Report No. BC-965

STUDY OF THE FEASIBILITY OF VIDEO LOGGING WITH PAVEMENT CONDITION EVALUATION

M. Gunaratne, Ph.D., P.E.
Principal Investigator

and

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Graduate Assistants

submitted to

The Florida Department of Transportation

by the

Department of Civil and Environmental Engineering
College of Engineering
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16. Abstract : The Florida Department of Transportation (FDOT) needs a higher frequency of comprehensive data acquisition related to highway operation in Florida and an efficient centralized system to manage, process, and store such data. In response to these needs, an automated high-speed pavement evaluation vehicle has been developed. This evaluation vehicle is a Class I profiler van equipped with a laser profiling, land navigation, and imaging sub-systems consisting of three cameras; front-view and side-view digital area-scan cameras for capturing images of traffic signs and right-of-way safety features, and a downward-view digital line-scan camera for capturing images of the pavement surface. In addition to the 3-laser and accelerometer-based profiling system, the vehicle is also equipped with differential global positioning equipment (DGPS) and an inertial measurement unit (IMU) for cross-slope, curvature and grade measurements. The quality and accuracy of images, and the precision of GPS, IMU and laser measurements were investigated during a limited testing program conducted at the University of South Florida. A field survey of Hillsborough county's highway network was accomplished within a four-week period to probe the functionality and reliability of the vehicle and its subsystems.

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Length	ft	m	3.048E-1
Pressure	lb/ft^2	N/m^2	4.788E+1
Velocity	ft/s	m/s	3.048E-1

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EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) recognizes the needs for a higher frequency of comprehensive field data acquisition related to highway operation in Florida and an efficient centralized system to manage, process, and store such data. In response to the above needs, an automated high-speed pavement evaluation vehicle has been developed through a research collaboration among FDOT, the University of South Florida (USF) and International Cybernetics Corporation (ICC) of Largo, Florida. A preliminary investigation was conducted in which ten (10) transportation agencies in different parts of the US were surveyed by telephone to learn about their experiences with similar survey vehicles assembled by different manufacturers. Of the agencies which routinely use survey vehicles for high-speed automatic highway data collection, only a minority had performed systematic validation of their survey equipment. Hence an important task of this research project involved the validation of data acquired by the FDOT's survey vehicle.

The FDOT evaluation vehicle is essentially a Class I profiler van equipped with a laser profiling, land navigation, and imaging sub-systems. The imaging sub-system consists of three cameras; front-view and side-view digital area-scan cameras for capturing images of traffic signs and right-of-way safety features, and a downward-view digital line-scan camera for capturing images of the pavement surface. In addition to the 3-laser and accelerometer-based profiling system, the vehicle is also equipped with differential global positioning equipment (DGPS) and an inertial measurement unit (IMU) for cross-slope, curvature and grade measurements. The quality and accuracy of images, and the precision of GPS, IMU and laser measurements were investigated during a limited testing program conducted at the University of South Florida.

The user is able to compile and store data from all of the above devices in a format that is compatible with FDOT's existing pavement management databases. Using imaging practices similar to those adopted at present, the FDOT district offices would be able to acquire a more complete set of relevant highway data, conveniently and expeditiously. As the final phase of this project, a field survey of Hillsborough county's 800 miles of state highway network was accomplished within a four-week period to probe the functionality and reliability of the vehicle

and its subsystems and evaluate the feasibility of using such equipment for surveying the state's entire highway network. The authors were able to acquire valuable information regarding survey crew scheduling, appropriate timing for conducting such surveys, and the reliability of the system and each subsystem.

1.0 RESEARCH NEED

Until recently, the Florida Department of Transportation (FDOT) has used forward-looking images of the highway network, which were made available on a three-year cycle through a Consultant. In May of 2000, a study was conducted to explore potential improvements to FDOT's videolog program (Dougan, 2001) which resulted in the following recommendations: (1) increasing the frequency of video-logging (2) upgrading the scale of image acquisition to obtain right-of-way data from outer or center lane and condition data from the pavement, and (3) creating a department-wide unit to manage the consolidated image and field data acquisition, processing, storage and retrieval operations.

Hence, this study was initiated to explore a fully automated exhaustive evaluation operation that includes adding the following functionalities to existing imaging in the forward direction: (1) imaging in the side-view mode to identify up-to-date roadway features that also include *safety related features* such as bridge and railroad crossing identification, edge line of pavements and images of ramps (2) imaging in the downward direction (3) global positioning for location referencing of the collected data (4) acquiring roadway cross-slope data, and (5) collecting pavement roughness and rut data for pavement distress evaluation. It was envisioned that the above objectives could be achieved by using a profiler van equipped with a video camera system for imaging in forward, sideward, and downward directions, an inertial measurement unit for collecting pavement cross-slope data, and a Differential Global Positioning System (DGPS) equipment for data geo-referencing purposes.

Presently, FDOT pavement evaluation crews conduct "windshield" surveys to identify the types of surface cracking and other distresses at relatively slow speeds. On the other hand, for quality control of manual condition survey data, videologged images that provide a permanent record of the pavement surface condition can be evaluated and analyzed. Pavement imaging can even preclude the need for conducting hazardous surveys, especially on high speed facilities. Hence another objective of the above study is to implement imaging of highway facilities as part of the Pavement Condition Survey (PCS) conducted annually by the State Materials Office.

The final objective of the study was to setup a comprehensive video image, GPS, cross-slope database structure that is compatible with FDOT's existing linear referencing system and GIS databases. This could be made accessible to FDOT staff later on through networks through viewer and browser software.

1.1 State-of-the-art in video-logging

According to Wang (2000), a common method of imaging pavement surfaces was using the analog format through area-scan cameras. A digitizing process converts the analog–based images, in which analog data is transformed into computer-understandable digital format. Wang (2000) discusses the advantages of the relatively new digital camera technology.

On the other hand, the line-scan cameras scan one line at a time with a resolution as high as 6,000 pixels per line (2Kx2K) with a data rate of 30 MHz. Captured single lines are then compiled to form a 2-D area for analysis. Although several problems associated with analog area-scan cameras, such as the relatively low resolution and the necessity for digitizing, do not exist with digital line-scan cameras, Wang (2000) emphasizes the need for higher light intensity in line scan cameras.

For area scanning at highway speeds, the maximum available exposure time is about 90 μs while in line scanning, the maximum available exposure for one line is about 80 μs in order to capture a crack that is less than 2 mm. Since these short exposure times require high illumination intensity, strobe-illuminating devices are effective for area-scan cameras. However, for line-scan cameras, high intensity continuously illuminating devices are needed.

The main difficulty associated with automated survey of pavement surface distress is the rapid rate of data collection and the corresponding extraordinary computational needs, when real-time processing is to be implemented. However, real-time processing technology is still in development. When a compromise is made with respect to computing performance, both the data quality and performance speed are affected. However this issue is gradually being resolved with the continued development of high speed processors. Wang (2002) describes a pavement imaging system that is capable of analyzing automated distress survey data on a real-time basis at speeds of up to 20 mph.

2.0 PRELIMINARY STUDY

The first phase of this investigation involved a survey of 8 state agencies that have adopted similar automated pavement evaluation processes to examine their experience with respect to practices, equipment, specifications, methodologies, system reliability, and other pertinent issues relevant to this project. This survey was primarily limited to agencies that have adopted equipment from Roadware Corp., IMS Corp., and International Cybernetics Corp. (ICC). The main findings of the preliminary survey that covered transportation agencies of SC, NE, VA, IA, FL, PA, AL and NM is documented in the next section.

2.1 Survey of existing video-imaging systems

2.1.1 *RoadWare* Corporation

Roadway Corporation manufactures the ARAN Ford cube van type survey vehicle that uses the following instruments / elements:

1. Sony DXC 9000 (640x480) or higher resolution (1300x1030) analog area-scan cameras for right-of-way pictures at intervals of 5.22 feet captured at highway speeds.
2. At least 5 similar cameras installed at different orientations that can obtain roadside data (including guide rails etc.).
3. Similar cameras for pavement distress data collection, in conjunction with high intensity strobe lights which produce high quality pictures without interference.
4. Laser detectors that can measure the IRI and rutting and detect cracking.
5. *Applanix* gyroscope with a GPS receiver producing differential GPS readings within an accuracy of about 5 feet.
6. Automatic real time crack data analysis using the *WiseCrax* system. This system is said to have been verified to be repeatable and fairly accurate with respect to visual inspections in states such as PA, IA and AL. Data is typically more accurate on asphaltic pavements than in concrete pavements. One of the reported drawbacks is the inability of this system to differentiate between edge cracking and longitudinal cracking. The other issue involves interruptions due to the noise produced by recent pavement treatments such as chip seals etc.

7. A digital rating system known as *D-rate,* which has been used extensively by Louisiana DOT.

RoadWare Corporation has been actively using the *WiseCrax* system for automated survey of pavements. The data collection uses two area-scan analog cameras synchronized with a strobe illumination system, with each camera covering about half-width of a pavement lane. *RoadWare* Corporation is currently experimenting with a scanning laser system to automatically measure the shoulder drop-off. A summary of information gathered from state agencies that use *RoadWare* Corporation's pavement evaluation systems is provided in Table 2.1.

2.1.2 *IMS* Corporation

IMS Corporation produces roadway evaluation vehicles that use the following instruments/elements:

1. Moderate resolution (720x480) and higher resolution (1400x1040) area-scan cameras for right-of-way pictures at time intervals of 30 or 15 frames per second, respectively. Thus, for highway speeds (60 mph), the cameras can obtain high resolution frames at about 5 feet intervals. The images are stored on digital tape in AVI or .jpg format.

Table 2.1 Summary of DOT Interview Results for *Roadware Inc.*

Agency/ Operations	PA DOT[1]	IA DOT[2]	AL DOT[3]
No. of Vehicles	4	2	1
Surveyed Mileage Lane miles	54,000	30,000	36,000
Frequency	Bi-annual (contract basis)	Bi-annual (contract basis)	Bi-annual (contract basis)
Forward-looking Camera	For panoramic view (2)	Used only for some counties	For right of way and safety data
Side-view Camera	Used (2)	Used only for some counties	None
Pavement Camera (Area Scan)	Used (2)	Used	Used
Validation	IRI, rutting, Wisecrax Satisfactory	IRI,rutting, Wisecrax Satisfactory	IRI,rut,Wisecrax Satisfactory
GPS Survey used	Yes Validated	Yes Validated	Yes Off at overpasses
Cross-slopes measured	Yes every 52.8 ft	Planning to measure	Tried, only the average obtained
Manual Pavement Condition Survey	Yes, only on projects	Automatic Not manual any more	For quality control only
Laser profiling	Roughness/Rut	Roughness/Rut	Roughness/Rut
Extent of use of video-logs	Safety and ITS features and PCS at the network level	PCS at the network level	PCS at the network level
Manpower Requirements	2	2	2
Operational Difficulties	None	None	Block/Alligator unidentifiable
Overall Assessment	Very Satisfactory	Very Satisfactory	Very Satisfactory

Sources:
[1] Pennsylvania – Ms. Janice Arellano – Penn. DOT, Harrisburg, PA. Dept

[2] Iowa – Dr. Omar Smadi – Iowa State University Center for Transportation Research, IA

[3] Alabama – Mr. Harmon Moore – Alabama DOT (Research and Development), AL

2. A number of similar cameras installed at different orientations that can obtain roadside images.
3. Similar cameras for pavement distress data collection in conjunction with high intensity strobe lights which was reported to produce high quality pictures without interference. The strobe illuminating devices are synchronized with the camera shutter opening.
4. Conditioners to provide an uninterrupted power supply (UPS).
5. Up to eleven (11) laser detectors that can measure the IRI and rutting, accurately.
6. *Applanix* gyroscope with a GPS receiver producing differential GPS readings with a reported accuracy of 1 meter in real time. Three (3) separate receivers and the International Navigation System are used to determine GPS coordinates. When the data is post processed, and while the vehicle is within 10 miles from a base station, this accuracy can be improved to be within a few inches of the exact reading.
7. Automatic real time crack data reduction is performed using an optical method. This system is reported to have been verified as repeatable and accurate with respect to visual inspection in states/counties in TN, VT, FL, OR, GA and SC. This system also is claimed to be able to differentiate between edge cracking and longitudinal cracking.

A summary of information from state agencies using *IMS* Corporation's pavement evaluation systems is provided in Table 2.2.

Table 2.2 Summary of DOT Interview Results for *IMS Inc.*

Agency/ Operations	**NM DOT**[4]	**CO DOT**[5]	**Hillsborough County, FL**[6]
No. of Vehicles used	1	1	1
Surveyed Mileage Lane miles	14,000 Primary arterials	43,000	3000
Frequency	One time	One time contract	One time contract
Forward-looking Camera	Used two (2) for assets	Used two (2) for assets/road features	Performed by a different company[7]
Side-view Camera	Used one (1) for assets	Used one(1) for roadway features/signs	Performed by a different company[8]
Pavement Camera (Area Scan)	Not used very much used	Not interested in using	Used with automation
Validation	Still on contract	Still on contract	Validated at 4 locations
GPS Survey	Yes	Yes (not validated)	with inertial navigation
Cross-slopes Measured	Some of it done	Not interested	Yes
Manual Pavement Condition Survey	Yes (not concurrently)	Yes (not concurrently)	Yes (concurrently)
Laser profiling	Some roughness/Rut	not interested	Roughness/Rut
Extent of use of Video-logs	Network assets	PCS	County level PCS
Manpower operator + driver)	At least 2	2	3 (raters + Replacement)
Operational Difficulties/ Problems	No basis for comment	No basis for comment	Mis-match of data with route maps and sections
Overall Assessment	Undecided	Undecided	Unsatisfactory

Sources:
[4] Mr. Richard Byrne, New Mexico State Highway and Transportation Dept.
[5] Mr. John Coil, Denver Regional Council of Governments, CO
[6] Mr. Jim Thigpenn, Hillsborough County, Public Works Dept., FL
[8] Talcan Inc.

2.1.3. International Cybernetics Corporation (ICC)

ICC produces a Ford E-350 XLT type inspection vehicle equipped with all or some of the following instruments / elements:

1. High resolution (1300x1024) area-scan camera for right-of-way pictures at intervals up to 5.22 feet at highway speeds (60 mph).
2. One other similar camera installed at a different orientation that can obtain roadside data (including guide rails etc.).
3. Downward line scan cameras (2K) for pavement distress data collection in conjunction with a high intensity continuous lighting system.
4. Laser detectors that can measure IRI and rutting.
5. *Applanix* Position and Orientation System (POS) integrated with an 8 channel DGPS receiver producing differential GPS readings at an accuracy of 1 to 3 meters. A reading is taken every second and the position of the immediately intermediate points reported at 0.25 second intervals.
6. Manual crack data analysis system.

The Principal Investigator also conducted telephone interviews with a number of engineers who are familiar with ICC video-logging equipment used by several Departments of Transportation including Virginia, Nebraska and South Carolina. Table 2.3 provides a summary of these results. Details of these interviews are found in Appendices I –III.

Table 2.3 Summary of DOT Interview Results for *ICC Inc.*

Agency/ Operations	VA DOT[8]	SC DOT[9]	NE DOT[10]
No. of Vehicles	2	1	1
Surveyed Mileage Lane miles	13,000	42,000 (1,600 Interstate)	10,000
Frequency	Annual	Interstates - Annual US/SC/Sec. – every 3 yrs.	Annual
Forward-looking	Yes (1)	No	Yes
Side-view Camera	No	No	No
Pavement Camera	Digital Line-scan	Area scan (panoramic)	Area scan
Validation	Somewhat	Inadequate	Inadequate
GPS Survey Used	Yes, Diff. GPS/tied to DMI	Yes, Tied to DMI	Yes, Diff. GPS Tied to DMI
Cross-slopes Measured	No	No	No
Manual Pavement Condition Survey	Yes/not tied to imaging	Combined with video-logging	Yes, not tied to imaging
Laser profiling	Profile/Rut	Profile/Rut	Profile/Rut
Extent of use of video-logs	Special projects and research	QC of PCS data	Network level
Manpower Requirements	2 operators + 3-4 raters	4 operators	3 operators alternating
Operational difficulties	Generator/ Software Problems	Storage problems at the network level	Data acquisition Computer mis-communication
Overall Assessment	Very Satisfactory	Very Satisfactory	Very Satisfactory

[8] Mr. Doug Gillman, Virginia Transportation Dept
[9] Mr. Tom Shea, South Carolina Dept. of Transportation
[11] Mr. Gary Brahel, Nebraska Dept. of Transportation

2.2 Summary of preliminary findings

1. Although the practice of using both forward-view and pavement cameras in their surveys is seen to be common among the surveyed agencies, none of them reported collecting a complete set of highway and pavement data that include safety, pavement, highway geometry and position location data

2. The surveyed agencies have not performed systematic validation of all of the devices used by their survey vehicles.

3. Most agencies report data collection on an annual or bi-annual basis.

4. Only one agency (VDOT) reported in-house imaging of part of its highway network while most agencies contract this work to outside agencies.

5. Most of the surveyed agencies expressed their satisfaction with the quality of videos and only one agency (SCDOT) reported data storage difficulties.

3.0 DETAILED DESCRIPTION OF THE SURVEY VEHICLE

The main features and functionalities of the FDOT evaluation vehicle produced by International Cybernetics Corporation (ICC) (Fig. 3.1) are described in this Chapter.

Fig. 3.1 FDOT Survey Vehicle

3.1 Front-view and Side-view Cameras

The survey vehicle uses two high resolution (1300 x 1024) digital area-scan cameras for front-view and side-view pictures at a rate up to 12 frames per second enabling digital image capture up to an operating speed of 60 mph. The front-view camera (Figure 3.2) captures the view straight in front of the van while the side view camera is set up at an angle to obtain images of features mostly out of the front camera field of view. These cameras are mounted in a Pelco enclosure with a fan and a heater to protect them from environmental effects. The front-view camera uses a 8.5 mm focal length lens while the side-view camera uses a 25 mm focal length lens.

Figure 3.2 Front-view/Side-view Cameras of the FDOT Survey Vehicle

The front-view camera is used to record right of way features, including but not limited to:

- Pavement markings
- Number of lanes
- Permanent roadway signing
- Work zones
- Traffic control and monitoring devices
- Structures

The Side-view camera is used to record the following features:

- Permanent roadway signs, street signs and bridge numbers
- Miscellaneous safety features

3.2 Downward-view Camera

The main characteristics of the FDOT Survey Vehicle's downward camera system are as follows:

- Line scan camera (Figure 3.3) to provide quality pictures with a linear resolution of 2048 pixels, which is later compressed for data storage purpose.
- A rigid mounting to minimize disturbance to imaging during vehicle movement.

Figure 3.3 Downward Camera of the FDOT Survey Vehicle

3.3 Global Positioning System (GPS) and Inertial Measurements

GPS is a network of 28 satellites and is funded and controlled by the U. S. Department of Defense (DOD). While there are many thousands of civilian users of GPS world-wide, the system was originally designed for the U. S. military. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling it to compute position, velocity and time. Four GPS satellite signals (Figure 3.4) are used to compute positions in three dimensions and the time offset in the receiver clock.

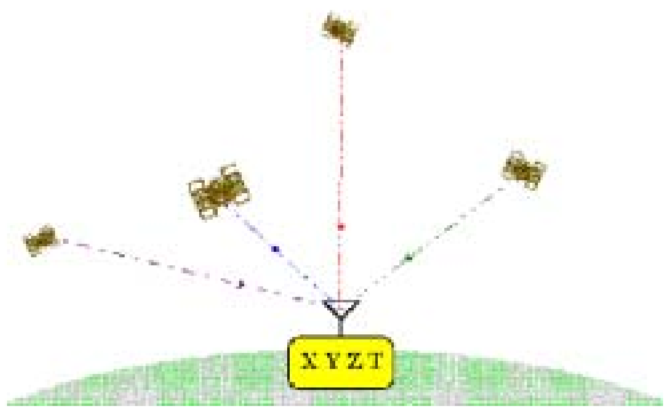


Figure 3.4 The GPS system

The GPS system contains the following segments:

- Space Segment. The Space Segment of the system consists of the GPS satellites (Figure 3.5). These space vehicles (SVs) send radio signals from space. The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours. The orbiting of satellites closely resonates with the earth's rotation period (2 orbits per day) so that the orbit track repeats itself within each 24-hour day gaining approximately 4 minutes each. There are six orbital planes (with nominally four SVs in each), equally spaced (60 degrees apart), and inclined at about fifty-five degrees with respect to the equatorial plane. This constellation provides the user with between five to eight SVs visible from any point on the earth.
- Control Segment. The Control Segment consists of a system of tracking stations located around the world. The Master Control facility is located at Schriever Air Force Base, Colorado. These monitoring stations measure signals from the SVs, which are

incorporated into orbital models for each satellite. The models compute precise orbital data (ephemeris) and SV clock corrections for each satellite. The Master Control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals.

Figure 3.5 GPS satellite

- User Segment. The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and T (time). GPS receivers are used for navigation, positioning, time dissemination, and other research. Navigation in three dimensions (Figure 3.6) is the primary function of GPS. Navigation receivers are made for aircraft, ships, ground vehicles, and for hand carrying by individuals. Precise positioning is made possible at reference locations using GPS receivers that provide corrections and relative positioning data for remote receivers. Surveying, geodetic control, and plate tectonic studies are examples.

Time and frequency dissemination, based on precise clocks on board the SVs and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers.

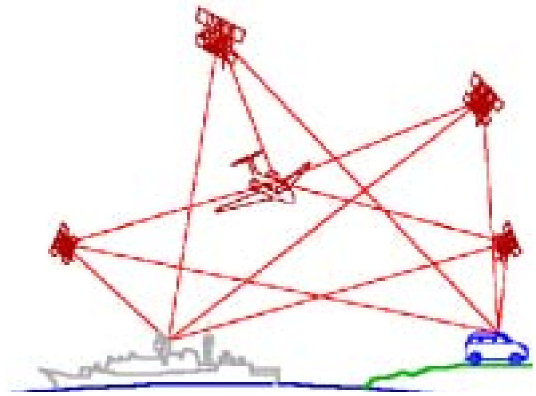


Figure 3.6 GPS navigation

The GPS Navigation Message consists of time-tagged data bits marking the time of transmission of each subframe at the time they are transmitted by the SV. A data bit frame consists of 1500 bits divided into five 300-bit subframes. A data frame is transmitted every thirty seconds. Three six-second subframes contain orbital and clock data. SV clock corrections are sent in subframe one and precise SV orbital data sets (ephemeris data parameters) for the transmitting SV are sent in subframes two and three. Subframes four and five are used to transmit different pages of system data. An entire set of twenty-five frames (125 subframes) makes up the complete Navigation Message that is sent over a 12.5 minute period. Despite their strengths, GPS systems suffer from a number of drawbacks. Common types of errors that affect GPS are:

- **Selective Availability (SA)**. This is the intentional degradation of the SSV signals by a time varying bias. SA is controlled by the Department of Defense (DOD) to limit the accuracy for non U. S. military and government users. The potential accuracy of the Coarse/Acquisition (C/A) code of around 30 meters is reduced to 100 meters (two standard deviations). This restriction is being relaxed.

- **SV clock error** which when uncorrected by Controlling Station can result in one meter errors.

- **Troposphere delays.** The troposphere is the lower part (ground level to from 8 to 13 km) of the atmosphere that experiences the changes in temperature, pressure, and humidity associated with weather changes. Complex models of troposphere delay require estimates or measurements of these parameters. This error can result in errors of the order of 1 m.

- **Unmodeled ionosphere delays.** The ionosphere is the layer of the atmosphere from 50 to 500 km that consists of ionized air. The transmitted model can only remove about half of the possible 70 ns of delay leaving a ten meter un-modeled residual. This delay can result in 10 m errors.

- **Multipath.** Multipath is caused by reflected signals from surfaces near the receiver that can either interfere with or be mistaken for the signal that follows the straight line path from the satellite. Multipath is difficult to detect and sometime hard to avoid and it contributes to about 0.5 m inaccuracy.

- **Blunders** can result in errors of hundreds of kilometers. Source of error can be Control segment mistakes due to computer or human error, user mistakes, including incorrect geodetic datum selection, and receiver errors from software or hardware failures.

- **Noise and bias errors.** When combined these result in an error range of around 15 meters for each satellite, as shown in Figure 3.7.

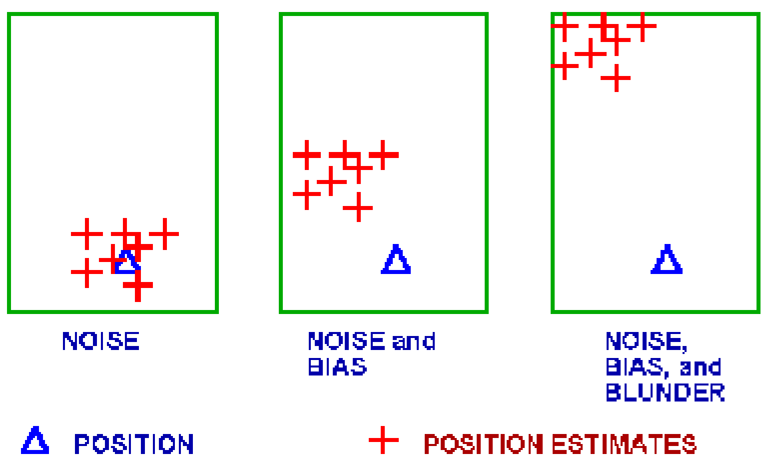


Figure 3.7 Errors in the position estimates

Differential positioning technique is used to correct the bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal and relays the information to users. FDOT survey vehicle uses a differential GPS system produced by *Applanix* Corp. (Fig. 3.8).

Figure 3.8 Differential GPS Receiver Antenna

GPS is an excellent tool for position location, especially for slow moving vehicles in open areas. However, in road survey one cannot afford the occasional loss in position data caused by blocked satellites, and one requires data updated more frequently than is possible with current receiver technology. In many of these cases, the requirement can be met with an inertial system which can update very frequently (300+ times a second). The use of inertial technology for measuring position and orientation has a number of advantages, especially for moving vehicles. It provides high accuracy irrespective of vehicle motion, and is self-contained. However, inertial systems require an external position fix at the start/end of the vehicle's run to provide geographic context for the system's observations, and errors grow over time, making an inertial system best suited for short duration testing only. In the FDOT survey vehicle, regular external position fixes are incorporated using GPS.

The heart of an inertial navigation system is the Inertial Measurement Unit (IMU) which is a self-contained sensor consisting of three accelerometers and three gyroscopes. This sensor is bolted to the vehicle, so that it undergoes the same motion as the vehicle. The accelerometers measure acceleration along each of the three axes (X, Y and Z), and therefore provide a measure of the vehicle's acceleration. If the IMU's initial location is known, integration of the accelerations experienced by the vehicle will yield vehicle position. The three gyroscopes measure angular rotation around the corresponding axes and are used to determine vehicle orientation, grade, and curvature of a road. The *Applanix* system is used for global positioning and inertial navigation of the FDOT survey vehicle.

Figure 3.9 *Applanix* System

The *Applanix POS*^{TM} (Position and Orientation System) (Figure 3.9) family of products integrates GPS and inertial technologies into one robust, precise position and orientation system that provides the benefits of both technologies, while minimizing their shortcomings. The core of an *Applanix* system is the IMU, which provides the advantages of an inertial solution. The IMU is complemented with one or more GPS receivers, whose position information serves to provide the inertial solution with position updates, thereby controlling the error growth. If the GPS receiver is unable to provide position information (e.g. due to blocked satellites), the IMU will continue to provide position and orientation information, unaided.

The IMU of the *Applanix* system contains three fiber-optic gyros, three silicon accelerometers, and data processing and conversion electronics. The physical principle of this type of gyroscope operation is analogous to the Doppler effect, but in this instance it involves determination of the phase shift between two counter propagating light beams. This system uses strap down inertial navigation, Kalman filtering, GPS, GPS azimuth measurement and distance measurement indicators (DMI) to provide position and orientation data that have a high bandwidth, excellent short-term accuracy and minimum long-term errors. Figure 3.10 shows the Block configuration of the GPS/IMU system.

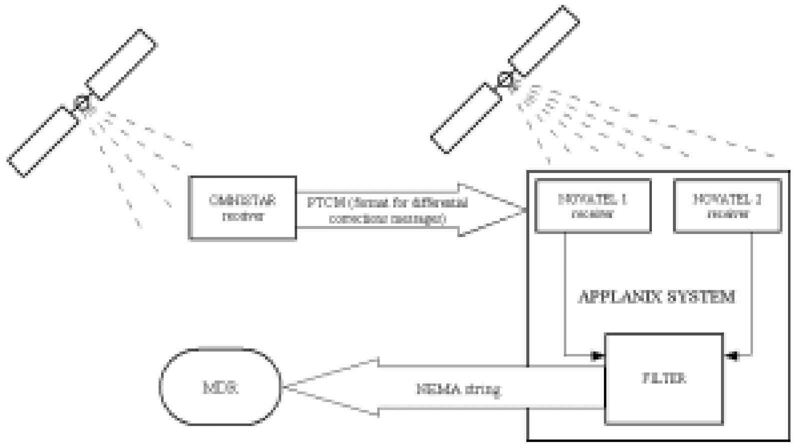


Figure 3.10 Block Diagram of the GPS/IMU System in the Survey Vehicle

3.4 High Speed Laser Profiler

The profiler consists of a 3 laser (two 32 KHz and one 16 KHz), and 2-accelerometer system conforming to ASTM E950 Class I, an industrial hardened Pentium IV computer, two active Matrix flat panel display monitors, an internal 80 Gigabyte data storage hard drive, floppy drive, a mass removable storage drive, an ink-jet printer, an event marker board, and Distance Measuring Instrument (DMI).

3.5 Computer Systems

The FDOT surveying van contains four computers, each controlling the following devices:

- Downward-view camera
- Forward-view camera
- Side-view camera
- DOS Mobile Data Recorder (MDR)

Each of the four computers uses an Intel Pentium IV processor with 512 MB of system memory and operates under Microsoft Windows 2000. All of the processes related to the pavement camera are performed by a line scan camera computer. This computer contains a special encoder board that controls the timing of the pavement camera triggering, and a capturing card that controls image capture.

The MDR computer controls all the information produced through several sensing devices. It processes and collects information like the distance traveled, measured by the Distance Measuring Instrument (DMI), GPS data, information related to all three digital cameras such as the settings for lighting condition, f-stop, compression ratio, starting frame, ending frame, IRI data and other information entered by the raters such as road and section identification etc.

3.6 Digital image processing

The heart of the imaging system is the Charge Coupled Device (CCD) chip. It is a silicon photosensitive chip containing numerous photosensitive diodes that convert photons into electrical charge. A layer of the Bayer filter is placed over the silicon chip. This filter (Figure 3.11) contains a number of small filters for each photosensitive diode, so that each photosensitive pixel recognizes one designated color out of G, R or B. The CCD contains twice as much green photosensitive pixels as the other color pixels due to human eyes' unequal sensitivity to the three colors.

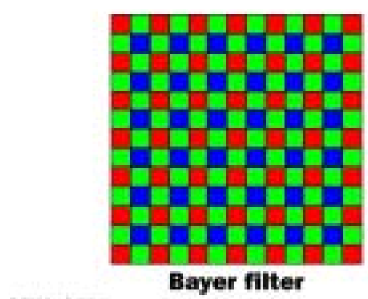


Figure 3.11 Bayer filter

The CCD sensor creates an unprocessed (raw) image. In this image (Figure 3.12), each pixel records information about one color. In the next step, the digital camera uses a demosaicing algorithm to convert mosaic of separate colors, or RAW file, into equally sized mosaic of true colors. To get the true color of a single pixel, an averaging technique (Appendix V) that considers the colors of the neighboring pixels is used. This is another function of the Bayer filter.

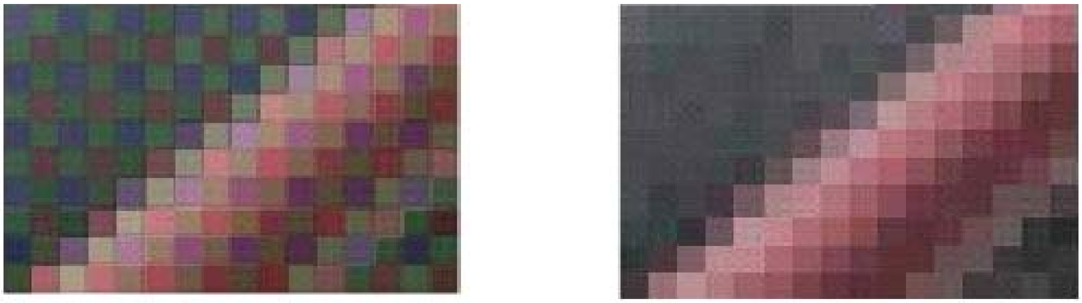


Figure 3.12 Comparison of raw and processed images

When setting up the digital imaging system for the evaluation vehicle (Fig. 3.13), one performs the white balance adjustment for front-view and side-view cameras. In the first step, a raw image is created by the CCD sensor. This image is then processed by the Bayer pattern function which determines the required individual R, G and B corrections to be applied to each pixel based on the white balance settings. The Bayer pattern function is also used to create a true color image, the histogram of which is evaluated to determine the camera's best exposure and gain settings. With these values, a second image is obtained and the white balance is determined through the Bayer pattern function again. Then, a new set of values for gain and exposure are determined and set. This process is repeated several times until the best settings are set and matched by trial and error.

Figure 3.13 also shows, in dashed lines, a still unutilized *Appix* capturing system that could automatically adjust the contrast, the brightness, and apply gamma correction and other functions in real-time. This would certainly be a potential image quality improvement that precludes the need for post processing quality enhancement.

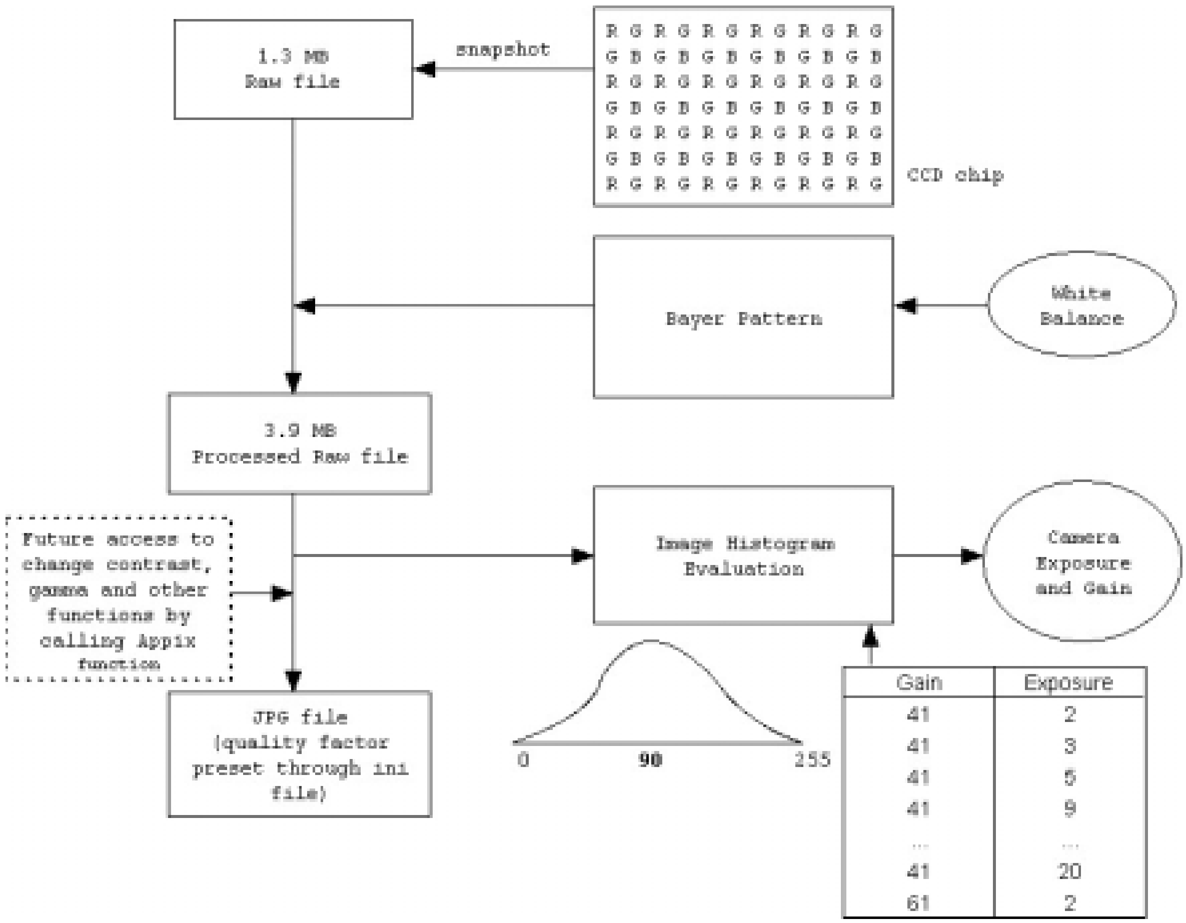


Figure 3.13 Potential Image Processing for the Survey Vehicle

Finally, when the correct values for white balancing are set, the imaging system would be ready for real time capturing. In the subsequent process, the white balance is not altered any further and only values for gain and exposure for the camera are re-evaluated and changed with varying lighting conditions. Through the capturing process, the true color image can be saved on the hard drive of the particular computer in the JPEG format using a desired compression ratio and other quality factors. This issue will be addressed further in the next section.

3.7 Processing and storing of images in the evaluation vehicle

As described in the preceding section, the imaging system of the survey vehicle first creates a raw image of an object which is then processed to create a true-color or processed raw image in real time through *Appix* capture software. This raw image is processed once more to create a JPG file with a predefined optimum compression ratio of 75%. Because of its relatively fast access time, most of the operations are done in the RAM of the camera computers. In the early stages of the evaluation vehicle development, the above raw image was created as a Bitmap file which was later changed to the JPEG format in order to improve the efficiency of the capturing and storing procedure.

Typically, Windows Bitmap file format is the standard file format used by Microsoft Windows to store device-independent and application-independent images. Bitmap files can contain either 2 (black and white), 16, 256, or 16.7 million colors. Most Windows Bitmap files are not compressed. The default file extension for this file format is "*.BMP." Figure 3.14 shows a typical bitmap image.

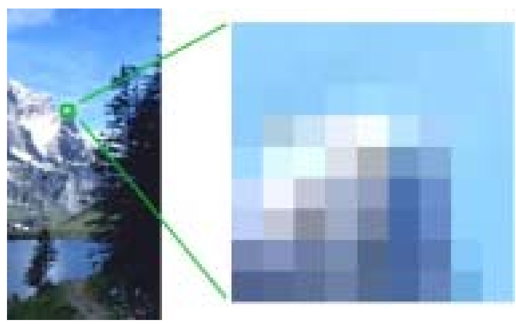


Figure 3.14 Typical Bitmap image

Joint Photographic Experts Groups, or JPEG, is a common compression scheme that works well for natural scenes, such as scanned photographs or images taken by digital cameras. Some information relevant to the survey vehicle, such as clarity of road signs and the identification ability of fine cracks can get lost in the compression process. JPEG color images store 24 bytes per pixel, and thus they are capable of displaying more than 16 million colors. On the other hand, JPEG File Interchange Format (JFIF) is a file format commonly used for storing and transferring images that have been compressed according to the JPEG scheme. These JFIF files, displayed by Web browsers, use the "*.JPG" file name extension.

The level of compression in JPEG images is configurable, but higher compression levels (smaller files) result in larger loss of information. A 20:1 compression ratio often produces an image that the human eye finds difficult to identify with respect to the original. Figure 3.15 shows a BMP image and two JPEG images that were compressed at ratios of 4:1 and 8:1 from the corresponding BMP image.

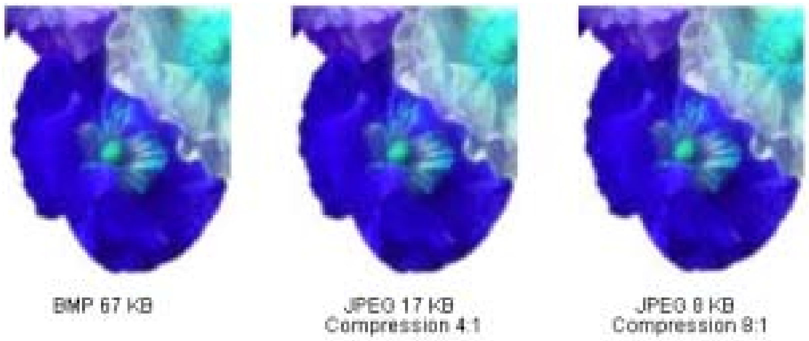


Figure 3.15 Original image and two JPEG images compressed from the original

JPEG compression does not work well for line drawings, blocks of solid color, and sharp boundaries. Figure 3.16 shows a BMP image along with two corresponding JPEG images compressed from the BMP one. The compression ratios are 4:1 for the smaller JPEG image and 8:3 for the larger JPEG image. It is noticed that conversion to the JPEG format tends to blur the boundaries.

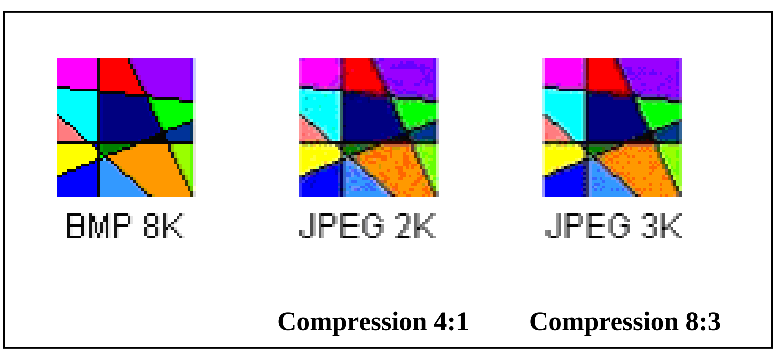


Figure 3.16. Comparison of linear features quality in pictures after compression

4.0 TESTING OF CAMERA SYSTEMS

The preliminary study described in Chapter 2 demonstrated that most highway agencies that use ICC's pavement evaluation equipment have not conducted any systematic validations of their instruments. Hence a testing program was initiated at USF for a methodical validation and quality control of the ICC survey vehicle subsystems.

4.1 Image quality check for front-view and side-view images

The image capture software in the FDOT survey vehicle automatically controls exposure time of system cameras to adjust for varying lighting conditions. The automatic exposure control allows the vehicle to travel through shadows or overpasses while maintaining excellent image quality. It was observed during testing that this would be effective only after the vehicle travels long enough through a different lighting environment since the data imaging system needs several pictures to adjust to the new lighting conditions. On-board computers and software control the operation of all cameras and sensors. The wheel encoder sets the system timing to trigger camera image capture events. The high-precision Distance Measuring Instrumentation (DMI) sets the DOS Mobile Data Recorder (MDR) system timing and triggers events at specified distance intervals. From a keyboard, the operator initiates the beginning and end of road sections or project segments and initializes the DMI (if desired). In addition, the DOS MDR also collects profile data from laser sensors.

An investigation was carried out to evaluate the quality of frontview and sideview images captured by the FDOT survey vehicle with respect to existing FDOT frontview images from previous year's surveys which were used as a reference for this evaluation. A test run on Fowler Avenue, Tampa in Florida was used for this purpose. In addition, a mass photo enhancement scheme was used using *Adobe PhotoShop* software package to investigate the possibility of improving the quality of images. Photo enhancement is based on the *Action* feature of *Adobe PhotoShop* (Fig. 4.1)

The *Action* feature initiates a predefined set of values for image quality alteration that can be applied for images of a subsequent entire run. Mainly three adjustments are used in this operation:

- Tonal level adjustment which corrects the tonal range and color balance of any image by adjusting the intensity levels of the image's shadows, midtones, and highlights (Fig. 4.2).
- Contrast and brightness adjustment is an adjustment of tonal range that makes uniform adjustments in every pixel of the image.
- Color balance adjustment for achieving the optimum color combination.

Fig. 4.3 illustrates a comparison of a raw sideview image and the corresponding adjusted image.

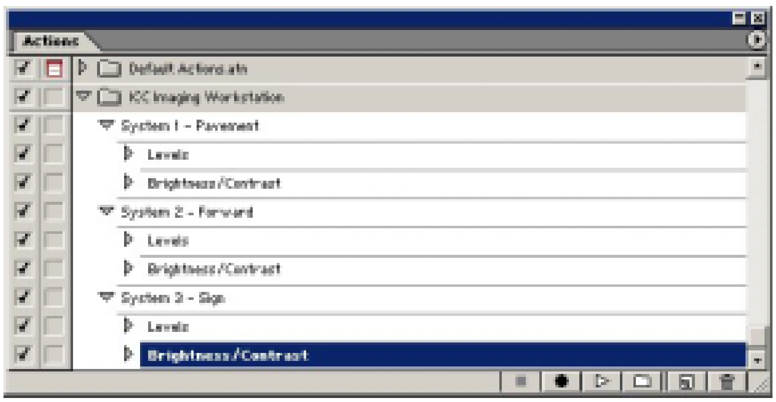


Figure 4.1 Predefined Action features of Adobe PhotoShop

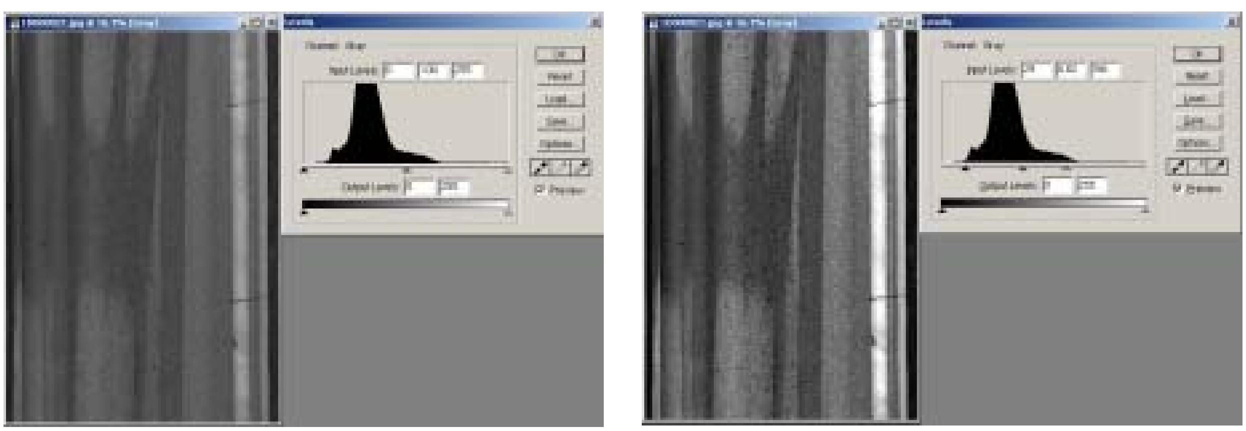


Figure 4.2 Tonal Level correction of downward image

(a) Raw image **(b) Adjusted image**

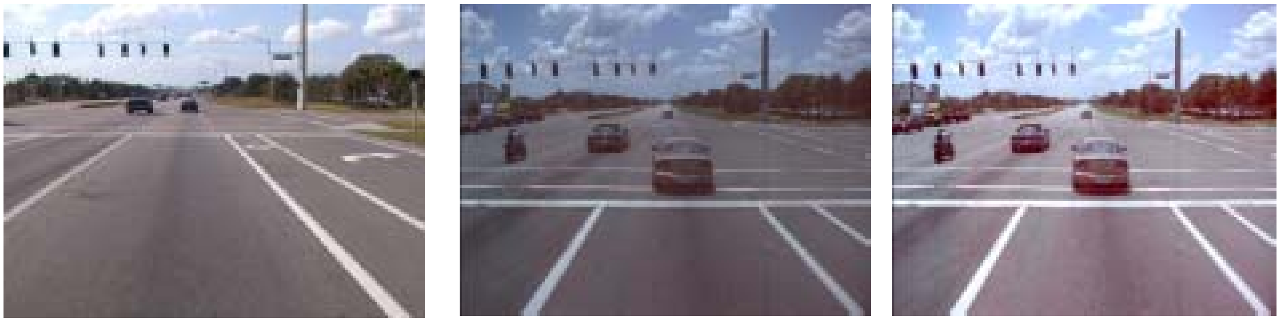
Figure 4.3 Tonal level, contrast, brightness, and color adjustment of side-view image

Figures 4.4(a) - (c) illustrate a comparison of frontview images. It was revealed that the relative darkness seen in Fig. 4.4(b) compared to Fig. 4.4(a) was due to the position and orientation of the frontview camera which over exposed this camera to bright sunlight reflected from the sky. Darkness of frontview images can be attributed to the following:

1) the optical system of the camera. This is explained by the more satisfactory image quality obtained with the sideview camera which uses the same hardware except for the optics.
2) the settings of the capturing software, such as the white-balance and exposure settings that one has to properly set inside the capturing program, before a run is performed.

The following suggestions are made for improvement of the image quality:

1) perform white-balance when conditions change from sunny to cloudy, and vise versa.
2) use a lens hood to shield the frontview camera from direct sunlight.
3) use of built-in ability of the capturing software to alter tonal level, contrast, and brightness (Section 3.6, Fig. 3.13). This development has been addressed with ICC.
4) better understanding of the Bayer pattern process used for setting the correct color combination of a image in conjunction with white-balance.
5) tilting down the frontview camera so that clouds fill a minimum portion of the view.



(a) 2001 FDOT image on Fowler/Spectrum Blvd. b) Image from FDOT Survey Vehicle (c) Enhanced image b

Figure 4.4 Comparison of front-view images of the survey vehicle with existing images

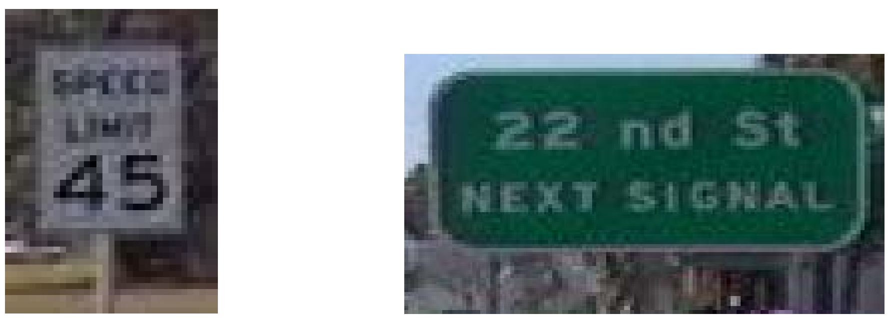
Later, this problem was partly rectified by designing a sunshade for the camera (suggestions 2 and 5), which reduced the need for picture enhancement. In general, the quality of these images was significantly improved by Adobe PhotoShop software used in conjunction with ICC workstation program (Fig. 4.4c). It must be noted that the image enhancement technique becomes practical only if the general lighting condition does not change drastically during the run. Otherwise the initial image chosen to obtain the enhancement settings would not be representative of the quality of the entire set of images. Hence this solution may be useful when enhancing a small number of images captured within a relatively short period of time and certainly not for capturing of images at the network level.

In addition to the above problem, an unusual pink color appeared on video images captured by the frontview camera due to over-exposure to sunlight. As shown in Figure 4.5, this condition does not occur where shadows (shown with yellow arrows) are cast on the road.

Figures 4.6 (a) and (b) show the comparison between right-of-way traffic signs captured by the sideview camera and the currently available FDOT images of the same traffic signs recorded with a single frontview camera. To make an allowance for the different sizes of the images (1300 x 1024 pixels for the sideview camera versus 640 x 480 pixels for the existing FDOT images), the existing FDOT images have been zoomed in. The use of a sideview-camera with a narrow view range lens is seen to improve the picture resolution and clearly preclude the need for any enhancement. Furthermore, the sideview images show acceptable contrast, brightness, and tonal level with no issue of a pink color.

(a) Occurrence of the unusual pink color (b) reduction of pink color under shadows

Figure 4.5 Occurrence of an unusual pink color on two front-view images except where shadows are cast on the road



(a) Existing 2001 images from FDOT files (zoomed in)

(b) Current images from FDOT Survey Vehicle

Fig 4.6 Comparison of side-view images of the survey vehicle with existing images

4.2 Quality check of downward camera images

4.2.1 Pavement Distress Surveys

The ultimate goal of a pavement distress survey is to evaluate the pavement surface and determine different distress types, their severities and extents. Pavement distress surveys can be performed manually, or with the aid of imaging equipment which will make the survey a semi-automated one. Table 4.1 summarizes the differences between the two types of pavement distress surveys.

Table 4.1 Key differences between Manual and Imaging surveys

Variable	Manual	Imagery
Traffic Control	Full lane closure	Not required
Lighting Conditions	Daylight (uncontrolled)	Uniform artificial illumination
Required Manpower	At least two	At least one
Duration of survey	Relatively long	Short
Permanent Record	Visual Evaluation (subjective)	Digital photograph (objective)
View of Pavement Surface	Direct, three-dimensional	Indirect (photograph), two-dimensional image
Ability to See Fine Cracks	Limited by eye sight	Limited by image resolution

4.2.2 Crack Classification

The FHWA Distress Identification Manual describes a crack classification system developed by the Federal Highway Administration as part of the Strategic Highway Research Program (SHRP)(Table 4.2). This is commonly used by many transportation agencies for crack severity evaluations.

Table 4.2 Most common asphalt pavement distress types

Distress type	Low level	Medium level	High level
Fatigue cracking	Fine, longitudinal hairline cracks. Cracks are not spalled	Pattern of cracks that may be lightly spalled	Progressed pattern cracking, well defined and spalled at the edges.
Longitudinal cracking	≤ 0.25"	> 0.25 " and ≤ 0.75 "	> 0.75 "
Transverse cracking	≤ 0.25"	> 0.25 " and ≤ 0.75 "	> 0.75 "
Patch / Pavement deterioration	Patch has any low severity distress type	Patch has any medium severity distress type	Patch has any high severity distress type

The main characteristics of the FDOT survey vehicle's downward camera system are listed below:

- Ability to capture high-resolution digital images of the pavement under various lighting conditions and at varying posted speeds.
- Capability to work in conjunction with ICC's imaging workstation software.
- A line scan camera with a linear resolution of 2048 pixels covering a width of approximately 14.5 feet. This camera is attached to a system able to produce image lengths according to the users' need. For example, 20 feet is the current image length of the downward images, providing a frame of 2048x2942 resolution.
- A lighting system of 10 lamps at 150 watts each with polished reflectors, which is used to illuminate the road. This lighting system is used to ensure that the downward camera acquires good quality images of the pavement within a very short period of time.

In order to test the imaging capabilities of the FDOT Survey Vehicle's downward camera system, three asphalt pavement sections were evaluated using two different methods; (1) visual evaluation of the pavement, and (2) using the digital images from the Survey Vehicle. The visual survey was conducted according to the Distress Identification Manual (FHWA, 1993).

4.2.3 Survey Sections

Three different asphalt pavement sections were evaluated during this study. The details of these sections are shown in Table 4.3.

Table 4.3 Details of surveyed sections

Section	City	Length (ft)	Date
(a) US 441	Gainesville, FL	100	Feb 2002
(b) SR 331	Gainesville, FL	100	Feb 2002
(c) 50th Street	Tampa, FL	300	Jun 2002

4.2.4 Comparison between manual surveys and image capturing

The information provided in Tables 4.4(a) – 4.4(c) was used to cross-reference between the manual surveys and captured data.

Table 4.4 Cross-reference aid between the manual survey and digital imaging

(a) US-441

Manual Survey		Photographic Imaging	
Distress map no.	Distance post (ft)	Image no.	Distance post (ft)
1	0 - 30	1d000059	0 - 20
1 - 2	-	1d000060	20 - 40
2	30 - 60	1d000061	40 - 60
3		1d000062	60 - 80
3 - 4		1d000063	80 - 100
4	60 - 90	1d000064	100 - 120

(b) SR-331

Manual Survey		Photographic Imaging	
Distress map no.	Distance post (ft)	Image no.	Distance post (ft)
1	0 - 30	1d000118	0 - 20
1 - 2	-	1d000119	20 - 40
2	30 - 60	1d000120	40 - 60
3		1d000121	60 - 80
3 - 4		1d000122	80 - 100
4	60 - 90	1d000123	100 - 120

(c) 50th street

Manual Survey		Photographic Imaging	
Distress map no.	Distance post (ft)	Image no.	Distance post (ft)
1	0 - 30	1d000030	0 - 20
1 - 2	-	1d000031	20 - 40
2	30 - 60	1d000032	40 - 60
3		1d000033	60 - 80
3 - 4		1d000034	80 - 100
4	60 - 90	1d000035	100 - 120
5		1d000036	120 - 140
5 - 6	90 - 120	1d000037	140 - 160
6		1d000038	160 - 180
7		1d000039	180 - 200
7 - 8	120 - 150	1d000040	200 - 220
8		1d000041	220 - 240
9	150 - 180	1d000042	240 - 260
9 - 10		1d000043	260 - 280
10		1d000044	280 - 300
11	180 - 210	1d000045	300 - 320
11 - 12		1d000046	320 - 340
12	210 - 240	1d000047	340 - 360
13		1d000048	360 - 380
13 - 14		1d000049	380 - 400
14	240 - 270	1d000050	400 - 420
15		1d000051	420 - 440
15 - 16	270 - 300	1d000052	440 - 460
16		1d000053	460 - 480

Table 4.5 shows the comparison of distress evaluation based on the two methods, for the previous pavement sections. Significant differences were observed between the two methods - surveyed and captured fatigue and longitudinal cracking. The difference in the estimates of the extent of cracking can be attributed to the higher accuracy with which cracks can be detected using images. The semi-automatic crack analysis software used in image evaluations has the

ability to track the shape of a crack and hence determine, in a more realistic manner, the real length of the crack. In addition one is able to zoom in the crack image for more precise evaluation. On the other hand, freedom for such meticulous evaluation is certainly limited when conducting manual surveys.

Table 4.5 Comparison between manual pavement survey and digital imaging

Distress type	Severity	US 441			SR 331			50th Street		
		Manual	Photog.	Diff.	Manual	Photog.	Diff.	Manual	Photog.	Diff.
Transverse cracking (ft)	Low	21	20	-5%	52	55	6%	130	154.6	19%
	Medium	28	27	-4%	33	32	-3%	9.5	8.8	-7%
	High	14	15.5	11%	4	4.5	13%	0	0	
Longitudinal cracking (ft)	Low	80	82	3%	47.5	46	-3%	61	55.5	-9%
	Medium	157	155	-1%	15.5	16	3%	28	20.2	-28%
	High	25	25	0%	0	0		0	0	
Fatigue cracking (sq ft)	Low	45.5	45	-1%	132.5	128	-3%	33.5	45.4	36%
	Medium	30	28	-7%	0	0		0	0	
	High	0	0		0	0		0	0	
Patching (sq ft)	Low	0	0		0	0		42	41	-2%
	Medium	0	0		0	0		0	0	
	High	0	0		0	0		0	0	

4.2.5 Spot checks

A number of spot checks were also conducted to verify the accuracy of imaging. Figure 4.7 shows the corresponding distress map and the video images of a location on the 50th street, Tampa, FL, which illustrates a reasonably good comparison.

4.2.6 Pavement imaging issues to be resolved

1) Minimum measurable crack width

For crack widths less than 0.1 in, the extent of zooming needed for gauging the width produces distortion as seen in Figure 4.8. Thus, it was determined that the width of any crack had to be at least 0.1 inches in order to gauge its width using the zooming tool available in the viewer software. Thus, one can conclude that the resolution provided by pavement distress images is certainly adequate for identifying low-severity cracks (Table 4.2).

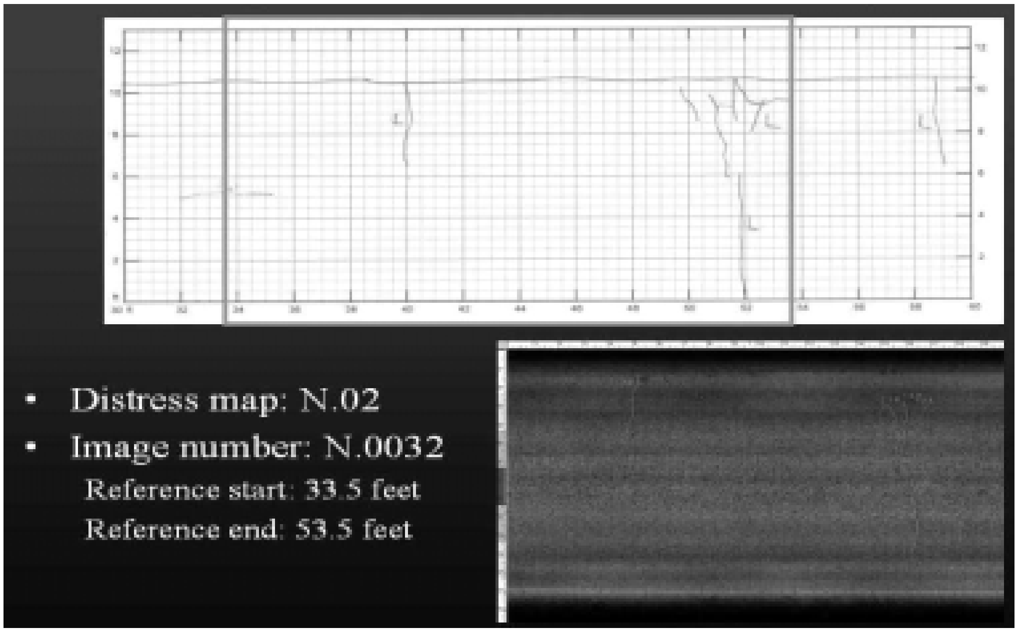


Figure 4.7 Comparison of manual survey and digital imaging

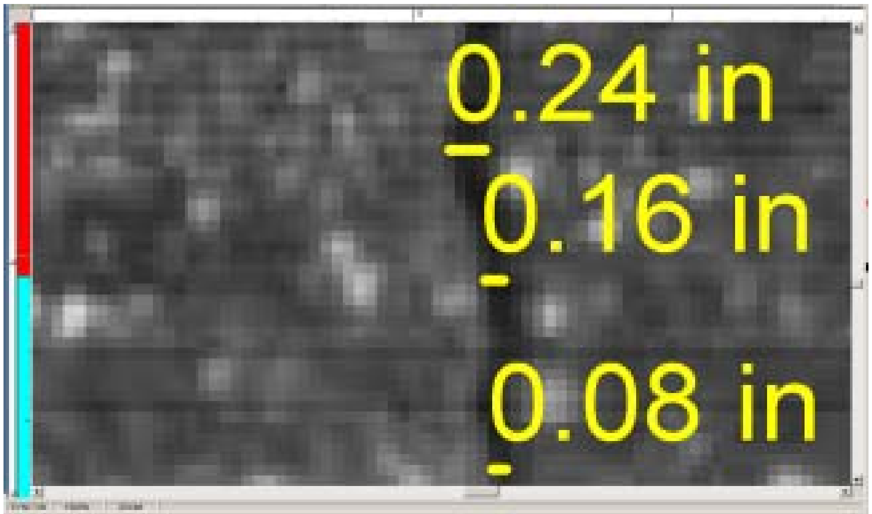


Figure 4.8 Appearance of crack at 1500 % zooming in

2) Distortion on curves

Some distortion was observed in the downward images both during curved and straight runs. On curves this effect is caused because of the very nature of line-scan imaging. The line-scan camera takes 2 mm wide image strips of the pavement at a time and combines these strips to form one image frame. Hence when the van traverses a curve, the inner part of the focused area will overlap in several consecutive frames because of the relatively slow linear speed of the inner part of the focused patch.

Figure 4.9 Distortion in downward images on curves

3) Shadows in the downward images

The illumination system does not cover the entire area that is captured at a given instance. This is especially the case at edges of pavements and in cases where shadows appear on the pavement surface (Fig. 4.10). The above deficiency produces shadows on the images depending on the position of the sun. Such shadows often appear on the images particularly when surveying is performed on bridges.

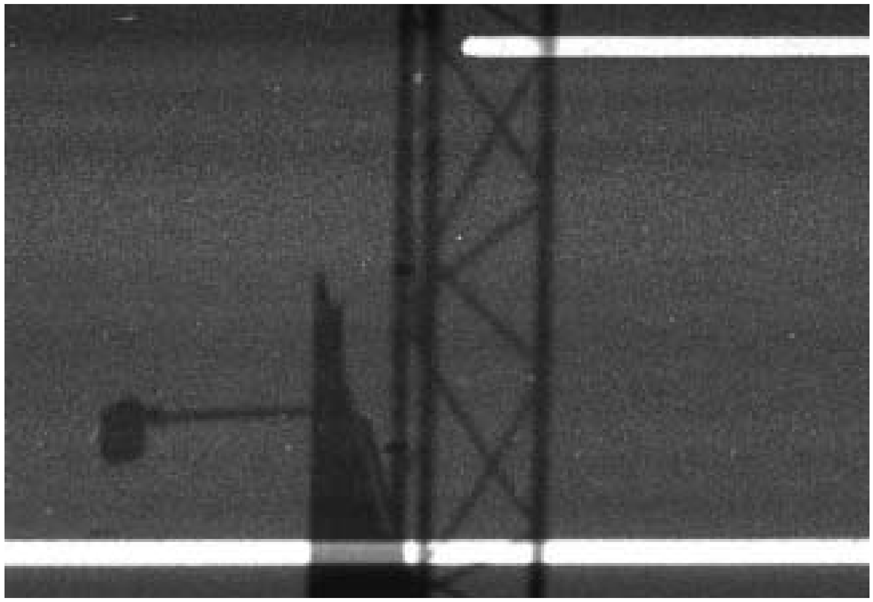


Figure 4.10 Shadow of a sign reflector visible on the pavement image

4.3 Verification of Safety Features Captured by Surveying Vehicle

Two sites each on US 301 and US 41 in Hillsborough County were selected to verify the completeness of imaging coverage of right-of-way and safety features including pavement markings, permanent roadway signing, work zones, crash cushions, traffic control devices, ITS applications, safety barriers, guardrails, and rumble strips etc. Tables 4.6 and 4.7 contain data collected manually on U.S 301, while Tables 4.8 and 4.9 illustrate such data collected on US 41. The corresponding sideview images of the two roadway sections were also analyzed, and it was determined that the images certainly did not miss any of the right-of-way and safety features that exist in the field.

Table 4.6 Manual Survey of Safety Features of US 301 (Milepost 21.950 to 22.244)

Road ID	Road Name	SR	Milepost	
			From: 22.244	To: 21.950
10-010-000	U.S301	43		
Median		Land Use Type: Commercial	Density: Average	No. of lanes: 2
Type: Divided	Width: 42 ft			
Parking: No	No. of Signals: 0	R/R Crossing: No	Pavement Type : Flexible	Pavement Condition: Dry
Length: 1790 ft	Weather: Good	Visibility: Good	No. of crashes(96-98): 11	Speed Limit: 50 mph
Average Lane Width: 23'5"	Roadside Clearance: Fair	Pedestrian or Cyclist: No		
No of Exiting Lane		No. of signs		No. of Minor road intersection
Left Turning	Right Turning	Speed Limit	Others	
2	2	1	1	1
# of Driveways	No. of Median Opening			
	Nondirectional	Directional		
1	2	0		

Table 4.7 Manual Survey of Safety Features of US 301 (Milepost 22.244 to 21.950)

Road ID	Road Name	SR	Milepost	
			From: 21.950	To: 22.244
10-010-000	U.S301	43		
Median		Land Use Type: Commercial	Density: Average	No. of lanes: 2
Type: Divided	Width: 42 ft			
Parking: No	No. of Signals: 0	R/R Crossing: No	Pavement Type : Flexible	Pavement Condition: Dry
Length: 1790 ft	Weather: Good	Visibility: Good	No. of crashes('96-'98): 11	Speed Limit: 50 mph
Average Lane Width: 23'5"	Roadside Clearance: Fair	Pedestrian or Cyclist: No		
No. of Exiting Lanes		No. of Signs		No. of Minor Road Intersection
Left Turning	Right Turning	Speed Limit	Others	
3	2	1	1	1
No. of Driveways	No. of Median Opening			
	Nondirectional	Directional		
1	2	0		

The only difficulty involved in automatic safety survey of roadway features is that it is sometimes difficult to differentiate a driveway from a minor street intersection. In such cases the user has to exert judgment based on experience or other information such as minor street identification name etc. It can be concluded that the image survey indeed provides an efficient and accurate means of collecting images of roadway safety features.

Table 4.8 Manual Survey of Safety Features of US 41 (Milepost 16.276 to 17.139)

Road ID	Road Name	SR	Milepost	
			From: 16.276	To: 17.139
10-060-000	Tamiami	41		
Median				
Type: Divided	Width: 40 ft	Land Use type: Residential	Density: High	No. of lanes: 2
Parking: No	No. of Signals: 0	R/R Crossing: No	Pavement Type : Flexible	Pavement Condition : Dry
Length: 4557 ft	Weather: Good	Visibility: Good	No. of crashes(96-98): 12	Speed Limit: 55 mph
Average Lane Width: 11.5 ft	Roadside Clearance: Fair	Pedestrian or Cyclist: Few		
No of Exiting Lanes		# of signs		# of Minor road intersection
Left Turning	Right Turning	Speed Limit	Others	
2	0	1	2	5
# of Driveways	# of Median Opening			
	Nondirectional	Directional		
12	5	0		

Table 4.9 Manual Survey of Safety Features of US 41 (Milepost 17.139 to 16.276)

Road ID	Road Name	SR	Milepost	
			From 17.139	To 16.276
10-060-000	Tamiami	41		
Median				
Type: Divided	Width: 40 ft	Land Use type: Residential	Density: High	No. of lanes: 2
Parking: No	No. of Signals: 0	R/R Crossing: No	Pavement Type : Flexible	Pavement Condition : Dry
Length: 4557 ft	Weather: Good	Visibility: Good	No. of crashes(96-98): 12	Speed Limit: 55 mph
Average Lane Width: 11.5 ft	Roadside Clearance: Fair	Pedestrian or Cyclist: Few		
No of Exiting Lanes		# of signs		# of Minor road intersection
Left Turning	Right Turning	Speed Limit	Others	
4	0	1	2	2
# of Driveways	# of Median Opening			
	Nondirectional	Directional		
18	5	0		

5.0 TESTING OF GPS, IMU AND LASER PROFILER EQUIPMENT

5.1 Testing of the *Applanix* DGPS unit

In order to verify the accuracy of the GPS system used in the FDOT survey vehicle, a benchmark reference with known NGS coordinates was selected on the USF campus. At the selected locations, the horizontal NGS coordinates are of the second order while the vertical ones are of the third order. The GPS readings from the survey vehicle were obtained during the daytime under clear skies and were compared with the corresponding NGS coordinates in the WGS 84 spherical coordinate system. Analysis of the 30 readings collected at the site during the first run produced the results shown in Tables 5.1. In addition, Tables 5.2 and 5.3 show separate statistics of the longitude and latitude measurements while the corresponding plots are in Figs. 5.1. and 5.2. Figure 5.3 depicts the variation of the observed data from the mean value. It is seen that the GPS readings obtained by the stationary vehicle are clustered around one area illustrating low noise and a high level of precision. Furthermore, the data collected from the survey vehicle seems to provide sub-meter precision with respect to its own reading (i.e. good repeatability).

However, the known GPS coordinates of the NGS location do not exactly match the mean values of instrument readings as seen in Fig. 5.4, showing the existence of a bias error. Assuming the equatorial radius of the earth to be 6378 km, the curvilinear error in latitude is equal to (0.15635*6378*1000*2*3.14) / (360*60*60) or 4.8 m. Similarly the curvilinear error in longitude is equal to 0.57234*6378*1000*2*3.14) / (360*60*60) or 17.6 m. Since the earth's radius decreases with increasing latitude, a correction factor of 0.866 (or sin (60^o)) has to be applied for an approximate latitude of 30 degrees North in Tampa, FL. Thus, the modified deviations in latitude and longitude measurements are 4.8 m and 15.2 m respectively. This level of accuracy does not seem to be adequate in the context of pavement management applications.

Table 5.1 Statistics of GPS data

Statistics		Northings (m)	Eastings (m)
Total N	Valid Data	30	30
	Missing Data	0	0
St. Deviation		0.029	0.0114
Variance		0.00084	0.00013
Minimum		412689.426	157590.538
Maximum		412689.537	157590.571

Table 5.2 Histogram of Longitude data

Northings (Y) [m]	Frequency	Percent	Valid Percent	Cumulative Percent
157590.538	10.0	33.3	33.3	33.3
157590.554	15.0	50.0	50.0	50.0
157590.571	5.0	16.7	16.7	16.7
Total	30.0	100.0	100.0	100.0

Table 5.3 Histogram of Latitude data

Northings (Y) [m]	Frequency	Percent	Valid Percent	Cumulative Percent
412689.426	2	6.7	6.7	6.7
412689.445	1	3.3	3.3	3.3
412689.463	2	6.7	6.7	6.7
412689.482	1	3.3	3.3	3.3
412689.5	4	13.3	13.3	13.3
412689.519	10	33.3	33.3	33.3
412689.537	10	33.3	33.3	33.3
Total	30	100.0	100.0	100.0

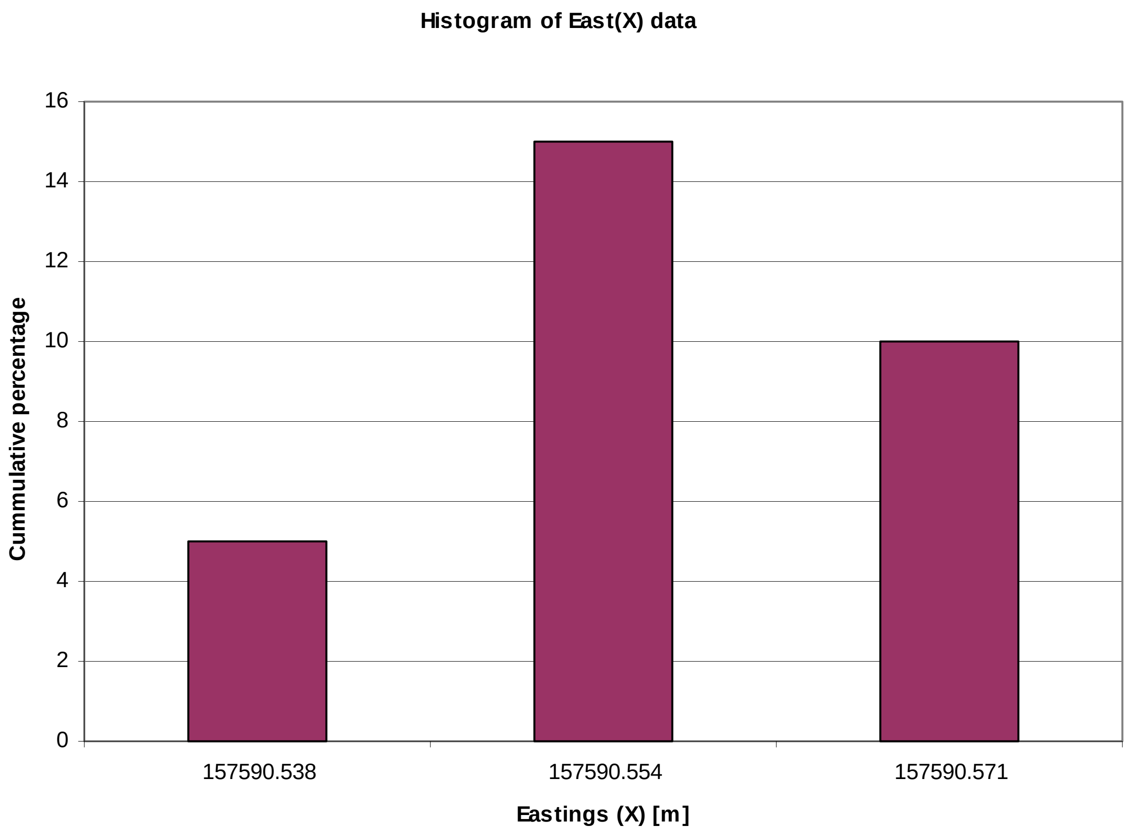


Fig. 5.1 Histogram of Longitude Data

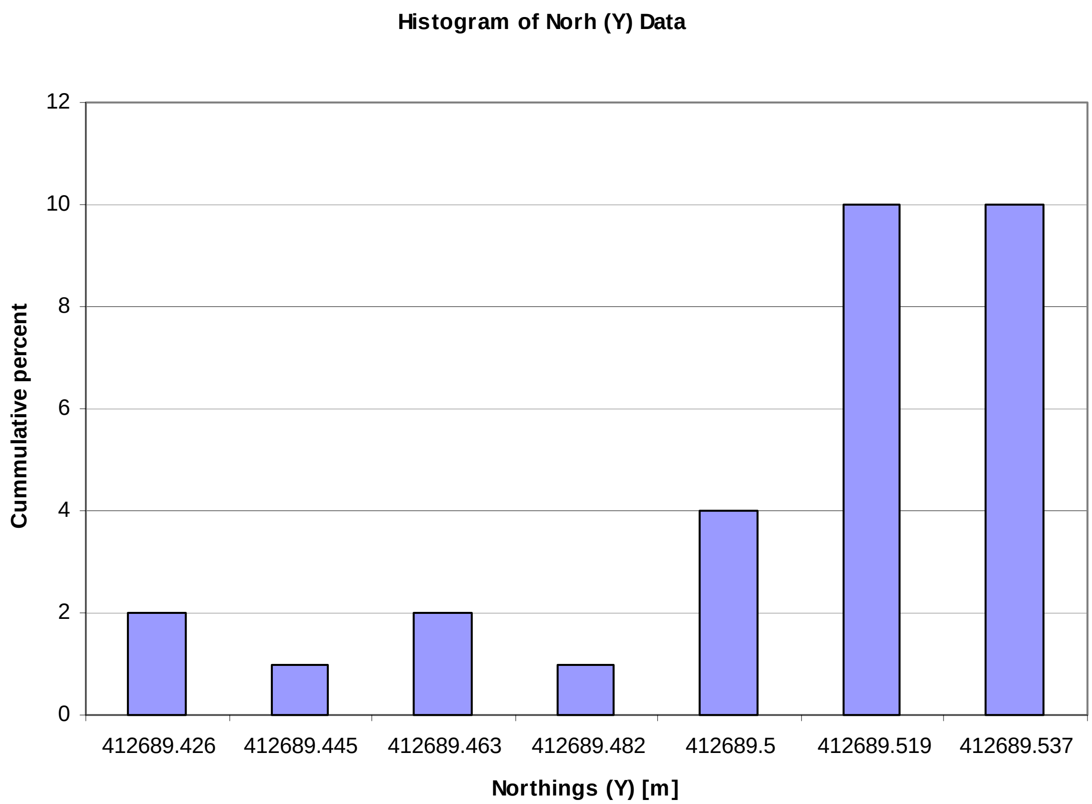


Fig. 5.2 Histogram of Latitude Data

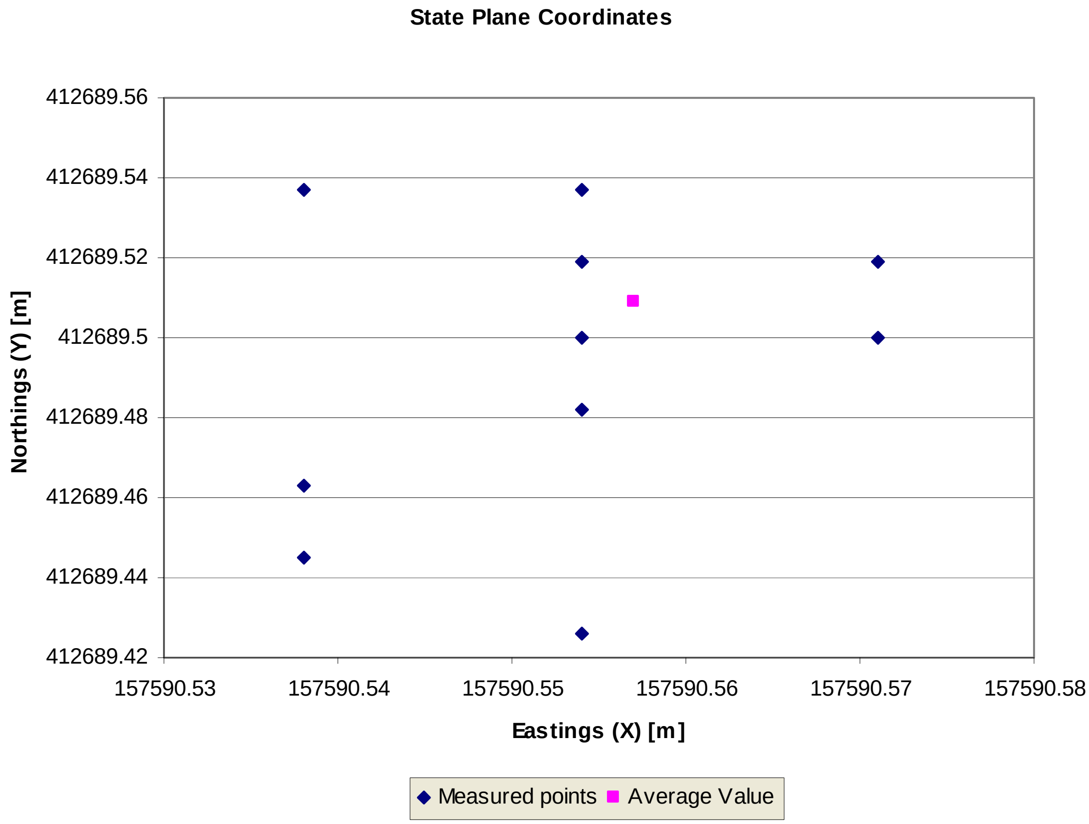


Figure 5.3 Variation of observed data from the mean

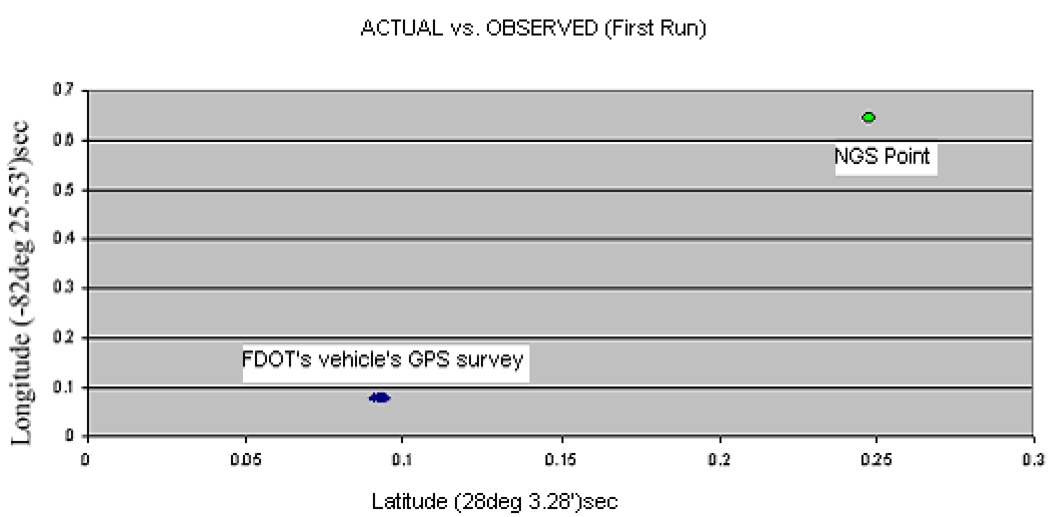


Figure 5.4 Comparison of measured GPS Coordinates with NGS values

5.2 Comparison of two differential GPS systems

An additional test was conducted to compare the results of the DGPS in FDOT survey vehicle (*Applanix* unit with a frequency of 20 Hz) to that of the ICC survey vehicle (*Trimble* unit with a frequency of 1 Hz) at the same location.

The mean position values of the GPS coordinates obtained by the *Applanix* unit (Figure 5.5) are as follows:

Latitude = 27.86900859 degrees

Longitude = 82.74253234 degrees

Similarly, the mean position values of the GPS coordinates obtained by the *Trimble* unit (Figure 5.6) are as follows:

Latitude = 27.86903267 degrees

Longitude = 82.74255356 degrees

Hence the following differences between *Applanix* and *Trimble* units can be reported:

Latitude = 0.00002408 degrees

Longitude = 0.00002123 degrees

The above differences translate to a total positional error of 3.389 meters (Fig. 5.7). Additional information regarding the survey comparing *Applanix* and *Trimble* units are given in Table 5.4.

Table 5.4 Comparison of *Applanix* and *Trimble* Unit Measurements

	APPLANIX survey	**TRIMBLE survey**
Date of Observation	07/08/2002; 10:36 am	07/09/2002; 6:22 am
Number of visible satellites	8	5
HDOP	1.1	1.5

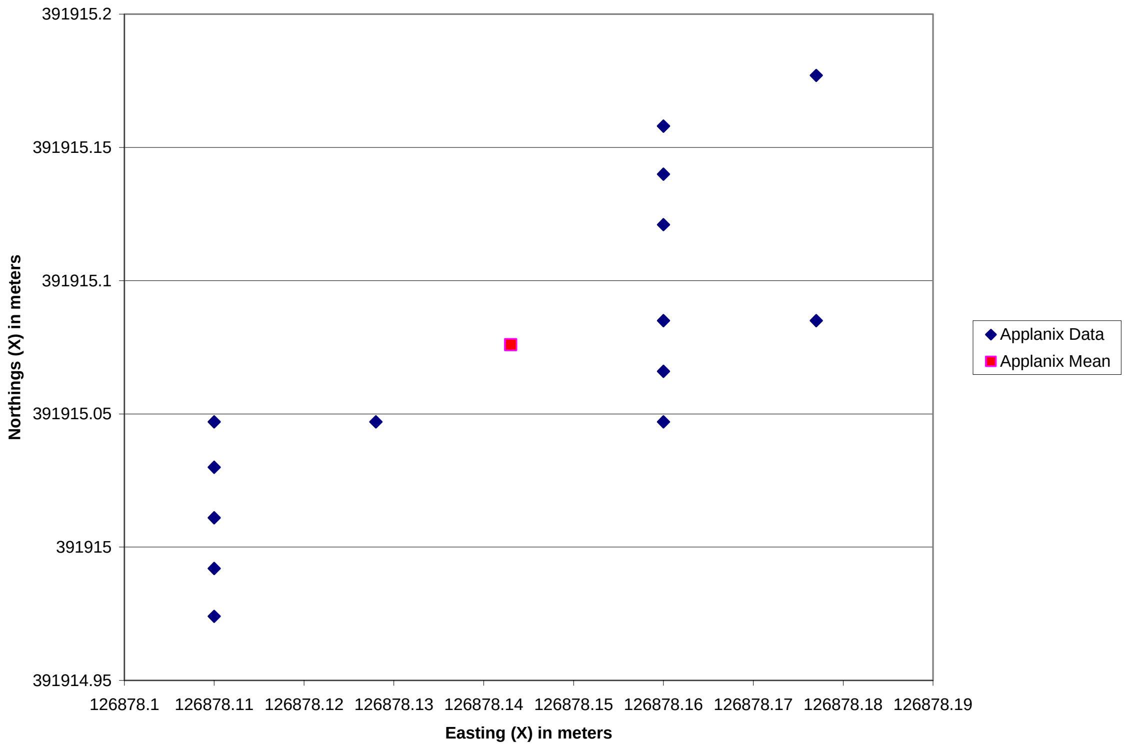


Figure 5.5 Variation of observed readings from the mean (*Applanix* system)

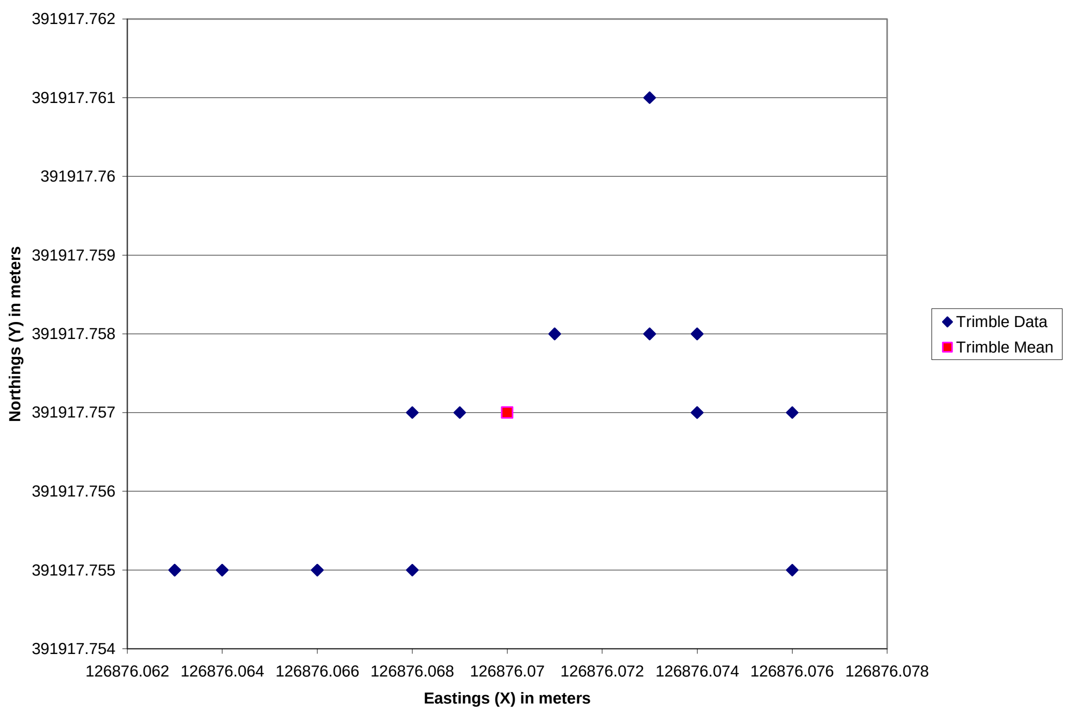


Figure 5.6 Variation of observed readings from the mean (*Trimble* system)

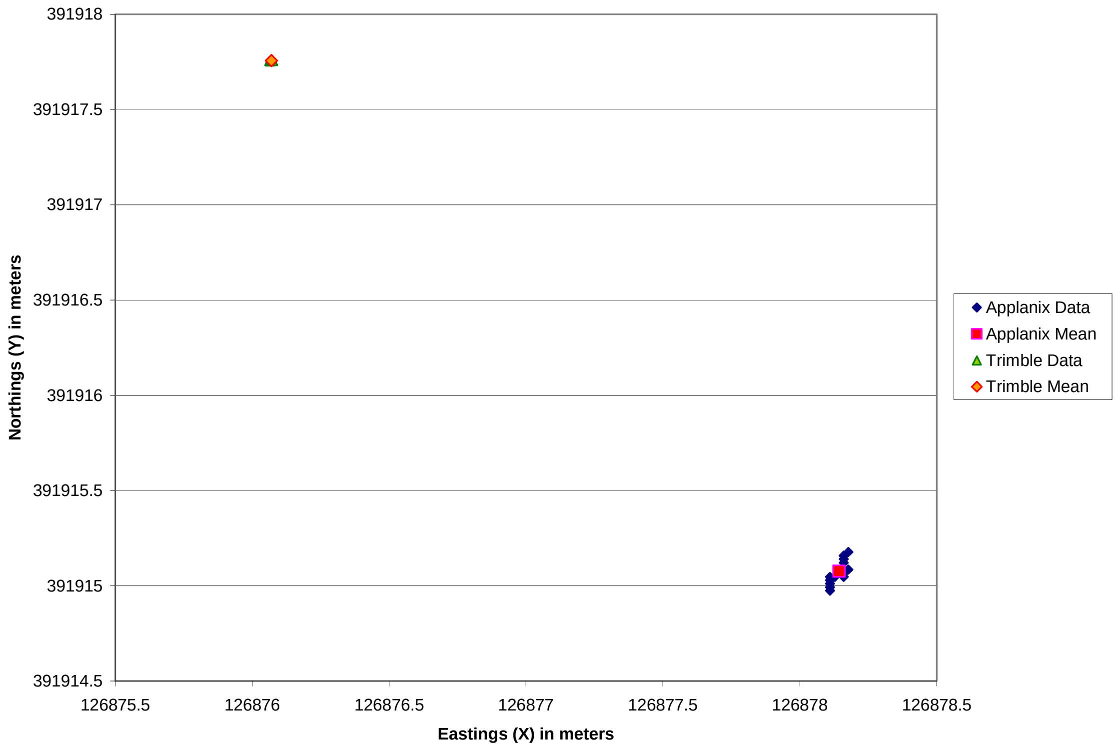


Figure 5.7 Variation of observed readings from the mean (*Applanix* and *Trimble* systems)

5.2 Validation of curvature and grade measurements

For the grade and curvature verification study, a road section consisting of reversed horizontal curve with a tangent in-between them was selected on the USF campus after a thorough survey of candidate sites (Fig. 5.8).

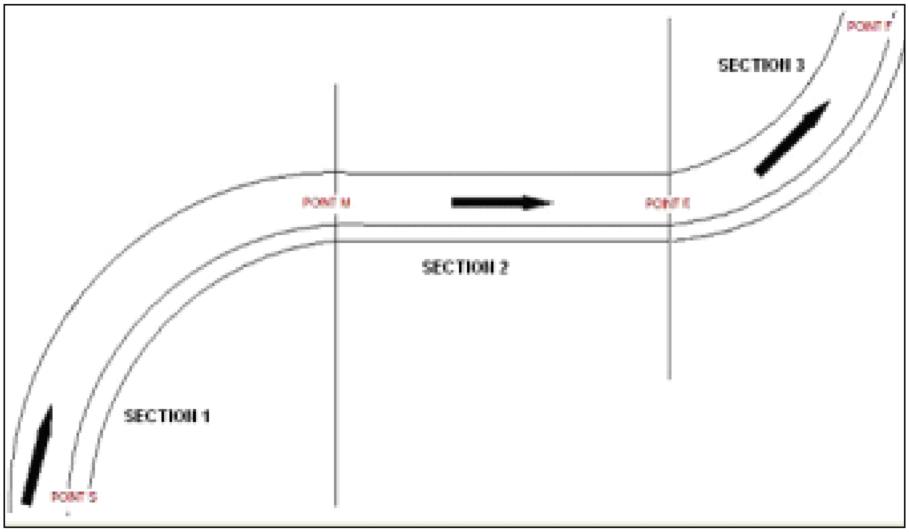


Figure 5.8 Plan view of the road section used for curvature and grade study

Curvatures of both curves (sections 1 and 3) and the vertical grade of section 2 were manually surveyed using a total station. Although the manual survey was performed only once, adequate care was taken to minimize observation errors, as is typically done in standard route surveys. The evaluation vehicle was used to survey the same highway geometrical parameters at speeds of 10, 20, and 30 mph. The cross-slopes were not considered in this test since a separate study was designated entirely for cross-slope verification (Section 5.3). Table 5.5 illustrates the comparison of the results of the manual survey and the measurements. Table 5.5 also indicates a reasonable level of agreement between the two types of survey and that there is no systematic relationship between the observed error and vehicle speed.

Table 5.5 Verification of curvature and grade measurements of the IMU

Speed / Section	10mph	20 mph	30 mph
Section 1	Average Curvature From 3 runs = 90.39 ft Computed from manual survey = 92.31 ft (standard error = 0.0123) **Percent Error 2.07 %**	Average Curvature From 3 runs = 94.34 ft Computed from manual survey = 92.31 ft (standard error = 0.0123) **Percent Error 2.21 %**	Average Curvature From 3 runs = 94.89 ft Computed from manual survey = 92.31 ft (standard error = 0.0123) **Percent Error 2.80 %**
Section 3	Average Curvature From 3 runs = 104.28 ft Computed from manual survey = 108.32 ft (standard error = 0.0343) **Percent Error 3.73 %**	Average Curvature From 3 runs = 105.09 ft Computed from manual survey = 108.32 ft (standard error = 0.0343) **Percent Error 2.98 %**	Average Curvature From 3 runs = 117.28 ft Computed from manual survey = 108.32 ft (standard error = 0.0343) **Percent Error 8.27 %**
Section 2	Average Grade From 3 runs = 0.716 deg = 1.25 % Computed from manual survey = 0.765 deg = 1.33 % **Percent Error 6.44 %**	Average Grade From 3 runs = 0.658 deg = 1.15 % Computed from manual survey = 0.765 deg = 1.33 % **Percent Error 13.92 %**	Average Grade From 3 runs = 0.724 deg = 1.26 % Computed from manual survey = 0.765deg = 1.33 % **Percent Error 5.31 %**

5.3 Validation of Cross-slope data

In order to check the cross-slope measurements of the IMU, the evaluation vehicle performed three repeat runs on 500 ft road sections in Gainesville and St. Petersburg, Florida. The results of the survey are indicated in Fig. 5.9a and Fig. 5.9b respectively. It is clearly seen that the cross-slope measurement is satisfactory from a repeatability standpoint since the maximum differences (Fig. 5.9) are within the FDOT specified tolerance of 0.2%.

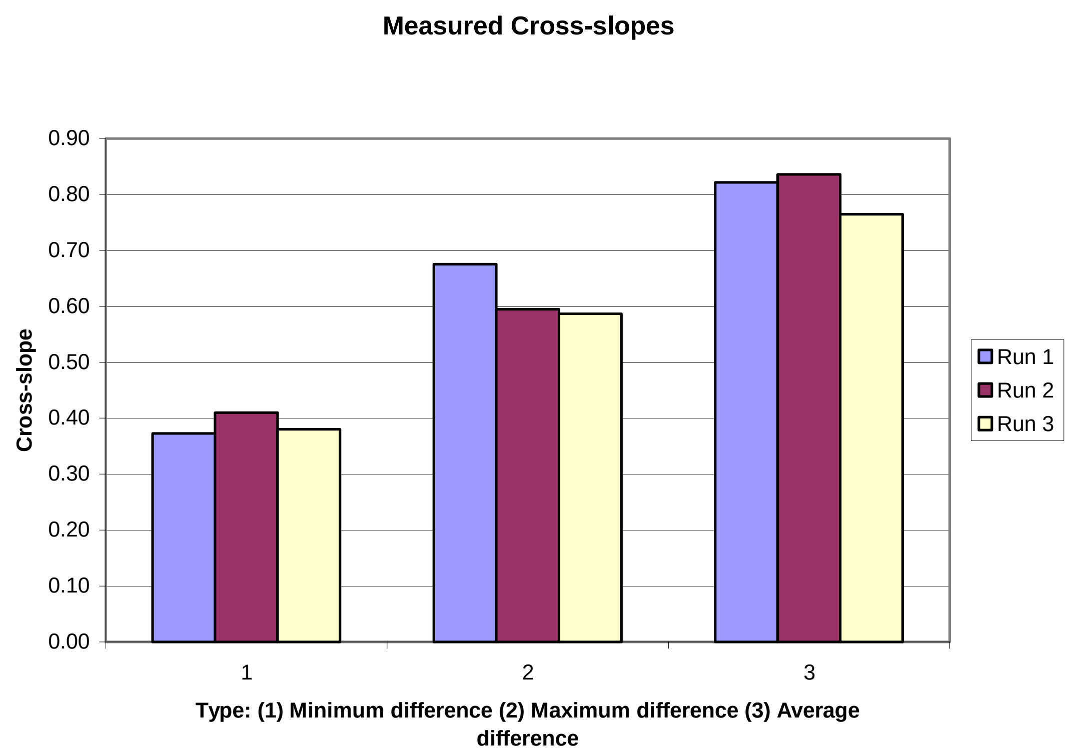


Figure 5.9a Measured cross-slopes within the distance range of 0 - 500 ft (Gainesville)

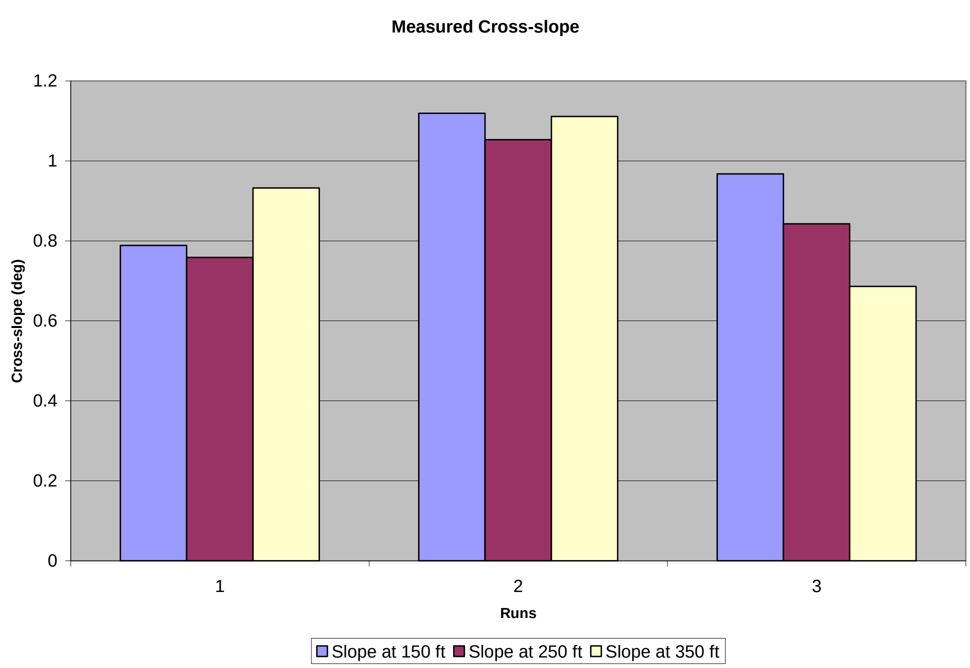


Figure 5.9b Measured cross-slopes within the distance range of 0 - 500 ft (St. Petersburg)

The above road section was manually surveyed at three stations (1+50, 2+50 and 3+50) using a *rod* and a *total station* to evaluate the cross slopes. As seen in Figure 5.10, the manually surveyed elevations were fitted with a smooth curve to estimate the transverse pavement profile. Using this transverse profile, one can determine the tilt of the vehicle knowing the vehicle's transverse position. Then, the tilt can be compared to the IMU cross-slope, which is computed by combining the IMU slope with sensor slope, as shown in Table 5.6. Once again, reasonable agreement is obtained between the manually surveyed cross slopes and the IMU measurements.

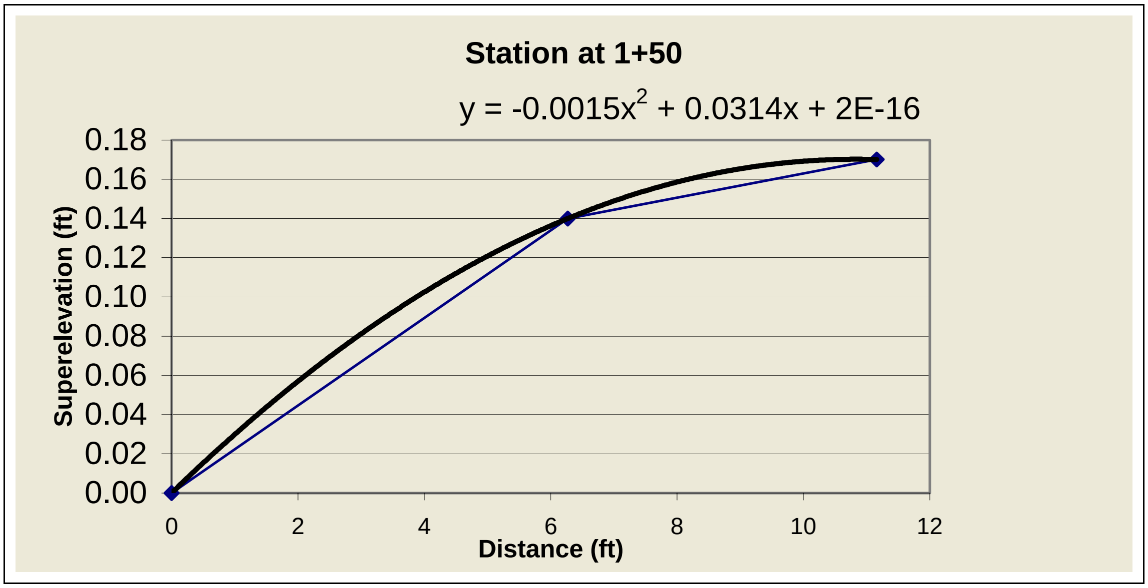


Figure 5.10 Mathematical representation of the measured cross slope

Table 5.6 Comparison of measured slopes and Survey Vehicle readings

Station	Slope (deg) Run 1	Slope (deg) Run 2	Slope (deg) Run 3	Surveyed Vehicle Slopes (deg)	Surveyed Vehicle Max Range of Slope (deg)	Total Station Slope (deg)	Difference Deg / percent
1+50	0.78867	0.75864	0.93235	0.82655	± 0.10	0.840016	0.013466 / 0.02%
2+50	1.11924	1.05317	1.11135	1.09459	± 0.04	1.232622	0.138032 / 0.24%
3+50	0.96777	0.84238	0.68607	0.83207	± 0.14	0.839896	0.007826 / 0.04%

5.4 Validation of Roughness and Rut Measurements

Two tests were conducted to validate the roughness and rut measurements of the FDOT survey vehicle. Table 5.7 illustrates the comparison of the survey vehicle's IRI (International Roughness Index) reading to that of a Class I walking profilometer having a sampling interval of 1 foot. These results were obtained during an initial test performed at a University of South Florida (USF) parking lot. Table 5.7 also indicates that the sampling interval used in the survey vehicle's laser based IRI computation has no significant influence on the final result.

During the second test performed at the FDOT's IRI calibrated site in Gainesville, FL, the IRI and rut readings shown in Table 5.8 were obtained. Table 5.8 clearly shows that the profiling setup of the survey vehicle provides reasonably accurate readings.

Table 5.7 Comparison of IRI data of Survey Vehicle and Walking Profilometer

Measuring System Section Identification	IRI from Walking Profilometer		IRI from FDOT Survey Vehicle		
	Trial 1	Trial 2	Sampling Interval (in)		
			3	6	12
Section 1	4.01	4.05	4.19	4.20	4.19
Section 2	1.14	1.21	1.26	1.27	1.27

Table 5.8 Comparison of Survey Vehicle evaluations with calibrated data

Calibrated IRI	SECTION 1	SECTION 2	SECTION 3
Mean	41.55	68.24	109.96
Low	36	64	99
High	55	91	142
Coeff. Of Var.	10.07%	8.22%	7.03%
IRI from Survey Vehicle			
Run 1	39	67	110
Run 2	38	68	107
Run 3	37	68	110
Mean	38.00	67.67	109.00
Calibrated Rut			
Mean	0.07	0.24	0.36
Low	0	0.18	0.3
High	0.12	0.29	0.43
Coeff. Of Var.	36.65%	10.93%	8.86%
Rut evaluation from Survey Vehicle			
Run 1	0.12	0.27	0.35
Run 2	0.12	0.27	0.41
Run 3	0.12	0.27	0.42
Mean	0.12	0.27	0.39

6.0 STUDY OF DATA STORAGE DETAILS

6.1 Determination of in-service data storage needs

Captured data from frontview, sideview, and pavement cameras of the survey vehicle are stored in the corresponding computers in two sets of 80 GB removable hard disks. Further, the MDR computer contains one non-removable 80 GB hard disk and a ZIP drive for transferring data into the workstation. It is important for the operators to be aware of the maximum mileage that can be surveyed with the above storage capacity. To provide this knowledge, a computation was performed to determine the mobile data storage needs of the survey vehicle. The data required for this computation illustrated in Table 6.1 was collected during a 5.077 miles run in West Palm Beach, FL.

Table 6.1 Information on mobile data storage

Data Type	Storage Space Used (MB)	Storage per 100 miles (GB)
Frontview data	53.4	1.1
Sideview data	54.1	1.1
MDR data	3.4	0.067
Pavement data	1,194.3	23.5
Total	1,305.2	25.7

The mileage limitations per one 80 GB removable hard disk were determined as shown in Table 6.2.

Table 6.2 Mileage limitations based on mobile data storage

Type of Data	Estimated maximum mileage per hard drive (HD) (and total amount per 2 HD)
Frontview data – 2 x 80 GB	727 (1,454)
Sideview data – 2 x 80 GB	727 (1,454)
Pavement data – 2 x 80 GB	340 (680)
MDR data – 80GB + 200 MB ZIP disk	119,403 (238,806)

6.2 Determination of optimum compression

One of the objectives of this study was to determine the extent of storage optimization that can be achieved by data compression in the .jpg format. First, the original .jpg image files were transformed back to uncompressed (.bmp) format so that the compression of the images could be performed under different degrees (ratios) of compression. To perform the compression study for the downward camera, images from a survey performed in Gainesville, Florida were used. For the frontview and sideview cameras, images from a survey in Tampa, Florida were used. Because the vehicle automatically saves images in the .jpg format, all testing images had to be first converted back into .bmp. With ACDSee Version 4 software, the .bmp files were systematically transformed back into .jpg files at compressions of 70% – 80% in steps of 5%. The storage information is tabulated in Table 6.3. Careful scrutiny of images showed that compression exceeding 75% for downward images and 80% for frontview and sideview images introduce pixelization and visible loss in quality.

Table 6.3 Comparison of file size at different compression ratios

File Name	Compression Ratio (%)	File Size (bytes)
test_file_downward_BMP.bmp	0	6,026,294
test_file_downward_JPG30.jpg	70	857,552
test_file_downward_JPG25.jpg	75	844,598
test_file_forward_BMP.bmp	0	3,981,366
test_file_forward_JPG30.jpg	70	102,759
test_file_forward_JPG25.jpg	75	100,447
test_file_forward_JPG20.jpg	80	85,527
test_file_sideview_BMP.bmp	0	3,981,366
test_file_sideview_JPG30.jpg	70	82,429
test_file_sideview_JPG25.jpg	75	80,402
test_file_sideview_JPG20.jpg	80	68,714

Thus, the optimum compression ratio was determined to be 75% for the downward images. However, for frontview and sideview images, a compression of 80% was also determined to be acceptable.

7.0 PILOT STUDY IN HILLSBOROUGH COUNTY, FLORIDA

As the final phase of the research project, a pavement evaluation survey was conducted in Hillsborough County, Florida, based on the FDOT survey vehicle. The survey was performed during a four-week period (June 24th 2002 through July 23rd 2002) by a crew of specialists sent from the Pavement Evaluation section of the FDOT State Materials Office. The network surveyed consists of 434 centerline miles of state roads with a wide variation of characteristics such as pavement type and condition, traffic level, and functional classification. The Hillsborough County's highway network was selected as it is representative of the entire state highway network. Moreover, the versatility of Hillsborough County road conditions presented an opportunity for testing the amenability of the survey vehicle to rigorous operational demands.

7.1 Role of Manual Pavement Condition Survey

Current FDOT pavement condition surveys (PCS) consist of automated ride and rut rating coupled with subjective windshield crack rating. FDOT envisions an ideal future PCS with automated rut, ride, and cracking to be performed simultaneously with imaging of roadway features. However, the windshield surveys will continue to be used in PCS until FDOT acquires reliable software for automatic analysis of pavement distress. Hence one objective of the pilot study was to test the logistics and efficiency of the simultaneous operation of PCS and digital imaging.

7.2 Details of the survey

Preliminary discussions with the FDOT pavement evaluation personnel revealed some important considerations related to conducting PC surveys in conjunction with video-logging. These discussions also enabled the investigators to draft an effective work plan for the pilot project. The survey started on Monday of every week when the FDOT survey team arrived from Gainesville, which typically occurred around midday. Then on the following two days, Tuesday and Wednesday, the work typically started at 7:00 am and ended at 5:00 pm. The survey week concluded on Thursdays around midday when FDOT survey team returned to Gainesville. The van was parked at the USF Physical Plant facility where it was refueled and picked by the FDOT survey team in the morning of every survey day. One USF student-research partner also accompanied the survey team on every evaluation trip, to record time and manpower requirements for combined imaging and PCS operations. Appendix IV shows a sample data logging form used by the USF staff assistants during this study. All in all, it took less than twenty (20) working days for two well-trained survey specialists to perform a comprehensive evaluation of 434 centerline miles (860 lane miles) coupled with a pavement condition survey (Table 7.1). Table 7.2 summarizes the survey status on a day-by-day basis.

The survey production per day was found to depend on many factors like the weather, the type of road, its function, level of traffic, etc. However an average production of 75 miles of survey was achieved during a normal working day of 10 hours, under favorable weather conditions. The process of transferring the collected data from the removable hard drives to the workstation computer can be lengthy. During the pilot survey, the process of downloading one full downward camera hard drive (80 GB) lasted about 3 to 6 hours.

The only significant interruption was the reoccurring of skips of downward images from the start of the survey. This was attributed to a number of reasons one among them being the trapping of moisture in the downward camera system. This problem was later rectified by improving the design of the data transfer cable.

Table 7.1 Imaging / PCS Survey of Hillsborough County State Highway System

Roadway ID	Surveyed length (centerline miles)	Survey date (direction 1)	Survey date (direction 2)
10 002 000	14.217	16-Jul	16-Jul
10 005 000	2.845	18-Jul	18-Jul
10 005 001	0.085	22, 23-Jul	22, 23-Jul
10 010 000	25.775	10-Jul	10-Jul
10 020 000	11.211	2-Jul	2-Jul
10 020 101	3.245	22, 23-Jul	22, 23-Jul
10 030 000	24.593	11-Jul	11-Jul
10 030 001	0.925	22, 23-Jul	22, 23-Jul
10 030 002	1.410	22, 23-Jul	22, 23-Jul
10 030 101	1.782	22, 23-Jul	22, 23-Jul
10 040 000	15.426	2-Jul	2-Jul
10 060 000	27.604	11-Jul	11-Jul
10 070 000	5.535	15-Jul	15-Jul
10 075 000	39.835	25-Jun	25-Jun
10 080 000	5.190	22, 23-Jul	22, 23-Jul
10 080 001	0.607	16-Jul	16-Jul
10 080 101	0.607	16-Jul	16-Jul
10 090 000	10.777	10-Jul	10-Jul
10 110 000	23.740	7-Jul & 15-Jul	15-Jul
10 120 000	23.381	17-Jul	17-Jul
10 130 000	9.064	16-Jul	16-Jul
10 130 001	2.960	22, 23-Jul	22, 23-Jul
10 140 000	9.303	17-Jul	17-Jul
10 150 000	12.838	2-Jul	2-Jul
10 160 000	12.767	17-Jul	17-Jul
10 180 000	1.814	16-Jul	16-Jul
10 190 000	32.836	16-Jul	16-Jul
10 200 000	10.910	15-Jul	15-Jul
10 210 000	10.231	10-Jul	10-Jul
10 230 000	0.213	22, 23-Jul	22, 23-Jul
10 250 000	9.627	17-Jul	18-Jul
10 250 001	0.945	18-Jul	22, 23-Jul
10 250 101	1.264	22, 23-Jul	18-Jul
10 260 000	5.947	10-Jul	10-Jul
10 270 000	3.362	22, 23-Jul	22, 23-Jul
10 270 001	0.508	22, 23-Jul	22, 23-Jul
10 270 002	0.536	22, 23-Jul	22, 23-Jul
10 290 000	7.829	25-Jun	25-Jun
10 310 000	6.863	2-Jul	2-Jul
10 320 000	16.021	25, 26-Jun	25, 26-Jun
10 330 000	6.169	15-Jul	15-Jul
10 340 000	12.292	16-Jul	16-Jul
10 350 000	0.499	2-Jul	2-Jul
10 360 000	0.501	2-Jul	2-Jul
10 470 000	16.052	17-Jul	17-Jul
10 471 000	3.790	17-Jul	17-Jul
TOTAL	434.005 Centerline miles		

Table 7.2 Survey status on a day-by-day basis

Monday 24-Jun-02	Tuesday 25-Jun-02	Wednesday 26-Jun-02	Thursday 27-Jun-02
Stopped ***(Start of survey)***	*Successful*	*No survey*	*No survey*
Due to rain.	Runs with problems on DW system	Problems with encoder	Problems with encoder
Monday 1-Jul-02	Tuesday 2-Jul-02	Wednesday 3-Jul-02	Thursday 4-Jul-02
Stopped	*Successful*	*Stopped*	*No Survey*
Problems with the forward system	Runs with problems on DW system	Problems with DW pictures (gain)	Holiday
Monday 8-Jul-02	Tuesday 9-Jul-02	Wednesday 10-Jul-02	Thursday 11-Jul-02
Stopped	*No survey*	*Successful*	*Successful*
Problems with DW pictures (gain)	Van at ICC facilities	Runs with problems on DW system	Runs with problems on DW system
Monday 15-Jul-02	Tuesday 16-Jul-02	Wednesday 17-Jul-02	Thursday 18-Jul-02
Successful	*Successful*	Successful	Successful
Runs with problems on DW system	Runs with problems on DW system	Runs with problems on DW system	Runs with problems on DW system
Monday 22-Jul-02	Tuesday 23-Jul-02	Wednesday 24-Jul-02	Thursday 25-Jul-02
Successful	*Successful* ***(End of survey)***		
Runs with problems on DW system	Runs with problems on DW system		

7.3 Transfer of data

During the pilot project, from time to time, it was necessary to use 80 GB removable hard drives to transfer the information collected by the video cameras to the workstation. Similarly, zip drives were used to transfer the corresponding MDR (Mobile Data Recorder) data. The process of transferring data from one full hard drive to the workstation computer or to a different removable hard drive can take up to 3 hours depending on the amount of information collected during a particular run. The downward camera records much more information during a given run due to the higher resolution of the pavement image and the relatively higher frequency of pavement imaging. Hence by the time one 80 GB hard disk of the downward images is filled, only 6% of the forward view and sideview camera hard drives generally get filled. Therefore, there is a need to download the data from the downward camera computer at a higher frequency. For two (2) completely full downward camera hard drives, the entire data transfer takes approximately 6 hours, at an observed transfer rate of 0.5 GB/min. The transfer rate depends on the hardware of the computer which is used for the data transfer. For this study, a computer with a 1.4 GHz Pentium IV processor, 512 MB or memory, and Windows 2000 was used. Transfer of data was performed by the *Explorer* program having no other software engaged on the computer.

7.4 Hillsborough County Survey Summary

Figure 7.1 was developed by the investigators to depict the relative percentages of time consumed by the three outcomes of the survey: (1) successful survey (2) no survey and (3) downtime. This is based on the information recorded during the seventeen working days of the nearly four weeks of the survey. Average distribution of the relative percentages of time required for various tasks on a day of successful survey is also shown in Figure 7.2. It is seen that the net production time is generally only about 35% of the entire operation even during an uninterrupted survey. Most of the remaining time is seen to be spent in- between productive runs followed by the time spent on transportation to and from evaluated sections. The rest of the work time is spent on performing the white-balance test (once per day) and initializing the computers, which typically occurred twice per day due to the lunch breaks. Performance of subsidiary tasks like fueling, making work related telephone calls, external checks of the van, etc also occupy a significant time slot.

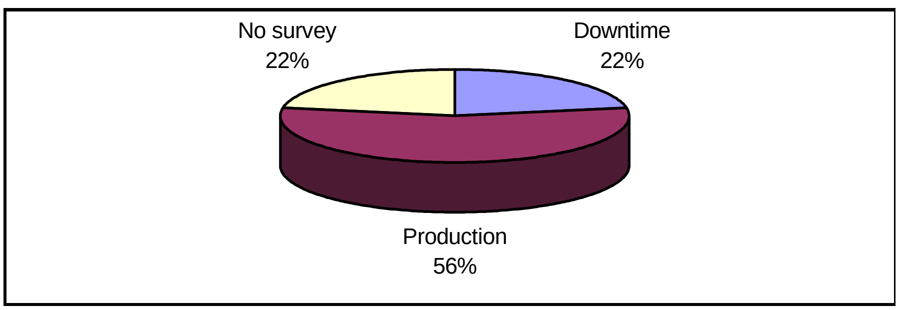


Figure7.1 Pilot project productivity summary

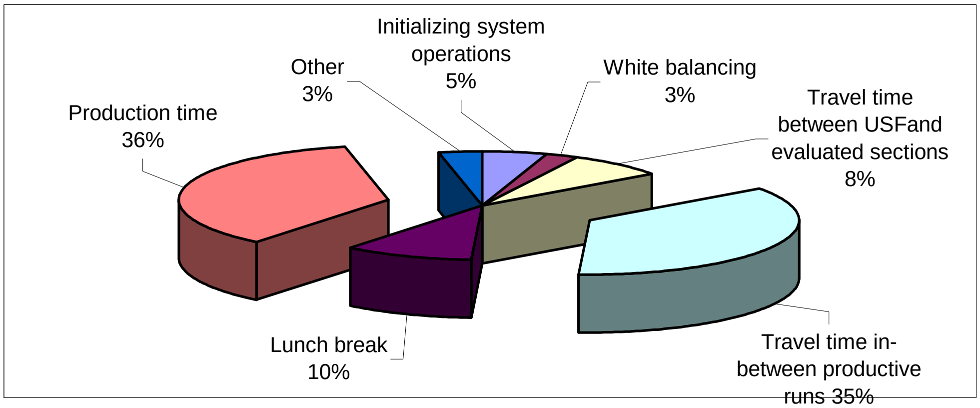


Figure 7.2 Average daily time distribution for Hillsborough County Survey

Based on the data presented in Figs. 7.1 and 7.2, the system reliability, defined as the ratio of production time to total time, can be estimated approximately as 56%.

7.5 Survey conclusions

Many important issues related to the evaluation vehicle surfaced during the pilot study. They are as follows:

1) Constant skipping of downward camera images due to hardware problems in the camera, cables, connectors and/or software results in interruption of the survey. Attempts are being made currently to permanently address this problem.
2) The summer season is generally not recommended for this kind of surveys in Florida due to intermittent heavy showers and storms, especially in the afternoon.
3) Survey productivity can vary significantly depending on the level of traffic and function of the evaluated roadway.
4) The time consumed by the data downloading process must be taken into account when estimating survey production and future production work scheduling
5) Approximately equal travel speeds can be used to conduct separate PCS and imaging operations. Hence a higher survey mileage can be achieved in PCS as a single operation since there is no need for initializing and setting computers and performing of white balancing function during PCS.

6) If the periods of equipment malfunctioning and downloading of data are disregarded, then so significant difference was seen between the time requirements for imaging and windshield PCS operations.
7) Two well-trained survey personnel are adequate to conduct daily field data collection, imaging and PCS operation, simultaneously.

Possibilities of engaging different numbers of identical FDOT survey vehicles were considered to forecast the time and manpower needs for network-wide evaluation. Based on the centerline mileage and productivity results from the pilot project in Hillsborough County, the above projections for the FDOT controlled highway network are summarized in Table 7.3. These estimates also incorporate the time requirements for downloading the survey information from the hard drives.

The minimum time period required by a single survey team comprising two crewmembers and one vehicle for simultaneous PCS and imaging operations covering the state-wide highway network on an *annual basis*, would decide the number of such teams needed at a given time. Based on the estimates in Table 7.3 and the survey conclusions (6) and (7), the investigators propose that FDOT would ideally need to mobilize two survey teams (2 vehicles and 4 trained crewmembers) to perform both pavement condition survey and imaging of the state highway network on an annual basis. However, if two Pavement Evaluation office staff members can be exclusively trained and assigned to download and manipulate the collected data, even a single survey team (1 survey vehicle and two crewmembers) would be able to achieve FDOT's annual evaluation goals.

Table 7.3 Projections of time requirements for survey of the FDOT controlled state highway network

Productivity information	Videologging	PCS
Number of working days(10 working hours/day) per week	4	4
Daily average production (centerline miles)	40	60
Weekly average production (centerline miles)	160	240
Centerline mileage involved in pilot project in Hillsborough county	430	430
Number of weeks needed for pilot project	2.7	1.8
State Highway network centerline mileage (both directions)	24,000	24,000
Possible scenarios for surveys:		
Number of weeks needed for FDOT state network with 1 survey team	150.0	100.0
Number of weeks needed for FDOT state network with 2 survey teams	75.0	50.0
Number of weeks needed for FDOT state network with 3 survey teams	50.0	33.3
Number of weeks needed for FDOT state network with 4 survey teams	37.5	25.0
Transfer time (image logs only)	**Hours**	**Days (8 ho/day)**
Hillsborough county State Highway centerline mileage: 860	7.4	1
State Highway network centerline mileage: 18000	205.7	26
Assumming that 160 GB can store the information for 350 centerline miles and 6 hours as download time.		

7.4 Summary of cost benefits

Per-lane cost information related to outside contracting was also collected by the investigators in order to estimate the cost benefits that FDOT would gain by performing highway evaluation operations using the survey vehicle developed through this study. This information is listed below and it must be noted that the cost estimates are made based on 2001 dollars.

1. Cost of imaging assets (*Vendor 1*) = $ 23.50
2. Cost of imaging assets + GPS evaluation (*Vendor 2*) = $ 25.30
3. Cost of cross slope evaluation (*Vendor 3*) = $ 35.52
4. Estimated cost of imaging assets + GPS + cross slope evaluation (items 2 + 3) = $ 58.82
5. Estimated cost of imaging assets + GPS + cross slope evaluation + imaging pavement distress + IRI + Ruts = $ 86.50

(this figure was obtained from Vendor 3 in 2003 and converted to 2001 dollars based on an inflation rate of 2%)

6. The cost per lane mile for FDOT survey based on the
current PCS rate (Item 4, Appendix VII) = $ 41.35

Based on the details provided in Appendix VII, it is noted the cost estimate in item 6 has to be upgraded to include additional costs incurred in the imaging exercise due to the needs for equipment warranties (approximately 17,000 per year) and personnel travel associated with repairing of malfunctioning imaging equipment etc. In this regards, cost information with respect to the scope of evaluation and expenditure was obtained from other states surveyed during this study. Based on this comparison (Table VII.1, Appendix VII), an upgrade was made to item 6 as indicated in item 7:.

7. Upgraded cost per lane mile for FDOT imaging + PCS survey = $ 50.00
8. Estimated cost saving per lane mile (item 5 – item 7) = $ 36.50

Total estimated cost saving in conducting in-house survey of
24,000 lane miles = $ 876,000

Hence FDOT could anticipate a net saving of approximately $ 876,000 per evaluation cycle, if the evaluation vehicle is set in operation during routine pavement condition surveys.

8.0 CONCLUSIONS

An automated high-speed comprehensive pavement evaluation vehicle has been developed through research collaboration among FDOT, USF and International Cybernetics Corporation (ICC), Florida. This vehicle consists of three video cameras; front-view and side-view cameras for capturing traffic signs and right-of-way safety features and a downward-view camera for video-imaging of pavement distress information. In addition to these, the vehicle is also a Class I profilometer comprising a laser and accelerometer system, Differential Global Positioning equipment (DGPS) and an inertial measurement unit (IMU) for cross-slope, curvature and grade measurements.

The investigation consisted of four distinct tasks; (1) survey of agencies that use similar vehicles (2) vehicle development (3) validation of vehicle measurements and (4) a data collection pilot study. Based on the results of the first task, it was determined that the imaging equipment and other road evaluation instrumentation used by the surveyed agencies are generally comparable. And a number of agencies evaluate road roughness, GPS and cross-slope data in addition to video imaging of roadway features. A few of the surveyed agencies have been also successful in combining manual pavement condition survey with video-imaging. As for automated image-based distress evaluation, several agencies claim to have reasonably accurate software, whereas the other agencies are in the process of developing them through contracts. However, at the inception of the current investigation, the investigators were not aware of any agency that combines all of the operations and functionalities of the FDOT survey vehicle.

All of the tested devices are seen to produce accurate data in general, with some refinement required in the areas of GPS and forward-view picture quality. Since the testing program was limited to a relatively narrow range of operating speeds, all of the equipment in the vehicle needs to be tested at highway speeds before the vehicle is placed in production.

The pilot study conducted in Hillsborough County was interrupted on many occasions due to skipping of downward images attributed to a malfunctioning encoder. However, since this condition did not entirely disrupt the operation of other subsystems, the investigators were able to obtain valuable information regarding the timing of survey, scheduling of manpower and survey productivity. Another useful finding was that the pavement images can very well be used for quality checking of condition evaluation data. The pilot study also revealed that comprehensive pavement evaluation can in fact be performed in conjunction with pavement condition surveys. Hence the investigators believe that FDOT would be able to successfully combine many components of pavement evaluation such as routine PCS with video-imaging, This finding is encouraging at a stage where FDOT is considering the possibility of performing at least the data collection portion of the process using in-house resources and particularly since PCS has to be continued until reliable algorithms for fully automated distress evaluation become available. A comprehensive evaluation operation would not only minimize manpower requirements, but also increase the frequency of acquisition of some types of data such as cross-slope data and images that are not as often collected as condition data. Thus, the implementation of the combined operation would furnish a frequently updated, comprehensive and reliable evaluation database of the highway network to FDOT staff.

The investigators are confident that the operational difficulties encountered during the pilot study would be resolved eventually by the ICC technical staff. Based on this study, it can be concluded that the FDOT is well on its way to developing a state-of-the-art highway evaluation vehicle that is expected to result in significant saving of Florida State's pavement evaluation resources.

The significant findings of the preliminary investigation can be summarized by the following:

1. The surveyed agencies that use similar survey vehicles produced by the ICC have had to overcome hardware and software issues on their way to state-wide implementation of evaluation procedures. Nonetheless, some agencies such as South Carolina Department of Transportation (SCDOT) has been able to resolve the above issues. At present SCDOT Pavement Evaluation Engineers are satisfied with the in-house survey capability of the ICC vehicle and especially its cost-effectiveness.

2. The laser/accelerometer system of the evaluation vehicle provides repeatable pavement roughness and rut data which was also found to be accurate, based on the limited measurements performed at USF's calibrated sites.

3. The inertial measurement unit (IMU) of the evaluation vehicle provides precise cross-slope, grade and curvature data irrespective of the speed. IMU data was also found to be accurate and within FDOT specification up to speeds of 30 mph on tangent sections.

4. The *Applanix* DGPS system of the evaluation vehicle provides precise readings in the stationary mode. However, determination of the accuracy of GPS data with respect to known GPS coordinates of the surveyed location is inconclusive. Hence it is recommended that verification of the positional accuracy and precision of the *Applanix* DGPS system be continued in both static and dynamic modes.

5. The majority of traffic and right-of-way images captured by the evaluation vehicle had to be post-processed or manually enhanced to upgrade their resolution and color reproduction. Further studies are needed to investigate the camera lens types and optimum software settings to achieve better quality in those images.

6. Distress images captured by the pavement camera were seen to reveal accurate details on fine cracks and other distress up to speeds of 45 mph, under well-lit conditions. Further investigation is also needed to verify the accuracy of distress images at higher operating speeds up to 65 mph, and under relatively inferior lighting conditions.

7. Simultaneous performance of multi-function evaluation and PCS is deemed feasible and speedy, based on the success of the pilot study confined to the Hillsborough County in Florida. It was encouraging to observe that, even when one sub-system of the survey vehicle was malfunctioning, all other operations

could be carried out unhindered. However, further collaboration with ICC is required to minimize the fairly significant equipment downtime.

8. Transfer of image data from the vehicle to other storage and distribution devices was found to be time consuming. Hence more efficient data transfer processes and techniques have to be explored prior to state-wide implementation of the evaluation process.

References:

Dougan, C.E., “Florida Department of Transportation Image Program”, Final Report, BC-528, April 2001.

FHWA, "Distress Identification Manual for Long-Term Pavement Performance Project," SHRP-P-338, Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

Wang, K.C.P., “Design and Implementations of Automated Systems for Pavement Surface Distress Survey”, Journal of Infrastructure Systems, ASCE, Vol. 6, No.1, March 2000.

Wang, K.C.P., “Data Analysis of a Real-Time System for Automated Distress Survey”, Proceedings of the Transportation Research Board meeting, January 2002.

Appendix I

Experience of Nebraska Dept. of Transportation

Experience of the Nebraska Dept. of Transportation with ICC video-logging vehicle

Nebraska DOT uses data from one ICC vehicle

Spokesman:
The following description is based on a conversation with Mr. Gary Brahel of Nebraska DOT.

Type of equipment (used since 1996):

1. Downward-looking camera data (pavement distress). (area-scan images are used)
2. Differential GPS (real-time) data and DMI measurements tied to instrument readings.
3. Laser detection of profile and rut data.

Note: A forward-looking camera is used in Nebraska DOT with a separate system to acquire data on bridges, roadway signs etc. (This is supervised by Mr. Dan Bruggeman – 402-479-4317)

Also, PCS is a separate operation, undertaken by 5 operators alternating every two weeks in the summer. Typically a windshield survey is done for every pavement section after selecting a 200-300 feet of a representative sub-section.

Number of ICC instrumented vehicles: 2

Number of operators: 3 (only the driver is used)

Length of surveyed roads:

10,000 miles annually

Duration of survey:

Three months

Up-to-date experience:

Initially, a lot of problems were experienced with the ICC vehicle due to the following reasons:

1. The main computer was not communicating with data acquisition instruments/boards probably because the operating system (Windows NT 4.0) was incompatible.

   There were error messages with the gain, exposure settings etc. Thus, software updates had to be done.

2. BIOS was not setup properly initially.

ICC was helpful with trouble-shooting and finally the system was perfected by trial and error. Currently the system performs well and it can be recommended.

Validation:

DGPS validation has not been done adequately.

Downward camera pictures were validated on a few multi-lane high traffic roads by imaging them every 500 feet. The obtained pictures generally agreed with what was seen on those well-known locations.

Cautions:

Operator adjustment is needed to obtain good detailed pictures from the downward pavement camera, especially in terms of the gain, lighting etc. (Note: Neb. DOT does not possess the automatic lighting and the line-scan camera).

Overall assessment:

Very satisfactory

Appendix II

Experience of South Carolina Dept. of Transportation

Experience of the South Carolina Dept. of Transportation with ICC video-logging vehicle

South Carolina DOT uses data from one (1) ICC vehicle. They are in the process of instrumenting three (3) more vehicles of the same kind with digital cameras of a higher resolution.

<u>Spokesman:</u>
The following description is based on a conversation with Mr. Tom Shea (803-737-1451) of South Carolina DOT.

<u>Type of equipment (used since 1997):</u>

4. Video camera (for detection of pavement distress).
   (digital aerial images are used)
5. GPS to tie locations to instrument readings.
6. Laser detection of profile and rut data.

Note: The above camera is installed <u>in front of the vehicle</u> and acquires pavement data from a panoramic position. There is no downward looking camera.

Also, PCS is performed as a <u>combined operation,</u> undertaken by a rating crew of 2 people (front seat rater and back seat rater).

<u>Number of ICC instrumented vehicles:</u> 1

Number of operators: 4 (driver, equipment operator, front seat rater and back seat rater)

<u>Length of surveyed roads:</u>

8,000 interstate miles annually
4,000 US/SC system every three years
32,000 secondary road miles every three years (with the help of three satellite stations each dealing with approximately 10,000 miles).

(based on only the first year's experience)

<u>Duration of survey:</u>

Three months (typically from January to March) with the data analysis period ending after May each year.

<u>Usage:</u>

The Pavement Management office collects PCS data to be used for the following purposes:

Interstate: Rehabilitation and future rehabilitation optimization (Note: Interstate rehabilitation decisions are taken by an Interstate Rehabilitation Committee)

US/SC system and secondary roads: Prioritization and optimization

Equipped with these data, PMS office communicates very well with regional offices and ensures other engineers' needs.

Video pictures are used ONLY for quality control of rated PCS data.

Hence video-logging and PCS have to be done as a combined operation

Up-to-date experience:

Initially, a few software problems were experienced with the ICC vehicle due to system incompatibility. ICC was helpful with trouble-shooting and currently, the system performs very well.

Validation:

GPS validation has not been done separately due to lack of manpower. SCDOT relies on the sub-meter accuracy as claimed by ICC. The GPS contact point is Mr. Kelvin Washington (803-737-1678).

Video camera pictures were validated during a number of spot checks made on known mile-posts. The obtained pictures generally agreed with what was observed on those locations.

Cautions:

The rutting, IRI and video-logging data are brought into the offices on portable hard drives. They are downloaded in the office into the mainframe. Due to the lack of storage capacity, the previous images of the same locations have to be flushed out. With the 44,000 miles of video-logging, SC DOT is facing acute computer storage problems. Hence the computer storage capacity has to be seriously considered by any agency that is ambitious of such operations.

Overall assessment:

Very satisfactory

Appendix III

Experience of Virginia Dept. of Transportation

Experience of the Virginia Dept. of Transportation with ICC video-logging vehicle**.**

VDOT uses data from two ICC vehicles. One belongs to TMT Inc. which is on contract to VDOT while the other vehicle has been acquired and used by VDOT

Vehicle I

Spokesmen:
The following description is based on conversations with Mr. Doug Gillman of VDOT and Mr. Bill Swindell of TMT Inc. under contract to VDOT.

Type of equipment:
VDOT used an automatic device developed at the University of Kansas up to October of 2000 and bought the ICC version after that.

VDOT does not perform a manual PCS. Instead TMT Inc. uses automatic means of collecting the following information and submits the results of the final analysis to VDOT:

9. Forward-looking images.
10. Downward-looking camera data (pavement distress).
    (line-scan images are used)
11. Differential GPS (real-time) data and DMI measurements tied to instrument readings.
12. Laser detection of profile and rut data.

(Note: Side-view camera and gyroscope are not used in the VDOT system.)

Number of instrumented vehicles: 2

Number of operators: 2 (driver and the computer operator) per vehicle

Length of surveyed roads:

VDOT surveys 56,000 miles annually

TMT is responsible for mainly highway mileage totaling 13,000 miles annually.

Up-to-date experience:

Initially, a lot of problems were experienced by TMT and VDOT with the ICC vehicle, due to the following reasons:

1. 15000 W generator was malfunctioning (a wire chasing problem!) because the ½ ton truck (Chevy truck) was not adequate. Typical size is ¾ ton which they have now. Some software problems were encountered too.

2. Digital images were unclear due to shadows and software bugs. Black lines started appearing in the images.

   The system had to be de-assembled and re-assembled more than once. ICC was very helpful with trouble-shooting and finally the system was perfected by trial and error.

3. Currently the system performs well and it can be recommended as the best in the market.

Vehicle II

Spokesman:
The following description is based on conversations with Mr. Chuck Larson of VDOT who is in charge of pavement evaluation at VDOT.

Up to one year ago they had satisfactory experience with ICC profilometers and skid-trucks.

Then, the following were retrofitted in a FORD E350 XLT profilometer:

1. 1300 x 1024 forward-looking camera.
2. 2K x 2K line-scan downward-looking camera
(experienced as the best in the market).

Uses:

- In special projects and research over the last 3-4 months.
- Anticipate use at the network level PCS at the end of this summer.

Validation:

- Performed at a test grid (16' x 250') at VDOT
- Verification of the instrument readings were done at every 1 foot interval at different speeds.
- Reported that image sizes were consistent and images "remained in sync" with the distance measurements (1 image of the forward camera for every 4 images of the pavement camera) needing only minor enhancements.

Cautions:
Power requirements for artificial illumination. The customized generator power demand is amply met by the FORD truck (as opposed to the CHEVY truck).

Overall assessment:
Very satisfactory

Future enhancements:

VDOT hopes to include ICC's Gyroscope soon.

Anticipated network level application:

Total mileage to be surveyed: **5,000**
No. of instrumented vehicles: **1**

No. of pavement raters 3-4
No. of operators: 2 (driver + operator)

Note: The vehicle operators will be drawn alternatively from the group of pavement raters to create a variation in their routine tasks.

No. of computer staff: 2
(they will be working at the workstation bought from ICC).

Appendix IV

Sample Pavement Distress Survey Control Form

Pavement Distress Survey Control Form

Hillsborough County, Florida

Van operators ______________________________ *Date* | | | |

______________________________ USF companion ______________________________

	Time Management			*According to van odometer*		
Survey Shift	Start	Finish	**Total**	Start reading	End reading	**Length (miles)**
1						
2						
Total						

		Road characteristics					*Time*			*Videologging condition*				*Delay Skips*		*Success*	
Run	Section ID	Road name	Lane	Direction	Pav.Type	Length	Start	Finish	Total	Light/EC	Speed	Traffic	*Data directory*	Number	No	Yes	No
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	

Comments ______________________________

Appendix V

Bayer Filter Averaging Function

Bayer Filter Averaging Function

Let us assume the following color sequence for the left top corner of the CCD sensor:

G11	B12	G13	B14	...
R12	G22	R23	G24	...
G31	B32	G33	B34	...
...	...	...		

Then, the averaging equations suggested in technical literature for the DVC camera are as follows:

PIX22 (originally green) = Avg(R21,R23); G22; Avg(B12,B32)
PIX23 (originally red) = R23; Avg(G13,G22,G33,G24); Avg(B12,B32,B34,B14)
PIX32 (originally blue) = Avg(R21,R41,R43,R23); Avg(G31,G42,G33,G22); B32

Pixel on the edge:
PIX11 = R21; G11; B12

Top Row:
PIX13 = R23; G13; Avg(B12,B14)

Left Column (except PIX11):
PIX21 = R21; Avg(G11,G22,G31); Avg(B12,B32)

Note: The evaluator has to consider the scheme of CCD sensor, the
position of the particular pixel that is going to be evaluated the full color values with respect to its neighbors.

Appendix VI

Inventory of the FDOT Survey Vehicle

990639601 **IMAGING SYS (LINESCAN / 2 FWD. CAMERAS, GYRO) W/4 LASER PROFILER (FLDOT)**

902000400 A	**VEHICLE ASSEMBLY FOR FORD IMAGING SYSTEM**	**MANUFACT.**
900100102 A	**DUAL MONITOR/KEYBOARD IMAGING ASSEMBLY FOR 2001 FORD VAN**	
1	OMNIVIEW CABLE KIT	BELKIN
1	MOUSE, KEYBOARD, TRAY	ICC
1	LOGITECH TRACKMAN	LOGITECH
2	VIEWSONIC 15" DISPLAY SUBSYSTEM	VIEWSONIC
	ACCESSORIES	
901300200 A	**AURA-GEN GENERATOR SYS FOR 97-00 FORD 5.4L TRITON VANS**	
	BASE MOUNTING KIT	
	120/240V, GENERATOR	
	DASHBOARD CONTROL UNIT	
	ACCESSORIES	
930000802	**2002 FORD E-350 XLT SUPER DUTY VAN**	
	2002 FORD E-350 XLT SUPER DUTY VAN	
910010401 A	**SONIC BUMPER ASSEMBLY KIT**	
	ICC STANDARD BUMPER BASE	
	ACCESSORIES	
900030112 A	**SWITCH BOX ASSEMBLY**	
	8 PORT MATRIX KVW SWITCH	
	CABLES	
900200100 A	**WHELEN LIGHT BAR ASSEMBLY FOR LRS VANS**	
	STROBE LIGHTS, 6" ROUND AMBER	
	ASSEMBLY, TAIL-LIGHT MOUNTING KIT	
	SUPPLEMENTAL TAIL-LAMP ASSEMBLY	
	ACCESSORIES	
061257300 A	**ENCODER ASSEMBLY KIT, FOR FORD CLUB WAGON XLT**	
	HOLLOW SHAFT ENCODER/INCREMENTAL	
	ENCODER AXLE STUDS	
	ACCESSORIES	
900578001 A	**COMPUTER RACK SUB'ASSEMBLY**	**ICC**
	COMPUTER RACK SUB'ASSEMBLY	

	ACCESSORIES	
900007000 A	**NETWORK ASSEMBLY** NETWORK ASSEMBLY ACCESSORIES	
900601106 A	DOWNWARD LINESCAN IMAGING SYSTEM (FLDOT) S/N:3026	**MANUFACT.**
860601005 A	**DOWNWARD LINESCAN IMAGING CHASSIS - RACK MOUNT (FLDOT)** CHASSIS - RACK MOUNT 350 WATT POWER SUPPLY CAMERA POWER RELAY INTEL 850 P4 MOTHERBOARD 128MRD RAM INTERNAL ZIP 250MB FLOPPY DISK ACCESSORIES	**ICC**
900000401 A	**DOWNWARD CAMERA ASSEMBLY** ASSEMBLY CAMERA BOX ASSEMBLY CAMERABOOM MOUNTING SUPPORT BICS FOR L102B-2K CAMERA 24 V-AC PLUG-IN TRANSFORMER ACCESSORIES	
220012000 A	**PC CARDS FOR DOWNWARD IMAGING CHASSIS** ULTRA 100 PCI IDE CONTROLLER CARD GENESIS BOARD DIGITAL INTERFACE ENCODER TRIGGER ASSEMBLY ACCESSORIES	
220001900 A	**EXTERNAL CABLES FOR DOWNWARD IMAGING SYSTEM** EXTERNAL CABLES FOR DOWNWARD IMAGING SYSTEM ACCESSORIES	
980409200 A	**SOFTWARE FOR DOWNWARD IMAGING SYSTEM** MS WINDOWS 2000 PRO FIREHAND NORTON ANTIVIRUS	
910100200 A	**CAMERA/LIGHTING MOUNTING ASSEMBLY** LIGHT MOUNTING FRAME 150 W ALTMAN PAR-CDM WELDING ROOF SUPPORT MOUNTING PAR LIGHTS POWER SUPPLY ACCESSORIES	

900602103 A	FORWARD/SIGN 1300 X 1024 IMAGING SYSTEM (FLDOT)	MANUFACT.
860602004 A	**FORWARD IMAGING CHASSIS - RACK MOUNT (FLDOT)** CHASSIS - RACK MOUNT 350 WATT POWER SUPPLY INTEL 850 P4 MOTHERBOARD 128MRD RAM INTERNAL ZIP 250MB FLOPPY DISK ACCESSORIES	**ICC**
900000301 A	**FORWARD/SIDEVIEW CAMERA ASSEMBLY** CAMERA, DIGITAL, COLOR 1300H*1300V*10 BIT/12F/S 15" LONG CAMERA ENVIROMENTAL ENCLOSUREWITH HEATER / DEFROSTER VIDEO CAMERA MOUNT CAMERA LENS 2/3", 8.5 MM, MANUAL IRIS AND FOCUS CAMERA LENS 2/3", 25.0 MM, MANUAL IRIS AND FOCUS TRANSFORMER 24VAC ACCESSORIES	**ICC**
220014000 A	**PC CARDS FOR FORWARD IMAGING CHASSIS** ULTRA 100 PCI IDE CONTROLLER CARD VIDEO CARD VIDEO IMAGING BOARD 3COM ETHERNET NETWORK CARD ACCESSORIES	
220002000 A	**EXTERNAL CABLES FOR FORWARD IMAGING SYSTEM** EXTERNAL CABLES FOR FORWARD IMAGING SYSTEM ACCESSORIES	
980409300 A	**SOFTWARE, FORWARD IMAGING SYSTEM** MS WINDOWS 2000 PRO FIREHAND NORTON ANTIVIRUS	

APPENDIX VII

Survey Cost Information

1. Cost Estimates Obtained from Other Surveyed States

Most surveyed transportation agencies do not have readily available information on expenditure involving automated evaluations. On the other hand, the transportation agencies that possess cost estimates are unable to provide systematically itemized cost details. Hence an estimate of the total cost involved per surveyed lane mile was obtained from all of the agencies (Table VIII).

Another difficulty encountered by the investigators was the fact that all of the surveyed agencies that use the *Roadware* ARAN system and the IMS evaluation vehicle outsource the evaluation jobs. Therefore, the cost estimates reported by them were total cost of the services of the respective vendors per surveyed lane mile (Table VIII).

It was encouraging to find that the surveyed states that use ICC vehicles, namely, Virginia, Nebraska and South Carolina perform the majority of their surveys in-house (Table VIII). Extremely valuable information regarding the feasibility of in-house implementation of automated highway evaluations was gathered from the latest round of conversations with the South Carolina DOT in particular. This is because SCDOT is ahead of FDOT in utilizing the ICC survey vehicle in their evaluations. Currently the ICC vehicle is being used to survey 14,000 lane miles of highways in annual cycles. This mileage consists of their interstate system and one third of the US, SC and the secondary systems. Thus, the entire US, SC and the secondary systems of roads in SC get evaluated on tri-annual basis. Although SCDOT have had to overcome hardware and software issues in their path to implementation, the Pavement Evaluation Engineers in SCDOT are quite satisfied with the cost-effectiveness of in-house surveys.

Table VII.1 Cost estimates of Automatic Highway Evaluation

Agency	Scope of work	Vehicle type In-house /Outsource	Cost/lane mile
Virginia	IRI, rut, pavement distress, Forward-view, GPS	ICC – In-house and outsource	**$ 40***
South Carolina	IRI, rut, pavement distress, PCS GPS	ICC In-house	**$ 50**
Nebraska	IRI, rut, GPS, PCS, imaging**	ICC In-house	**$ 4**
Pennsylvania	IRI, rut, pavement distress, right-of-way, cross-slopes, GPS	Roadware Outsource	Unavailable
Alabama	IRI, rut, pavement distress, right-of-way, cross-slopes, GPS	Roadware Outsource	**$ 50**
Iowa	IRI, rut, pavement distress, GPS	Roadware Outsource	**$ 40**
Colorado	IRI, rut, right-of-way, GPS	IMS Outsource	**$ 50**
New Mexico	IRI, rut, right-of-way, GPS	IMS Outsource	**$50**
Hillsborough County, FL	IRI, rut, pavement distress, cross-slopes GPS, PCS, imaging	IMS Outsource	**$100*****

* - Approximate
** - Imaging done for quality control of PCS data only
***- Small network rate (involving slow survey speeds)

2. Estimated Cost of Pavement Condition Survey for FDOT (2001)

1) Total Annual salaries for PCS staff. Includes field staff of seven, one office support, one Supervisor, one Unit Head and one Section Head at 25 %.

Total Salaries = $346,943.00 X 1.59 (overhead) = $551,639

2) Total equipment cost is based on the Department's Equipment Life figures from EMIS data. Includes five Laser Profiler Vans and two support vehicles.

The highest cost for the five Laser Vans was used for all five ($20,652 per unit per year).

Replacement cost of Laser Units was calculated at the present cost of replacement or $110,000.00 each (ten year life expectancy with up grades is 11,000.00 per unit per year). Repairs to electronics are calculated again at highest cost or $2,000.00 per unit per year.

Equipment Cost = $33,652 per survey unit X 5 units = $168,260
$ 3,415 per support vehicle X 2 = $ 6,830
Total Equipment Cost = $175,090

3) Travel cost for entire staff = $ 24,500.00

4) Cost per rated mile (All Programs combined) = [$551,639 (personnel) + $175,090 (equipment) + 24,500 (travel)] ÷ [(18,169 (PCS rated miles) + 4,370 (other programs rated miles)]= $ 33.33 per mile

NOTE: That the cost calculations are exaggerated in that the highest cost was used for every category (personnel and equipment). The unit accomplishes several other programs in addition to PCS, including the Highway Performance Monitoring System (HPMS) both on and off system, the Small County Assistance Program (SCRAP), the Small County Outreach Program (SCOP), Experimental project evaluations, Ride acceptance testing (evaluations and specification requirements), premature pavement failure investigations and research activities associated with related issues.