, accuracy, frequency, and completeness. Then effective steps can be taken to implement priority applications.

The current research has focused on the use of roadway inventory database development. For many transportation applications, not only the extracted information that is mostly valuable, but also information in its image form or information that can be potentially extracted from the imagery. Therefore bringing together the information that is extracted from remotely sensed data along with the images directly to application users and helping them develop new ways or change existing ways of using the information and images

will not only improve the usage of the remote sensing data, but also broaden the user base of the technology.

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