PILOT STUDY ON IMPROVING THE EFFICIENCY OF TRANSPORTATION PROJECTS USING LASER SCANNING

CTRE Project 02-109

Sponsored by
the Iowa Department of Transportation

Iowa Department
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Research and Education

IOWA STATE UNIVERSITY

Final Report • January 2003

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Technical Report Documentation Page

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle
Pilot Study on Improving the Efficiency of Transportation Projects Using Laser Scanning

5. Report Date
January 2003

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
MTC Project 2002-03

9. Performing Organization Name and Address
Midwest Transportation Consortium
2901 South Loop Drive, Suite 3100
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address
U.S. Department of Transportation
Research and Special Programs Administration
400 7th Street SW
Washington, DC 20590-0001

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
This project is co-sponsored by the Iowa Department of Transportation.

16. Abstract

Laser scanning is a terrestrial laser-imaging system that creates highly accurate three-dimensional images of objects for use in standard computer-aided design software packages. This report describes results of a pilot study to investigate the use of laser scanning for transportation applications in Iowa.

After an initial training period on the use of the scanner and Cyclone software, pilot tests were performed on the following projects: intersection and railroad bridge for training purposes; section of highway to determine elevation accuracy and pair of bridges to determine level of detail that can be captured; new concrete pavement to determine smoothness; bridge beams to determine camber for deck-loading calculations; stockpile to determine volume; and borrow pit to determine volume. Results show that it is possible to obtain 2–6 mm precision with the laser scanner as claimed by the manufacturer compared to approximately one-inch precision with aerial photogrammetry using a helicopter. A cost comparison between helicopter photogrammetry and laser scanning showed that laser scanning was approximately 30 percent higher in cost depending on assumptions. Laser scanning can become more competitive to helicopter photogrammetry by elevating the scanner on a boom truck and capturing both sides of a divided roadway at the same time. Two- and three-dimensional drawings were created in MicroStation for one of the scanned highway bridges. It was demonstrated that it is possible to create such drawings within the accuracy of this technology. It was discovered that a significant amount of time is necessary to convert point cloud images into drawings. As this technology matures, this task should become less time consuming.

It appears that laser scanning technology does indeed have a place in the Iowa Department of Transportation design and construction toolbox. Based on results from this study, laser scanning can be used cost effectively for preliminary surveys to develop TIN meshes of roadway surfaces. It also appears that this technique can be used quite effectively to measure bridge beam camber in a safer and quicker fashion compared to conventional approaches. Volume calculations are also possible using laser scanning. It seems that measuring quantities of rock could be an area where this technology would be quite beneficial since accuracy is more important with this material compared to soil. Other applications for laser scanning could include developing as-built drawings of historical structures such as the bridges of Madison County. This technology could also be useful where safety is a concern such as accurately measuring the surface of a highway active with traffic or scanning the underside of a bridge damaged by a truck. It is recommended that the Iowa Department of Transportation initially rent the scanner when it is needed and purchase the software. With time, it may be cost justifiable to purchase the scanner as well. Laser scanning consultants can be hired as well but at a higher cost.

17. Key Words
aerial photogrammetry, as-built survey, asset management, CAD, data collection, inspection, laser scanning, preliminary survey, 3D imaging

18. Distribution Statement
No restrictions.

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	80	N/A

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Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its research management agreement with the
Center for Transportation Research and Education.

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Final Report • January 2003

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ACKNOWLEDGMENTS

The authors thank the Iowa Department of Transportation for sponsoring this research project and Mitch Dillavou for supporting it.

The authors are also very grateful to all the individuals who provided assistance. Alice Welch and Dennis O’Brien assisted us with much of the project execution including setting up the training classes, assisting with field scanning operations, and helping us perform the analysis in the photogrammetry office. Dean Bierwagen and Ken Dunker provided suggestions as to the usefulness of laser scanning bridge structures. We appreciate the support from many individuals who assisted us in the field with professional surveying services: Curt Benson, Greg Ellis, Scott Miller, Mike Murray, and Randy Wahl. Wayne Mander was instrumental in setting up the computer equipment that supported this project. We acknowledge Chris Gibbons for the time spent with the research team explaining how to use the Cyrax scanning equipment and software as well as the time provided by Brad Burgess of Cyra Technologies, Inc., and Pat Stack of Seiler Instruments. We thank Annette Jeffers and Gary Novey for their support in developing two-dimensional and three-dimensional bridge models in MicroStation using the laser-scanned point cloud images. Finally, thanks to John Smythe, Office of Construction, Iowa Department of Transportation.

EXECUTIVE SUMMARY

This report describes results of a pilot study to investigate the use of laser scanning for transportation applications in Iowa. Laser scanning is a terrestrial laser-imaging system that creates highly accurate three-dimensional images of objects for use in standard computer-aided design software packages. After an initial training period on the use of the scanner and Cyclone software, pilot tests were performed on the following projects:

1. intersection and railroad bridge for training purposes
2. section of highway to determine elevation accuracy and pair of bridges to determine level of detail that can be captured
3. new concrete pavement to determine smoothness
4. bridge beams to determine camber for deck-loading calculations
5. stockpile to determine volume
6. borrow pit to determine volume

Results show that it is possible to obtain 2–6 mm precision with the laser scanner as claimed by the manufacturer compared to approximately one-inch precision with aerial photogrammetry using a helicopter. The measurement of the stockpile was within two percent of the estimate attained using standard surveying techniques. Furthermore, it is possible to measure the bridge beam camber without having to send surveyors on the beams to measure the profile. Camber measurements using laser scanning compared quite favorably to the more traditional approach. For the selected beam series, the difference in camber ranged from less than 1 mm to approximately 10 mm. It is not possible to measure concrete pavement smoothness because the laser scanner is not precise enough to capture the subtle imperfections. The borrow pit pilot had to be discarded because it was not possible to register all scans due to missing targets. A cost comparison between helicopter photogrammetry and laser scanning showed that laser scanning was approximately 30 percent higher in cost depending on assumptions. Laser scanning can become more competitive to helicopter photogrammetry by elevating the scanner on a boom truck and capturing both sides of a divided roadway at the same time.

Two- and three-dimensional drawings were created in MicroStation for one of the scanned highway bridges. It was demonstrated that it is possible to create such drawings within the accuracy of this technology. It was discovered that a significant amount of time is necessary to convert point cloud images into drawings. As this technology matures, this task should become less time consuming.

It appears that laser scanning technology does indeed have a place in the Iowa Department of Transportation design and construction toolbox. Based on results from this study, laser scanning can be used cost effectively for preliminary surveys to develop TIN meshes of roadway surfaces (assuming that both sides of the divided road are captured simultaneously). It also appears that this technique can be used quite effectively to measure bridge beam camber in a safer and quicker fashion compared to conventional approaches. Volume calculations are also possible using laser scanning. It seems that measuring quantities of rock could be an area where this technology would be quite beneficial since accuracy is more important with this material compared to soil. Other applications for laser scanning could include developing as-built drawings of historical structures such as the bridges of Madison County. This technology could also be useful where safety is a concern such as accurately measuring the surface of a highway active with traffic or scanning the underside of a bridge damaged by a truck.

It is recommended that the Iowa Department of Transportation initially rent the scanner when it is needed and purchase the software. With time, it may be cost justifiable to purchase the scanner as well. Laser scanning consultants can be hired as well but at a higher cost.

INTRODUCTION

Background

As transportation projects become more complex to design and build, it is important to take advantage of appropriate innovative technologies for reducing project cycle time. Laser scanning is one such technology that has potential benefits over standard surveying techniques such as total station or aerial photogrammetry for providing accurate as-built drawings. Laser scanning is a terrestrial laser-imaging system that quickly creates a highly accurate three-dimensional (3D) image of an object for use in standard computer-aided design (CAD) software packages. It is anticipated that such a system can produce more accurate as-built data and/or drawings in less time compared to the standard approaches.

Project Objectives

This project involves a pilot test to investigate the use of laser scanning to assist the Iowa Department of Transportation (Iowa DOT) in delivering projects in a safer and more efficient manner. The objectives are as follows:

1. Learn about how to use the laser scanner and software.
2. Select appropriate pilot projects to test the capabilities of this technology.
3. Determine the benefits and costs associated with using this technology compared to conventional approaches.
4. Provide recommendations regarding the future use of laser scanning for the Iowa DOT.

Study Approach

The approach used for this study included the following activities:

1. Learn how to use the Cyra hardware and Cyclone software.
2. Identify potential applications for the laser scanning pilot tests and establish objectives or goals for each pilot test activity.
3. Perform pilot tests on various types of projects including an intersection and railroad bridge (for training purposes), a highway segment and a pair of bridges to determine elevation, a newly paved concrete pavement to determine smoothness, bridge beams to determine camber, and a stockpile and borrow pit to determine volume.
4. Process scanned images.
5. Compare the accuracy of the results from the laser scanning tests with those using conventional techniques for each of the applicable pilot projects.
6. Perform time and cost comparisons between conventional aerial photogrammetry (using a helicopter) and laser scanning.
7. From the point cloud data, develop two-dimensional (2D) and 3D drawings of a bridge structure using MicroStation.
8. Provide recommendations for using laser scanning technology on future Iowa DOT projects.
9. Write final report.

Report Structure

Following this introduction, a brief description of the laser scanning technology, applications, learning process is provided. The pilot projects are described, along with the field operations and data processing involved. The results of the pilot projects are provided, along with time requirements for performing laser scanning and a cost comparison between laser scanning and aerial photogrammetry for use in preliminary surveys. Next, a description of the development of the 2D and 3D drawings is provided. An overall summary of the project findings is included in the final chapter along with project recommendations and conclusions.

INTRODUCTION TO LASER SCANNING

Basic Description

Laser scanners offer a wealth of information about a structure's surface in the form of a dense set of 3D point measurements using a laptop computer, laser scanner, and tripod. Images are developed from a pulsing laser beam capable of capturing approximately 2,000 data points per second up to 150 meters away. Several terrestrial laser-imaging systems have been developed by the following companies: Cyra, Maptek I-Site, Soisic, and Mensi. The operating principle is similar for all devices (Patterson, 2001). Figure 1 shows a photograph of the Cyra 2500 Laser Scanning Unit that was used in this project.

Figure 1. Cyrax 2500 Laser Scanning Unit

The laser's pulsed, visible green beam is moved across a target in a raster scan as shown in Figure 2 (Cyra, 2002). The horizontal and vertical angles of the beam and the time of flight of the pulses are measured for each point. Once an object is encountered, the laser beam is reflected back to the unit with the time of flight, which generates a measurement of distance. These measurements produce an impact location, which in return displays a cloud of points. Measurements taken from the "cloud" can be used to do interference detection and constructability studies. Each point has embedded x, y, z data, so it can be directly loaded into a CAD program without any need of digitizing. Less than 6 mm (1/4-inch) accuracy can be obtained using this technology (Patterson, 2001).

As an object is being scanned, each 3D measurement appears immediately as a graphical 3D point image on the laptop screen as shown in Figure 3. This cloud of points is a dimensionally accurate representation of the existing object. Further enhancements, such as shrink-wrapping using Cyra's Cyclone software, can be made depending on the laser scanning software capabilities. Shrink-wrapping an image incorporates several computer-processing steps. First, the scanned points are connected together as a "triangulated mesh." Edge detection algorithms are applied to the triangulated mesh, which identify the outlines of specific objects. Then both intensity mapping and rendering are applied to the mesh. The result is visualization that gives clear outlines and color differentiation to geometric elements (refer to Figure 4) (Patterson, 2001).

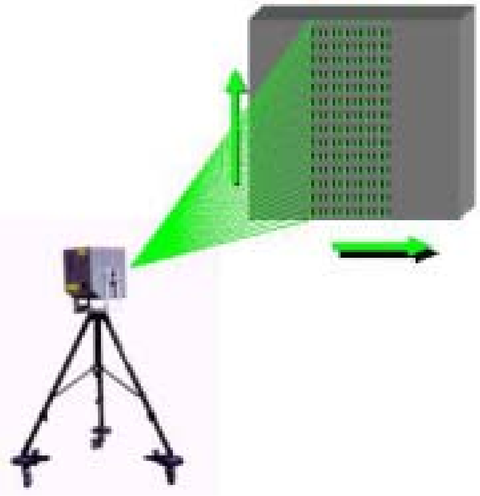

Figure 2. Laser Beam Scanning the Target

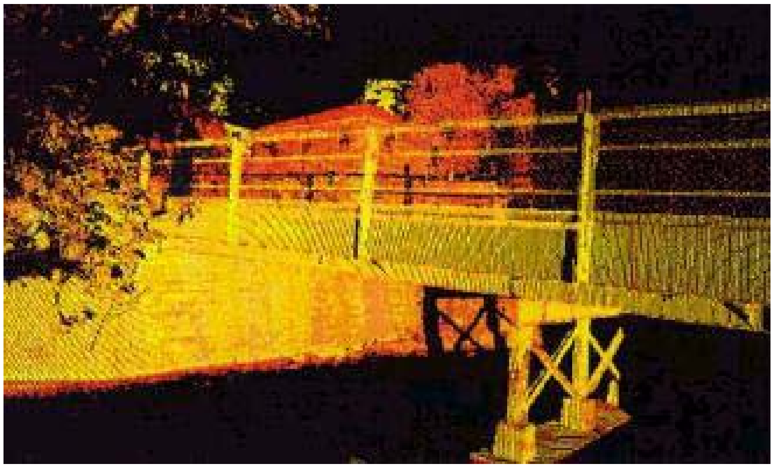

Figure 3. 3D Point Cloud of Bridge Structure

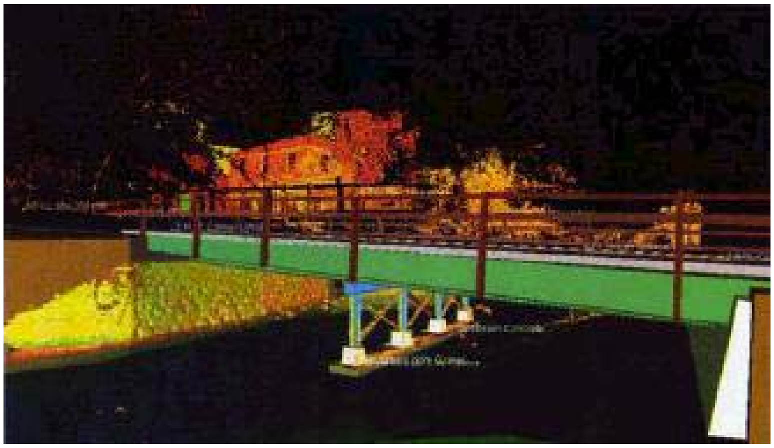

Figure 4. 3D Point Cloud Image Shrink-Wrapped

Besides obtaining 3D images from laser scanning and the provided software, it is possible to export point cloud data to CAD applications such as AutoCAD, MicroStation, and 3-D Studio Max. However, the large point cloud image and triangulated mesh files can sometimes overwhelm a CAD application. The size of a file depends on the size of the project that will be scanned. In order to successfully complete the transfer, some of the points will need to be deleted. This usually does not distort the model or accuracy of the scan (Patterson, 2001).

Current Laser Scanning Applications

Laser scanning technology has been successfully demonstrated on numerous projects related to developing bridge as-built drawings, highway widening, power plant retrofits, refinery expansion projects, water utility construction project archives, rock face surveys, dam foundation surveys, cave scanning, tie wire inspection, and visual effects for movies (Cyra, 2002). In several cases, field and office time was reduced using laser scanning compared to conventional methods.

LEARNING ABOUT LASER SCANNING

The first activity of the project involved learning how to use the Cyrax 2500 laser scanner and Cyclone software. A Cyra trainer provided training to six people (four from the Iowa DOT and two from Iowa State University) using a two-session format. The first session occurred in June 2002 and lasted approximately one week. A follow-up training session was provided in July 2002 and lasted two days. Training began with an overview of the Cyclone software then moved to the field where a complete indoctrination of the laser scanner was provided. A training manual was also provided, which helped to further explain the intricacies of the hardware and software.

Field Setup

Hands-on laser scanning training was performed using the intersection of Grand Avenue and Lincoln Way in Ames, Iowa, and the Union Pacific railroad bridge at Grand Avenue (refer to Figure 5). Several important concepts were learned during the field training exercise. First, it is important to create a database for the soon-to-be-scanned point cloud data to reside. A unique database is established for each pilot project. Second, it is important to establish a coordinate referencing system that helps tie all of the scans together during the registration process and identifies the location of all points in a known reference system. Globe targets were introduced into the scene as registration objects and were scanned and surveyed to identify their x, y, z coordinate location. Each target needs to be acquired after the initial scan and given an identification number. A coordinate file from survey control is then imported into the scanworld database before the registration process begins. Third, it is vital to include at least three targets in each scan as this is essential for precise registration of the various scans. Fourth, laser scanning time varies depending on the scanner resolution. For example, the highest resolution (999 x 999 pixels) required about 16 minutes whereas a 250 x 250 pixel scan takes about 5 minutes to complete.

Figure 5. Laser Scanner Field Setup

Data Processing

The main steps involved in processing the point cloud images captured from the field were registration, fitting and editing, mesh editing, developing contours and line drawings, and using the virtual surveyor function. Each activity is described in more detail below.

Registration

Registration is an essential step that ties together all of the individual scanworlds into a complete image of the scanned object. A scanworld is defined as the image captured for one single scan. It is during this stage that errors are identified with the target numbering and coordinates assigned to the targets. Registration involves three steps. The first step is the registration of targets including the locations and names or labels of each target. The target in the scanworld should have the same label as the one in the control survey coordinate system. The second step involves registration of the targets to the survey data. This can be accomplished by creating the coordinate system file and importing it into the Cyclone software. The third step involves registering all of the scanworlds together to generate the total 3D image of the scene.

Fitting and Editing

After registration is completed, a model space is created for the registered scanworlds. Scanned images may contain superfluous points (or noise), such as vertical lines representing traffic or clouds in the sky, that need to be removed. The process of cleaning the noise and modifying the registered images is called fitting and editing. The Cyclone software provides the capability to remove the superfluous data using segmenting, region growing, and other special editing tools. Segmenting is subdividing a point cloud or scanned image into smaller subsets. Segmenting involves cutting (drawing a fence around a portion of the scanned image), fitting patches (filling in known objects with geometric shapes such as cylinders or squares), and merging segments back into the original point cloud. Region growing involves modeling an object to the desired shape within a point cloud without segmenting. During this process, an object can be merged, translated, resized, and rotated. Generally, 90 percent of the noise of one image can be eliminated using the above fitting and editing techniques. The remaining noise can be removed in the mesh editing routine.

Mesh Editing

To make a cleaned and edited point cloud more manageable in Cyclone or for further use by exporting to other CAD packages such as MicroStation, a mesh must be created. There are different mesh styles to consider. In this pilot project, all of meshes are TIN meshes. The process of meshing includes mesh creation (including point cloud reduction), mesh editing (including edge and spike clean up and break-line setup), and mesh decimation, which involves eliminating a portion of the mesh.

Contours and Line Drawings

In order to measure the clouds and meshes and export the object to 2D drawing software packages, contour and line drawings must be created. A reference plane and a cut plane are useful with this process. The reference plane, which is an infinite two-dimensional plane, can be used as a reference for measuring the mesh volume, creating contour lines, and orienting the cut plane. The contours can be drawn parallel to the current coordinate system or any other reference plane. The cut plane, which can be set up on either the reference plane or objects on the point clouds, can facilitate exporting these data to MicroStation (or AutoCAD) or to draw 2D lines.

Using the Virtual Surveyor Function

Virtual Surveyor is a useful tool in Cyclone to easily obtain information without physically being at the site. Using scanned point cloud data, one can easily select coordinates, assign codes and notes, and export data to other applications. It is possible, for example, to determine the x, y, z location of a manhole cover in the middle of a busy intersection without ever physically standing at this location.

More Information

For more information regarding the use of the Cyra 2500 laser scanner and Cyclone software, please refer to the training manual provided with the course. It is important to note that it takes time to become proficient with this technology. The trainer mentioned that it took approximately six months to become completely familiar with the Cyclone software.

DESCRIPTION OF PILOT PROJECTS

In total, there were six test areas involved in this pilot study: (1) an intersection including a railroad bridge, (2) a section of highway including a pair of bridges, (3) new concrete pavement, (4) bridge beams on an unfinished bridge structure, (5) a stockpile, and (6) a borrow pit. These projects were selected because they were of particular interest to the Iowa DOT as areas where greater efficiencies could be attained. Table 1 summarizes the purpose for each pilot project. More specific information is provided on each of the pilot projects below. Detailed maps showing the location of these pilot tests can be found in Appendix A.

Table 1. Purpose of Pilot Projects

Pilot Project	**Purpose**
Intersection and railroad bridge	Learn about the Cyrax 2500 scanner and Cyclone software (training exercise).
Section of highway and pair of bridges	Determine surface elevation of highway and compare to aerial photogrammetry. Also, determine the level of bridge detail available using laser scanner.
New concrete pavement	Determine smoothness of freshly paved concrete
Bridge beams on unfinished bridge	Assess camber on bridge beams for determining optimal loading requirements.
Stockpile	Determine volume of stockpile and compare to traditional methods.
Borrow pit	Determine volume of borrow pit and compare to traditional methods.

Intersection and Railroad Bridge

The intersection of Lincoln Way and Grand Avenue in Ames, Iowa, was selected as the first test project using laser scanning at an intersection and railroad bridge. The purpose of this test was to learn how to use the laser scanner in the field by collecting point cloud data and then using the data to learn about the Cyclone software in the training class. This site provided a suitable location since it is across the street from the Iowa DOT facilities where the training class was conducted. Several scans were made and included one to two scans from each corner of the intersection. At least four globe targets were captured in each scan for purposes of registering the scans. Figure 6 shows a picture of the southeast corner of Lincoln Way and Grand Avenue in Ames. At least two scans were performed on the Union Pacific railroad bridge located immediately north of this intersection, involving the use of both globe and flat magnetic targets. The instructor demonstrated how it is possible to create 3D drawings from the point cloud images using the intersection as an example. No further analysis was performed using this pilot test site. One can clearly see the value of this technology for creating as-built drawings since it is not essential for survey crews to stand over features in the middle of the intersection to obtain coordinate locations. It is important to note that a physical presence is required to verify certain feature characteristics such as the depth of manholes and utility type and condition.

Figure 6. Grand Avenue and Lincoln Way (Intersection and Railroad Bridge)

Section of Highway and Pair of Bridges

This pilot test involved scanning approximately 400 meters of I-235 and a pair of bridges at Broadway Avenue. The site is located immediately south of the I-80/I-235 intersection in Des Moines, Iowa (refer to Appendix A). Both north and southbound bridges at Broadway Avenue were used in the pilot test. The Iowa DOT is particularly interested in comparing the elevation accuracy using both laser scanning and aerial photogrammetry for roadways surfaces and determining the level of detail that can be provided on bridge structures. During the I-235 highway pilot test, four globe targets spaced 50 meters apart were used in each scan with two common targets in each scan. The scanner was generally about 20 meters from the front row targets (refer to Figure 7). Figure 8 shows a side view of the southbound I-235 Broadway bridge.

Figure 7. I-235 (Section of Highway)

Figure 8. Southbound Broadway Bridge (Pair of Bridges)

New Concrete Pavement

The purpose of this pilot test was to investigate how accurately the laser scanner could determine the smoothness of a newly paved concrete pavement and perform a comparison to a profileometer. The location chosen was Highway 5 approximately one mile west of Highway 28 at mile marker 98 (refer to Appendix A). This pavement had recently been placed and had been cured sufficiently to perform the tests. Approximately 100 meters was scanned using the highest resolution possible (refer to Figure 9). Local control was established without tying into the control coordinates for that specific location because it was not necessary since the research team was simply trying to determine the smoothness. Also, the research team did not need to superimpose the laser-scanned images over the construction drawings.

Figure 9. Highway 5 (New Concrete Pavement)

Bridge Beams on Unfinished Bridge

The bridge selected goes over a private railroad line and is located on Highway 520 in Hardin County, Iowa (near the intersection of S56 and the relocated four-lane Highway 20). Figure 10 shows a profile of this bridge. Figure 11 shows the scanning operation on the eastbound bridge (the westbound bridge was not included in the scope of this study). Note that the deck has not been constructed at this point in time. The purpose of this pilot test was to determine the camber on the main bridge beam members prior to the deck placement. In order to determine the optimal deck dead load on a bridge, it is important to assess the amount of camber on each bridge beam. This is typically accomplished using standard surveying techniques whereby a surveyor takes elevation shots on top of the beams, putting the surveyor at risk of falling and injuring him/herself. Figure 12 shows a surveyor team taking traditional beam camber measurements on a bridge located in Minneapolis, Minnesota.

Figure 10. Hardin County Bridge Facing South (Bridge Beams)

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Figure 11. Hardin County Bridge Facing East (Bridge Beams)

Figure 12. Conventional Approach to Measuring Bridge Beam Camber

Stockpile

It was suggested by a materials engineer at the Iowa DOT that we should test how accurately the laser scanner can determine the volume of a stockpile, which is important for determining contractor pay quantities. A stockpile was selected approximately 1/4 mile west of the railroad bridge on Highway 520 in Hardin County, Iowa. Figures 13 and 14 show a top and side view of the stockpile. Notice how irregular it is in shape and depth. For comparison, a traditional approach was also used to determine the quantity of soil in the stockpile.

Figure 13. Top View of Stockpile

Figure 14. Side View of Stockpile

Borrow Pit

Similar to the stockpile, it is important for the Iowa DOT to determine quantities of soil removed from a borrow pit in order to accurately determine pay quantities to the contractor. Traditional surveying methods provide a reasonable approximation. The location of the test borrow pit is in the northeast corner of the I-35/I-80 mix master. The borrow pit is an irregularly shaped area (refer to Figure 15) approximately 1,000 feet by 200 feet; as a result, four different scanner positions were required to scan the borrow pit. Due to heavy rains the night before, the borrow pit was very muddy; consequently, a tarp and boxes were used to protect the equipment (refer to Figure 16).

Figure 15. I-35/I-80 Borrow Pit

Figure 16. Equipment Protected Using a Tarp and Boxes (Borrow Pit)

FIELD OPERATIONS

Field operations involved two major tasks: (1) set up survey control points and targets (i.e., globe targets mounted on tripods) and (2) scan the desired objects and acquire targets. The research team consisted of two separate crews, surveying crew and scanning crew, for these two activities. The scanning operation involved several activities related to properly using the Cyclone software such as creating a database, operating scan control window, and target acquisition. To help with future scanning projects, Appendix B has been added to provide a detailed procedure for operating the scanning equipment and software.

Surveying

The survey crew consisted of five surveyors and one coordinator. The surveyors were Curt Benson, Greg Ellis, Scott Miller, Mike Murray, and Randy Wahl. Dennis O'Brien served as the coordinator for the survey crew as well as scanning crew. The survey crew used traditional methods to set up targets and tie them into the Iowa state plane coordinate system. Thus, different scans could be registered and matched to each other with a high degree of accuracy. The surveying time was not specifically tracked but should be similar to the scanning time. This is because the surveyors worked the same hours as the rest of the team.

Scanning

The scanning crew consisted of two operators (Edward J. Jaselskis and Zhili Gao), plus one coordinator (Dennis O'Brien). Table 2 shows the basic information related to the number of scans and duration of each scan. Scanning time defines the difference between start and end times of scanning. Start time is when the scanner begins to take the point cloud image while end time is the time point of disconnection from computer to scanner. Scanning times varied per scan primarily because scans were performed using different resolutions. For example, the research team used a lower resolution scan for much of the borrow pit (250 x 250 pixels) compared to a high-resolution scan on the new concrete paving pilot test (999 x 999 pixels). The highest resolution scans took approximately 16 minutes versus about 5 minutes for the lower resolution scans.

Table 2. Field Scanning Information for Pilot Projects

Pilot Project	**No. of Scans**	**Total Scanning Time (hrs.)**	**Average Scanning Time (min.)**
Intersection and railroad bridge	*	*	*
Section of highway and pair of bridges	30	14	28
New concrete pavement	3	1.6	32
Bridge beams on unfinished bridge	5	2.9	34.8
Stockpile	3	1.5	30
Borrow pit	17	4.4	15.5

* Accurate times were not recorded for the intersection and railroad bridge pilot project since this was part of the training exercise.

Lessons Learned

Several lessons were learned during the two week training and field scanning process as they related to the set-up and operation of the equipment.

Scanner Resolution

The scanner resolution should be adjusted according to the image being scanned and the desired level of accuracy. The higher the resolution implies a better defined image but at the cost of longer scan times. The highest quality scans (999 x 999 pixels) took approximately 16 minutes each. Large timesavings can be experienced if less image quality is satisfactory. The research team found that an 850 x 850 pixel scan was sufficient for most cases. For targets that are farther away (>50 meters), it is best to use a higher resolution scan so as to acquire enough points to define the globes during the target acquiring process. For the borrow pit and stockpile pilot tests, a lower resolution scan of approximately 250 x 250 pixels seemed appropriate. A 100 x 100 scan did not provide enough pixels to easily locate and acquire the targets.

Battery Management

Battery management for the scanner and portable computer is essential. It is important to make sure that the batteries are fully charged prior to going out into the field. Power cables need to be connected to laser scanner and power source prior to turning on the power source. The research team found that plugging the laptop computer into an inverter plugged into the cigarette lighter in the vehicle ensured sufficient power. Additional extension cables were required to scan the borrow pit because it was not possible to position the vehicle close to the scanner due to wet soil conditions. It is essential to keep the vehicle running so as to continue charging the automobile battery since it is does not take long before the car battery is drained of energy. A portable electric generator is useful if the vehicle is out of reach using extension cords. This was especially helpful when scanning the new concrete pavement pilot project since the roadway was inaccessible by vehicle due to wet soil conditions and was far away.

Sun Glare

In order to see the computer screen better, the laptop computer was placed inside a box to shield the screen from the sun. This seemed to work very well and sped up the field scanning process.

Cable Management

A longer crossover cable would be helpful connecting the scanner to the portable computer—this would allow using the computer in a vehicle out of the direct sunlight, which significantly hampers screen viewing. Also, it is not always possible to have close access to a power source for the portable computer, as was the case when the research team worked on the new concrete pavement pilot test. Placing the equipment in the back of a pickup truck seems to work well when the weather is fine. A van works well when there is a possibility of inclement weather.

Target Overlap

Since the research team had adequate control on each target, it was not necessary to have common targets in every scan. Overlapping targets are necessary when there is no knowledge of the x, y, z coordinates for each location. To obtain proper registration, at least three targets need to be common in each scan when control is not established on the targets.

Target Acquisition

Target acquisition is a critical issue for scanning and registration later. During the scanning process a few different types of mistakes were made that created additional work in the field and office. Some of the more common examples are listed below:

- Targets were completely missed during the initial scan, reducing the number of targets in the scanworld and causing difficulty during the registration process.
- Failure to scan the correct targets. This is typically detected during the acquisition process and requires the operator to reacquire the correct target.
- Paired targets were mislabeled (switched). This could be corrected during the registration process.
- Targets with labels that do not exist in the control files. This could be corrected during the registration process by including the correct coordinates.
- Targets without labels. This lead to difficulties during the registration process because it is hard to tell which target is being used.
- Targets with double labels. This is happens because the same two targets were acquired during the acquisition process using different labels. This problem is corrected during the registration process.

Vibration

It was found that vibrations or scanner movement during the scanning operation makes it very difficult to align images during the registration process. This is because the scanned image becomes distorted once the scanner is moved from its initial position. Thus, it is important that the laser scanner be mounted on a stationary, nonvibrating surface.

DATA PROCESSING

The primary procedures involved with analyzing the scanned data from the field include importing coordinate data, registration, image fitting and editing, mesh editing, contouring, and using the virtual surveyor routine. Not all of the projects required each of these steps as the requirements were dependent upon the desired outcome. Sometimes special steps were necessary in order to meet the unique requirements of the pilot tests. Table 3 provides details related to the image processing for each of the pilot projects (except for the intersection and railroad bridge training exercise).

Table 3. Analysis of Pilot Projects

Analysis and Facts	**Pilot Projects**					
	Section of Highway	**Pair of Bridges**	**New Concrete Pavement**	**Bridge Beams**	**Stockpile**	**Borrow Pit**
Importing coordinates	X	X	X	X*	X	X
Registration	X	X	X	X	X	X
Fitting and editing	X	X	X	X	X	
Mesh editing	X	X	X	X	X	
Contouring		X	X		X	
Using virtual surveyor	X		X	X	X	
Exporting	X	X		X	X	
2D drawing		X				
No. of Scans	18	12	3	5	3	17
No. of Valid Scans	17	12	3	4	3	17
Coordinate control problems	Many	Many	None	Few	None	Many
Amount of cleanup required	Substantial	Substantial	Less	Average	Average	Less
Extra procedures	Yes	Yes	Yes	Yes	Yes	Yes

* Not tied to state plane coordinate system.

Section of Highway and Pair of Bridges

This pilot project has 30 scanworlds, with one scanworld not being used due to scanner movement during scanning. The roadway portion of I-235 has valid scans out of 18. Two analysis trials were performed for I-235. The first trial was after the initial one-week training and focused on registration, fitting, and meshing. The second trial was conducted after the researchers obtained more skills from advanced training and resulted in the final analysis results.

Registration

This project was the first one that the research team did on its own after training. As a result, there were many mistakes related to correct target acquisition, which made the registration process more time consuming. A total of nine targets in eight scanworlds had target problems. It was found that checking and measuring target locations and distances between targets in the control space is an efficient and effective way to identify the problems once large errors appear in the registration window. The correction action, however, was performed in model space and then a new control space was created from model space. For more information related to the correction procedures please refer to Appendix C. The coordinate control file used in registration is listed in Table D.1 of Appendix D.

Because some mistakes were made with the first few scanworlds, extra work was required to minimize the registration errors. When an auto-add constraints function was used, it lead to unexpected constraints, which increased the amount of error and required manual intervention to remove unwanted data (refer to Appendix C for a more detailed explanation). In order to solve this problem, the tolerance was decreased from 0.009 to 0.0009 meters. Moreover, after registration and related cleanup work had been successfully finished, there were still some targets with errors slightly larger than the original tolerance of 0.009 meters. Most of targets with errors ranged from zero to 0.007 meters. Those errors could be caused by either a physical setting deficiency of targets or distortion of the laser beam but not by the targets labels. Because the greatest errors were in pairs of targets with distances greater than 50 meters, distortion is most likely the reason. For this pilot study, the amount of error identified during the registration was considered acceptable.

Fitting

The process of removing the noise and modifying the registered scanworlds went smoothly for I-235 and primarily involved removal of superfluous data representing traffic on the roadway surface. Because the scanned images are 3D objects, different perspective views had to be checked in order to make sure the traffic noise was completely removed. Although the research team expended a significant amount of effort on mesh editing the point cloud file, this step was not really necessary since elevations could be measured directly using the virtual surveyor routine.

Using the Virtual Surveyor Routine

Figures 17 and 18 illustrate the virtual survey of I-235. The surveyor generated a text file by picking points along the desired path. Figure 17 shows the top view of the I-235 roadway using a reference plane. Figure 18 demonstrates a close-up view of the left edge of the I-235 northbound lane using the virtual surveying approach. The coordinate text file for I-235 includes the following information (shown in Appendix E):

- identification number
- y coordinate
- x coordinate
- z coordinate
- feature
- code

The identification number for each point can be integrated into any identification system. The research team used the Iowa DOT ATM coordinate system for final analysis of I-235. Identification of the elevation coordinate values (z) of the I-235 roadway is the major goal of this pilot project, while feature shows the location of points and code shows the abbreviation of the feature. The accuracy of the surveying results will be discussed in the results section.

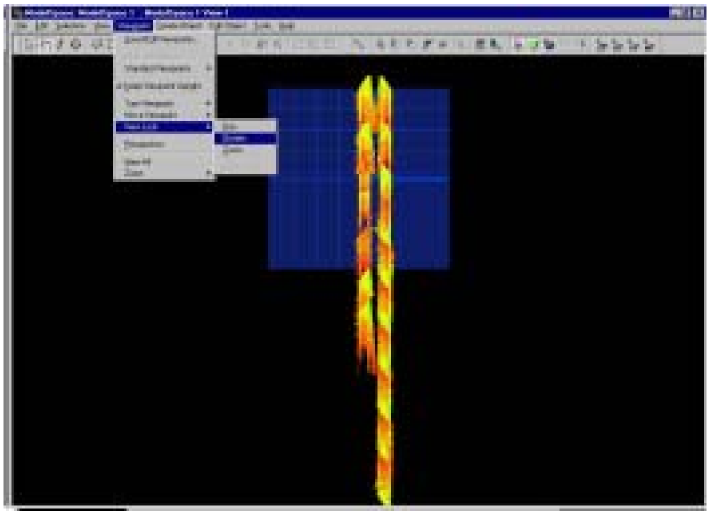

Figure 17. Top View of I-235 Roadway with Reference Plane

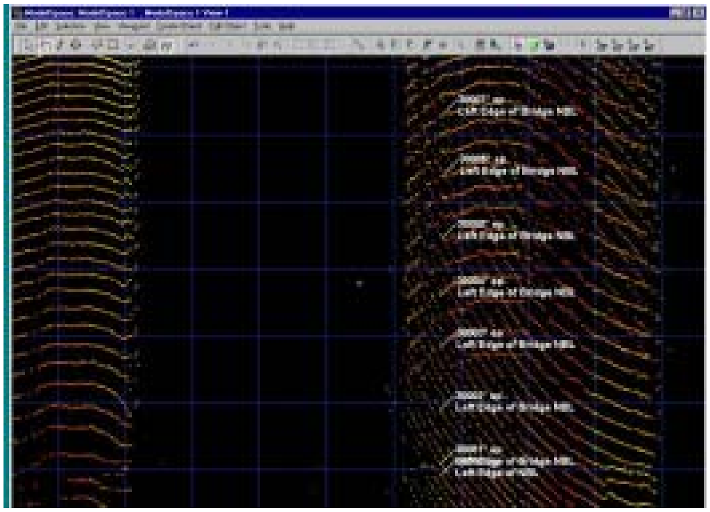

Figure 18. Close-up View of Virtual Surveying at Left Edge of I-235 Northbound Lane

New Concrete Pavement

Registration of the new concrete pavement project did not take much time due to the small number of scanworlds and accurate target acquisition in the field. All three scanworlds matched precisely. Figure 19 shows a clear image of the surface without traffic noise. The fitting effort focused on eliminating the surrounding features (tall grass and the ditches) and targets. Figure 20 shows a cleaned scan with a TIN mesh.

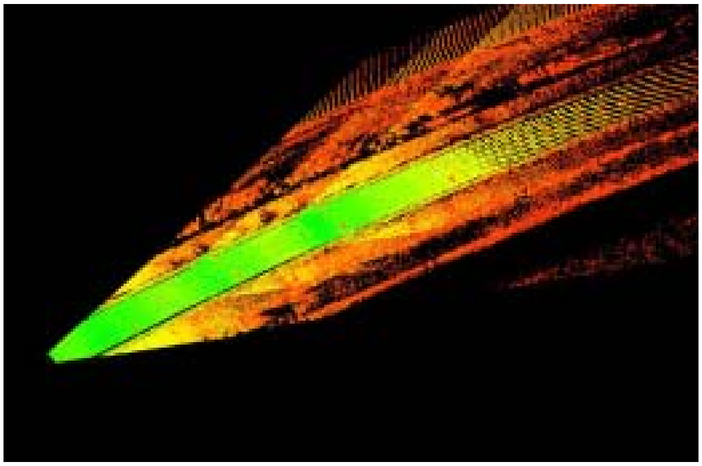

Figure 19. Registered Concrete Pavement Scans

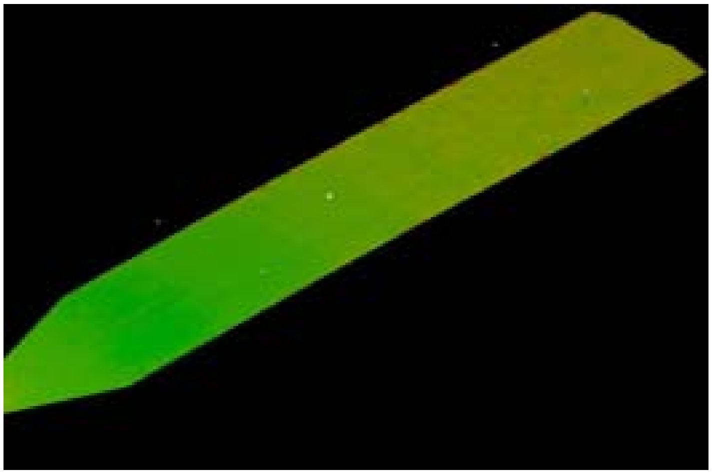

Figure 20. Cleaned Point Cloud with TIN Mesh

Bridge Beam Camber

This pilot project has five scanworlds, one of which was disregarded due to a deficient field scan (two of the targets were acquired twice). This problem was solved by deleting the extra target and correcting the incorrect labels during registration. A total of 11 beams on the bridge were scanned. Five analysis trials were performed for the Hardin County Bridge. The first three trials were made after the first training session and focused on fitting and meshing. These three trials were disregarded due to failure to adequately measure the beam camber. The last two trials (the fourth and fifth) were conducted after the second training session. The fourth trial was accurate but used a flawed coordinates system, and the last (fifth) trial resulted in the final analysis results. Because the Hardin County Bridge was under construction, there was no traffic noise and thus minimal data cleanup was required. Figure 21 shows the original point cloud image of the bridge. After removing abutments and other details around the bridge, a more simplified image was possible (Figure 22). Determining camber involves measuring the elevation of many points along the top of each beam. Therefore, meshing is not necessary and virtual surveyor can be used directly on the point cloud images.

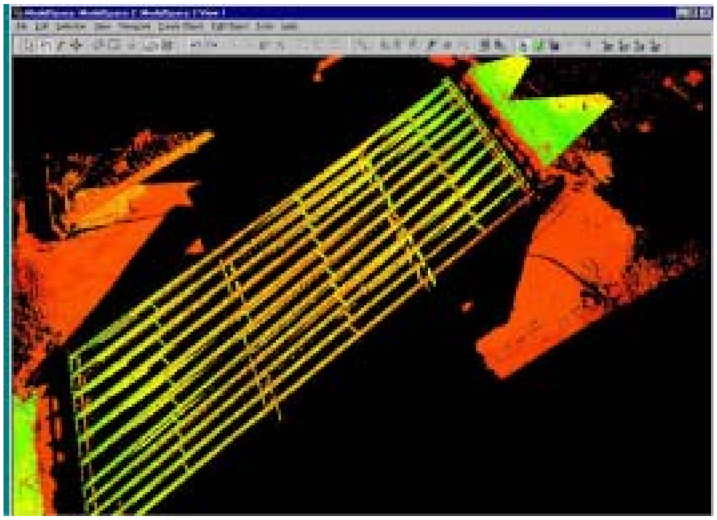

Figure 21. Original Point Cloud of Hardin County Bridge

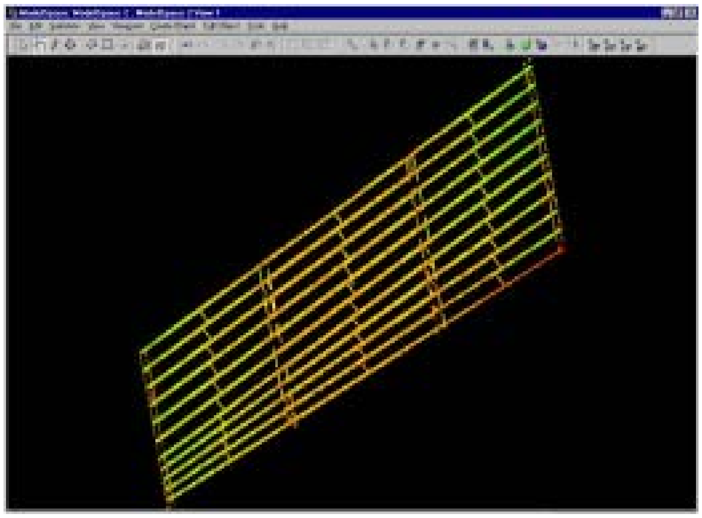

Figure 22. Fitted Point Cloud of Hardin County Bridge

A few new special features were applied to the Hardin County Bridge because the beams were not parallel to the reference plane axis, and establishing the true top of beam surface was challenging because of the protruding steel reinforcing loops present on the top surface. To be able to use the virtual surveyor routine along the beam, a new coordinate system was created by drawing a line on the beam, which was set as a new x-axis instead of the default system (refer to Figure 23). Also, one end of that beam was set as the new origin. The new x-z plane was used as new reference plane to cut the beam into slices. By defining a proper thickness of each slice, the top boundary line can clearly be determined by the front view of the beam slice. After this step, the normal virtual surveying process can be applied.

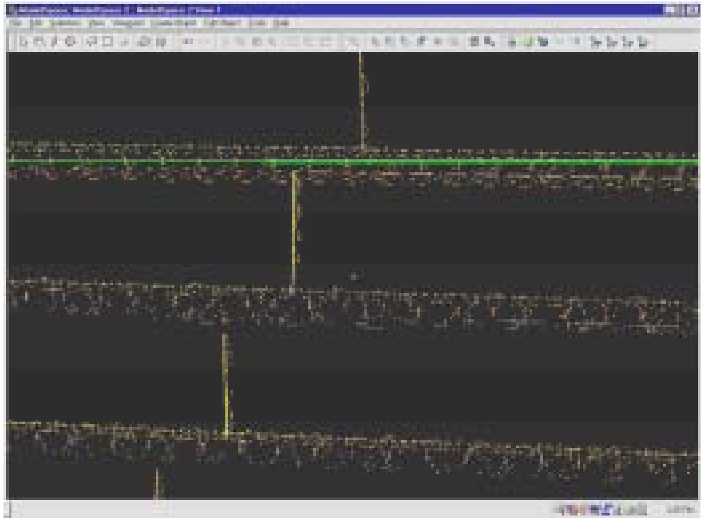

Figure 23. X-Axis Reference Plane Used on Hardin County Bridge

The virtual surveying results were sent to the Hardin County Bridge design and construction engineers to help them to design and place the slabs.

Stockpile

This project involved most of the data processing steps. Registration of targets and scanworlds was simple and without any major problems due to a small number of scanworlds and satisfactory target acquisition in the field. The registration process, however, still took more time than it should have, because this was the first pilot project analyzed in the office. Due to a few errors with the coordinate file (related to duplicate coordinate data) and mistakes during data importation, one of the scanworlds did not match with the other two scanworlds. Therefore, the first trial of stockpile showed a poor alignment of the scanworld images (refer to Figure 24). The researchers had to go through four trials before satisfactory results were achieved. Because of the irregular shape of the stockpile, the fitting and editing processes were more difficult than those for the other projects. In particular, it was difficult to remove some of the brush and vegetation without removing portions of the stockpile.

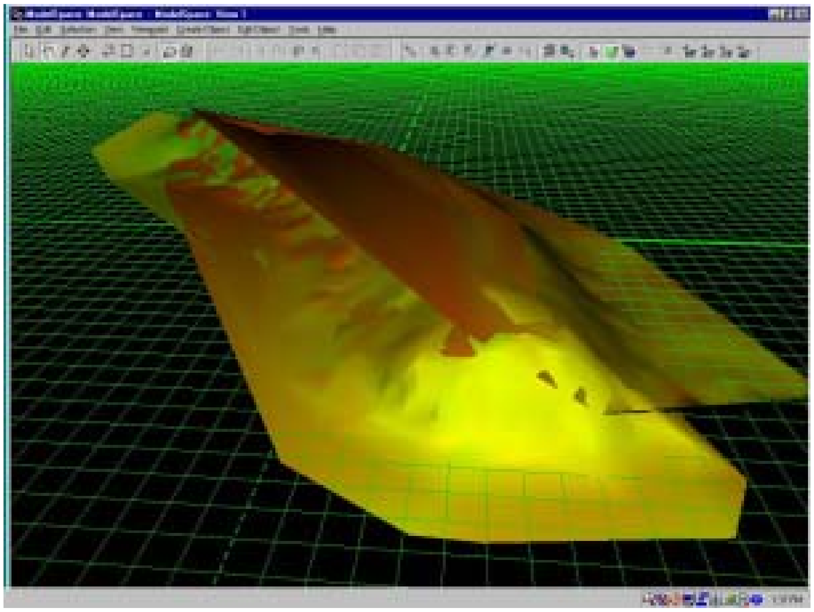

Figure 24. Poor Registration of Stockpile

Fitting

Vegetation removal on the stockpile was the most difficult part of the editing process. After numerous trials, a set of parameters was determined as a best solution to remove the brush and vegetation with minimal disruption to the stockpile. After applying the region growing routine, some leftover target tripods still required removal using a manual approach. This usually also deleted some of the stockpile but did not influence the final result because the density of the point cloud was sufficiently high. Figure 25 shows the point cloud after final point cloud cleaning. Figure 26 shows a graphical representation of the contours on the stockpile pilot project.

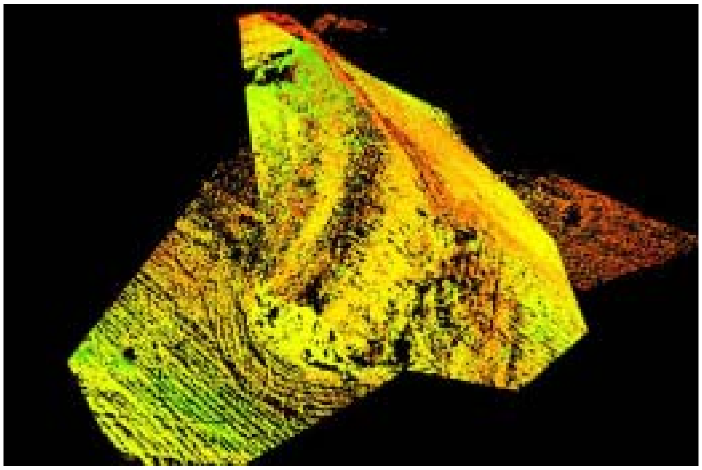

Figure 25. Cleaned up Point Cloud Image of Stockpile

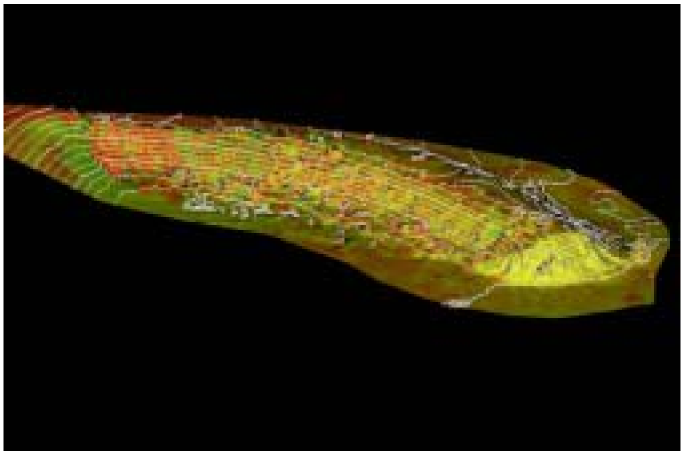

Figure 26. Contour Lines for Stockpile

Meshing

Meshing was particularly important for determining the stockpile volume. A TIN mesh was provided with minimal decimation of the boundary edges. The analysis of the stockpile project eventually provided a reasonable shape for the stockpile, which is almost identical to the actual stockpile. By using the created 3D image, the volume, contours, and coordinates of any points on the stockpile can be measured. The nature of digital 3D images allows users to rotate, pan, and zoom in any combination. On a computer screen, the user can view and measure from any side of the stockpile.

To measure the volume of stockpile correctly, the mesh volume had to be measured taking into consideration the sloping ground below the stockpile. Since it was not possible to establish a curved reference plane that follows the upward sloping stockpile, it was necessary to create two separate meshes with one reference plane. The top mesh is based on the entire cleaned point cloud (refer to Figure 27). The bottom mesh is based on the surrounding area of this point cloud (refer to Figure 28). The desired volume of the stockpile is calculated by taking the volume difference between the top mesh relative to an arbitrary reference plane and bottom mesh relative to the same reference plane. The reference plane can be randomly chosen but must be below the top of the bottom mesh in order to simplify the calculation.

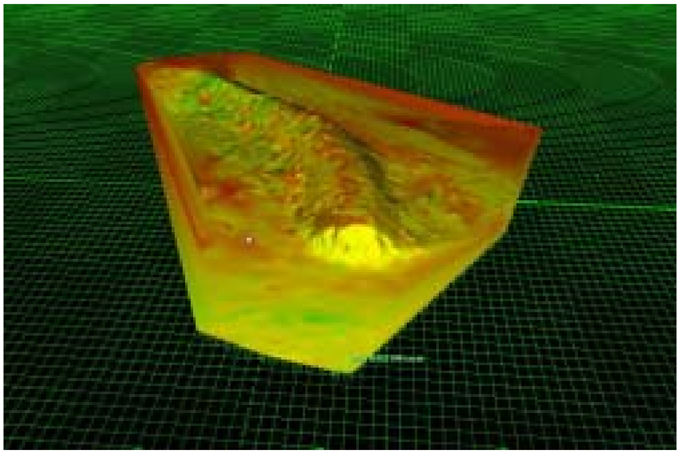

Figure 27. Top Mesh of Stockpile

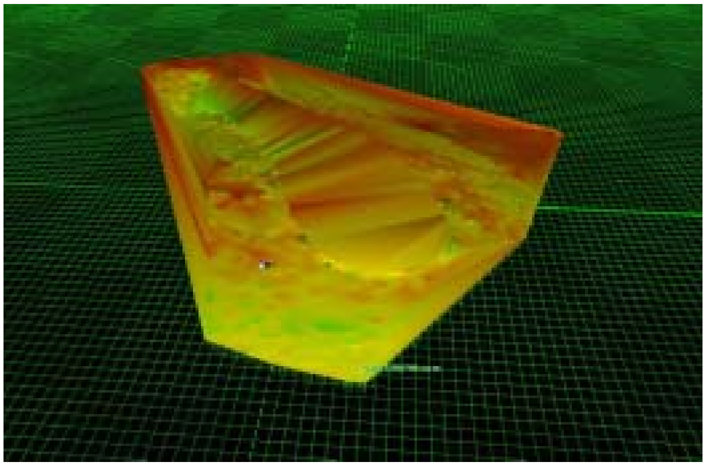

Figure 28. Bottom Mesh of Stockpile

Borrow Pit

There were some difficulties registering all of the scanworlds associated with the borrow pit pilot test. This was because only two targets were used during field scanning in one of the scanworlds with no overlap with other scanworlds. This meant that the research team was unable to register the entire borrow pit into one complete 3D image. Consequently, it was decided to discard this pilot project and rely on volume-measuring capabilities using the stockpile pilot project.

PILOT PROJECT RESULTS

This section includes information related to the technical results from the pilot tests, time expended to perform the pilot tests, and a cost comparison between aerial photogrammetry and laser scanning.

Technical Results

Technical results discussed in this section relate the determining I-235 (section of highway and pair of bridges) elevations, stockpile volume, and bridge beam camber. As previously discussed, there were no results for the borrow pit due to the omission of critical targets in the field during the scanning process. The intersection and railroad bridge was not analyzed any further as this project was used for training purposes. The Broadway Bridges were used to develop as-built drawings as discussed in the next section.

I-235 Elevation Measurements

Elevation measurements were taken of the I-235 roadway centerline, lane edges, and shoulders using the Cyclone virtual surveyor. The measured results were exported into an ASCII format file. To determine the accuracy of those data points and to compare them with those from other surveying methods such as aerial photogrammetry, an ASCII file was converted into a MicroStation and GEOPAK file to create the plan views of I-235 as shown in Figures 29 and 30.

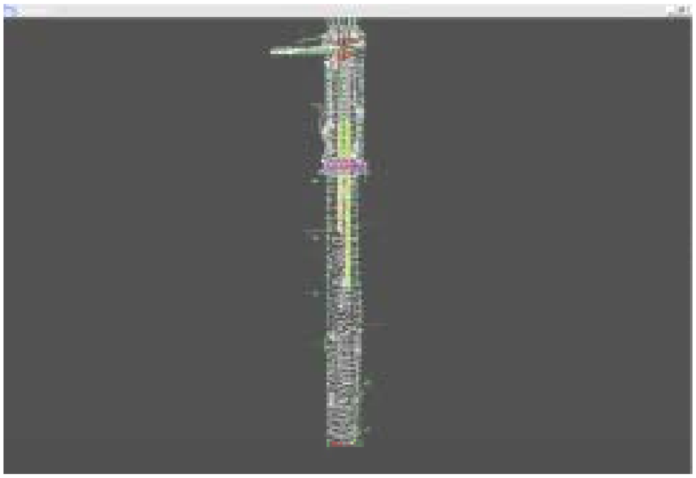

Figure 29. 2D Drawing of I-235 Roadway Elevation within MicroStation

Figure 30. Close-up View of I-235 Roadway Using MicroStation

While the difference between those methods can be clearly seen from the MicroStation file, a detailed accurate comparison was also conducted. Table 4 shows the average difference between Cyra laser scanning and traditional surveying methods. A comparison is also made between Cyra laser scanning and aerial helicopter photogrammetry. The average difference for measuring elevation at the lane edges between traditional surveying and Cyra laser scanning ranged from 0.001 meters to -0.009 meters, while the difference ranged from -0.006 meters to -0.023 meters between aerial photogrammetry and Cyra laser scanning. The comparison of centerlines between traditional surveying and Cyra laser scanning was not conducted due to lack of data. The comparison of shoulder elevations was also disregarded because of their irregular shape. This comparison demonstrates that much more accurate measurements can be obtained from Cyra laser scanning technology than from the photogrammetry method.

Table 4. Accuracy Comparisons between Different Survey Methods

Location	**Elevation Difference between Traditional Survey and Cyra Laser Scanning (meters)**			**Elevation Difference between Photogrammetry and Cyra Laser Scanning (meters)**		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Left edge of NBL	0.000	-0.017	0.001	-0.001	-0.044	-0.006
Right edge of NBL	0.006	0.018	0.007	0.001	-0.055	-0.015
Centerline of NBL	—	—	—	-0.001	-0.04	-0.009
Left edge of SBL	0.001	-0.025	-0.007	-0.002	-0.042	-0.021
Right edge of SBL	-0.001	-0.025	-0.009	-0.002	-0.058	-0.023
Centerline of SBL	—	—	—	0.004	0.048	-0.026

Note: NBL stands for northbound lane and SBL stands for southbound lane.

Smoothness of New Concrete Pavement

Despite the fact that the research team used the highest resolution possible, it was not possible to adequately determine the smoothness of the surface (refer to Figure 31 for a surface view of the pavement). The primary reason is because the laser scanner has an accuracy of two to three millimeters. Most smoothness irregularities will fall within or below the accuracy range of a laser scanner. Therefore, the application of this new technology, in its current state, is not sufficiently sensitive to monitor the smoothness of freshly paved concrete.

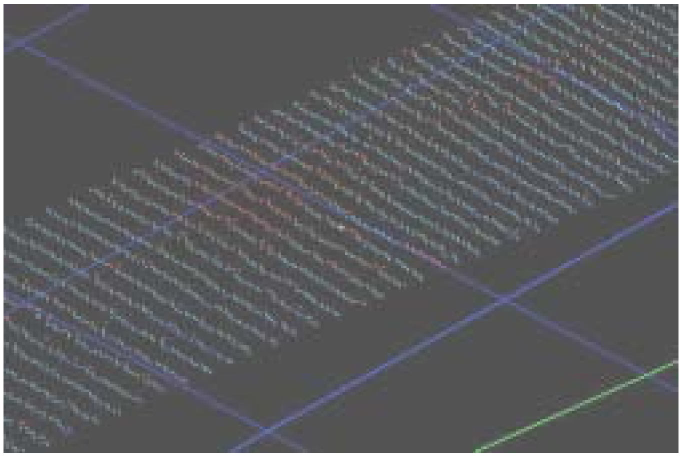

Figure 31. Close-up View of "Roughness Map" (New Concrete Pavement)

Stockpile Volume

The stockpile volume is calculated assuming that the reference plane is established at 300 meters. Using this assumption, the top and bottom mesh volumes are 2,176.849 and 1,669.78 cubic meters, respectively. Thus, the stockpile volume is 507.07 cubic meters. The volume of this stockpile was calculated using a traditional surveying approach and GEOPAK software and was found to be 512.96 cubic meters. It can be seen that the results of both surveying methods are fairly close to one another (1.2 percent difference, or 6 m^3).

Bridge Beam Camber

Results show that it is possible to measure bridge beam camber using the virtual surveyor routine in the Cyclone software. Figure 32 shows the camber for a series of three beams where the x-axis represents an orthogonal projection of the beam and the z-axis represents the beam elevation. This represents the "B" series of beams per the bridge plans. All of these points represent the top surface of each beam.

It is possible to rapidly calculate the amount of bridge beam camber in the field by selecting desired coordinates for the top center of the beam and ends of the beam and measuring the perpendicular distance as shown by Δ in Figure 33. This was accomplished and results can be found in Table 5. Beam 1 is the first beam on the left of Figure 32 followed by Beams 2 and 3. It is possible to automate the process of determining the load necessary to reduce the camber. This was not part of the scope of this research project, however. It is interesting to note that the point of peak camber is not necessarily in the center of the beam as can be seen in Table 5.

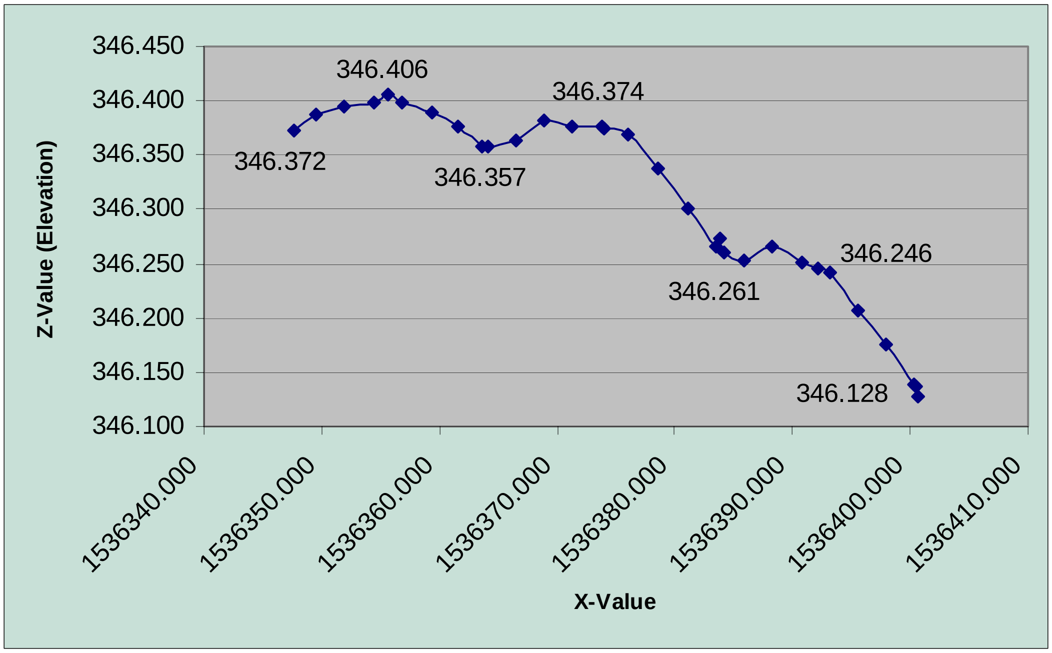

Figure 32. Beam Camber for Series of Three Beams on Hardin County Bridge

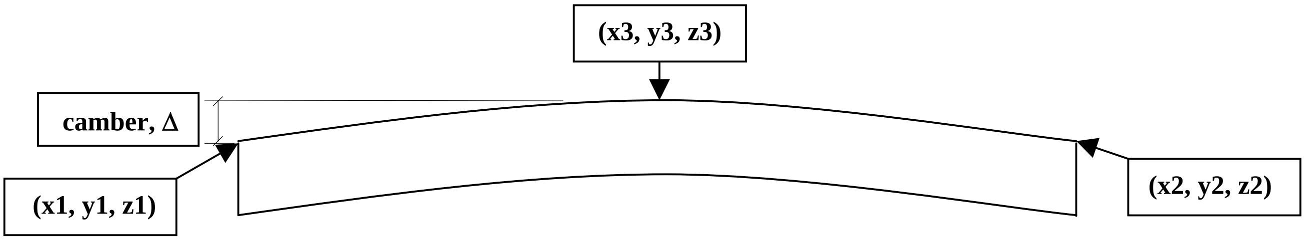

Figure 33. Bridge Beam Camber (not to scale)

Table 5. Bridge Beam Characteristics Using Laser Scanning

Characteristics	**Beam 1 (Laser Scan/Actual)**	**Beam 2 (Laser Scan/Actual)**	**Beam 3 (Laser Scan/Actual)**
Length (m)	20.44/20.25	24.67/25	20.58/20.25
Camber (mm)	39.4/39.0	53.3/46.5	32.9/43
Peak location on beam from right side (m)	10.62	12.48	10.59
Peak location on beam from left side (m)	9.82	12.19	9.99

Time Requirements

This portion of the report presents an in-depth presentation of the time required to perform this pilot study. These data can be used for planning the duration of future laser scanning projects. Overall, a total of approximately 870 hours (15.1 hours per scan) were spent on this pilot study, including 403.1 hours for fieldwork, 153.5 hours for lab analysis, and 313 hours for training.

Different groups of participants, including a training group, a scan crew, a survey crew, and lab analysts were involved in different phases of the learning process. Some people who attended the training course did not participate further with the project. Also, an assumption was made that the same field time was spent by the scan crew and the survey crew. All of these facts make the time tracking and analysis a complicated process. The details of this analysis can be found Appendix F. Both the total pilot study time and time spent in each specific project are discussed below.

Overall Project Time Requirements

Table 6 summarizes time spent on the entire project, and Figures 34 and 35 give a graphic view of the actual and projected man-hours categories. In Figure 34 (actual hours spent on this project), note that 31 percent of the total hours were spent on learning while 50 percent were spent on field scanning and 19 percent were spent on lab analysis for a total of 805.6 hours. In order to evaluate the project more accurately, the time spent by people who attended training but who were not involved in any other tasks was removed from the total hours, yielding the actual hours (see Table 6). Clearly, the learning time is more significant than may be expected.

Table 6. Summary of Total Time Spent on Pilot Projects

Type	Actual Time[1] (hrs.)	Projected Time[2] (hrs.)
Field Time[3]	**403.1**	**262.5**
Scanning operation	187.4	121
Transportation	114	75
Breaks	57	37.5
Setup	38	25
Support	6.7	4
Lab Analysis Time[4]	**153.5**	**80**
Learning Time[5]	**249**	**135**
Training course	120	80
Reading and studying	40	20
Watching videos	30	15
Defining procedures	9	10
Discussion	20	10
Meetings	30	0
Total	**805.6**	**477.5**

[1] Actual hours equal total hours minus learning time from one participant (64 hours).

[2] Projected hours are projected time to complete the same study by reducing unproductive resources.

[3] For field time, some non-operation time (e.g., transportation, breaks, setup, and support) were counted because these are necessary for performing fieldwork and are counted in the total work time.

[4] Lab analysis time includes time for all the trials regardless of productivity, and note-taking time.

[5] Learning time includes several different learning methods: training, reading, video watching, and discussion. Among them, the two-session training (basic and advanced) is the primary approach to starting this project while the video watching is the review of the training course.

In order to maximize production and efficiency, the size of the training and scan crew can be reduced to one scanning operator and one coordinator while the survey crew can be reduced to three surveyors and one coordinator (the same person as the scan coordinator) without influencing work quantity or quality. Therefore, projected hours were calculated based on these crew sizes and are listed in Table 6. The total hours are reduced to 477.5 from 805.6 (a 40 percent reduction). A distribution of these recommended hours is illustrated in Figure 35. The field time, lab time, and learning time account for 55 percent, 17 percent, and 28 percent of the total hours, respectively.

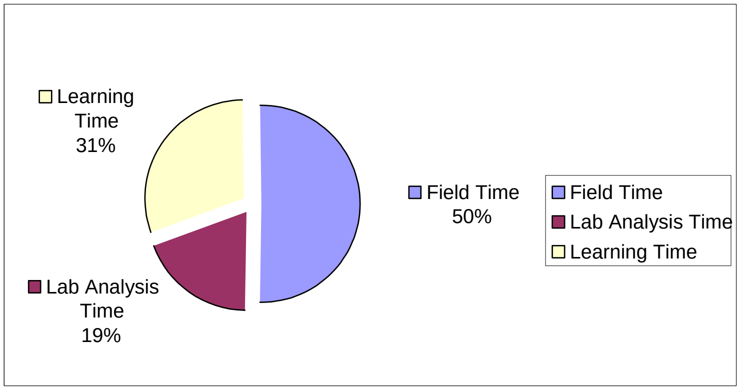

Figure 34. Actual Time Distribution

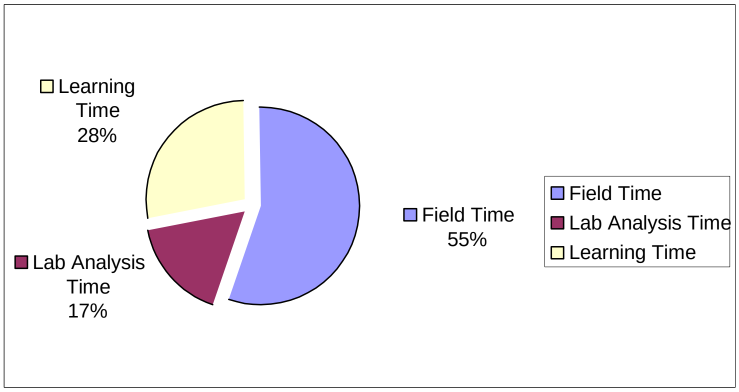

Figure 35. Projected Time Distribution

The total hours above can be converted into hours per scan as shown in Table 7. The actual hours per scan are 14 (7.0 in the field, 2.7 in the lab, and 4.3 for learning). Learning time is a one-time investment and will have less impact on total time as more projects are scanned and analyzed.

Table 7. Actual Scanning Time by Classification

Classification	**Total Time (hrs.)**	**No. of Scans**	**Time Per Scan (hrs.)**
Field	403.1	58	7.0
Lab analysis	153.5	56	2.7
Learning	249	58	4.3
Total	**805.6**		**14.0**

Individual Pilot Project Time Requirements

To analyze the project time more meaningfully, the time spent on each pilot project is discussed. Because the time for learning and field non-operation activities cannot be allocated to a specific project, it will not be analyzed here. Instead, only individual equipment operation time and lab analysis time are considered, while lab analysis time is considered only for three projects (I-235, Hardin County Bridge, and stockpile) that produced final results.

Table 8 shows the individual pilot project scan times. For scanning equipment operations, the time per scan over four projects (excluding the borrow pit project) ranges from 3.5 to 4.0 hours with an average of 3.7 hours. Individual project scanning equipment operation time depends on the total number of scans for a certain project. It takes about the same time to scan two different projects with the same number of scans as shown by the new concrete pavement (three scans, 10.7 man-hours) and stockpile (three scans, 10.5 man-hours) projects. The minor difference is caused by scan resolution and differences in technique. The reason that the time per scan on the borrow pit project is less than other projects is that fewer targets were acquired. For the lab analysis portion, the average time per scan is 2.5 hours for the total project and 0.8 hours for the final trial.

Table 8. Individual Pilot Project Scan Times

	Overall	Section of Highway	Pair of Bridges	New Concrete Pavement	Bridge Beams	Stockpile	Borrow Pit
Scanning Equipment Operations							
No. of scans	58	30		3	5	3	17
Total time (hrs.)	187.3	111.1		10.7	20.1	10.5	34.9
Time per scan (hrs.)	3.2	3.7		3.6	4.0	3.5	2.1
Lab Analysis Total							
No. of scans	56	17	12	3	4	3	17
Total time (hrs.)	138.5	39	15	15	28	31.5	10
Time per scan (hrs.)	2.5	2.3	1.3	5.0	7.0	10.5	0.6
Lab Analysis Final Trial							
No. of scans	36	17	12	—	4	3	—
Total time (hrs.)	28.0	14.0	3.5	—	6.5	4.0	—
Time per scan (hrs.)	0.8	0.8	0.3	—	1.6	1.3	—

Cost Comparison between Aerial Photogrammetry and Laser Scanning

This portion of the report provides a cost comparison between the use of laser scanning and aerial photogrammetry to develop TIN meshes of a roadway. Helicopter photogrammetry costs were provided by the Iowa DOT and are converted into a cost per foot basis so that an appropriate comparison can be made.

Aerial Photogrammetry

Aerial photogrammetry is a method of generating digital terrain maps that offers fast and inexpensive results useful for preliminary planning. The process involves laying out targets in the area to be examined and taking stereo aerial pictures of the area from a helicopter. From this, triangulation is performed to determine elevations and locations of key features, and digital terrain maps are developed. Accuracy with aerial photogrammetry is based on many factors, the largest being the height of the helicopter. Standards for accuracy, set by the American Society for Photogrammetry and Remote Sensing (ASPRS), place limits on the root mean square error for a given point. These are dependent on the scale of the map being developed, and reflect the accuracy of the map as a whole, rather than a specific point on the map.

Activities include field time (including time for painting targets and establishing horizontal and vertical control and travel time) and photogrammetry time (including time for selecting photo control target locations, creating diapositives, performing aerial triangulation, collecting DTM and planimetric data, performing aerial photogrammetry, and purchasing of diapositive material). Each of these cost items is defined in greater detail below. Relevant definitions can be found in Appendix F. The costs for performing aerial photogrammetry are based on four to six lanes of a half-mile segment of I-235 (refer to Table 9). This translates to a cost of $2.66/foot ($7,016/2,640 feet).

Table 9. Aerial Photogrammetry Time and Costs

Activity	Staff Time (hrs.)	Per Diem Total Cost
Field Time and Cost		
Set control	16	$204
GPS observations	27	$340
Three-wire level run	18	$227
Traverse	36	$453
Painting targets	30	$385
Horizontal control for targets	29	$362
Vertical control for targets	23	$294
Subtotal	**179**	**$2,265**
Overhead at 22.754%		$515
Car mileage		$85
Per diem		$847
Total Field Survey Cost		**$3,712**
Photogrammetry Time and Cost		
Select photo control target locations	1	$20
Create diapositives	1	$20
Perform aerial triangulation	35	$861
Collect DTM and planimetric data	44	$968
Subtotal	**81**	**$1,869**
Overhead at 22.754%		$425
Aerial photogrammetry		$1,000
Diapositive material		$10
Total photogrammetry cost		**$3,304**
Total Cost		
Total cost for half-mile section (4–6 lanes)		**$7,016**
Cost per linear foot		**$2.66**

Laser Scanning

The cost for performing the entire pilot study is illustrated in Table 10. These costs include the rental of the laser scanning equipment and Cyclone software, training fee, researcher's time, and report preparation costs. Excluded from these costs are the surveying crew and Iowa DOT professional staff time. Assumptions are made to include all relevant costs including surveying and management needs for determining a comparable laser scanning cost per foot. Based on the costs found in Table 10, it is possible to determine costs on an hourly basis as shown in Table 11.

Table 10. Laser Scanning Pilot Study Cost Distribution

Type	Cost	Duration	Notes
Scanner rental	$10,000	2 weeks	Rent with laptop computer
Cyclone rental	$3,000	3 months	
Cloudworx	$995	Lifetime	Purchase (not necessary for I-235 pilot project)
Accessories rental	$2,000		Includes globe targets
Training fee	$7,500	8 work days	Two-session training course
Training fee	$7,500	8 work days	Two-session training course
Subtotal: costs directly paid to Cyra	**$23,495**		
Researcher salaries	$13,551	8 months	
Payroll benefits	$2,531		
Travel	$470		
Communications	$1,050		
Printing	$450		
Indirect costs	$4,693		
Subtotal: costs directly paid to Iowa State University	**$22,745**		
Total Cost	**$46,240**		

Table 11. Projected Laser Scanning Equipment and Software Rental Costs

Rental Item	Rental Cost
Laser scanner rental, per hour of field operations	$125.00
Cyclone rental, per hour of lab analysis	$6.25
Accessories, per hour of field operations	$25.00

Note: All costs based on rental costs above, and a 40-hour workweek.

The cost for laser scanning used in the cost comparison is based on the I-235 project and can be seen in Table 12. One and a half days of field surveying time was included with a crew of field surveyors and one party chief to establish survey control. Two days of scanner rental is assumed for scanning a half-mile section of the northbound and southbound lanes of I-235. During the scanning operation, it is assumed that two laser scanner operators are necessary and three surveyors are needed for moving targets. Accessories include the rental cost of the targets. It is also assumed that each scan will cover 50 meters and that three scans can be accomplished per hour. Lab analysis time is assumed to be between 0.9 hours and 3.7 hours per scan. A training allowance cost is provided for each of the two scanning operators.

Table 12. Projected Costs for I-235 Project

Activity	Staff Time (hrs.)	Per Diem Total Cost
Field Time and Cost		
Set control	16	$204
GPS observations	27	$340
Three-wire level run	18	$227
Traverse	36	$453
Field scanning operations	96	$2,464
Laser scanner and accessory rental		$2,050
Subtotal	**193**	**$5,738**
Overhead at 22.754%		$839
Car mileage		$91
Per diem		$913
Total Field Cost		**$7,581**
Lab Analysis Time and Cost		
Lab analysis	52.5	$1,155
Subtotal	**52.5**	**$1,155**
Overhead at 22.754%		$263
Cyclone software rental		$67
Total lab analysis cost		**$1,485**
Total Cost		
Total cost for half-mile section (4–6 lanes)		**$9,066**
Cost per linear foot		**$3.43**

Comparison Analysis

As can be seen in Figure 1 below, aerial photogrammetry costs approximately $2.66 per linear foot. Based on the I-235 research, laser scanning costs $3.43 per foot. Although the laser scanning cost is approximately 30 percent higher than that for aerial photogrammetry, laser scanning offers advantages in terms of accuracy. Due to this characteristic, it may be possible to use laser scanning for the initial project planning and design phases. However, scanning would need to be carefully coordinated, as the scan makes no distinction between the differing surfaces involved. Aerial photogrammetry does offer some benefits here because features such as centerlines and shoulders can be visually identified. Laser scanning costs can be reduced if the scanner were to be mounted on platform vehicle, allowing both sides of the divided highway to be scanned at the same time. It is surmised that the costs would then be comparable to aerial photogrammetry.

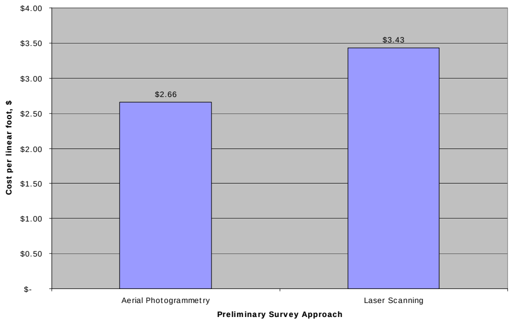

Figure 36. Preliminary Survey Costs: Aerial Photogrammetry vs. Laser Scanning

TWO-DIMENSIONAL AND THREE-DIMENSIONAL DRAWINGS

The research team was interested in experimenting with developing 2D and 3D drawings from point cloud images generated using laser scanning. We worked with the Iowa DOT Bridge Division on this portion. They were particularly interested in developing accurate as-built drawings for the I-235 Broadway Bridges since these bridges may be modified (widened or filled in). Figures 37 through 39 depict the point cloud file in a MicroStation environment. It was discovered that is was possible to import the point cloud files into MicroStation. Moreover, it was discovered how time consuming the process of creating accurate as-built drawings can be from point cloud images. Geometric objects such as line and circles need to be physically drawn into the point cloud images. It is sometimes difficult to identify the edges of objects in order to draw the lines. Our level of expertise with MicroStation is limited, thus making it even more difficult to produce the drawings. This is an area for further exploration.

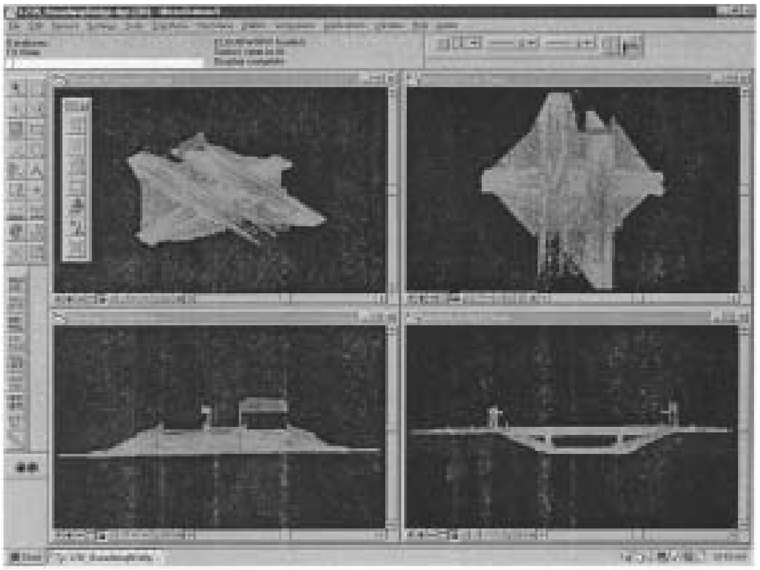

Figure 37. Broadway Bridges in MicroStation

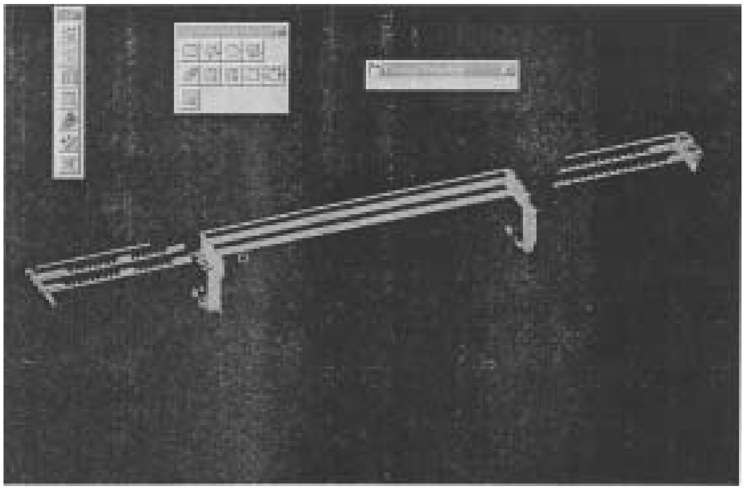

Figure 38. Broadway Bridge Beams in MicroStation

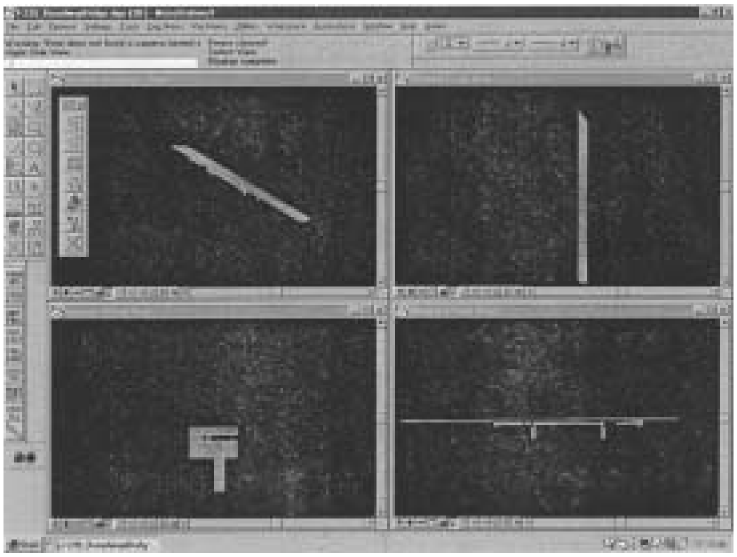

Figure 39. Broadway Bridge Deck in MicroStation

CONCLUSIONS AND RECOMMENDATIONS

Summary of Findings

Laser scanning appears to have its applications for transportation projects. Applications of greatest benefit using the strengths of this technology appear to be ones where there is a significant amount of detail that needs to be captured and/or applications where safety may be an issue such as providing accurate measurements on an active roadway. The laser scanner was able to provide accuracy to within 2–6 mm. This was significantly better than results using aerial photogrammetry.

Laser scanning performed quite well on the stockpile but so did the surveying team using a more conventional volume measurement approach. Determining quantities of rock, such as on a rock face, might be a suitable application for laser scanning. It was also suggested by a bridge specialist that laser scanning could be used to archive bridge damage due to a vehicle collision, for example. Laser scanning was found to be particularly helpful in measuring bridge beam camber. This technique was able to determine the beam camber quite efficiently and accurately. It was also ascertained that the laser scanner is not suitable for measuring concrete pavement smoothness on newly paved concrete. This is because slight imperfections in the concrete are lost due to the accuracy of the laser scanner. Furthermore, it was difficult to create 2D and 3D drawings due to the difficulty in determining the edges in point clouds of data. This may be overcome by using the next version of Cyclone (4.0).

Recommendations

It appears that laser scanning has its place in helping to design and build transportation projects for the right applications. The technology was particularly helpful for measuring bridge beam camber. Laser scanning also demonstrated its precision for measuring volumes of a soil stockpile. It seems to take a significant effort to become proficient with this technology and then one needs to continue using it to maintain a level of sharpness. It is also possible to develop as-built drawings, but it seems to be rather time consuming with the version of the Cyclone used in this study (Version 3.2). Version 4.0 is designed to make developing 2D and 3D drawings more easily done by allowing one to more easily identify edges of objects (e.g., top edge of curbing).

Should the Iowa DOT invest resources in this technology? That depends on the number of times it is necessary to measure rock quantities and beam camber, record archival structures in 3D, assess bridge damage, etc. If there are sufficient opportunities to use this technology, then it is recommended that the Iowa DOT purchase the Cyclone software and purchase or rent the scanner; initially, it may be prudent to rent the scanner. If there are very few occasions, then the Iowa DOT should use more traditional approaches to capturing these data or hire a consulting firm with this expertise to provide the laser scanning services.

Conclusions

This report has provided a description of laser scanning technology and discussed its application to various transportation projects. The learning process was very instrumental in helping the research team better understand the capabilities of this technology. Several pilot tests were performed related to determining elevation, volume, and bridge beam camber.

Several lessons were learned by the research team during the pilot tests related to the use of both the laser scanner and processing software. From the team’s perspective, it appears that laser scanning allows one to quickly capture more accurate 3D and 2D data and produce reasonable as-built images. This technology can provide safer data capture of hard-to-reach or hazardous areas, such as the centerline of roads and on top of beams. Although the cost was slightly higher when compared to aerial photogrammetry, laser scanning most certainly has a place in more efficiently and effectively designing and constructing certain transportation projects in Iowa.

REFERENCES AND ADDITIONAL RESOURCES

References

Cyra. 2002. Cyrax and Cyclone Basic Training Course. Cyra Technologies, Inc. http://www.cyra.com. Accessed July 30, 2002.

Patterson, Cynthia 2001. Technology Transfer of As-Built and Preliminary Surveys. Masters Thesis, Iowa State University.

Additional Resources

For more guidance on Cyclone operations, see *The User Guide of Cyclone.*

For more general information on Cyrax, see *http://swww.cyrax.com*.

For more information on MicroStation, see *http://www2.Bentley.com*.