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# **EVALUATION OF 3-D LASER SCANNING EQUIPMENT: 2018 FINAL REPORT**

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**ICT PROJECT R27-45-T1**  
**Evaluation of 3-D Laser Scanning Equipment**

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<b>16. Abstract</b> <p>As a follow-up to ICT Project R27-030, Evaluation of 3-D Laser Scanning, this report provides findings of an evaluation of 3-D laser scanning equipment to determine the tangible costs versus benefits and the manpower savings realized by using the equipment in place of or in conjunction with conventional surveying methods. The Trimble TX5 laser scanning unit was used for this study.</p> <p>Two projects in District 8 were used for comparing manpower requirements for conventional surveying methods with those for 3-D laser scanning. Other projects were included in this evaluation under the objective of expanded use of the laser scanning equipment and included surface topography mapping of bridge decks, bridge beam deflection scans, and detailed surface mapping of various structures.</p> <p>Overall, the evaluation of the 3-D laser scanning equipment as a new technology for IDOT has been successful in documenting the benefits and shortcoming of its use on IDOT projects. It is the opinion of the participants that implementation of this technology in the various phases of IDOT projects is warranted and will benefit the department. Direct benefits of use of 3-D laser scanning technology included reduction in total project time; better accuracy of data; reduction in personnel hours spent in the field, which results in improved worker safety and less disruption to the traveling public; and innovative and alternate uses of the equipment.</p>					
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## EXECUTIVE SUMMARY

At the conclusion of their April 2010 study, the Technical Review Panel (TRP) for ICT Project R27-030 (Slattery & Slattery 2010) determined that enough benefit to the Illinois Department of Transportation (IDOT) existed to warrant implementation of the findings into department practice.

The objective of this project was to determine the tangible costs versus benefits and the manpower savings realized by using the 3-D laser scanning equipment in place of or in conjunction with conventional surveying methods. The Trimble TX5 laser scanning unit was used for this study, which is an updated model to the previous study.

Several projects in IDOT's District 3 and District 8 were used for comparing manpower requirements for conventional surveying methods with those for 3-D laser scanning. Other expanded uses of the 3-D laser scanner were evaluated and they include ADA ramps, intersections, mine subsidence, slope failures, bridge decks, and bridge strikes.

Overall, the evaluation of the 3-D laser scanning equipment as a new technology for IDOT has been successful in documenting the benefits and shortcomings of its use on IDOT projects. It is the opinion of the participants that implementation of this technology in the various phases of IDOT projects is warranted and will benefit the Department. Direct benefits of the use of the 3-D laser scanning technology included the reduction in total project time; better accuracy of data; the reduction in personnel hours spent in the field, which results in improved worker safety and less disruption to the traveling public; and innovative and alternate uses of the equipment.

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# CHAPTER 1: INTRODUCTION

## 1.1 BACKGROUND AND MOTIVATION

Between 2007 and 2010, ICT Project R27-030 (Slattery & Slattery 2010), focused research efforts on determining a cost-effective means to implement laser scanning technology in the construction phase of Illinois Department of Transportation (IDOT) projects. The primary goal was to study the use of a laser scanner for evaluating pay quantities for earthwork operations. A second objective was to evaluate the use of the laser scanner for the real-time monitoring of settlement during pile driving operations. A third objective was to evaluate the feasibility of using a scanner for other applications such as providing initial survey data for design, evaluating gravel and pavement thickness, assessing pavement roughness, surveying damaged bridges, and documenting archaeological investigations.

This study concluded that laser scanning technology could have several feasible applications for IDOT in construction and surveying. Some of the expected benefits included a reduction of crew time in the field, a better data collection process that facilitates additional analysis without further trips to the field, and in certain scenarios, an increase in safety caused by scanning from the shoulders of the roads and keeping crews out of traffic lanes.

## 1.2 OBJECTIVES

The objective of this project was to determine the tangible costs versus benefits and the manpower savings realized by using the 3-D laser scanning equipment in place of or in conjunction with conventional surveying methods.

The individual objectives of this project were to document the following:

- The manpower utilization and cost–benefit analysis for pre-survey, field survey, and data compilation/reduction to useable outputs;
- The equipment required to conduct the surveys;
- The impact on worker safety;
- The effect on the accuracy of the data collected and the amount of post-survey data processing required to produce a format suitable for use by IDOT’s Bureau of Design and Environment;
- Any other possible savings related to increased efficiency throughout the various processes.

## 1.3 METHODOLOGY

Slattery & Slattery (2010) used a Trimble GS 200 laser scanning unit. The GS 200 unit is capable of scanning 360° horizontally and 60° vertically. The manufacturer gives the maximum range as 1150 ft. (350 m), but for the purposes of increased speed and accuracy, a distance of 650 ft. (200 m) was used.

This project uses the Trimble TX5 laser scanning unit, which is an updated version of the model used in the previous R27-030 study. The Trimble TX5 provides automated sensors to assist with scan registration and to allow a minimal number of targets needed in the field. One large advantage that the newer TX5 system has over the previous unit is a dual axis compensator, which enables every scan to have integrated level information. The TX5 system also has an electronic compass to associate directional data into the scans. The TX5 unit is capable of scanning 360° horizontally and 300° vertically. However, the average range of a single scan is approximately 400 ft. (120 m), which is significantly less than that of the previous version.

Laser scanning equipment was utilized on numerous projects of varying types to evaluate the advantages and disadvantages of its use. The individual projects are summarized below, with more detailed descriptions and discussion in Chapter 2 of this report.

- District 8:
  - Sidewalk Ramps along US 50 11<sup>th</sup> to 3<sup>rd</sup> Street
  - Intersection Improvements at IL 158/IL 177 and Plum Hill School Road
  - Mine subsidence - US Highway 50 in O'Fallon
- District 3:
  - I-57 Bridge over Kankakee River south of Kankakee
  - Slope Failure / Shoulder Erosion – Route 251
  - Engineering Plans – ADA Ramps
  - Engineering Plans – Bridge
  - Engineering Plans – Route 113 and 47 Intersections
  - Engineering Plans – Route 178 and US 6 Intersections
- Bureau of Bridges and Structures (BBS):
  - Various Overpasses
  - Van Buren Street Bridge in Chicago

- IL Rte. 157 over Tributary to Silver Creek – Culvert Replacement
- Bridge Reconstruction US 51

## **CHAPTER 2: EQUIPMENT USAGE RESULTS**

The following sections of this report provide details of the projects included in this evaluation. In addition, an internet article was written and published (Culton 2017) that covers some of the information from these projects. A full copy of this article is included in the Appendix for additional reference.

### **2.1 DISTRICT 8**

#### **2.1.1 Sidewalk Ramps Along US 50 11th to 3rd Street**

On April 21, 2015, a survey request from District 8 was made on an extension of Contract No. 76H11. The new extension of resurfacing and Americans with Disabilities Act (ADA) improvements on US 50 ran from 11th Street to 3rd Street in Carlyle. A full topographic survey was requested for the ADA ramps at each of the nine intersections for a distance of 50 ft. (15 m) from the pavement. This includes the edge of the pavement as well as the curb and gutter flow lines. Samples of the documents produced from this work are provided as Figures 1 and 2, in the Appendix.

Conventional ground survey methods for the field phase required 309.5 hours of field work to collect the necessary measurements. Once that information was returned to the office, an additional 64 hours of processing was required to produce finished CAD files. The total time spent for the conventional survey method was 373.5 hours. A breakdown of the tasks and personnel hours for conventional surveying is provided in Table 1, in the Appendix.

The laser scanner survey methods placed the crew in the field for a total of 194 hours to acquire the scans and lay out the benchmarks and control ties for the designers and consultants. The office processing of the scanner data required 121 hours to produce finished CAD files. The total time to collect data and process to a finished CAD document was 315 hours. A more thorough breakdown of the time spent performing the tasks of each method for each phase is available in Table 2, in the Appendix.

An immediate benefit was realized by a reduction of 58.5 hours for the total time required to complete the project. However, the post-processing time required for the laser scanner method was approximately double that of the conventional survey method. A portion of the increased processing time revolves around workflow issues and a learning curve with the new equipment. Conventional survey methods placed personnel near or in traffic for a total of 294 hours. The laser scanning method placed personnel near traffic for a total of 194 hours. The safety of the work crew was improved by 100 hours, or approximately 34% less time exposed to traffic hazards using the laser scanning equipment.

#### **2.1.2 Intersection Improvements at IL 158/IL 177 and Plum Hill School Road**

On June 9, 2016, Location Studies requested a survey at the intersection of IL 158/IL 177 and Plum Hill School Road, located near Belleville. The survey was to include 1000 ft. (305 m) on the east and west approaches as well as 80 ft. (24 m) from the centerline to both sides. The project intent was to

install a westbound left-turn lane on IL 158/IL 177. Samples of the documents produced from this work are provided as Figures 3 and 4, in the Appendix.

Conventional ground survey methods for the field phase required 80 hours of field work to collect the necessary measurements. Once that information was returned to the office, another 26 hours of processing was required to produce finished CAD files. The total time spent for the conventional survey method was 106 hours. Table 3 in the Appendix provides a detailed breakdown of the required hours for the conventional surveying method.

Using the laser scanner equipment, the survey crew required 51.5 hours in the field to acquire the scans and to lay out the benchmarks and control ties for the designers and consultants. Office processing of the scanner data took 53 hours to produce finished CAD work. The total time to collect data and process to an acceptable CAD document was 104.5 hours. A more thorough breakdown of the time spent performing the tasks of each method for each phase is provided in Table 4, in the Appendix.

The use of laser scanning equipment shortened the overall project time by only 1.5 hours. Once again, the post-processing time required for the laser scanning method was double that required for the conventional survey method. Conventional methods placed personnel in or near traffic for a total of 80 hours, while the laser scanning method placed personnel in or near traffic for only 51 hours. The safety of the work crew was improved by 29 hours, or approximately 36% less time exposed to traffic hazards by using the laser scanning equipment.

### **2.1.3 Mine Subsidence – US Highway 50 in O’Fallon**

District 8 personnel used the laser scanning equipment to scan a section of US Highway 50 in O’Fallon, IL. This section of US Highway 50 has experienced settlement due to the subsidence of a previous underground mine, the St. Ellen Mine (533). Multiple scans were integrated together into a 3-D image of the existing ground surface. Samples of the documents produced from this work are provided as Figures 5 through 8 in the Appendix.

Conventional survey methods required 24 hours in the field to collect the data. The post-processing of the field data required an additional 7 hours, for a total of 31 hours to complete the work. Table 5 in the Appendix provides a detailed breakdown of the required hours for the conventional surveying method.

Using the laser scanning equipment, the crew required 12 hours in the field to acquire the scans. The office processing of the scanner data took approximately 9 hours, for a total project time of 21 hours. A more thorough breakdown of the time spent performing the tasks of each method for each phase is provided in Table 6 in the Appendix.

The use of laser scanning equipment shortened the overall project time by 10 hours, which equates to a 33% reduction in the time required. Once again, the post-processing time required for the laser scanning method was more than the conventional survey method. Conventional methods placed personnel in or near traffic for a total of 24 hours, while the laser scanning method placed personnel

in or near traffic for only 12 hours. The safety of the work crew was improved by 12 hours, or approximately 50% less time exposed to traffic hazards by using the laser scanning equipment.

## **2.2 DISTRICT 3**

### **2.2.1 I-57 Bridge Over Kankakee River South of Kankakee**

It was discovered after construction that the I-57 bridge deck over the Kankakee River south of Kankakee was constructed with minimal cross-slope and longitudinal slope and had very little drainage. It was desired by IDOT to survey the bridge deck with high accuracy to examine the low spots and flat areas of the bridge deck. Once these locations were identified, designers could determine where to place additional deck drains.

The bridge on I-57 across the Kankakee River spans 540 ft. (165 m) from scupper to scupper and consists of two separate superstructures: one structure for the northbound lanes of traffic and another structure for the southbound lanes of traffic.

On or about July 5, 2016, the laser scanning equipment was used to survey the bridge structures under live traffic. Each structure required seven scans (set-ups) per structure. Each structure took approximately 2 hours to scan, for a total field time of approximately 4 hours. Samples of the documents produced from this work are provided as Figures 9 and 10 in the Appendix.

Traffic control was set up to restrict traffic to one lane on the southbound structure. Because of ongoing construction on the northbound structure, traffic was temporarily diverted to the opposite structure (the southbound structure) on another day.

The 3-D laser scanning equipment could create a contour surface map of the bridge decks in 0.02-ft (6 mm) intervals under live traffic. The accuracy of the contour intervals allowed designers to clearly identify the low spots in the bridge deck. Using the traditional survey methods would not have been possible at such high levels of accuracy under live traffic conditions. The traditional survey methods could have been used to achieve the desired accuracy only if both lanes of traffic on each structure were shut down, diverted, or detoured for a long period of time. In addition, a one-person crew could complete the survey in approximately 4 hours, with minimal exposure to traffic hazards.

Using the 3-D laser scanning equipment on this project provided a multitude of benefits including an extremely high level of data accuracy, reduced exposure of personnel to traffic hazards, minimized disruption of traffic flow, avoidance of full closures requiring detour routing, and timely execution of the project to move forward with a solution to improve the safety of the traveling public.

### **2.2.2 Slope Failure / Shoulder Erosion – Route 251**

A section of road along Route 251 was investigated due to subsidence of the pavement. The laser scanning equipment was used to determine the extent of the void caused by slope failure and/or the erosion of the pavement's supporting material. Samples of the documents produced from this work are provided as Figures 11 and 12 in the Appendix.

The use of the laser scanning equipment made an otherwise extremely difficult task relatively easy and quick. Scans were obtained from the right-of-way and did not require crews to be exposed to traffic hazards, nor did it require alteration of the flow of traffic. Safety was further increased by allowing for the measurement and evaluation of the gap between the pavement and underlying subgrade without physically measuring beneath the suspended pavement. In addition, the use of the laser scanning equipment did not require intrusive methods, such as coring of the pavement, to otherwise obtain measurements.

### **2.2.3 Engineering Plans – ADA Ramps**

Seasonal summer employees were trained in the use of the laser scanning equipment and obtained over 460 scans of ADA ramps. This information was then post processed to produce engineering plans saving the state hundreds of thousands of dollars in labor costs. Samples of the documents produced from this work are provided as Figure 13 in the Appendix.

The use of the laser scanning equipment increased productivity, which resulted in reduced time where the crews were potentially exposed to traffic. Scans were obtained from areas outside the travel lanes, which resulted in there being no need for traffic control and in turn less disruption to the motoring public.

### **2.2.4 Engineering Plans – Bridge**

Contract 66H48 consists of remediating scour issues adjacent to SN 053-0162 carrying IL 170 over a branch of Mud Creek approximately 3.8 miles south of IL 17 in Livingston County. For this project, the conventional survey data was combined with the TX5 laser scans to produce Engineering Plans for bidding and eventual construction. Samples of the documents produced from this work are provided as Figure 14 in the Appendix.

The use of the laser scanning equipment increased productivity and provided more detailed data that would not have been possible with only conventional surveying methods. A significant cost savings was realized for the design phase of this project, and it will likely reduce the need for contract modifications during construction due to the detailed data collected.

### **2.2.5 Engineering Plans – Route 113 and 47 Intersections**

The laser scanning equipment was used to survey the Route 113 and 47 intersection to produce Engineering Plans for upgrades to the pavement markings and the intersection island. Samples of the documents produced from this work are provided as Figure 15 in the Appendix.

The use of the laser scanning equipment increased productivity, which resulted in the reduction of time where the crews were potentially exposed to traffic. Scans were obtained from areas outside the travel lanes, which resulted in there being no need for traffic control and in turn less disruption to the motoring public.

### **2.2.6 Engineering Plans – Route 178 and US 6 Intersections**

Contract 66H45 consists of removing traffic control items and replacing them with wood poles and span wire mounted traffic signals at the intersection of US 6 and IL 178. Laser scans of the intersection were used to evaluate the potential conflicts with existing utilities by determining aerial utility wire heights. A sample of a document produced from this work is provided as Figure 16 in the Appendix.

The use of the laser scanning equipment provided a fast and safe method for obtaining the required aerial utility heights that reduced potential risk to employees and reduced potential damage to existing utilities.



## **2.3 BRIDGES AND STRUCTURES**

### **2.3.1 Various Overpasses**

IDOT's Central Bureau of Bridges and Structures (BBS) used the laser scanning equipment to obtain detailed and accurate scans of multiple overpasses that are frequently struck by vehicular traffic. The scans are used for a comparison of before and after conditions related to the damage and safety assessments leading to potential repair requirements. The scanning operations have been successful. It is difficult to evaluate the manpower or cost savings at this time, however, it can be stated that implementation of the scanners are a safety benefit to IDOT workers by reducing the amount of time obtaining field measurements under live traffic

### **2.3.2 Van Buren Street Bridge in Chicago**

The Van Buren Street bridge is a large, curved Interstate ramp structure in Chicago under construction at the time of this report. The segments of all four curved girders were erected. However, a period of a few weeks elapsed before the final segments of the four curved girders were erected and connected. The contractor could connect the splices of the fascia girders and then move to the bearing locations. This was performed because the girders were out of alignment.

The fabricator elected to use a 3D terrestrial scanner to determine the final shape and orientation of the girders to determine why the girders were out of alignment and to find possible solutions so that construction could resume. A sample of a document produced from this work is provided as Figure 17 in the Appendix.

The BBS personnel are using the fabricator's scan data to: 1) Verify that the substructure units were properly placed; 2) Verify the current shape of the girders; and 3) Verify the information submitted by the fabricator and contractor. The project team is attempting to find a workable and safe solution utilizing the existing structural steel.

The laser scanning methods were employed on this project due to the accuracy required and the location of the elements to be surveyed. The conventional survey instruments would not have been able to provide the degree of accuracy required, and would have involved significant safety risks in obtaining the data in the field.

### **2.3.3 IL Rte. 157 Over Tributary to Silver Creek – Culvert Replacement**

A non-typical culvert is located beneath IL Route 157 over a tributary to Silver Creek, in need of replacement at the time of this report. Adjacent to this structure is an old railroad bridge whose wingwalls are within very close proximity of the existing culvert. The old railroad bed was converted to a bike path that passes through Hamel, IL.

The adjacent bike path bridge is not to be disturbed during the replacement of the existing culvert. The initial survey using the total station did not include the data on the location of the adjacent structure. Preliminary design computations called for a structure with wingwalls that would interfere with the adjacent bike path structure. In addition, the design calculations indicated that a more severe skew angle was required that did not appear feasible based on the total station topography

information. Much more precise data was needed than was collected during the conventional total station survey to determine a workable solution.

Using the laser scanning equipment, the exact locations of the existing culvert and the adjacent structure were determined. The laser scanner data was used to determine a new culvert location and specify a more reasonable skew angle. The scan data will also be used during the design phase of the job to ensure that no problems are encountered during construction. Samples of a document produced from this work is provided as Figure 18 in the Appendix.

The accuracy and completeness of the laser scanner data was far superior to the conventional survey methods, which allowed the designers to implement a workable and safe solution at this construction project site.

### **2.3.4 Bridge Reconstruction US 51**

The US 51 bridge reconstruction project consists of a dual structure including a three-segment bridge with an overall length of 755 feet from back-to-back of the abutments. The existing substructures were being reused. However, the beams and decks were being completely replaced except for a single unit that reused its structural steel. A crossover was utilized so that the northbound, three-unit structure would be constructed while the other was used for traffic.

It became apparent during and after the construction of the northbound structure that issues were present regarding the rideability of the northbound structure, which was reported as unacceptable. It was also noted that the existing seat elevations provided in the bridge plans did not match the actual seat elevations in the field.

Because of the high volume of traffic on this segment of US 51, a laser scan would provide the most data in the shortest period of time. Nearly all potentially needed data was acquired with one laser scanning event, eliminating the need to have crews make multiple trips to the project site. Collecting data with a laser scanner minimized the amount of time that a crew needed to be in or around traffic lanes. The crew could set up on the shoulders, which along with traffic control, provided more than adequate protection. Because the bridges spanned the Sangamon River, the scans provided data above the water that would not have been able to be obtained otherwise.

It is important to determine what happened during construction or if there were errors with the data in the contract plans. To do so, it was decided that both the newly reconstructed bridge and the bridge that was yet to be reconstructed should be scanned and the data subsequently analyzed. Scans from above and below the structures provided the research team with the data to determine the contour of the wearing surface, in addition to other valuable data, such as plumbness of the beams as well as slab thickness. Samples of the documents produced from this work are provided as Figures 19 and 20 in the Appendix.

PowerGEOPAK and Descartes software was used to analyze the data. By manipulating the laser scanner data, cross-sectional data and schematics could be created at any location within the scanned areas. Using this technique, the engineers could determine that the longest unit, which reused the existing structural steel, had several issues. The fascia beams either tilted out or warped

up to 3 degrees during the deck pour and did not return to a plumb state after the Bidwell machine passed. It was determined that inadequate temporary bracing was used in the three spans of that unit, which allowed the beam movement. The movement of the fascia beams caused the slab to have varying thicknesses. The contract plans called for a uniform deck thickness of 8 inches. However, the actual deck thicknesses varied from about 6.5 to 10 inches, as measured by the laser scanner data.

The cross-sections that were created via the scan data, along with a surface model generated from the point cloud, assisted in determining areas of the investigated unit that could be ground and areas that could not be altered, to safely remedy some of the rideability issues. This data also helped the engineers to determine if there were any safety issues associated with the deck thicknesses that were less than the desired 8 inches. If the new concrete slab of the third unit required replacement, it would have cost well over \$427,000, which only covers the cost of concrete and reinforcement. The survey cost the department \$33,000 because the field scanning had to be completed by a consulting firm. The department's equipment was determined to be inadequate and would require many more set-ups than that of the consulting firm's equipment. The firm selected had much newer equipment with longer ranges and better accuracy.

The laser scanner data also enabled the team to verify that the beams were placed at the proper elevations on the northbound structure. In addition, the data allowed the team to verify that the southbound bearing and beam information was correct prior to its reconstruction.

It was discovered from the laser scanner data that the substructure elements from the original 1975 construction were not placed exactly where they were supposed to be. Actual locations of the substructure elements varied as much as 1 to 2 inches from the planned locations. While that did not appear to cause problems with this project, it does give the department a reason to question future rehabilitation jobs that reuse existing substructure elements. This kind of detailed accuracy of location is not something that could be easily caught using conventional surveying methods. It can, however, be determined using 3D laser terrestrial scans.

An estimate of the manpower savings was not practical to produce for this project. However, the use of the laser scanning technology provided far more accurate and detailed survey data than that of the conventional survey methods. It also resulted in reduced exposure to safety risks for the field personnel by reducing the time of exposure, and by allowing the scans to be made from the shoulder areas.

## **CHAPTER 3: CONCLUSIONS AND RECOMMENDATIONS**

### **3.1 BENEFITS**

The 3-D laser scanning equipment was used on multiple projects of differing types. This was needed to evaluate the benefits and disadvantages of this technology before, during, and after construction on IDOT projects. The major benefits realized to date include the following:

- An overall reduction in the total time required for a given surveying project;
- An approximate 35% time savings for personnel conducting tasks in the field, leading to a significant reduction in the exposure to traffic hazards;
- An increase in the accuracy of the data obtained;
- A decrease in the required survey crew size for certain project tasks;
- Innovative and alternate uses for the equipment were discovered, such as high-accuracy surface topography mapping, bridge and structure scanning, and forensic investigations of the structure components and other points of interest.

Based on the various applications and evaluation, all participants in this project agreed that the use of this type of technology is a benefit to IDOT and that developing an implementation program across the department is warranted. All participants who performed various tasks with the equipment and data also agreed that a steep learning curve exists with new technological equipment. As a result, increased reductions in manpower efforts, for both field and office tasks, would be realized through the implementation of a more-efficient workflow and possibly through alternate hardware and software equipment.

### **3.2 DISADVANTAGES**

During the evaluation of the 3-D laser scanning equipment, various setbacks and disadvantages were realized, including the following:

- Steep learning curve for the equipment and for workflow best practices;
- Large data files are problematic for sharing and storing;
- Currently available computing resources are very underpowered and bottleneck the workflow, especially during post-processing;
- Restrictions related to software licensing are problematic for multiple users;
- Functionality and manufacturer support of specific hardware and software used was found to have limitations or poor quality;
- Technology of this type improves at a rapid rate, potentially creating issues implementing and maintaining a department-wide program over time;
- The inability to accurately survey through vegetation. The survey detects the top of the vegetation and not the actual ground elevation.

As the evaluation progressed, some of the disadvantages had much less of an impact, particularly those associated with learning curves and workflow practices. However, the hurdles related to computing power technology and the user friendliness of the equipment and software persisted during the evaluation.

### **3.3 RECCOMENDATIONS**

Overall, the evaluation of the 3-D laser scanning equipment as a new technology for IDOT has been successful in documenting the benefits and shortcoming of its use on IDOT projects. It is the opinion of the participants that implementation of this technology in the various phases of IDOT projects is warranted and will benefit the department.

It was clearly demonstrated that this technology significantly reduces the exposure of department personnel to traffic hazards, improving worker safety in the field and minimizing disruption to the traveling public.

Despite the hurdles and issues encountered during this evaluation, the study participants could adapt and create workflow practices to increase the benefits received from the equipment chosen for use in this study, the Trimble TX5 system. All participants agreed that the equipment and software selection are the keys to maximizing the efficiency and benefits related to manpower savings. Furthermore, the technology upgrades will be required at the district office level to maximize the benefits. Another upgraded ability that warrants consideration in choosing equipment is the ability to scan bridge structures spanning waterways. The current equipment is limited in this capacity because of the maximum distance available per scan.

Since the start of this project, it became apparent that one single piece of equipment does not have the ability to be used effectively in every field application. Between the various manufacturers and even various models within a single manufacturer's line, different pieces of equipment are better suited for different tasks. Given these observations, careful consideration must be given to selecting the appropriate piece of equipment for the task at hand. For example, the equipment chosen for evaluation within this project was a mid-resolution laser scanner with total station capabilities. This type of unit is best suited to calculation of pay quantities, basic dimensional data, and short-range scanning. Once the users of this equipment saw opportunities for expanded use of the laser scanning equipment outside this basic level, it became apparent that a high-resolution laser scanner would be needed for some applications. Such applications include scanning bridges, structures, and other items that require a long range or increased detail for highly accurate positioning and/or measurement data. Outside consultants were hired for such applications due to the high-resolution laser scanning equipment that they possessed, which made some projects feasible to complete.

Due to the wide array of applications for this technology, the participants observed that choosing the correct equipment with the needed capabilities was key to obtaining the desired outcome and receiving the full benefits of this technology. To this end, the project team recommends that consideration be given to evaluating the costs of purchasing equipment versus leasing equipment. Historically, purchasing equipment has a lower overall equipment cost to the end user. However, laser scanning technology is changing and advancing very rapidly as this method gains popularity and

frequency of use. The goal is to maintain the level of technology required, receive the benefits of advancing technology in efficiency, and ensure the appropriate piece of equipment is available. To achieve this, leasing may well be the best option and result in overall savings through the reduced costs of field time required for surveys and reduced risk to workers and the travelling public.

Based on the use of laser scanning equipment during this project, all parties agree that the equipment provides significant benefits over conventional survey methods for a variety of applications. The participants of this project recommend the continued use of this technology on department projects.

## REFERENCES

- Culton, R. "Web Exclusive: Quick Scan - Illinois Utilizes 3-D Laser Scanners to Enhance Safety," *Roads & Bridges*, October 11, 2017, <https://www.roadbridges.com/web-exclusive-quick-scan>.
- Slattery, D. K., and K. T. Slattery. 2010. Evaluation of 3-D Laser Scanning for Construction Applications. Final Contract Report No. FHWA-ICT-10-068. Illinois Center for Transportation. April 2010. 53 pp.

## APPENDIX: TABLES AND FIGURES, ROADS AND BRIDGES ARTICLE

**Table 1. Conventional Survey Hours for US 50 11th to 3rd Streets in Carlyle**

<b>Conventional Ground Survey</b>		
<b>Description of Work</b>	<b>Man-Hours</b>	<b>Crew</b>
<b>Field</b> - Startup, site recon, sketches-maps.	15	1-man
<b>Field</b> - Horiz. Control - GPS site control points, control ties, processing.	58	1-man
<b>Field</b> - Vertical Control - Levels, Processing, Site Benchmarks.	50	2-man
<b>Field</b> - Topo/DTM @ 9 intersections	118.5	1-man
<b>Field</b> - Existing Alignment - pavement splits, stakeout, 3-point ties.	68	2-man
<b>Field time</b>	<b>309.5 hours</b>	
<b>Office</b> - Research records, project start-up.	4	
<b>Office</b> - Process, Review, QC/QA	30	
<b>Office</b> - CAD	30	
<b>Office time</b>	<b>64 hours</b>	
<b>Total hours</b>	<b>373.5 hours</b>	



**Table 2. Laser Survey Hours for US 50 11th to 3rd Streets in Carlyle**

<b>Laser Scanner</b>		
<b>Description of Work</b>	<b>Hours</b>	<b>Crew-Office</b>
<b>Field</b> - Startup, site recon - supplemental horizontal and vertical control for control on paper targets, sphere and target placement.	13	2-m
<b>Field</b> - Scan pavement.	5	2-m
<b>Office</b> - Download FLS field files from scanner	0.5	1-m
<b>Scanning Field time</b>	<b>18.5 hours</b>	
<b>Office</b> - Convert FLS files to RWP/RWI files in Trimble Realworks software	8.5	1-m
<b>Office</b> - Auto extract & register spheres. Geo reference the paper targets.	4.5	1-m
<b>Office</b> - Edit point cloud surface	27.5	1-m
<b>Scanning Office time</b>	<b>40.5 hours</b>	
<b>Field</b> - We pass along control ties, existing alignment ties and site benchmarks to designers and consultants for plan use and construction. Ground survey hours (Horiz-58 hrs, Vert-50 hrs, Align-68 hrs) need included.	176	
<b>Ground Survey field time</b>	<b>176 hours</b>	
<b>Office - Estimated hours</b> - Processing TBC files to Microstation DGN files and finished CAD work.	80	
<b>Estimated Office time</b>	<b>80 hours</b>	
<b>TOTAL HOURS</b>	<b>315 Hours</b>	

**Table 3. Conventional Survey Hours for IL 158/IL 177 and Plum Hill School Road in Belleville**

<b>Conventional Ground Survey</b>		
<b>Description of Work</b>	<b>Man-Hours</b>	<b>Crew</b>
<b>Field</b> - Startup, site recon, sketches-maps.	2	2-man
<b>Field</b> - Horiz. Control - GPS site control points, control ties, processing.	8	2-man
<b>Field</b> - Vertical Control - Levels, Processing, Site Benchmarks.	10	2-man
<b>Field</b> - Topo/DTM	40	2-man
<b>Field</b> - Existing Alignment - pavement splits, stakeout, 3-point ties.	20	2-man
<b>Field time</b>	<b>80 hours</b>	
<b>Office</b> - Research records, project start-up.	2	
<b>Office</b> - Process, Review, QC/QA	16	
<b>Office</b> - CAD	8	
<b>Office time</b>	<b>26 hours</b>	
<b>Total hours</b>	<b>106 hours</b>	

**Table 4. Laser Survey Hours for IL 158/IL 177 and Plum Hill School Road in Belleville**

<b>Laser Scanner</b>		
<b>Description of Work</b>	<b>Hours</b>	<b>Crew-Office</b>
<b>Field</b> - Startup, site recon, scan pavement - supplemental horizontal and vertical control for control on paper targets, sphere and target placement.	11 hours	2-m
<b>Field/Office</b> - Download FLS field files from scanner	0.5 hours	1-m
<b>Scanning Field time</b>	<b>11.5 Hours</b>	
<b>Office</b> - Convert FLS files to RWP/RWI files in Trimble Realworks software	7.5 hours	1-m
<b>Office</b> - Auto extract & register spheres. Geo reference the paper targets. (5 projects)	25 hours	1-m
<b>Office</b> - Edit point cloud surface	19 hours	1-m
<b>Office</b> - Create mesh/Tin & Extract Tin 3 meshes with the following point spacings 5', 10' & 15'	1 hour	1-m
<b>Office</b> - Create Line work	0.5 hours	1-m
<b>Scanning Office time</b>	<b>53 Hours</b>	
<b>Field</b> - We pass along control ties, existing alignment ties and site benchmarks to designers and consultants for plan use and construction. Ground survey hours (Horiz-10 hrs, Vert-10 hrs, Align-20 hrs) need included.	40	2-M
<b>Ground Survey field time</b>	<b>51.5 Hours</b>	
<b>Office time</b>	<b>53 Hours</b>	
<b>TOTAL HOURS</b>	<b>104.5 Hours</b>	

**Table 5. Conventional Survey Hours for US 50 Mine Subsidence**

**Topography - Robotic Total Station**

**PROJECT:**

*St. Ellen Mine (533) on US Highway 50 in O'Fallon*

*St. Clair County*

*Mine Subsidence along US Route 50*

**Site Location :** *US Highway 50 in O'Fallon*

**Description of field work:** *Survey US 50 pavement in O'Fallon in the mine subsidence area.*

*(2 person crew)*

<b>Total Station</b>	
<b>Description of Work</b>	<b>Hours</b>
Field - Topo/DTM of pavement	2m - 12 hrs.
<b>Field Time</b>	<b>24 Hours</b>
Office - Process field file & tin model, review & QC/QA	6 hrs.
Office - CAD	1 hrs.
<b>Office Time</b>	<b>7 hours</b>
<b>Estimated Man-Hours</b>	<b>31 Hours</b>

*2m - 2 man/person crew*

**Table 6. Laser Scanner Hours for US 50 Mine Subsidence**

**Topography - Laser Scanner**

**PROJECT:**

*St. Ellen Mine (533) on US Highway 50 in O'Fallon*

*St. Clair County*

*Mine Subsidence along US Route 50*

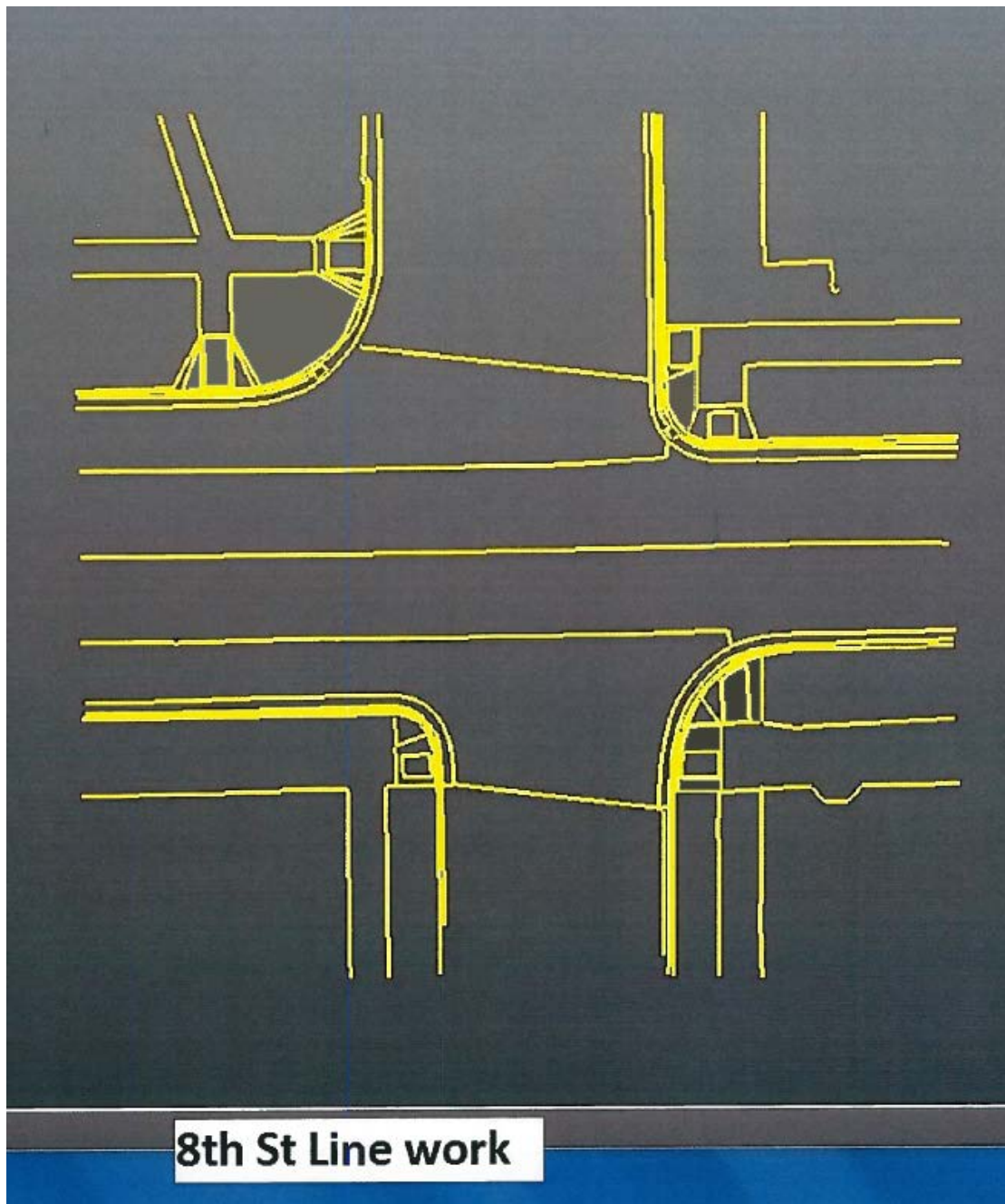
**Site Location :** *US Highway 50 in O'Fallon*

**Description of field work:** *Scan US 50 pavement in O'Fallon in the mine subsidence area.*

*(2 person crew)*

<b>Laser Scanner</b>	
<b>Description of Work</b>	<b>Hours</b>
Scan pavement, including planning scanner setups and sphere placement.	2m - 4 hrs.
Download FLS field files from scanner	2m - 2 hrs.
<b>Scanning Field Time</b>	<b>12 Hours</b>
Convert FLS files to RWP/RWI files in Trimble Realworks software (18 scans)	5 minutes
Auto extract & register spheres. Geo reference the paper targets. See note below.	3 hrs.
Edit point cloud surface	4 hrs.
Create Mesh/Tin	1 minute
Create Line Work	1 hour
Export Tin	1 minute
CAD	1 hour
<b>Office Time</b>	<b>9 hours</b>
<b>Total Man-Hours</b>	<b>21 Hours</b>

*Note: We had to manually match and unmatch some of the spheres to get the scans to seam together in the correct locations. This caused the software to crash several times during registration.*

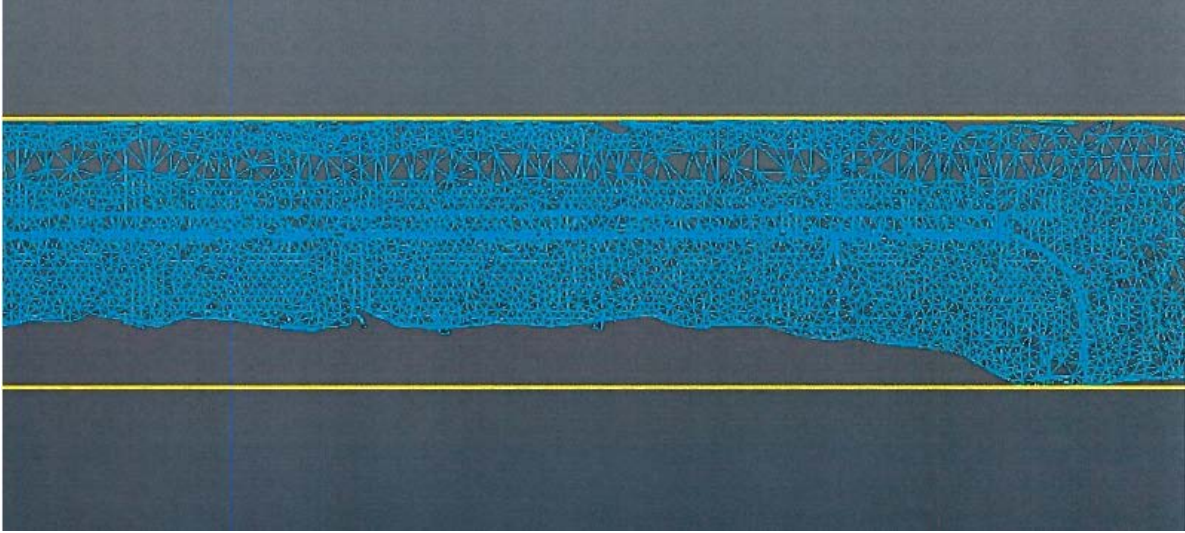


**Figure 1. Contract No. 76H11, ADA ramps on US 50, line work for 8th Street generated from laser scanning data.**

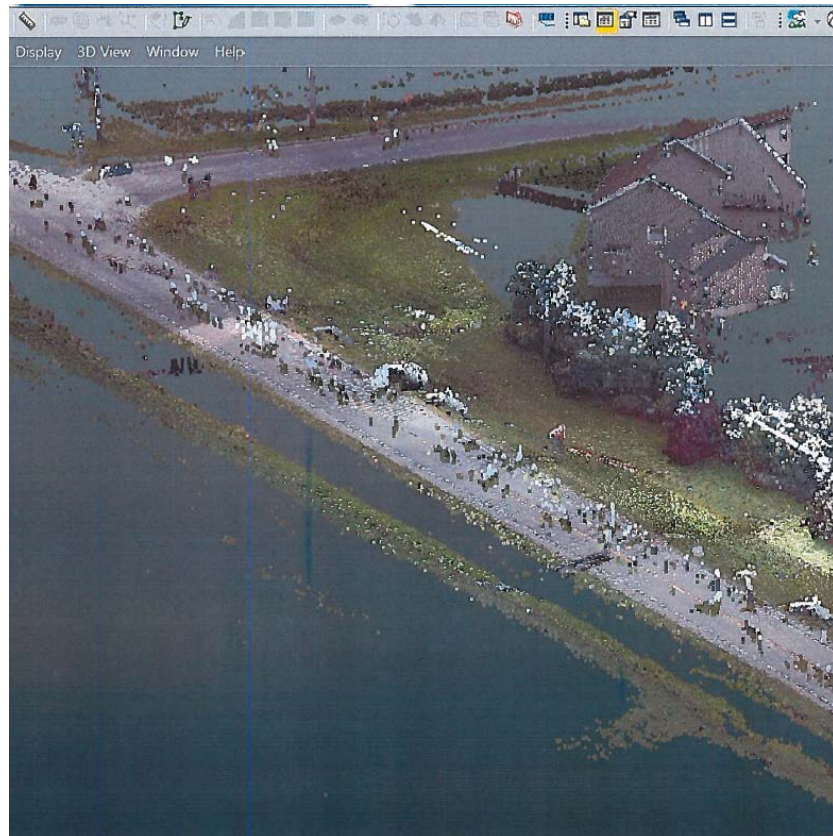


Figure 2. Contract No. 76H11, ADA ramps on US 50, 8th Street intersection generated from laser scanner point cloud with image superimposed.



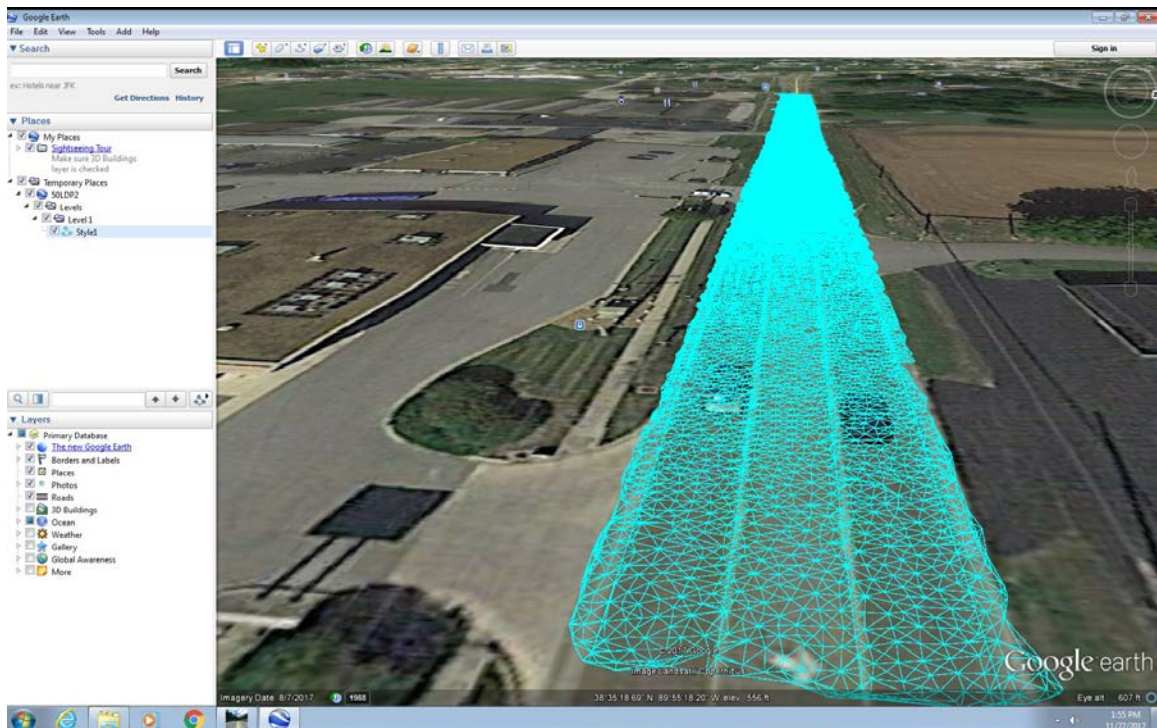


**Figure 3. Contract No. 76J0099, west side of intersection along IL 158 at Plum Hill School Road, TIN model.**

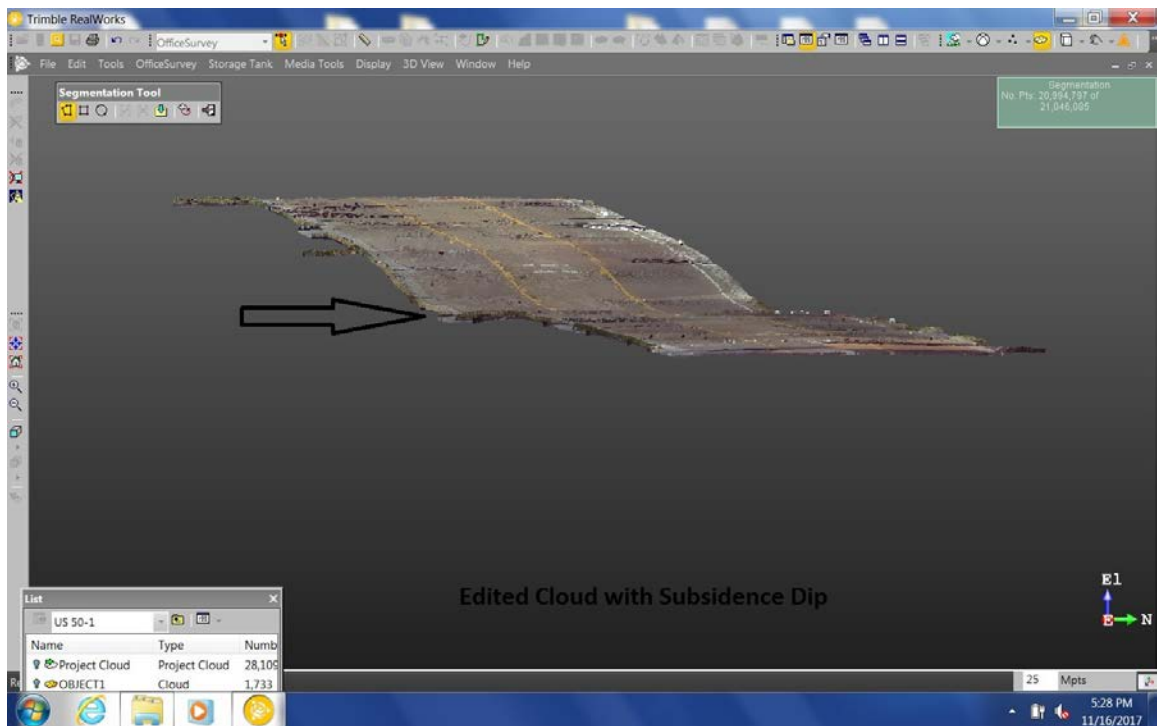


**Figure 4. Contract No. 76J0099, west side of intersection along IL 158 at Plum Hill School Road, laser scanner generated point cloud with image superimposed.**

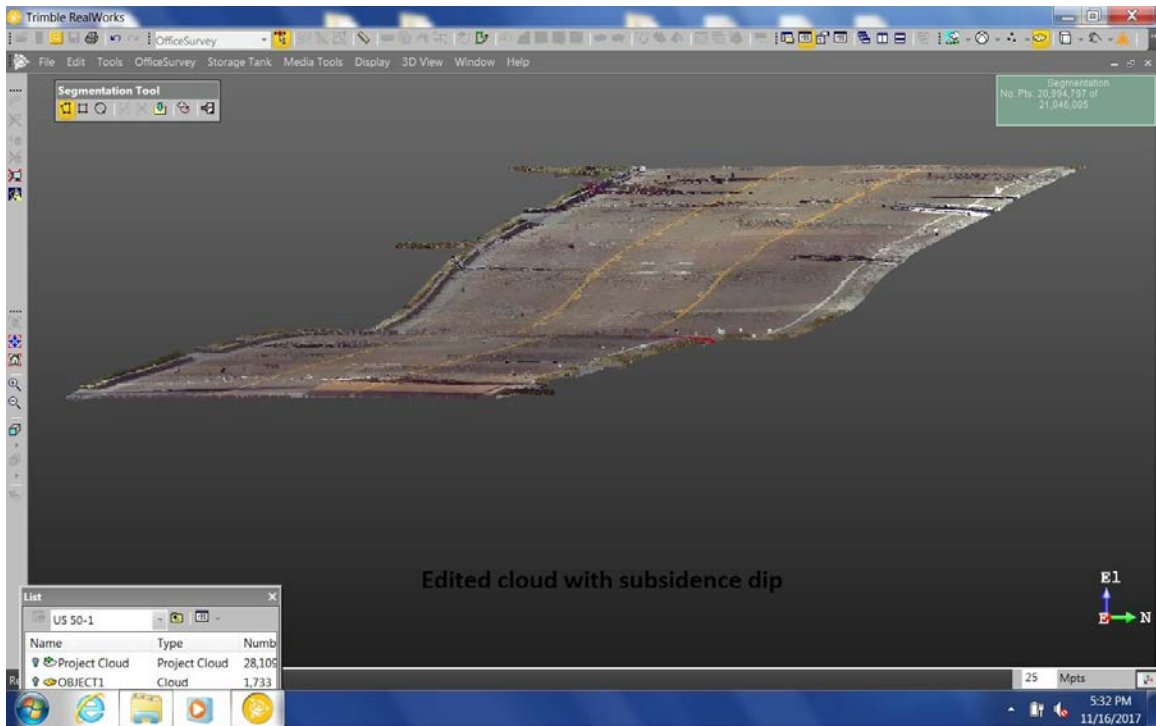




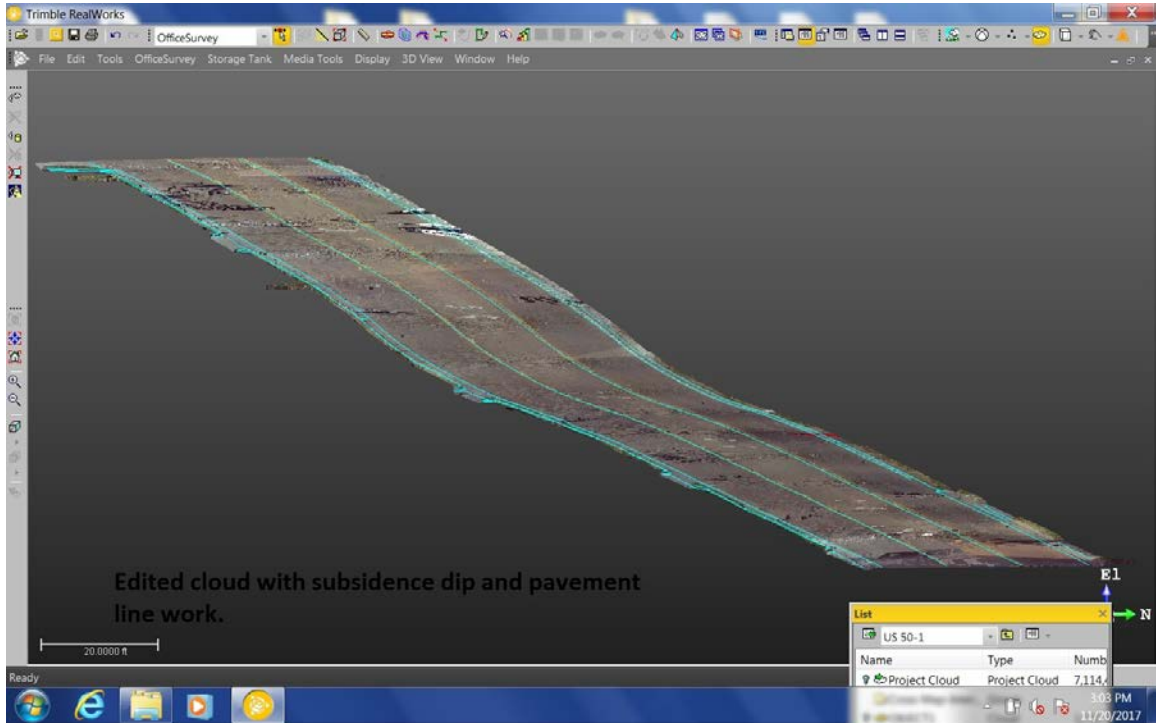
**Figure 5. Mine Subsidence US 50 O'Fallon – Google Earth with mesh superimposed.**



**Figure 6. Mine Subsidence US 50 O'Fallon – Laser Scan of problem area.**



**Figure 7. Mine Subsidence US 50 O'Fallon – Edited cloud data with subsidence dip.**



**Figure 8. Mine Subsidence US 50 O'Fallon – Edited cloud data with pavement line work.**

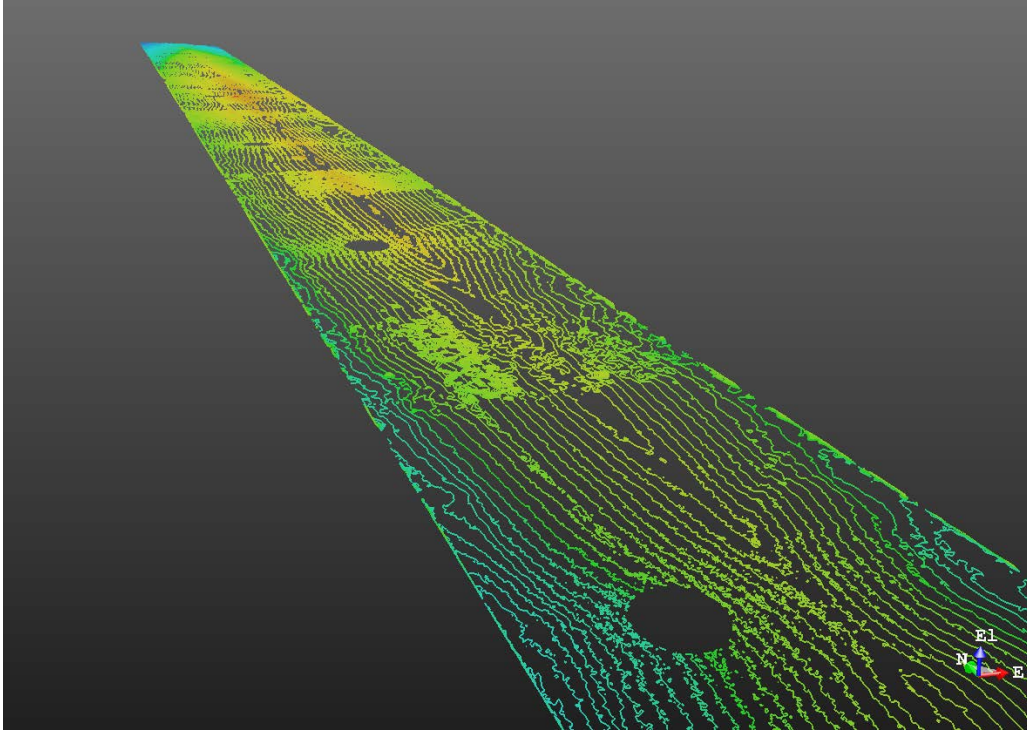


Figure 9. I-57 Bridge over Kankakee River – Cloud data elevation contour lines.



Figure 10. I-57 Bridge over Kankakee River – Laser scan compiled from cloud data.





**Figure 11. Route 251 Slope Failure – Shoulder Erosion, laser scanner generated point clouds with images superimposed.**



**Figure 12. Route 251 Slope Failure – Shoulder Erosion, laser scanner generated point clouds with images superimposed.**

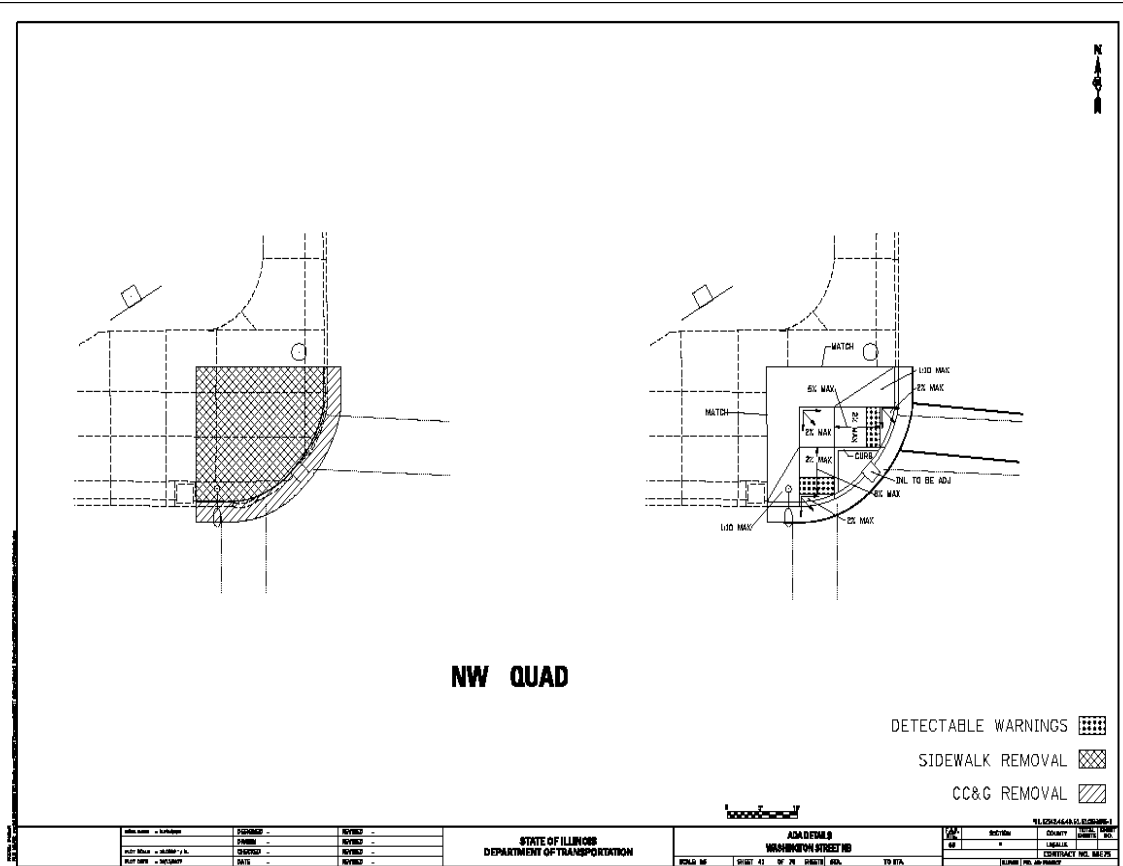


Figure 13. Engineering Plans – ADA Ramps, laser scanner generated point clouds with images superimposed. Critical Dimensions extracted for engineering plans.



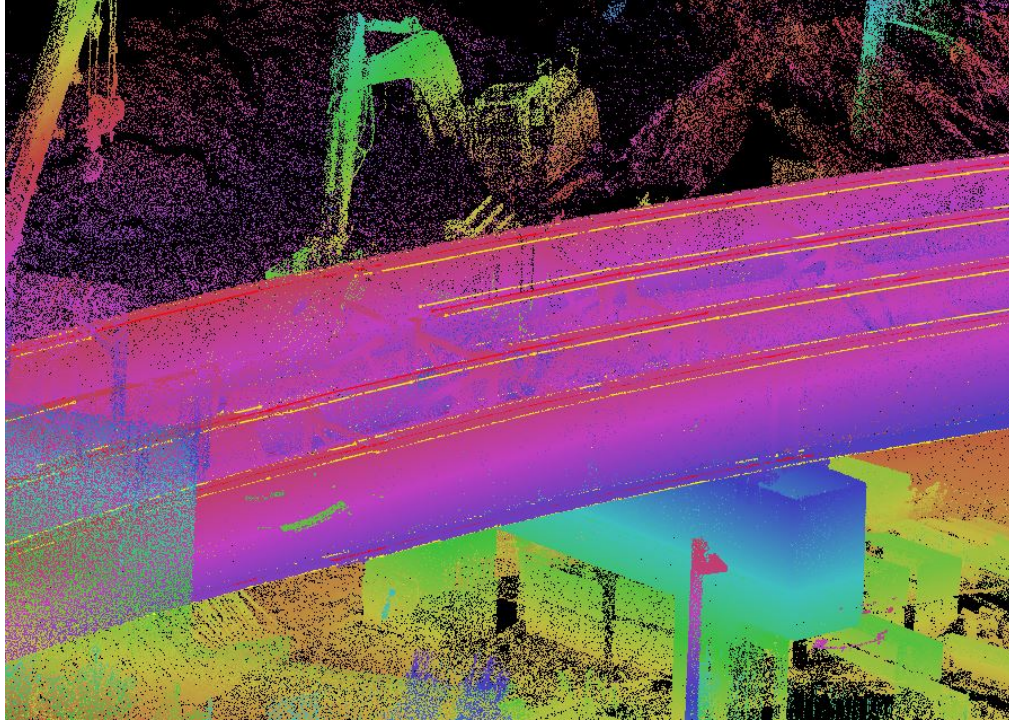




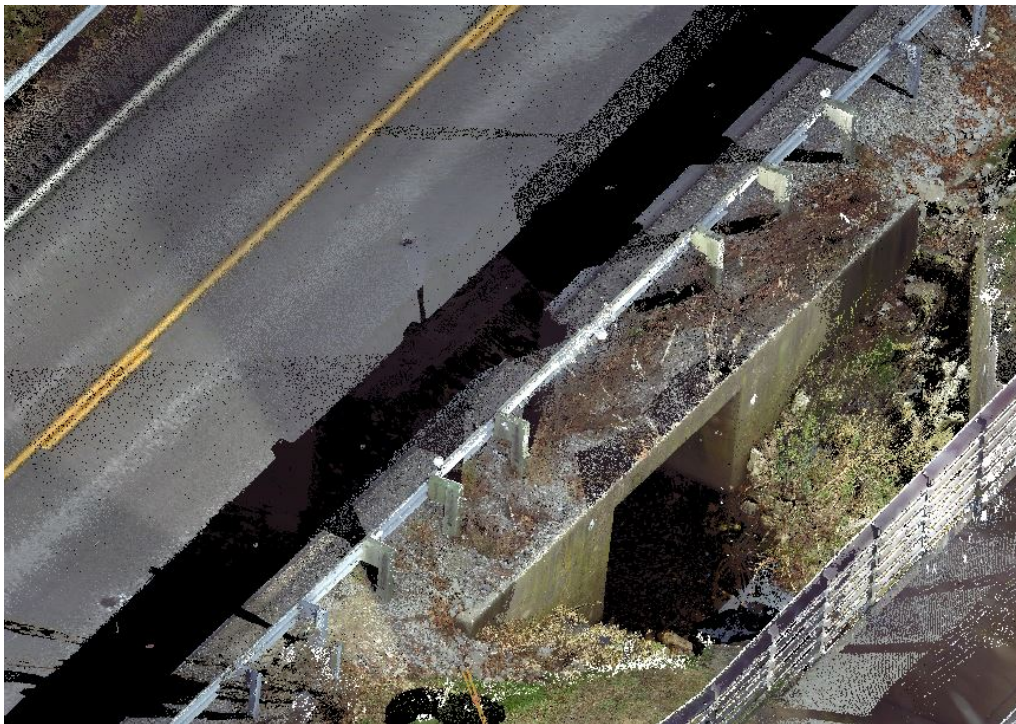




**Figure 16. Route 178 and US 6 intersection, laser scanner generated point cloud with image superimposed. Scanning for utility wire heights for potential conflicts.**



**Figure 17. Van Buren Street Bridge Chicago – Laser scan data combined to show locations of girders.**



**Figure 18. IL 157 Culvert Replacement – Scan data coupled with scan imagery used to engineer a solution to replacement of the existing culvert.**



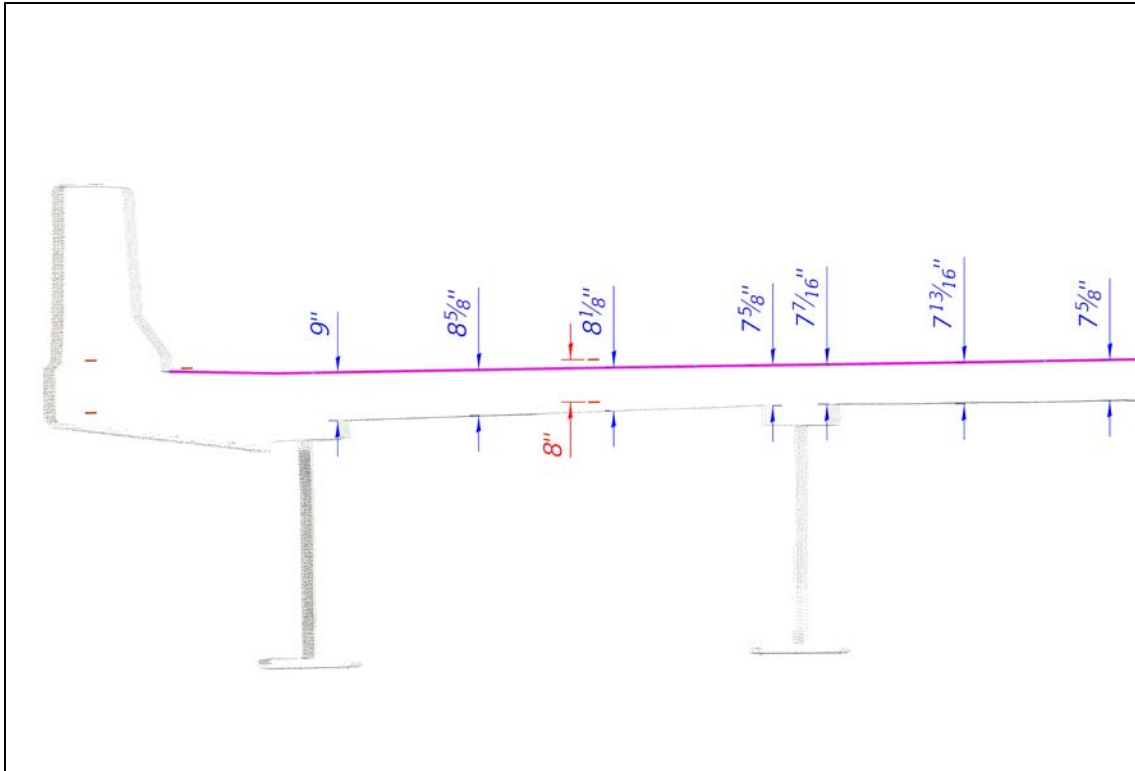


Figure 19. US 51 Bridge Reconstruction – Deck thicknesses measured using laser scanner data.

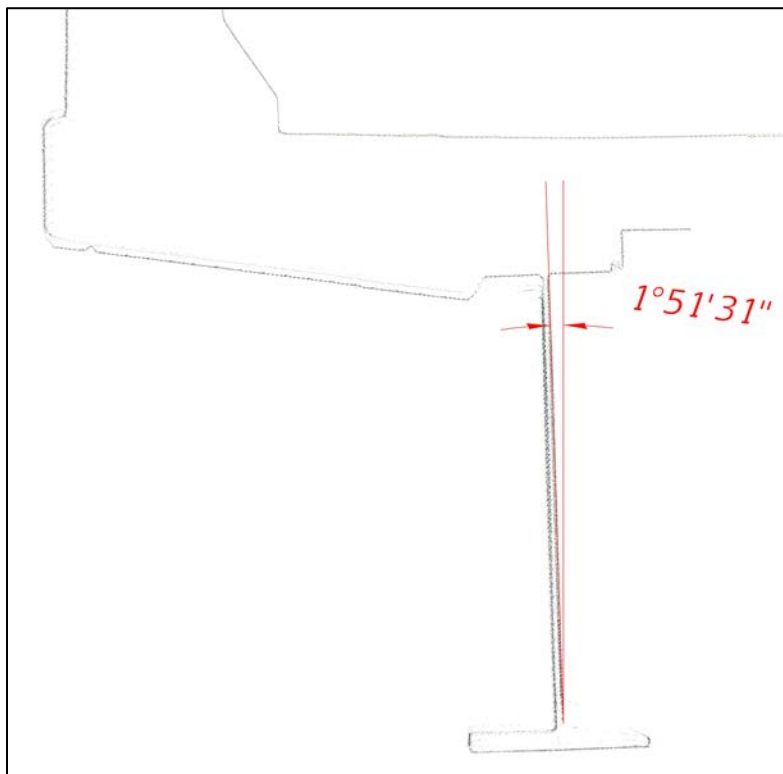


Figure 20. US 51 Bridge Reconstruction – Beam tilt measured with laser scanner data.

## Roads & Bridges Article

<https://www.roadbridges.com/web-exclusive-quick-scan>

### Web Exclusive: Quick scan

*Illinois utilizes 3-D laser scanners to enhance safety*

**WEB EXCLUSIVE** SAFETY ARTICLE BY RYAN R. CULTON, P.E. OCTOBER 11, 2017

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*IDOT survey crew member surveying intersection with 3-D scanner out of the path of live traffic. Photo courtesy of IDOT.*

In April 2010, the Illinois Department of Transportation (IDOT) and the Illinois Center for Transportation (ICT) published a research document titled Evaluation of 3-D Laser Scanning for Construction Application. The objective of this research was to study how 3-D laser scanning technology could be utilized in evaluating pay quantities in IDOT projects such as earthwork, gravel and pavement thickness, and pavement roughness, as well as documenting archaeological investigations.

The finding of the initial research project suggested that 3-D laser scanners could be a cost-effective way to aid in construction operations. Although the initial phase of the research project sought to identify practicum in construction operations, it was quickly realized that the 3-D laser scanners could be beneficial in additional surveying uses such as intersection, bridge girder and bridge deck surveys.

These additional survey uses allow IDOT to use innovative technology to carry out its mission as efficiently as possible while enhancing worker safety and creating fewer traffic delays.

In October 2013, IDOT embarked on a research implementation project to study the pros and cons of using 3-D laser scanners versus traditional methods of surveying using a three-person crew and a total station. IDOT procured three scanners, each one distributed to different offices—District 3 in northeastern Illinois, District 8 in southwestern Illinois, and the Central Bureau of Operations, Aerial Surveys Unit, in Springfield.

The methodology of the implementation project was straightforward: identify projects in which a 3-D laser scanner could be used, followed by a comparison of time wherein personnel are exposed to traffic versus conventional methods. Survey crews would perform a full survey using conventional methods from start to finish. Then, the same crew would perform another survey utilizing the 3-D laser scanner from start to finish. Personnel hours for each task were documented for field time, records research, and data processing.

The exception to this process was for the measurement of various components of bridges under live traffic. In these cases, it was apparent that the 3-D laser scanner was both the most effective and safest alternative to traditional methods, as it allowed traffic to flow normally while the survey was performed by the scanner off to the side of the roadway.

In June 2016, the Central Bureau of Research facilitated a demonstration, led by the survey team from District 8, on using the 3-D scanner for intersection surveying. Additional staff from District 3 Surveys, District 5 Operations, Central Bureau of Operations, Central Bureau of Construction, and the Illinois Capital Development Board Professional Services Section attended. An intersection in Springfield was surveyed, allowing attendees to see how efficient the actual surveying can be, and the types of data that are collected. IDOT also created a [demonstration video](#).

The IDOT implementation study's technical review panel met after the demonstration to discuss their recent experiences with the scanners and to identify past and future projects that could be evaluated using the 3-D laser scanner.



*Photo of IDOT maintenance crews assessing damage to a struck overpass bridge on U.S. 34. Photo courtesy of IDOT.*

## **Case studies**

### *U.S. 50 in Carlyle, Ill.*

In April 2015, IDOT survey crews in District 8 were tasked with completing an existing-conditions survey of resurfacing and ADA improvements on U.S. 50 from 3rd to 11th Streets in Carlyle. A full topographic survey was requested for the ADA ramps at nine intersections.

Conventional ground survey methods for the field phase required 309.5 hours of field work to collect the necessary measurements. An additional 64 hours of processing was required to produce finished CAD files, resulting in a total time of 373.5 hours.

Using the laser scanner survey methods, the crew was in the field for a total of 194 hours. Processing of the scanner data required 121 hours to produce finished CAD files, resulting in a total time to collect data and produce a finished CAD document of 315 hours.

While the post-processing time required for the laser scanner method was approximately double that of the conventional survey method, the total time to complete the project was reduced by 58.5 hours; most of the time savings was attributed to less exposure time of IDOT staff to traffic. Conventional survey methods placed personnel near or in traffic for 294 hours; however, the laser

scanning method placed personnel near traffic for 194 hours. The exposure of the work crew was decreased by 100 hours, or approximately 34%, using the laser scanning equipment.



*Damaged bridge girder with a 4-ft slice of a point cloud scan. Source: FHWA-ICT-10-068 Report*

### *Intersection improvements near Belleville, Ill.*

In June 2016, IDOT District 8 crews surveyed the intersection of S.R. 158/S.R. 177 and Plum Hill School Road near Belleville. The project intent was to install a westbound left-turn lane on S.R. 158/S.R. 177.

Conventional ground survey methods for the field phase required 80 hours of fieldwork to collect the necessary measurements. Once that information was returned to the district office, another 26 hours of processing was required to produce finished CAD files, resulting in a total time of 106 hours.

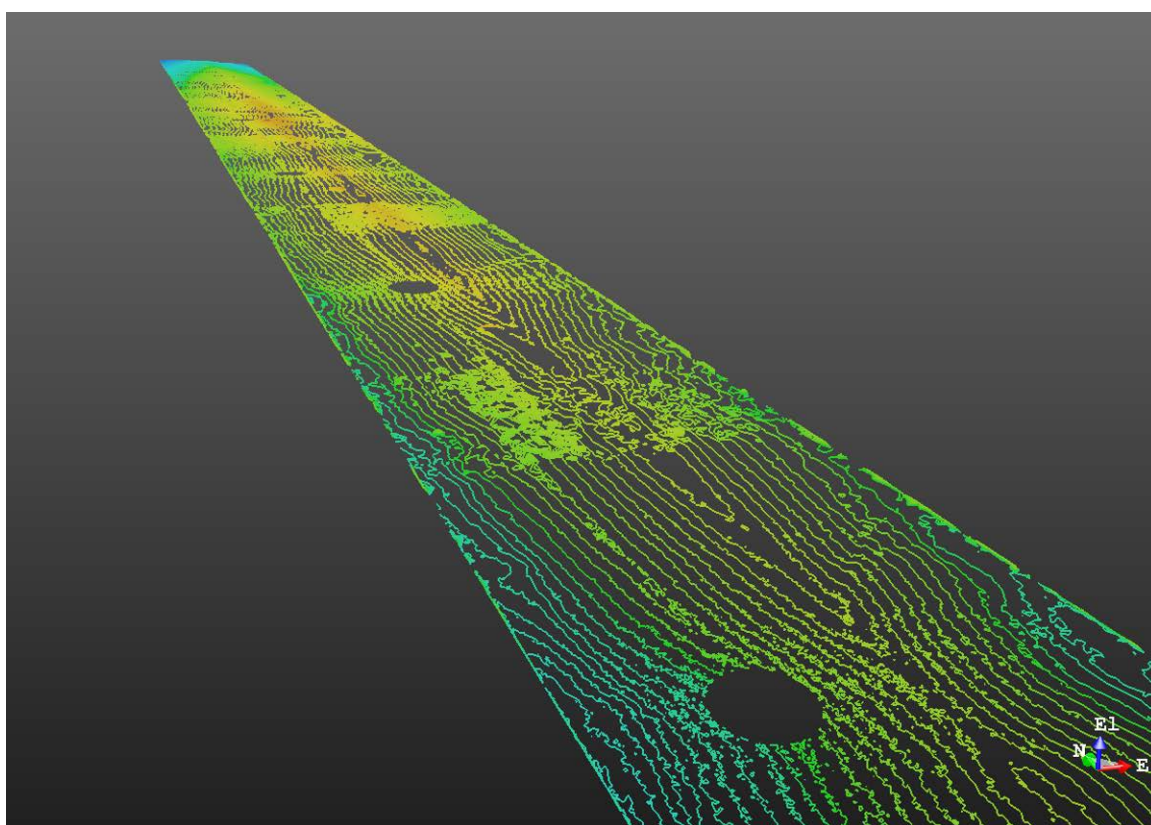
The 3-D laser scanner surveying method placed the crew in the field for 51.5 hours to acquire the scans, as well as lay out the benchmarks and control points for the designers and consultants. Processing of the scanner data took 53 hours to produce finished CAD work, resulting in a total time of 104.5 hours.

The use of laser scanning equipment on this project shortened the overall project time by only 1.5 hours, with the post-processing time required for the laser scanning method being twice as much as that required for the conventional survey method. The larger benefit was that while conventional methods placed personnel in or near traffic for a total of 80 hours, the laser scanning method placed personnel in or near traffic for only 51 hours. The traffic exposure of the work crew was decreased by 29 hours, or approximately 36%, by using the laser scanning equipment.



An important part of the implementation project has been gathering feedback from the surveying crews. Rick Porter, chief of surveys in IDOT District 8, was an early adopter of the 3-D Laser Scanning technology.

“District 8 has been using the 3-D laser scanner on ADA ramp surveys and intersection surveys,” Porter said. “The implementation of the work flow was definitely challenging. The new process was met with skepticism and excitement—skepticism, because you wonder if it really is that accurate; excitement, because it leaves little to the imagination. Moving forward, we foresee the scanner as a useful survey tool in addition to substantially limiting the amount of time staff spends in high traffic situations.”



*Bridge deck scan of I-57 over Kankakee River. Photo courtesy of IDOT.*

### *I-57 bridge over Kankakee River*

The I-57 bridge across the Kankakee River spans 540 ft. and consists of two separate superstructures—one structure for the northbound lanes of traffic, and another structure for the southbound lanes of traffic. After construction, IDOT crews observed that the I-57 bridge deck was experiencing drainage problems and water ponding after rain events. As a result, IDOT designers



wanted to accurately survey the bridge deck to identify its low spots and flat areas to determine where to place additional deck drains.

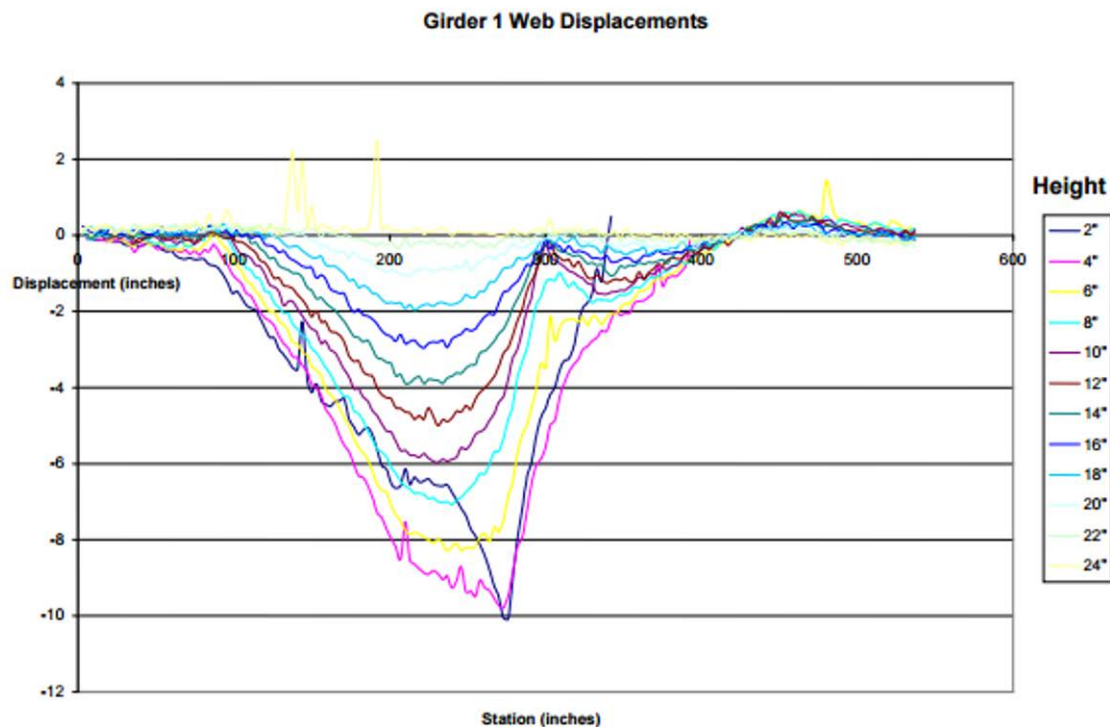
In July 2016, while utilizing the laser scanning equipment, the bridge structures were surveyed while regular traffic flow was maintained across the bridges. With only one person collecting the data, each structure required seven scans (set-ups) per structure. A one-person crew was able to set up the scanner and survey the bridge decks from a safe distance away from the traffic lanes. Each structure took approximately two hours to scan for a total field time of approximately four hours.

The 3-D laser scanning equipment was able to create a contour surface map of the bridge decks in 0.02-ft intervals.

The accuracy of the contour intervals allowed designers to clearly identify low spots in the bridge deck. Using traditional surveying methods would not have been possible at such high levels of accuracy under live traffic conditions. Traditional survey methods could only have been used to get the desired accuracy by shutting down both lanes of traffic on each structure, and diverting or detouring traffic for an extended period of time.

Utilizing the 3-D laser scanning equipment on this project provided a multitude of benefits: a high level of data accuracy, a brief time period of personnel exposure to traffic hazards, minimization of traffic flow disruption and timely execution of the project to move forward coupled with a solution for safety improvement to the traveling public.

“The scanner gave us the ability to identify the low spots under live traffic conditions,” said Peter Burbulys, PLS, acting chief of surveys for IDOT District 3 who performed the I-57 bridge scan. “This technology will revolutionize the way IDOT surveys hard surfaces, giving us the ability to take pavement measurements under live traffic conditions. It will probably bring about the biggest change to conventional survey methods since GPS, while saving lives.”



Web displacement curves calculated from point cloud scan. Source: FHWA-ICT-10-068 Report

## Scanning bridges and structures

Overpass structures are frequently struck by large trucks carrying oversized equipment. As part of this ongoing research project, IDOT's Central Bureau of Bridges and Structures is utilizing the laser scanning equipment to obtain detailed and accurate scans of multiple overpasses that are frequently struck by vehicular traffic. To date, IDOT has scanned 15 bridge superstructures that are routinely hit by trucks, and are continuously scanning more structures to include in a database of baseline scan information. This information will be used for a comparison of before and after conditions to quantify damage to the structure, determine potential safety issues, and identify repair requirements. Currently, IDOT maintenance crews use bucket trucks and have traffic control set up to measure deflections and damages by hand. Depending on the size of damage and the point of impact, this data collection can take at least two or three working days with a three-person crew.

In contrast, a one-person crew can erect a scanner off the side of the roadway and can, depending on traffic volume, either completely eliminate the need for traffic control or greatly reduce the lane closure. In some cases, a bridge girder scan could be completed in as little as 15 minutes. In most cases, bridge maintenance engineers need 2 ft of measurements on either side of the point of impact, as well as displacement measurements of the webbing.

Because a point cloud is gathered from the scanner, this data can be extrapolated and plotted in the safe environment of an office setting and not hand-measured in the field. These displacement measurements and timely delivery of that data are critical to structural engineers who need to analyze any reduction in structural capacity or adjust posted load ratings to the bridge until repairs can be made.

“The 3-D laser scanner is going to help us be very effective and expedite our processes,” said Victor Veliz, IDOT’s unit chief of bridge investigations and repair in the Central Bureau of Bridges and Structures. “In addition, the laser scanner will greatly reduce the amount of time that our maintenance personnel and contractors are exposed to work-zone traffic.”

The use of 3-D laser scanners has garnered attention from all IDOT districts, which are continuously looking for ways to improve their work efficiencies while increasing worker safety.

“Safety is a top priority here at IDOT, and 3-D laser scanners are helping us increase safety for our workers,” Illinois Transportation Secretary Randy Blankenhorn said. “By using this technology, we are reducing the need to have our employees near moving traffic, plus these scanners provide detailed survey information that is helpful for our planning and outreach purposes.”

IDOT intends to purchase additional 3-D laser scanners in the future so that each district has a machine.

Overall, the 3-D laser technology has demonstrated its effectiveness by reducing the exposure of IDOT personnel to traffic hazards, improving worker safety in the field, and minimizing disruption to the traveling public. The final report of the implementation project is scheduled to be published by April 30, 2018.



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