New Technologies for Photolog Image and Data Acquisition: HDTV Image Acquisition, Distribution and Utilization

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Report Number: CT-2236-F-16-2

Final Report

June 15, 2016

Research Project: SPR-2236

Connecticut Department of Transportation
Bureau of Policy and Planning
Roadway Information Systems Research Section

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipients Catalog No.
CT-2236-F-16-2	N/A	

4. Title and Subtitle New Technologies for Photolog Image and Data Acquisition: HDTV Image Acquisition, Distribution and Utilization	5. Report Date June 15, 2016 6. Performing Organization Code SPR-2236
7. Author(s) Bradley J. Overturf	8. Performing Organization Report No. CT-2236-F-16-2
9. Performing Organization Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131	10. Work Unit No. (TRIS) N/A 11. Contract or Grant No. CT Study No. SPR-2236 13. Type of Report and Period Covered Final Report February 2003 to June 2012
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131	14. Sponsoring Agency Code SPR-2236

15. Supplementary Notes

A study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The goal of this research project was to improve photolog imaging technology and subsequent image-to-client delivery in response to user-requests for enhanced desktop image retrieval capabilities, such as the ability to read small roadway signs, bridge numbers and utility pole numbers along Connecticut roadways.

The resulting implementation of state-of-the-art photolog imaging research, hardware and software has provided the Connecticut Department of Transportation with an all-HDTV ground-based automated image inventory of its entire roadway network. HDTV represents a 5X increase in image resolution and significant improvement in overall image quality, which has met project goals and led to an increase in photolog use at ConnDOT.

17. Key Words	18. Distribution Statement
High Definition, Photolog	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA. 22161

19. Security Classif. (Of this report)	20. Security Classif.(Of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	24	N/A

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ACKNOWLEDGEMENT OF SPONSORSHIP

This project was sponsored by the Connecticut Department of Transportation in cooperation with the Federal Highway Administration

AUTHOR ACKNOWLEDGEMENTS

The author wishes to acknowledge the support of personnel from the Federal Highway Administration, Connecticut Department of Transportation, and the University of Connecticut. In particular, the author would like to thank and acknowledge: Mr. James M. Sime for supporting technology improvements at CTDOT and the Department of Transportation's Photolog Section for their expertise in the field, year in and year out.

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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INTRODUCTION AND BACKGROUND

A High Definition Imaging System for Photologging

Figure 1: Connecticut Route 920 HDTV image

For thirty years, the Connecticut Department of Transportation has acquired ground-based images with state-of-the-art photolog vehicles. The photolog program in ConnDOT, administered by the Data Services Section (DSS), has been successful due to the emphasis placed on maintaining high image quality and internal marketing, which includes distributing acquired images to as many “clients” as will derive benefit from them. Over the years, Department-wide photolog retrieval tools had evolved from film viewing stations used through the 1970s and early 1980s, to thirty-four PC-controlled Photolog Laser Videodisc (PLV) workstations employed from the mid-1980s through the 1990s.

In 1997, the Photolog Unit upgraded its two photolog vehicles from outdated motion picture film cameras to progressive scan (full frame 640 X 480 pixel images) digital video cameras. Since their deployment, digital cameras and subsequent imagery have provided DSS with an opportunity to improve and greatly expand client use through the personal computer storage media Digital Versatile Disc (DVD) and

LAN/WAN image distribution. Concurrent improvements have been made by DSS in the area of image storage. New Redundant Array of Inexpensive Drives (RAID) storage systems installed at DSS have negated the storage problem associated with high quality imaging. As a result of improvements in digital file technology, 360 department PCs equipped with DVD-ROM drives, network cards and the photolog viewing software called DigitalHIWAY now access front and side-view digital photolog images (Fig. 1). Estimated cost savings derived from the use of photolog as substitute to or aid used in conjunction with a field trip now exceeds two million dollars annually, which is twice that of estimates calculated prior to the implementation of digital imaging and network distribution.

PROBLEM STATEMENT

In 2003, the previous photolog camera's low 640x480 pixel resolution precluded clear viewing. At the same time researchers at FHWA and the University of Connecticut were attempting to employ pattern recognition to automatically extract lane, pavement markings, sign, and curb attributes from photolog images, but had met with limited success due to the low image resolution (Fig. 2). Although many aspects of photologging had undergone upgrading and improvements, imaging improvements had not been addressed at ConnDOT since 1997. The Research Section and DSS became aware of technologies, such as high resolution digital cameras and high-definition cameras that could provide photolog's client-base immediate improvement in general viewing applications as well as potentially allow for many new applications (Fig. 3).

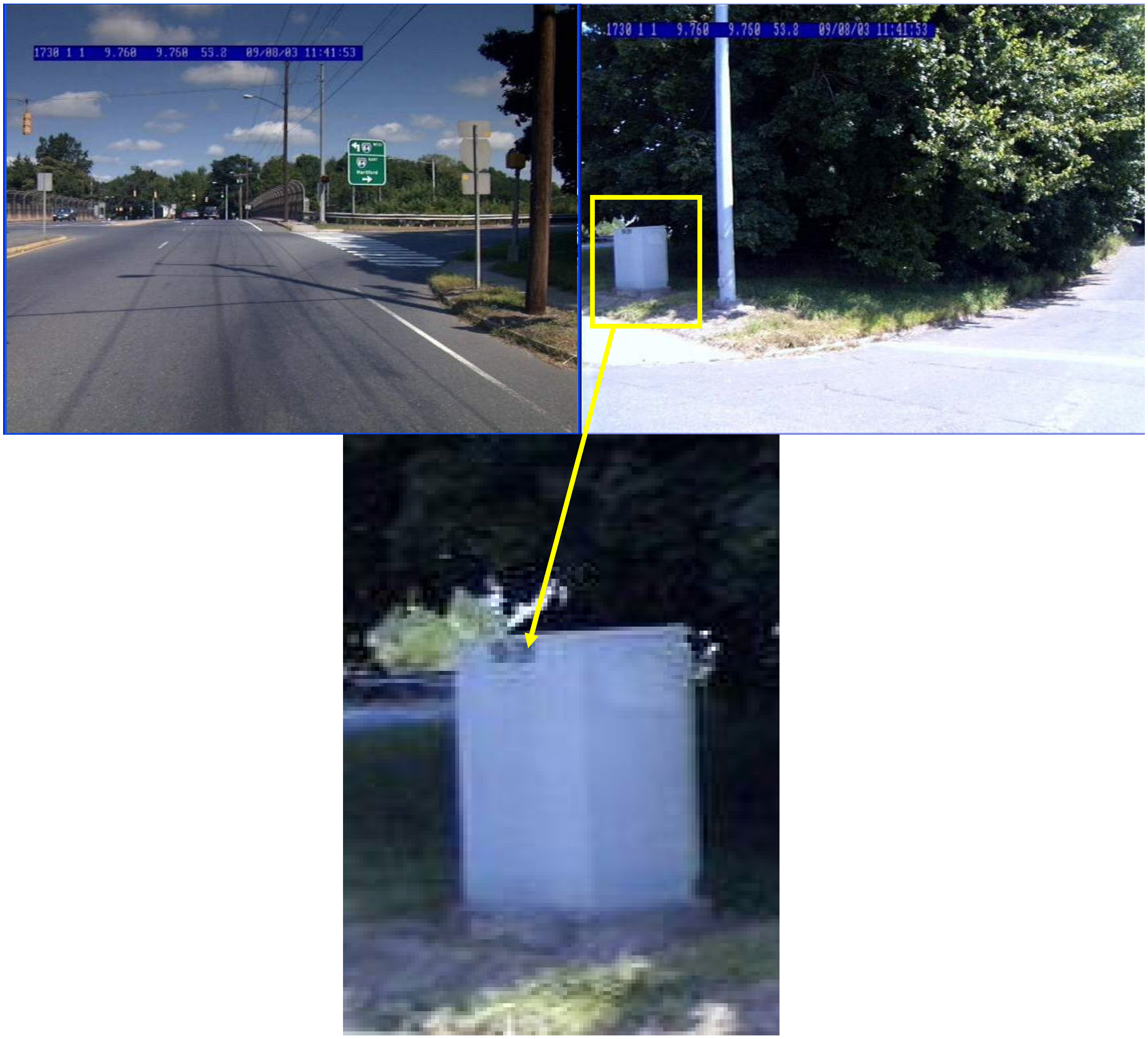

Figure 2: 2003 Zoom From 640x480 Photolog

Figure 3: 2006 Zoom From 1920x1080 Photolog

PROJECT GOAL

The goal of this project was to improve photolog imaging technology and subsequent image-to-client delivery. The project, entitled "New Technologies for Photolog Image and Data Acquisition," came at the request of photolog clients who wanted enhanced image retrieval capabilities such as the ability to read small roadway signs, bridge numbers, and utility pole numbers as depicted in Figure 3.

RESULTS / FINDINGS / IMPLEMENTATION

HDTV Photolog Retrieval

The project's first task was to identify a camera. This involved an extensive three-month search that ended at the 2003 National Association of Broadcaster's Convention in Las Vegas, Nevada. A photolog and imaging expert from ConnDOT's project partner, the University of Connecticut's Transportation Institute (CTI), was dispatched to the convention to identify a camera that would optimize ConnDOT imaging. The camera selected by the CTI and ConnDOT for evaluation was the Thomson Grass Valley Worldcam LDK 6000 MK II (Fig. 4). The Thomson camera captures progressive scan High Definition images with three 9.2-million pixel high definition charge-coupled devices (HD CCDs) in multiple formats. A demonstration by Thomson at the ConnDOT photolog facility in July of 2003 confirmed the functionality and extraordinary image quality.

Figure 4: Thomson Grass Valley Worldcam

Incorporating the HDTV technology into the vehicle was the job of the Roadware Group Incorporated, of Paris, Ontario Canada. ConnDOT has owned and operated two of Roadware's Automatic Roadway Analyzer (ARAN) vans since 1994 (Fig. 5). The vehicles consist of a standard cutaway van chassis affixed to a large rear cube with ample space for the vehicle system modules, an operator console, as well as power and backup generator. The onboard systems include a global positioning system (GPS), a gyroscope that accurately measures roadway curvature and grade, laser-based modules collecting roughness and vertical under-clearance, ultrasonic rut-depth measurement, automated pavement crack detection, and a new high definition television (HDTV) image capture system. The modular design of the vehicles allowed for the replacement of the existing imaging system with HDTV, though challenges were encountered.

Figure 5: ConnDOT's Photolog Vans

There were three primary challenges: 1) the image quality had to be dramatically improved over that of the existing camera; 2) the large format HDTV images had be converted to the JPEG file format on-the-fly; and, 3) onboard storage had to be increased to accommodate larger files. All of these had to be accomplished without adversely impacting clients who had become heavily dependent on the annual access to photolog roadway images and data in the face of a reduced fleet of state vehicles.

The Thomson camera answered the first challenge. Not only was the image quality better, but it also allowed ConnDOT to eliminate a dual camera system that had doubled the imaging hardware in the van and likewise accumulated twice as many images as a single camera system. This made the old system's images difficult for field and office personnel to manage and move across ConnDOT's LAN. The single HDTV camera, mounted just above the dashboard of the van, replaced two seven-year-old Sony DXC-9000 digital video cameras, one that faced forward and one that faced out the passenger side of the rear cube. These had provided "forward view" and "side view" photolog images.

A Canon HJ11EX4.7 High Definition lens was chosen for the new camera system. The Canon lens captures images at the HD standard 16x9 aspect ratio with a 4.7mm to 52mm zoom. ConnDOT collects images with the lens focal length fixed at 4.7mm to maximize the field of view. At this setting, the camera captures a single image (Fig. 7) that provides a similar field of view to that of the old dual camera system (Fig. 6), eliminating the need for a second camera (see comparison in photos below).

Figure 6: Dual Camera Views From the Old Camera System

Figure 7: Single HDTV Image From the New Camera System

The HDTV camera was acquired in the winter of 2004, and Roadware Group's imaging systems engineers set out to make it work in an ARAN. A critical task was identifying an HDTV capture card compatible with the camera and adaptable to Roadware's ARAN system. After a period of trial and error with cards that did not work, a suitable card was finally identified in November of the same year. An AJA Video Systems, Inc., Xena HD PCI card was procured, tested and installed in a new computer at the Roadware facility for software development in January of 2005.

Roadware had developed computer software called “Harvest” two years earlier to work with lower resolution digital cameras, and was able to adapt the program to work with the AJA card in the late winter and spring of 2005. This resolved Challenges 2 and 3. “Harvest” is user-configurable to collect at intervals ranging from 5-20 meters, and allows for various standard JPEG compression rates. It initiates at the time of ARAN system startup and runs seamlessly with all other subsystems. For ConnDOT’s purposes, Harvest is setup to capture a JPEG formatted image for every 10 meters that the ARAN travels. Each image is saved to an eighty-gigabyte removable hard drive, and a backup copy is simultaneously saved to a mirrored one-terabyte external hard drive.

With questions of file format and storage answered, the first of ConnDOT’s ARAN’s was delivered to DSS in May of 2005. After a short period of calibration and testing it was deemed operational and was used to collect HDTV for approximately 40% of the 2005 network. The second vehicle was retrofitted the following winter making ConnDOT ready for all-HDTV collection in the spring of 2006.

The DigitalHIWAY System: Effective Photolog Distribution

While Roadware upgraded the ARAN, ConnDOT worked with its systems developer to update and improve its client-server application, called “The DigitalHIWAY System.”

Prior to the HDTV project, ConnDOT had been photologging for nearly thirty years. DSS and the photolog program has been successful, not by archiving millions of images but by focusing on distributing them to as many clients as can derive benefit from the information. In the 1970’s, photolog was viewed on three filmstrip viewers in the basement of the Department’s headquarters building. In the 1980s, the userbase grew to sixteen customized laserdisc-based stations controlled by the then new personal computer (PC) and an exorbitantly priced graphics generator. The 1990s saw advancements in PC technology significantly lower the cost of individual PC-laserdisc stations to the point where thirty photolog stations were in use throughout the department. Finally, in the early part of this decade, ConnDOT converted to DVD and Agency-wide client-server distribution.

The DigitalHIWAY System includes three modules: DigitalHIWAY Incremental Index and Editor (IIE), DigitalHIWAY ImageServer (DH ImageServer), and DigitalHIWAY Client (DH Client).

The **IIE** post-processes raw collected data-streams into a form suitable for delivery to the DigitalHIWAY Client (on the end-user's desktop) by the DigitalHIWAY ImageServer. During this post-processing, image and non-image data-streams are associated and checked for completeness. Multiple photolog-filming sessions can be edited into a seamless ImageServer data set (This allows long routes to be photologged in separate segments). Traditional department linear-referencing locations are tied to the images that show them (by visually correlating with the image from the previous year) (Fig. 8).

Figure 8: IIE Linear-Referencing Screen Showing 2005 Year Image With 2006 Proposed Image for a Linear-Reference Checkpoint

The final step in IIE post-processing for a route/direction consists of the creation of a Concatenated JPEG Library file (".CJL") and an "upgrade file" (containing a new route index for use by the end-user). The CJL file serves as a single container for all images for a route/direction.

The CJL files are an efficient file format easily managed by both the administrator of the DigitalHIWAY system and the end-user. For the system administrator, image data is more easily managed when a single file replaces hundreds of individual image files in a complicated directory structure. Ease of copying is augmented by the implied assurance that no single picture can get lost in the shuffle. For the DigitalHIWAY end-user, the efficiency of the indexed CJL makes retrieval very fast.

Each individual JPEG image file from the ARAN is copied directly into the receiving CJL file, along with a small index that allows for rapid access to any image. DigitalHIWAY ImageServer accesses CJL files from a co-located RAID disk array for network transmission to DigitalHIWAY Clients. CJLs are also mastered on DVD for direct use by DigitalHIWAY Clients that are not on the network. IIE can be operated in a single-route mode, providing daily access of images and data to users, or in batch mode, which allows the operator to create indices and geo-referenced locations for multiple routes. The single-route mode provides quick post-processing following a day's photologging for rapid delivery of the images to the end-user's desktop PC.

In 2007, image compression was reduced in the vans, creating a much larger image. To accommodate the 1 terabyte of photolog images and data collected each year, a fiber-based Storage Area Network (SAN) was installed in 2007, and a fiber-based OC-3 line was installed between the photolog SAN unit in Rocky Hill, CT, and ConnDOT's headquarters building located in Newington, CT, where the bulk of photolog images are viewed.

DH ImageServer sends CJL route images to requesting users via the DigitalHIWAY System protocol layered on top of standard TCP/IP protocol. The software runs as a service* on any Microsoft Server-based PC and can be administered locally, or remotely, with the DigitalHIWAY ImageServer Controller. DH ImageServer distributes the index-file-updates created by IIE to client workstations. Client software upgrades and repairs are also done this way, maintaining uniformity and compatibility for all end-users.

DH ImageServer also distributes a "Data Services News" feature (Fig. 9) that lets DSS communicate with users regarding DigitalHIWAY and photolog operations.

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* If the server hardware is shut down for any reason, the DigitalHIWAY Server software starts automatically upon reboot when running as a "service."

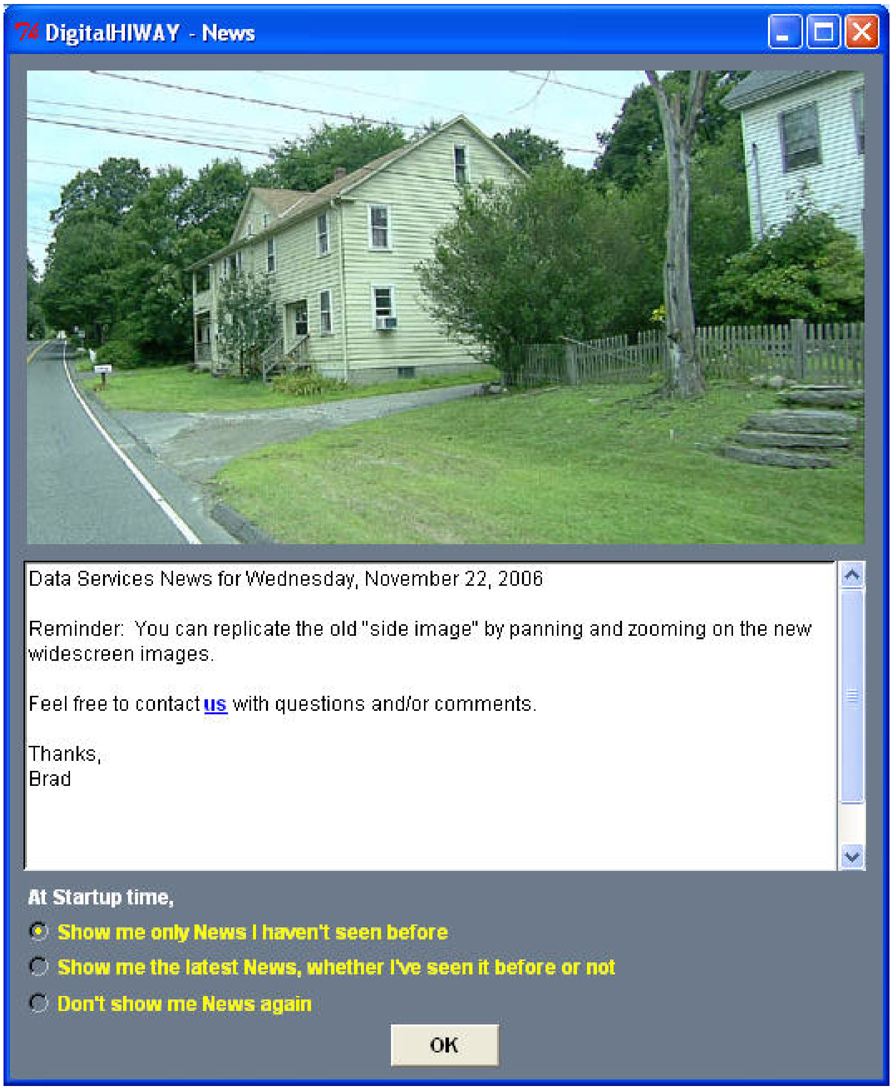

Figure 9: Data Services Section News

DH Client resides on individual PC workstations throughout ConnDOT and other State Agencies.* Installation consists of copying a single file to an empty subdirectory on the user's computer, and then running it once to perform setup chores. After completing the installation and starting the software, the general user interface consists, first, of a simple list of all state-maintained highways ordered by route and direction that the client is prompted to select from. After the client selects a route, the software loads the first CJL image representing the start of that route and direction along with a forward

* ConnDOT, State Police, and the University of Connecticut own site-licenses for DigitalHIWAY. At ConnDOT, every new PC is deployed with DigitalHIWAY preinstalled.

and reverse motion control window, HDTV image window and an interactive link to traditional linear referencing locations along each roadway (Fig. 10).

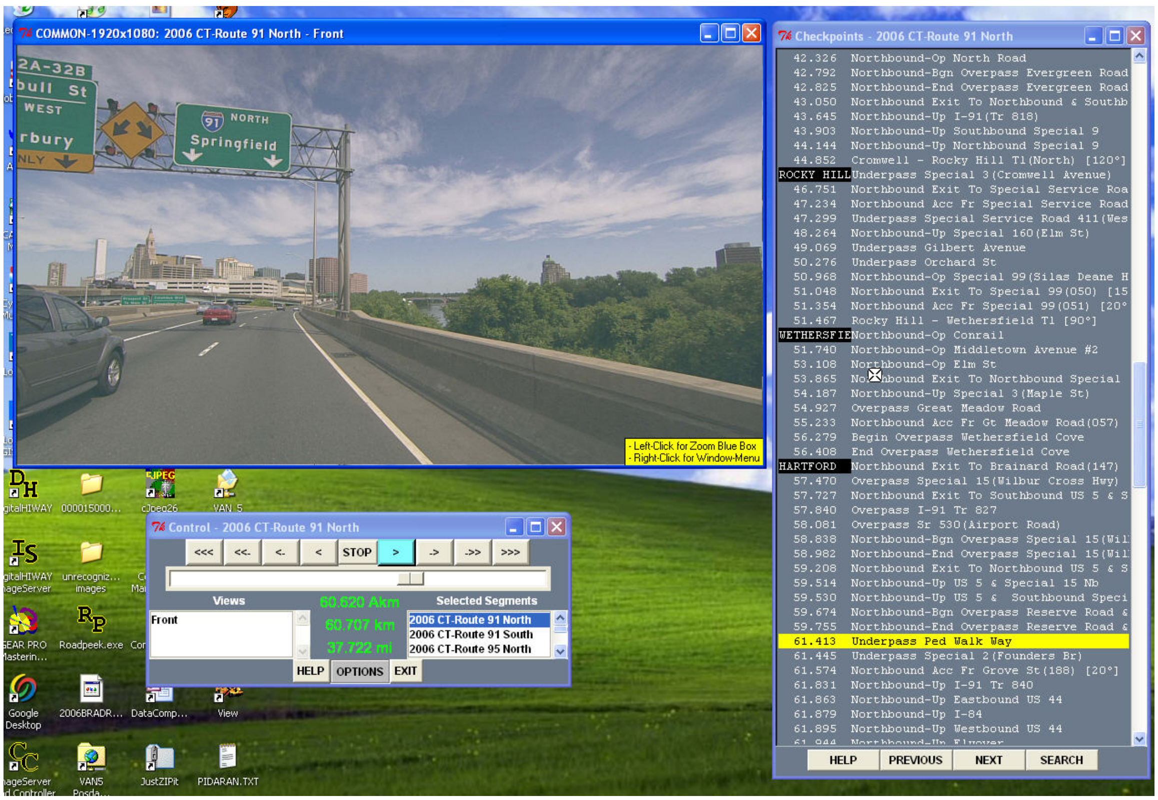

Figure 10: ConnDOT "Desktop" With DigitalHIWAY Client Running

Department End-Users

DigitalHIWAY is used daily by the following ConnDOT offices: Permits, Planning, Geographic Information Systems (GIS), Maintenance, Pavement Management, Traffic Signals, Traffic Engineering, Design, Rights-of-Way, Central Surveys, Research, Materials Testing, Landscape Design, Bridge Design, Bridge Safety, Incident Management, the four district offices, the State Traffic Commission, the Chief Engineer's Office, and the Commissioner's Office. Usage can be generally broken down into five categories: familiarization, review, confirmation, documentation, and presentation.

Familiarization: Photolog is a safe and efficient means of becoming familiar with a roadway location either prior to, or in conjunction with, a planned field trip. All Rights of Way Property Agents have DigitalHIWAY installed and use it to familiarize themselves with property being acquired or sold. Traffic Engineers study busy intersections without putting themselves, or state property, at risk during the workday. The Commissioner's office or the Chief Engineer can view a location in a matter of seconds, for any number of administrative issues that might arise.

Review and Documentation: When asked how they use photolog, most clients will immediately say "it is a great review tool." Each area within the organization finds new uses for photolog every time they start the software. This process usually begins by reviewing a route that is part of an ongoing project, or has come to the attention of the engineer, bridge inspector, maintenance supervisor or landscape designer. The review leads to ideas such as an improvement or new inventory. Recent inventories performed using photolog include: guide rails performed by Pavement Management; drainage features recorded by Central Surveys; and, sign locations documented by Maintenance garages responsible for signs. This valuable information was previously either unrecorded or recorded by a laborious manual method.

Confirmation and Documentation: ConnDOT photologs all state roads annually. DigitalHIWAY can access the data via online storage dating back to 1985. For state agencies as well as private sector use, photolog is often the only accurate documentation for a given piece of state roadway and its surroundings during a calendar year. Utility audits, accident reconstruction and investigation, and safety studies are all augmented by photolog technology. Connecticut State Police have DigitalHIWAY installed on multiple computers in their accident investigation unit.

Presentation: HDTV images make for a powerful presentation tool. DigitalHIWAY is used by the State Traffic Commission at public meetings to more clearly present proposed changes to roads that impact communities, enhancing public understanding. DigitalHIWAY's image export feature makes it easy for a client to save any individual picture for use in any word processing, spreadsheet and presentation software.

At the University of Connecticut and the University of Hartford, the client-server application is being used daily by professors and graduate students on classroom and research topics ranging from highway safety to GIS/GPS.

Usage Tracking and Benefits

Incremental distribution of photolog data began with the HDTV implementation at the start of the 2006 photolog season. Response to the improvements has been overwhelmingly positive. Personnel feedback, usage tracking and cost savings analysis software developed by ConnDOT have proven what ConnDOT has long observed: Agencies can derive millions of dollars in cost savings by using photolog technology. It stands to reason that viewing recently recorded roadway pictures on an office PC can often replace a field trip when the purpose falls into one of the five categories mentioned. The higher the quality of the collected data, the higher the user-confidence, and, thus, more field trips (fleet vehicle use and man-hours) are eliminated. All this translates to dollars saved.

Improvements to PCs, local area networks, global positioning systems (GPS), and storage technologies have made DigitalHIWAY usage-tracking an easy-to-implement, comprehensive and automated reporting tool. Usage tracking helps to justify the expense of photolog operations and improves client support and outreach.

DigitalHIWAY distribution and retrieval software takes advantage of information technology (IT) improvements to manage the flow of information to the users, and record information that can be later used by photolog staff to best understand how data is being used and derive critical cost savings from its use.

During a given session, photolog usage tracking software measures a straight line distance from the GPS coordinate of the DigitalHIWAY Client location, as determined by the computer's network name in the DH Server "userlog" file, to the coordinate of the route/direction and mile-point being fetched by the DH Client. From the workstation location and end point (route locations being viewed), coupled with personnel salary and fleet vehicle charges, DSS staff can determine a conservative round trip travel cost estimate for each occasion of use. Total savings, number of clients, logins, workstations, routes viewed, and percentage of all state routes viewed are reported to the FHWA quarterly. Standalone DVD-based user logs are not gathered and reported, but instead estimated in proportion to userlog data from the server.

The improvements made during the advanced imaging data acquisition technologies research project have led to a 58% increase in photolog use (routes viewed) and 51% increase in savings since full implementation was realized in 2006 (see comparison chart below, Fig. 11).

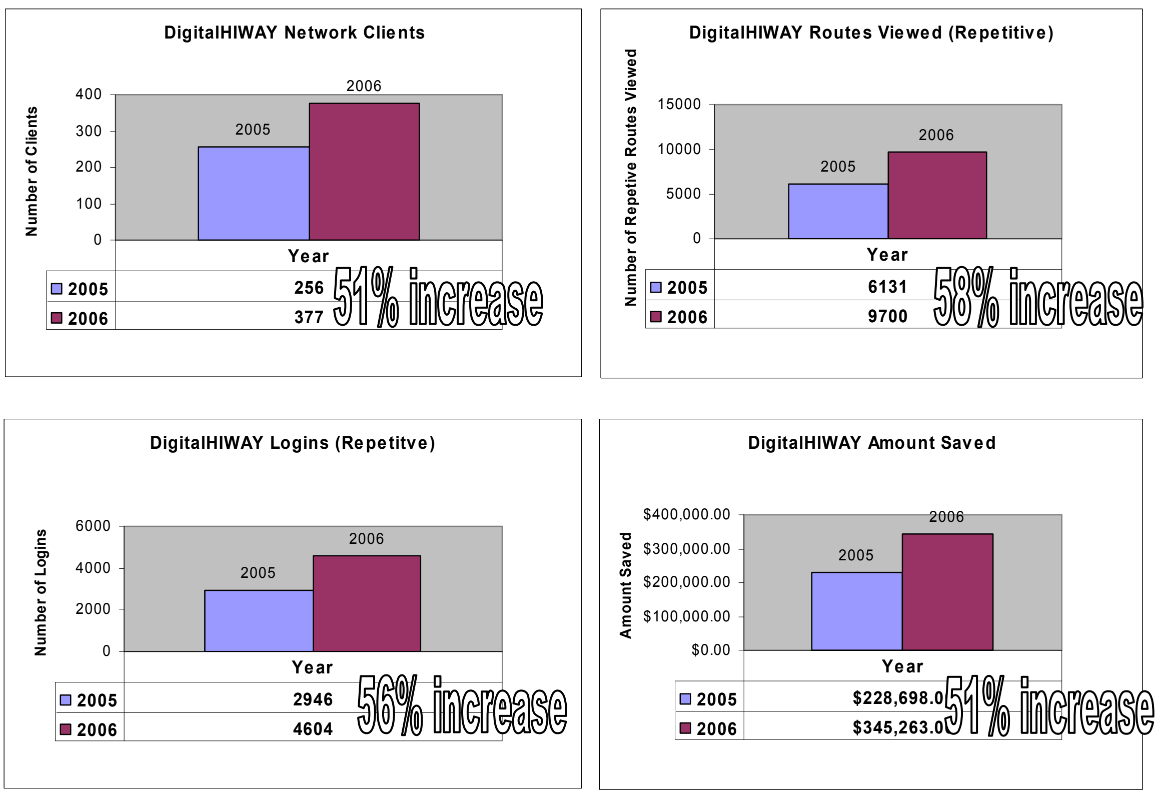

Figure 11: Photolog Use for DigitalHIWAY Network Clients (Oct-Dec 2006 Compared to Oct-Dec 2005)

CONCLUSIONS

HDTV images, bridge under-clearance, and incremental indexing and image distribution are the latest in a series of improvements to photolog in ConnDOT. As described herein, savings from these technologies are impressive even in a small state. Savings in states with larger areas should be equal, or more substantial, and it appears to make sound economic sense for state DOTs to place a high priority and adequate resources to continually improve and upgrade their ground-based image and data acquisition systems, as well as providing widely accessible LAN and non-LAN access to HDTV photolog images and data.

ConnDOT's 500 total users (including projected standalone use) save the state an estimated $2 million per year in costs associated with avoided field trips. This delivers an impressive 3:1 benefit/cost ratio, based on the annual operating budget for this Department function. Photolog has become a mainstream tool used daily by all Department Bureaus with a framework now firmly in place to maintain use and allow for growth as the Department changes over time. Based on ConnDOT's experience, the old adage "a picture is worth a thousand words" can be extended to include a thousand practical applications and millions of dollars saved.

Successful use of this technology is dependent upon proper network storage and bandwidth sufficient to carry images across a LAN efficiently.