GUIDEBOOK

Remote Sensing For Roadway Characteristics Inventory Database Development

Florida Department of Transportation	
Transportation Statistics Office	
December 1, 2004 FDOT Contract BD-591	

GUIDEBOOK

REMOTE SENSING FOR
ROADWAY CHARACTERISTICS INVENTORY (RCI)
DATABASE DEVELOPMENT

This document was prepared for the Florida Department of Transportation

Florida Department of Transportation
Transportation Statistics Office

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INTRODUCTION

The collection of roadway characteristics data, describing the physical characteristics of a roadway and its environment, has long been a requirement for transportation agencies. Up to the recent past, these data were primarily collected by field inventory, performed by teams of technicians who observed and recorded various data elements. Number of lanes, lane widths, types of pavement marking, and signs are but a few examples of these data. First recorded on field sheets, then stored and mapped with programs depending upon electronic computers, the process was unwieldy, time-consuming, and dependant upon considerable personnel effort.

Within the past two decades, advances in technology, particularly digital imaging and data recording, have eased this burden. First, aerial photography and automated interpretation and mapping provided an alternative to the older hand mapping procedures. Digital aerial imagery has also allowed significant technical advances, as well as geo-referencing to fixed landmarks and rectification with satellite geo-referencing systems. More recently, advanced techniques such as Light Detection and Ranging (LIDAR), hyperspectral photography or imaging allowing identification of pavement types or vegetative land cover, and further developments in image recordation and processing have provided even further advances.

ROADWAY CHARACTERISTICS INVENTORY AND REMOTE SENSING

FDOT, through its Transportation Statistics Office (TranStat), an important part of the Department's Intermodal Systems Development Division, is responsible for the inventory of roadway characteristics on the State Highway System. This inventory, the Department's Roadway Characteristics Inventory (RCI), is maintained through ongoing efforts in data collection and processing by districts and the central office.

RCI data are used by the Department for a variety of purposes. One of the more important involves the Federal Highway Performance Monitoring System (HPMS), which represents federally mandated data collection activities on Federal Highway Administration (FHWA) functionally classified roads. These in turn contribute to the federal financial aid equations. Other uses involve planning, traffic monitoring and operations, roadway maintenance, among others.

Over the past several years, the Department has upgraded its methodologies in collecting and maintaining RCI data. Wider use of aerial photography, video logging, and computerized data analysis and storage has been incorporated into the system. As a basis for the current project, the Department is investigating remote sensing of roadway characteristics data.

A basic definition of remote sensing is the collection of information about an object without being in contact with the object. Aerial photography is a typical example. A better definition of remote sensing, as applied to this project, is the enhanced use of technology currently available to the Department that can be applied to the collection, coding, and storage of data for the Roadway Characteristics Inventory.

THE ORNL/FDOT REMOTE SENSING PROJECT

The Federal Highway Administration (FHWA), through its Research and Special Programs Administration (RSPA), has encouraged increased usage and application of technology to the highway inventory process. As part of this effort, RSPA promoted and funded a program to study remote sensing applications for the Department's RCI activities. The Oak Ridge National Laboratory's (ORNL) Center for Transportation Analysis partnered with the FDOT for this project, which is a feasibility study regarding Highway Feature and Characteristics Database Development using Commercial Remote Sensing Technologies, combined with Mobile Mapping, GIS and GPS. This project, discussed at length in this Guidebook, is hereafter referred to as the ORNL/FDOT Remote Sensing Project.

The overall objectives of the ORNL/FDOT Remote Sensing Project are three-fold:

- To determine the feasibility of using remote sensing combined with GPS[1], GIS[2], and Mobile Mapping[3].
- To implement an integrated approach that explores the combined strengths of these technologies.
- To investigate the potential and benefits to the Department's RCI data collection process.

By design, the ORNL/FDOT Remote Sensing Project is limited to the development of data for the Department's RCI database, as contrasted to other types of data such as traffic flow information. Other State DOT data requirements vary, so we decided to use a pre-determined list of features of interest to FDOT Planning. In addition, as noted, the project is limited to technologies generally available to the Department which could be rationally implemented rather than exotic applications requiring excessive equipment or personnel costs.

The following techniques were chosen for examination:

- Aerial Photography
- Satellite Imagery
- Video Logging
- Mobile Mapping
- Field Data Collection

Each of these techniques is discussed in detail in subsequent sections of this Guidebook.

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[1] GPS – Global Positioning System. A GPS is a satellite-based navigation system funded and controlled by the U.S. Department of Defense that provides specially-coded radio signals that can be processed in a GPS receiver, allowing the computation of position, velocity, and time.

[2] GIS – Geographic Information System. The term GIS refers to combinations of computer software, hardware, data, and personal effort to combine, analyze, and visually present spatially referenced information.

[3] Mobile Mapping consists of the use of vehicles equipped for video logging of geo-referenced roadway features, but with equipment allowing more tightly constrained measurements resulting in a more precise determination of the location of roadway features.

REPORTING

Reporting for the ORNL/FDOT Remote Sensing Project is presented in two documents:

1. **Guidebook** (this document) describing the overall project process, remote sensing general information and suggestions on which data elements can be collected by using specific remote sensing technologies or combinations of technologies.
2. **Technical Document** (separate document) containing discussions of the overall Remote Sensing Project, including descriptions of the specific steps followed for the investigation.

EXPANDED USE OF RCI DATA

In addition to developing uses for the RCI database, the project encompassed the use of RCI data collection by other sections or divisions of the Department. Meetings were held with the Environmental Management, Maintenance, and the Traffic Operations Offices to explore the possible uses of RCI data and extraneous data that could be readily obtained during the RCI data collection phase. For this effort, all possible data categories represented by individual Features and Characteristics from RCI were arranged in tabular form by each office (Planning, Maintenance, Traffic Operations) and by analysis area. The analysis areas, represented in several occasions by questions, were as follows:

- If a physical characteristic, how is it measured: length, width, height, etc.?
- How do you determine condition?
- How is location identified?
- Locational accuracy (accuracy level).
- Ease in rectifying any problems found with the data after it has been collected.
- Measurement accuracy (tolerance).
- How do you measure fractions of a unit (precision)?
- Units (feet, meters, gallons, etc.).
- Frequency of data collection.
- What other physical information about the item is collected?
- What metadata (overall descriptive information) is collected about the item?
- Is there an ID or Number associated with the item (indexed)?
- Relative to other items, how would you judge the importance of this item (degree of importance)?
- Number of items comprising a single record of this item (quantity).

These questions were then used to narrow the list of potential Features and Characteristics to be investigated for remote sensing data collection. The Features and Characteristics are the detailed data entries for roadway characteristics collected for the database.

In addition, it soon became obvious that individual remote sensing data collection techniques would have different applications by general geographic environment. For example, visual techniques pertinent for use in open areas might not be usable within densely developed urban areas, where construction adjacent to the roadway might block visual angles (except perhaps directly overhead views). Thus, it was decided to develop the applications by three general areas: Open Terrain, Urban Canyons, and Forested Terrain. Matrices for these three area types were then developed for the candidate Features and Characteristics.

Open Terrain is a view of the roadway where there is little or no blockage from vegetation or physical obstructions. Cloud cover is not considered, because it blocks any type of aerial view regardless of ground cover. Urban Canyons are found in urban developments where buildings adjacent to the roadway form “canyons” on either or both sides of the roadway, and block all but directly overhead views. Forested Terrain is just that – terrain where trees and other foliage obstructions predominate to block the necessary ground views.

The FDOT’s primary method of data collection is through field work, followed by manual data entry, quality control, and checking. While this method produces good, usable data, it has been time-intensive and requires more personnel. There are also some safety issues, as field personnel are exposed to the traffic stream (safety issues also impact the traveling public). The use of remotely-sensed data as a replacement for manual procedures would offer efficiency, more cost-effective, and safer procedures.

Use of remote sensing techniques and data collection methodologies will also result in greater efficiency, cost savings, uniformity, and completeness of data than would be obtainable from the traditional field methods. Moreover, if topographic information is desired, it is clear that machine analysis of rectified aerial photographs is much more efficient and safer than manually collecting the required data through traditional ground surveying methods.

Each of the four tested remote sensing techniques (aerial photography, satellite imaging, video logging, and mobile mapping) has its uses, benefits, and limitations. In addition, for a complete definition of a roadway characteristic or attribute, two or more combined techniques may be required. An example would be obtaining information about a highway sign. Aerial photography or satellite imaging may be able to completely depict the longitudinal (along the roadway) and the offset position (lateral distance from the roadway edge or centerline) but may be unable to provide a view depicting the sign’s message. For this purpose, video logging, mobile mapping, or field data collection would be required. On the other hand, a fully equipped vehicle for mobile mapping may be able to completely inventory the sign (longitudinal and lateral position along the roadway, the sign’s message, and even the degree of retroreflectivity, and the conformance of the sign to installation guides for sign mounting height).

Thus, the combination of two or more data collection techniques may be required to collect complete information but, even so, may offer increased efficiency and safety in the overall process.

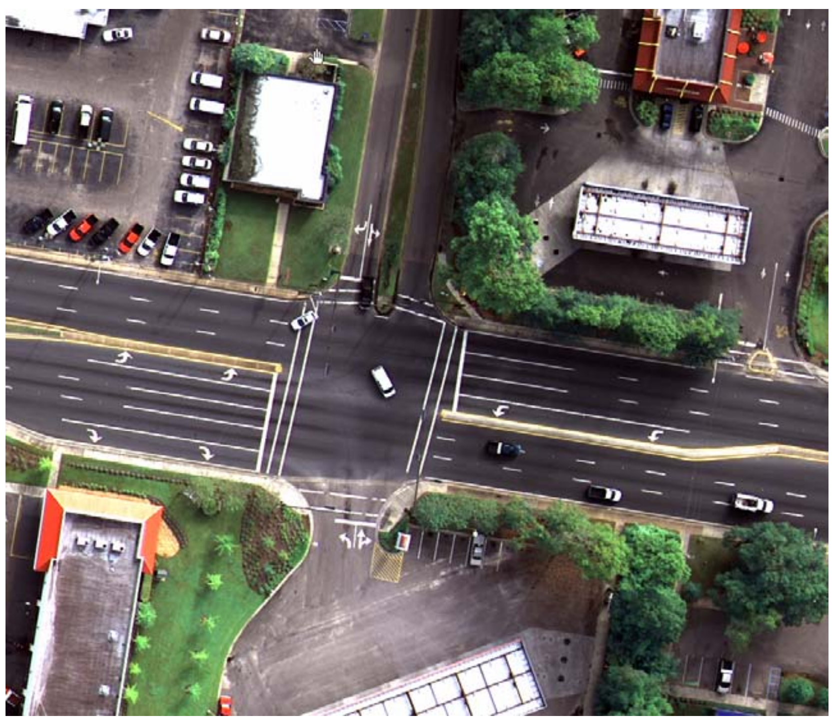
AERIAL PHOTOGRAPHY

Aerial photography, as discussed herein, is the taking of a photograph from above with an aircraft-mounted camera, and preparation of the resulting imagery for further usage. For the ORNL/FDOT Remote Sensing Project, aerial photography can be defined to include the extraction of RCI data by automated means from a rectified, film or digital, color or black and white, low or high altitude aerial photographic images.

Many of the discussion points concerning aerial photography also apply to images obtained from satellites. However, there are some important differences, which are discussed in the following sections.

AERIAL PHOTOGRAPHY AND TRANSPORTATION DATA

The Department has been involved with aerial photography since 1955. The Surveying and Mapping Office currently maintains about 600,000 negatives of Florida's roadways. In-house processes allow photos to be geo-coded or geo-referenced (adjusted to remove distortion and rectified to fit real-world map coordinates) as well as digitized. The images can be reproduced on Mylar film or paper, with enlargement factors up to 10. Scanned images can be provided on CDs or tape.



Aerial photography has long been used for transportation projects. Typical uses for transportation planning include general illustrations of roads and intersections, preliminary analyses for roadway improvements, traffic engineering, or traffic flow. With more advanced processing, determination of elevations, contours, and water courses for roadway planning applications can be accomplished. Air photos are an efficient method of illustrating corridor conditions for preliminary roadway planning. Aerial photography is also readily understood by non-technical persons at public hearings or presentations, which assists in communicating roadway improvement plans. Additional uses that require additional processing of a basic aerial photograph include map making and design of transportation facilities. One of the greatest benefits of basic aerial photography[4] is that it can be obtained without contacting the ground surface being covered.

Many of the newer techniques in aerial photography were facilitated with the ability to digitize data, which gave the ability to handle large or complex data flows involving extreme bandwidth, storage, rapid retrieval and complicated analyses. In contrast, analog techniques, such as conventional film negative and processing, and manual stereo compilation required more time and effort, and did not allow currently available processes until digital technology was developed.

Aerial photographs portray the objects photographed from an overhead ("plan" or "birds-eye") view, or an oblique view (at an angle from the side). Aerial photographs are useful in presenting the horizontal dimensions of the subject matter. However, a basic aerial photograph does not portray precise dimensions due to inherent distortion. Photogrammetric processes allow aerial photography to be adjusted to accurately depict both horizontal and vertical dimensions (contours or elevations) of terrain and other objects.

Aerial photographs are taken in timed sequence from a flight pattern with both longitudinal and lateral overlap. Aerial photography can be classified by the position of the camera, including vertical and oblique photography. With vertical aerial photography, the camera is positioned to look straight down, whereas in an oblique photo an angled view is produced. Aerial photographs can also be classified by type of film or filters used. Images may be recorded on film (analog) or digital media. Several of these variations are discussed below.

The type of photographic negative (or recording medium) impacts its usage. Color aerials provide more detail than black and white photographs, such as types of ground cover, types of roadway pavement, or similar characteristics. Color may be more desirable for presentations, as it appeals to the normal human eye view. Color photographs are more costly than black and white photographs. On the other hand, if the type of detail available from color photography is not needed, a black and white image will save money.

Other photographic processes include panchromatic, basic or color infrared, hyperspectral, or low-altitude photography. While not explored in this research, these techniques offer alternative benefits.

Panchromatic photographs result from the use of negative blue and yellow filters (removal of these colors) and yield images more suited to general photo interpretation or for water or forest identification. Infrared and color infrared (or false color) photography records red and near-red wavelengths. These photos have more usage in revealing vegetation type and are generally not appropriate for RCI purposes.

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[4] Some applications obviously require certain ground controls that must be supplied by surveying methods, although the use of GPS can often replace these requirements. The presence of ground cover (trees, foliage, etc.) and environmental conditions (rain, fog, cloud cover, etc.) also influence when an aerial photograph can be obtained.

Hyperspectral photography is the collection of reflected, emitted, or back-scattered energy in many bands of the electromagnetic spectrum. The technique requires use of an imaging spectrometer, allowing the reflected energy to be recorded in multiple bandwidth detectors. The analysis of hyperspectral data results in a spectral reflectance curve for each feature, which can provide detail such as mineral type, surface materials, or vegetation type when compared to known values. Hyperspectral imaging is applicable to both aerial photography and satellite imagery. However, for RCI purposes, hyperspectral photography is considered to be overly expensive for the benefits received.

The image rectification process prepares raw aerial photographs for more involved uses. Image rectification covers a range of various techniques applied to basic aerial photography. These correct the inherent distortion in the recorded images and render them useful in determining more precise measurements of size, distance, angle or elevation of objects on the earth's surface, including determination of topography. The rectification process includes geo-referencing, or the adjustment of the photographs to match a map coordinate system. Although there are several types of rectification, two particular types are orthorectification and triangulation. Orthorectification corrects for camera characteristics, tilt/platform displacement, and terrain details. Ground control points, camera calibration parameters, and a digital elevation model (DEM) are required. Triangulation depends more on ground control points, but results in less accuracy than orthorectified photography. Whichever adjustment process is used, when the process is complete, the photographic imagery better depicts the earth's surface and its features, and can be used for direct measurement of distance or development of maps.

With the advent of digital methodologies (as contrasted to analog, or mechanical methods) the rectification process is facilitated. Thus, the acquisition of aerial photographic data in digital format is beneficial. To accomplish this, there are two basic methods: direct acquisition of digital data (digital cameras) or utilization of scanned aerial film-based photographs.

Digital cameras use a Charge Coupled Device (CCD) to electronically record the visual image as digital values. A current constraint for digital cameras is the size limitation of the CCDs.

A second method for improved processing involves scanning a film-based photograph to produce a digital image (more precisely, digital data representing the image). While appearing to be an extra step, this allows the conversion of existing film images to digital images, which in turn allows much greater efficiency through computerized, automated processes in using the image.

AERIAL PHOTOGRAPHY AND GPS

Combining aerial photography with Global Positioning System (GPS) data provides a further increase in efficiency and usage. Earlier, GPS data was not sufficiently accurate for use in RCI-type data collection. Recent advances allow determination of geographic position within a few centimeters, allowing better ground control for the photographic process. Ground features are selected, and GPS positioning is collected for them, which can then be correlated to the photographic image. Other techniques include recording automated GPS-determined positioning with aerial photography, where the in-flight position is obtained with the recorded image. Accuracies of 2 to 5 meters are currently achieved. This method is especially useful where ground areas are not accessible.

As applied to the ORNL/FDOT Remote Sensing Project, two forms of aerial imagery were to be examined: analog (film-based) and digital. High-resolution analog (film) imagery is readily available and is the most commonly used. This type of imagery was originally acquired with film cameras, but was subsequently scanned and converted into digital data. The second is digital imagery acquired with digital cameras, thus not requiring subsequent conversion to digital format. Both types of imagery have the detail and resolution required for roadway data extraction, but there are some shortcomings. Vegetation or high-rise buildings may block some of the needed detail, particularly along roadway edges. Also, other features, such as signs, certain traffic devices, or utility poles are difficult to identify in aerial imagery. Some features, such as sign messages, cannot be seen at all from the aerial viewpoint, and require the aerial methodologies to be combined with surface technologies for a complete data detail.

To meet project schedule constraints, only analog data were used. However, both two-dimensional and three-dimensional feature extractions were examined. Further details are available in the Technical Report.

STRENGTHS AND WEAKNESSES OF AERIAL PHOTOGRAPHY FOR RCI DATA

Strengths

- Technique in place
- Services provided within the Department
- Greater safety for DOT staff as opposed to collecting field data
- Department already has necessary equipment and trained staff
- Product familiar to most potential users
- Easy to use product
- Wide application of product
- Process results in partial RCI data production
- Useful accuracy can be achieved
- Little ground intrusion (except for placing ground targets)
- No delay to road traffic
- Multiple uses/users of product

Weaknesses

- Expensive
- Time consuming – time required for flights and to obtain and process film data
- Cannot collect complete RCI data
- Cannot collect “administrative” type data or data requiring view from roadway
- Many environmental constraints (fog, cloud, and tree cover, etc.)
- Knowledge required for proper specifications (resolution, coverage, etc.)
- Size limitations for Charge Coupled Devices (CCDs)
- Up-to-date aerial images may not be readily available (would require flights)
- High performance personal computers, large disk storage space required
- Responding to user specific needs may be time consuming
- May be difficult to obtain aerial photography images for all roadway IDs

Equipment Needs – Aerial Photography

- Aircraft and cameras
- Airport access, hangar space, etc.
- Good flying conditions
- Highly trained staff: flight crews, camera operators, photogrammetry experts, etc.
- Photogrammetry equipment – stereo plotter, if controlled/rectified images are to be produced
- GIS coupled equipment
- Ground controls/targets
- Surveying crews and equipment to place ground targets
- Scanners if photos are to be converted to digital images
- Photo printers
- Storage facilities

The following matrix[5] provides information on the size of objects viewable at typical aerial photography flying altitudes.

Flying height		Digital Camera	Pixel Resolution		Analog Camera	Pixel Resolution
AGL (feet)		**horizontal (inches)**	**vertical (inches)**		**horizontal (inches)**	**vertical (inches)**
10000		12.0	39.0		11.0	28.0
9000		10.8	35.0		9.9	14.7
8000		9.6	31.3		8.8	16.5
7000		8.4	27.3		7.7	12.9
6000		7.2	23.4		6.6	11.0
5000		6.0	19.3		5.5	9.2
4000		4.8	15.6		4.4	7.4
3000		3.6	11.7		3.3	5.5
2000		2.4	7.8		2.2	3.7
1000		1.2	3.9		1.1	1.8
Size of object			**Resolution of pixel**			
(feet)			**(inches)**			
10			12			
5			6			
3			4			

[5] Provided by SimWright, Inc.

SATELLITE IMAGERY

Satellite remote sensing of transportation data involves gathering information about features on the earth's surface from orbiting satellites. For the ORNL/FDOT Remote Sensing Project, satellite imagery would be defined as obtaining suitable data for the RCI database from data image files obtained from orbiting satellites.

TYPES AND AVAILABILITY OF SATELLITE IMAGING SYSTEMS

Satellite remote sensing can be characterized by two general types: active or passive. Active sensing involves transmitting some type of electromagnetic radiation (light, radio waves, etc.) and measuring the intensity or other attributes of the return signal. Passive sensing does not involve sending a signal from the satellite, but rather measuring either reflected or emitted radiation from the earth's surface. Both types of received data are recorded digitally and are transmitted to ground stations for further processing.

Several types of government and commercial satellites are available. One example of government-provided data is the familiar weather-related imagery provided by the U.S. National Oceanic and Atmospheric Administration (NOAA) via the Geostationary Operational Environmental Satellite (GOES). This imagery is familiar to many users and is fully available on the Web. An example of a commercial system and its products involves the Quick Bird satellite, operated by the Digital Global Corporation which, among other similar providers, offers a range of products. Data from this satellite system was one of the two products used in this phase of the investigation. Due to the requirement of extensive and complicated equipment, including access to available satellites, satellite imagery is normally provided by commercial entities.

Satellite imagery applications appear to be best suited for large-area or temporal data collection and interpretation. Generally available satellite data cannot provide the high-level accuracy that is required for the measurement of small features, such as lane width and roadside element dimensions. Only high-resolution aerial photography can provide this level of detailed information. Satellite data collection has been used successfully for such applications as determination of land cover, urban development, or vegetation adjacent to a roadway; data required for environmental analyses, or land use determinations. Temporal mapping is facilitated by a relatively economical method of collecting time series data documenting changes over time via repeated passes of the satellite. For transportation projects, satellite imagery offers promise for applications with broad area coverage, such as land use, terrain cover, or corridor planning. Thus, while resolution of satellite data is potentially useful for roadway characteristics data collection, the availability of high-resolution aerial photographs renders the satellite data somewhat redundant for most RCI applications. Further details and discussions are presented in the Technical Report.

STRENGTHS AND WEAKNESSES OF SATELLITE IMAGERY FOR RCI DATA

Strengths

- Potential for some RCI data production
- Automated data collection
- Safer operations for personnel
- Facilitates area-wide data collection
- Facilitates temporal data collection (multiple passes)
- Provides general locational information
- No ground intrusion
- No delay to roadway traffic
- Exploits latest technology

Weaknesses

- New technique for Department
- Department staff not trained in this technology
- Cannot collect complete RCI data ("administrative" data or data requiring view from the roadway)
- No sub-meter resolution satellite images currently available
- Will require use of other techniques and equipment for full RCI data collection
- New technique combined with new technology – requires understanding of process
- Highest equipment, software, and technology needs
- Requires use of commercial providers
- Highest potential for proprietary software
- Cost may be high
- Requires extensive Department staff knowledge even for project management
- Potential environmental constraints (cloud/tree cover)
- High performance personal computers, large disk storage space required
- Responding to user specific needs may be time consuming
- May be difficult to obtain satellite images for all roadway IDs

Equipment Needs

- Highest equipment needs
- Not appropriate for Department to develop technology
- Must use commercial provider

VIDEO LOG

Video log defined for the ORNL/FDOT Remote Sensing Project refers to the extraction of RCI data from the Department's existing video log data files. The Department's video log process involves obtaining and storage of locational video images made from a specially equipped vehicle having distance measuring and global positioning systems. The process results in digital, geo-referenced visual records of roadway features.

THE DEPARTMENT'S VIDEO LOG SYSTEM

The Department currently obtains and maintains video log images of the state highway system. The Department's video log data provides a current visual record of the state highway system. The video log van is equipped with a distance measuring instrument, video cameras and associated computer equipment to record digital images of the roadway environment. The process also encompasses Global Positioning System data for each video image. Images are collected at 100 frames per mile and compressed into Joint Photographic Experts Group (JPEG) files, then placed on Digital Video Disks (DVDs). Records are obtained on a three-year schedule.

Many Departments of Transportation collect roadway video logs to provide a visual record of the roadway at the time the image is captured. The video log mileage indication (milepoint data) is not intended to be used to show the exact location of any given inventory element or condition of the roadway. Such information can be obtained from either the Roadway Characteristics Inventory (RCI) database, or Straight Line Diagrams (SLDs).

Video logs are available by Roadway ID, which is the numbering system that the FDOT uses to identify particular portions of roadways. Information on the Roadway ID system in use by the Department can be obtained either from the RCI Field and the RCI Office Handbooks maintained on the Transportation Statistics Office Web site or from the introductory RCI training images and programs also available on the same Web site.

The video log program is available to all Department employees and other authorized users via the Department's INFONET, but not to the general public. Once the application is accessed, available roadway information can be viewed by direction, milepoint, and limited pan (front frame, right frame, forward/backward, etc.). A full size view can be seen.

STRENGTHS AND WEAKNESSES OF VIDEO LOG FOR RCI DATA

Strengths

- Technique in place
- Department already has necessary equipment and trained staff
- Provides some RCI data
- Greater support function for RCI data than direct data production
- Product familiar to most potential users
- Easy to use results
- Wide application for data
- No additional time required to train staff
- Results available Department-wide
- Reduces the need for follow-up field visits
- Department-wide access via the FDOT INFONET
- Digital output/data available
- Readily understandable system and results
- Safer for personnel than on-site (ground) data collection operations
- Facilitates use of central team and equipment for statewide and District data collection
- Relatively uniform results
- Can possibly obtain services through outside providers

Weaknesses

- Cannot collect complete RCI data
- Inclement weather may constrain operations
- Less accuracy for distance measurements
- No direct extraction of RCI data
- Incomplete view of road environment
- Cannot clearly see all road/roadside features
- Some data may not be timely (age/time of collection)
- Some delay to other road traffic

Equipment Needs

- Van equipped with video recording equipment
- Office processing, images editing, and storage equipment
- Storage area for images

MOBILE MAPPING

Mobile mapping is a data collection system similar to the video logging process but captures more tightly constrained measurements of roadway features. Mobile mapping provides a precise determination of the longitudinal and lateral position, as well as information available only from a ground view along the roadway such as sign face data.

MOBILE MAPPING SYSTEMS

Mobile mapping systems consist of a vehicle (van) containing navigation and mapping sensors, in addition to the cameras used to record data. Included equipment could be GPS receivers, vehicle wheel sensors, other digital sensors, and Inertial Navigation Systems (INS) to provide both the track of the vehicle as well as positional and orientational data concerning the mapping sensors. The mapping equipment can include digital cameras, devices using a laser,[6] or radar. As the locational parameters of the collected data are automatically determined as the data is collected, subsequent detailed computations are minimized.

The system offers the dynamic collection of data during the course of the survey, with the option of post-survey digital data processing and extraction. One major advantage of mobile mapping is that data for highway purposes can be obtained without blocking other traffic using the roadway; another is that data collection personnel are shielded from direct exposure to other traffic, and thence safer operations result. Constraints include the requirement for GIS coverage (minimum “dead” areas), difficulty of identification of some roadway data features, and relatively high equipment cost.

Mobile mapping also involves the use of specialized data processing equipment and software, often proprietary. Examples are TRANSMAP (from TransMap, Inc.), GPSVision Mobile Mapping (from Lambda Tech International), and GEOVAN (by GEOSPAN Corporation), the system used in this research project. Most of these services can range from full recording and delivery of data, to provision of the software and vehicle systems for customers’ usage.

STRENGTHS AND WEAKNESSES OF MOBILE MAPPING FOR RCI DATA

Strengths

- Potential for some RCI data production
- Automated data collection
- Faster than field data collection
- Safer for personnel than on-site (ground) data collection
- Automated data reduction and storage
- Minimizes human error potential

[6] A laser is a device that uses energized atoms to release energy that can be converted to light. "Laser" is an acronym for *light amplification by stimulated emission of radiation*. Laser is useful, much like the radio frequency beam in conventional radars.

- Results produced in digital format
- Facilitates use of central team and equipment for statewide and District data collection
- More uniform results
- More accuracy for distance and lateral measurements
- Facilitates GPS usage
- Potential for automatic extraction of RCI data

Weaknesses

- New technique for Department
- Cannot collect complete RCI data
- Will require use of other techniques and equipment for full RCI data collection
- New technique combined with new technology – requires understanding of process
- High equipment, software, and training cost if developed in-house
- Cost to implement may be high
- Time needed to implement new process
- Detailed staff training required
- May require use of commercial providers
- May result in proprietary programs or software
- Inclement weather (rain, etc.) may constrain data collection
- Some environmental constraints (GPS may not work in some locations, etc.)
- Some feature data cannot be collected with mobile mapping
- Some delay to other traffic
- Sensitive equipment – downtime for repair or maintenance

Equipment Needs

- Fully equipped mobile mapping van
- Full suite of data reduction/analysis (computer) equipment and software
- Trained staff (equipment operators and office staff)

FIELD DATA COLLECTION

Field data collection retains an important place in the use of remote sensing for RCI data collection. Field data collection is, of course, the use of personnel, armed with various measuring and data recording devices, to collect RCI data from on-site, personal observation of various roadway features. Field data collection can also be thought of as the "traditional" method of RCI data collection, which may remain pertinent for collection of specific data items, field truthing, or calibration of automated data collection and processing techniques.

Field data collection has numerous advantages and disadvantages. One of the major advantages is that on-site personnel can ensure that complete data are collected and can normally resolve any questions or issues that arise. The thought processes available from experienced data collectors can help to ensure completeness, uniformity, and applicability of the collected data. Conflicting issues are immediately identified and resolved by referring to guidelines and procedures previously set forth.

One additional use of field data collection is its use in either calibration or use in "ground truthing." Calibration is the process of adjusting automated processes to match the actual ground conditions. Ground truthing involves comparing machine-derived or produced data with actual measured conditions to verify the accuracy and completeness of the automated processes. Both of these processes benefit by having field collected data.

For RCI processes, field data collection may offer more benefit than initially apparent. Numerous features and characteristics within RCI have many ways in which they can be measured and recorded. These issues require uniform determination in accordance with the guidelines set for RCI.

On the other hand, field data collection has several important disadvantages. Beyond being labor-intensive and time-consuming, personnel safety is a major issue. Having staff exposed to moving traffic while either operating a slow moving van or being on the ground collecting certain data creates issues of safety. For the traveling public, exposure to slow moving or stopped vehicles, or activities in the roadway or adjacent to it also impacts safety. Moreover, even with care in collection and processing, human error, the possibility of hand transcription errors, and interpretation of office documents can induce error into the process, which subsequently requires additional time to identify and correct. Automated processes hold promise in reducing such errors while increasing efficiency of the process.

STRENGTHS AND WEAKNESSES OF FIELD DATA COLLECTION FOR RCI DATA

Strengths

- Technique in place
- Easy to use results

- Traditional methodology, well understood
- Process results in complete data collection
- Facilitates iterative data updates
- Only way to collect some data
- Process works everywhere, not subject to environmental constraints such as tree cover
- Facilitates use of District teams for data collection
- Facilitates use of consultants to collect data
- Direct production of RCI data
- Equipment, trained staff, and product already available to Department
- On-site operations for data collection
- Immediate inspection of features on-site
- Facilitates data extraction from administrative sources, maps, etc.
- Relatively simple equipment needs
- Relatively simple to implement technique
- Staff training materials and courses already available
- Outside provider (consultant) processes already in place
- No proprietary software or processes required

Weaknesses

- Dangerous – personnel are exposed to roadway traffic
- Slow process – time consuming
- No direct extraction of RCI data
- Does not take full advantage of available technology
- Requires training of new staff
- Requires extensive office preparation
- Requires hand coding/entry of data
- Subject to human error
- Possibility of transcription errors
- Results in paper records
- Hindrance to other roadway traffic (slow data collection vehicles)
- Inclement weather affects work schedule
- Personnel may miss some needed features, requiring repeat visits
- Requires travel time to reach site
- Variable (time) demands on staff
- Requires frequent equipment calibration
- Requires vehicle

Equipment Needs

- Van with Distance Measuring Equipment
- Hand measuring devices
- Recording media
- Trained staff (field and office)
- Safety devices

METADATA

Metadata is an all-inclusive term describing the content, quality, lineage, condition, collection methodologies, and other characteristics of data. Metadata is "data about data." Generally, metadata about particular data applications or sources follows a prescribed format, which ensures complete descriptions of the data and facilitates further uses. Metadata is an important asset for data management, and provides guidance for usage of the data.

Development of metadata standards for RCI data is an important part of the ORNL/FDOT Research Project.

APPLICATIONS OF REMOTE SENSING FOR RCI DATA

This section presents a general discussion of the application of the various types of remote sensing to the collection of RCI data.

GENERAL APPLICATION OF AERIAL PHOTOGRAPHY FOR RCI DATA

Aerial photography has application to remotely-sensed RCI data. Usefulness for various features by three types of terrain ground cover conditions are shown in the Appendix to this Guidebook.

The suitability of aerial photography for RCI data can be correlated to these three differing ground cover conditions. This involves what can be seen on the photograph, as well as the amount of detail that is available. As noted previously, Open Terrain is considered to be views of roadways where there is little or no ground cover from trees, other foliage, or physical obstructions. Cloud cover is not considered in this classification, because it obviously limits any aerial photograph regardless of ground cover. Urban Canyons are those conditions found in urban developments where adjacent buildings form “canyons” on either side of the roadway, and block all but directly overhead photographs. Forested Terrain is just that – terrain where trees and other foliage obstructions predominate to block the necessary ground views on the photographs. In addition, the discussion covers aerials taken at altitudes of both 1,200 ft. and 2,400 ft.

Figures 2, 3, 8, 9, 14, and 15 provide details of aerial photograph applications for RCI by the three ground cover conditions and the two altitudes mentioned above. In general, aerial photography at 1,200 ft. altitude has more application than that at 2,400 ft., due to the greater detail available. Moreover, as expected, aerial photography has more application for Open Terrain than for Urban Canyons, and practically no application for Forested Terrain, where ground details cannot be seen.

Aerial photography applications are best suited for overall details, such as roadway centerlines, intersection type and configuration, number and type of lanes, median conditions, or pavement markings. Support information can be obtained for other details such as guardrail (location not type), shoulder and lane widths, location of sidewalks, and similar features.

GENERAL APPLICATION OF SATELLITE IMAGERY FOR RCI DATA

Satellite imagery has limited application for most types of remotely-sensed RCI data. Applications for three types of terrain conditions (Open, Urban Canyons, and Forested Terrain) are shown in the Appendix to this Guidebook. Open Terrain is considered to be views of roadways where there is little or no ground cover from trees, other foliage, or physical obstructions. Cloud cover is not considered in this classification, because it obviously limits satellite imagery, as it does aerial photograph regardless of ground cover. Urban Canyons are those conditions found in urban developments where adjacent buildings form “canyons” on either side of the roadway, and block all but directly overhead views. Forested Terrain is just that – terrain where trees and other foliage obstructions predominate to block the necessary ground views from above.

As with aerial photography, satellite imagery for RCI data relates closely to what can be seen from above, as well as the amount of detail that is available. Satellite imagery available for civilian uses may not have full detail available from other types of coverage.

Figures 4, 10, and 16 provide details of satellite imagery applications for RCI by the three categories of ground conditions mentioned above. In general, satellite imagery has broad application for gross details of conditions surrounding the roadways, such as land use. Some application is provided for such matters as general lane application, intersection and interchange configuration, and the like. Satellite imagery is not considered to be sufficiently accurate for details such as feature width, or features requiring height measurement.

GENERAL APPLICATION OF VIDEO LOGS FOR RCI DATA

Video logs have broad support usage in collection of RCI data. Applications are very similar for the three types of ground conditions noted – Open, Urban Canyons, and Forested Terrain. Interference of views from adjacent ground cover (trees and other foliage) does not generally affect use of video logs, although it may provide some interference of long-range views. Cloud cover or rain, obviously major factors in both aerial photography and satellite imagery, have no effect on video logging (with the exception of fog).

Video logs are particularly suited for viewing features that can be seen from a vehicle, such as number of lanes, lane markings, curbing, sign messages, or traffic signals. Features that require a closer view, such as culvert data, width or height measurements, or bridge or railroad crossing details, are exceptions. Video logs are particularly useful in providing an alternative view, which may reduce the need for an additional trip to the roadway location.

GENERAL APPLICATION OF MOBILE MAPPING FOR RCI DATA

Although certain equipment configurations may increase the overall application of Mobile Mapping, the process has particular application in obtaining data that requires distance or locational measurement, and for features that require detailed observation such as sign messages or traffic signal types.

Mobile mapping has proven to be effective for features that appear as points on overhead imagery, such as aerial photography. The mobile mapping process also provides good positional accuracy. However, the equipment and required programming is likely to be proprietary.

GENERAL APPLICATION OF FIELD DATA COLLECTION FOR RCI DATA

Field data collection has the basic attribute of being effective for collection of all types of RCI data. However, as discussed, it is not considered to be cost effective, and may expose the data collection personnel to danger from moving traffic as well as inclement weather. The process obviously involves human interaction, which may lead to rapid problem resolution, but may also lead to varying application of rules and procedures required to correctly resolve problems. Field data has proven effective in collection of RCI data, but is a cumbersome and personnel-intensive process. It may be more reasonable to supplement automated remotely-sensed data collection methodologies for specific data sets. This study has addressed these issues and applications.

APPENDIX

RCI Features Tabulated by Remote Sensing Data Sources