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**EVALUATION OF 3-D LASER
SCANNING EQUIPMENT:
2016 INTERIM REPORT**

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Evaluation of 3-D Laser Scanning Equipment

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16. Abstract 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. 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. 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.					
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EXECUTIVE SUMMARY

In April 2010, at the conclusion of their study, the Technical Review Panel for ICT Project R27-030, Evaluation of 3-D Laser Scanning, 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.

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.

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.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Between 2007 and 2010, ICT Project R27-030, Evaluation of 3-D Laser Scanning, focused research efforts on determining 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 use of the laser scanner for real-time monitoring of settlement during pile driving operations. Finally, 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 was also evaluated.

In April 2010, at the conclusion of their study, the Technical Review Panel for ICT Project R27-030 determined that enough benefit to the Illinois Department of Transportation (IDOT) existed to warrant implementation of the findings into department practice. This study concluded that laser scanning technology could have several feasible applications for IDOT in construction and surveying. Some of the benefits expected included reduction of crew time in the field, more complete data collection to facilitate additional analysis without further trips to the field, and, in certain scenarios, increased safety by scanning from the shoulders and keeping crews out of traffic lanes.

Improvements to efficiency are a must for an agency such as IDOT, for which funding is limited. Another motivating factor for this study was increased safety for IDOT personnel in the field.

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:

- Manpower utilization and cost–benefit analysis for pre-survey, field survey, and data compilation/reduction to useable outputs;
- Equipment required to conduct the surveys;
- Impact on worker safety;
- Impact on the accuracy of data collected and amount of post-survey data processing required to produce a format suitable for use by the Bureau of Design and Environment; and
- Other possible savings related to increased efficiency throughout the various processes.

1.3 METHODOLOGY

ICT Project R27-030 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 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 the newer TX5 system has over the previous unit is a dual axis compensator to enable 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 the previous scanners.

Two projects in District 8 were used for comparing manpower requirements for conventional surveying methods with those for 3-D laser scanning: Contract 76H11, ADA Ramps Along US 50 in Carlyle; and Contract 76J99, Intersection Improvements at IL 177/IL 158 and Plum Hill School Road, near Belleville. Details regarding these projects are provided in subsequent sections of this report.

Other projects were included in this evaluation under the objective of expanded use of the laser scanning equipment. These projects included the following:

- District 3: A new replacement bridge carrying I-57 over the Kankakee River was scanned to investigate bridge deck drainage conditions.
- Aerial Surveys: Various bridge beam scans were made to determine deflections.
- Bridges and Structures: Frequently struck overpasses were scanned to evaluate the use of laser scanning to define damage after vehicle collisions with the structures.

Details of the I-57 bridge project in District 3 are provided in a subsequent section of this report. Some of the other projects did not contain data or findings that warranted detailed discussion in this report. However, the experiences and opinions of the personnel involved in these projects are captured in the results and discussion sections of this report.

CHAPTER 2: RESULTS

The following sections of this report provide details of the projects included in this evaluation.

2.1 DISTRICT 8: ADA RAMPS ALONG US 50 11TH TO 3RD STREET

Contract No. 76H11
 FAP 327 (US 50)
 Section (20, 21) RS-5
 Clinton County
 D-98-035-14 / C-98-036-14

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 ADA improvements on US 50 ran from 11th to 3rd Streets in Carlyle. A full topographic survey was requested for the ADA ramps at each of nine intersections for a distance of 50 ft (15 m) from the pavement, to include edge of pavement, and curb and gutter flowlines.

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 were 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.

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

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

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. 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 tasks of each method for each phase is available in Table 2.

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

Laser Scanner		
Description of Work	Hours	Crew-Office
<i>Field - Startup, site recon - supplemental horizontal and vertical control for control on paper targets, sphere and target placement.</i>	13	2-m
<i>Field - Scan pavement.</i>	5	2-m
<i>Office - Download FLS field files from scanner</i>	0.5	1-m
Scanning Field time		18.5 hours
<i>Office - Convert FLS files to RWP/RWI files in Trimble Realworks software</i>	8.5	1-m
<i>Office - Auto extract & register spheres. Geo reference the paper targets.</i>	4.5	1-m
<i>Office - Edit point cloud surface</i>	27.5	1-m
Scanning Office time		40.5 hours
<i>Field - 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.</i>	176	
Ground Survey field time		176 hours
<i>Office - Estimated hours - Processing TBC files to Microstation DGN files and finished CAD work.</i>	80	
Estimated Office time		80 hours
TOTAL HOURS		315 Hours

An immediate benefit is seen in the total time to complete the project being reduced by 58.5 hours. However, 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 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.

2.2 DISTRICT 8: INTERSECTION IMPROVEMENTS AT IL 158/IL 177 AND PLUM HILL SCHOOL ROAD

Contract No. 76J0099
 FAU 9251 (IL 158/IL 177)
 Section 28, 29-N-1
 St. Clair County
 D-98-072-16/C98-065-16/76J99

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.

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 provides a detailed breakdown of the required hours for the conventional surveying method.

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

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

The laser scanner survey methods placed the crew in the field for 51.5 hours 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 tasks of each method for each phase is provided in Table 4.

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

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

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.

2.3 DISTRICT 3: I-57 BRIDGE OVER KANKAKEE RIVER SOUTH OF KANKAKEE

Contract No. 66750

FAI 57 (I-57)

Section (140)BR, BR-1 & I(1)

Kankakee County

Project ACNHPP-0057(307)

Job No C-93-027-08/3-37680-0100

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.

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 (southbound structure) on another day.

The 3-D laser scanning equipment was able to 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 low spots in the bridge deck. Using traditional survey methods would not have been possible at such high levels of accuracy under live traffic conditions. 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 was able to 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, a very small time period of personnel exposure 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.

2.4 BRIDGES AND STRUCTURES: VARIOUS OVERPASSES

IDOT's Central Bureau of Bridges and Structures used the laser scanning equipment on various projects during the evaluation phase of this study. The equipment was used to obtain detailed and accurate scans of multiple overpasses that are frequently struck by vehicular traffic. The scans will be used for a comparison of before and after conditions related to damage and safety assessments leading to potential repair requirements. The scanning operations have been successful; however, it is difficult to evaluate manpower or cost savings at this time.

CHAPTER 3: CONCLUSIONS AND DISCUSSION

3.1 BENEFITS

The 3-D laser scanning equipment was used on several projects of differing types in order 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 data obtained;
- A decrease in required survey crew size for certain project tasks; and
- Innovative and alternate uses for the equipment were discovered, such as high-accuracy surface topography mapping, bridge and structure scanning, and forensic investigations of structure components.

On the basis of the various applications and evaluation, all participants in this project agreed that 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 such as this and that increased reductions in manpower efforts, for both field and office tasks, would be realized through 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 equipment and, in particular, 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; and
- Technology of this type improves at a rapid rate, potentially creating issues implementing and maintaining a department-wide program over time.

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 equipment and software persisted during the evaluation.

3.3 DISCUSSION

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.

Despite the hurdles and issues encountered during this evaluation, the study participants were able to 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 equipment and software selection are the keys to maximizing efficiency and benefits related to manpower savings, and that technology upgrades will be required at the district office level in order 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.

It was also 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.

APPENDIX: SAMPLE PROJECT OUTPUT

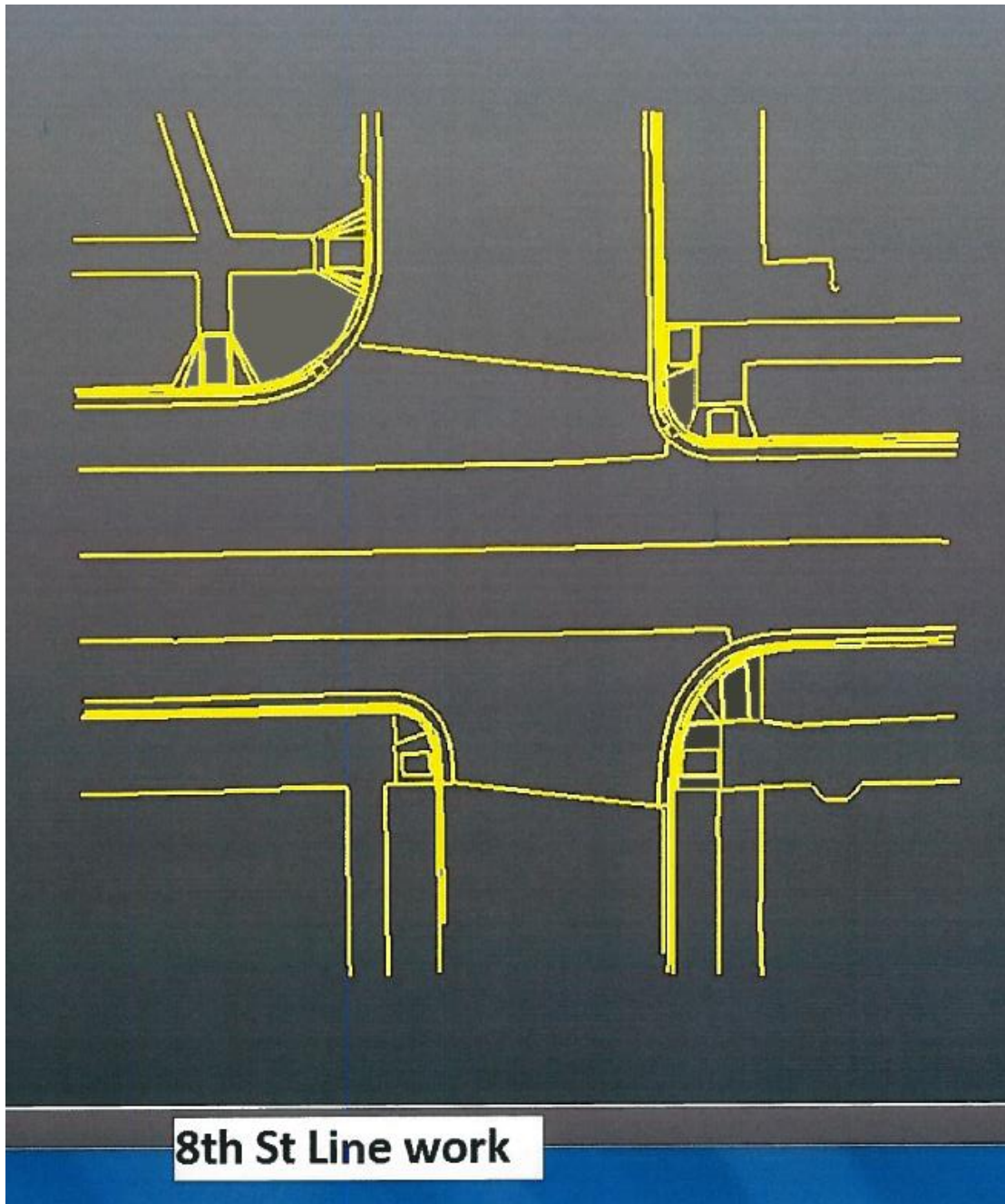


Figure 1: Contract No. 76H11, ADA ramps on US 50, linework for 8th Street generated from laser scanning data.



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

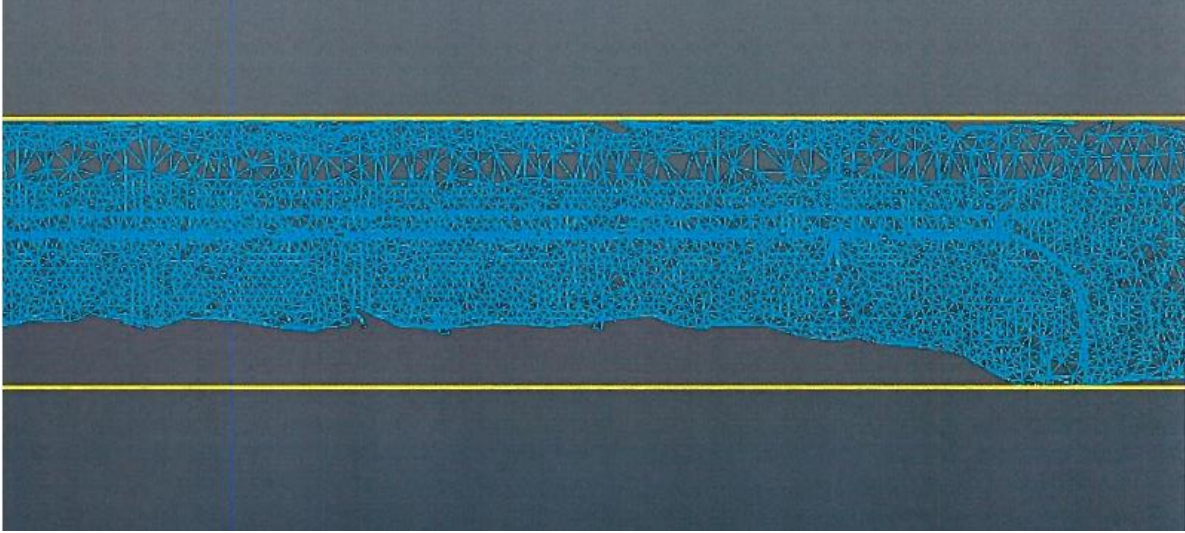


Figure 3: Contract No. 76J0099, west side of intersection along IL 158 at Plum Hill School Road, TIN model.

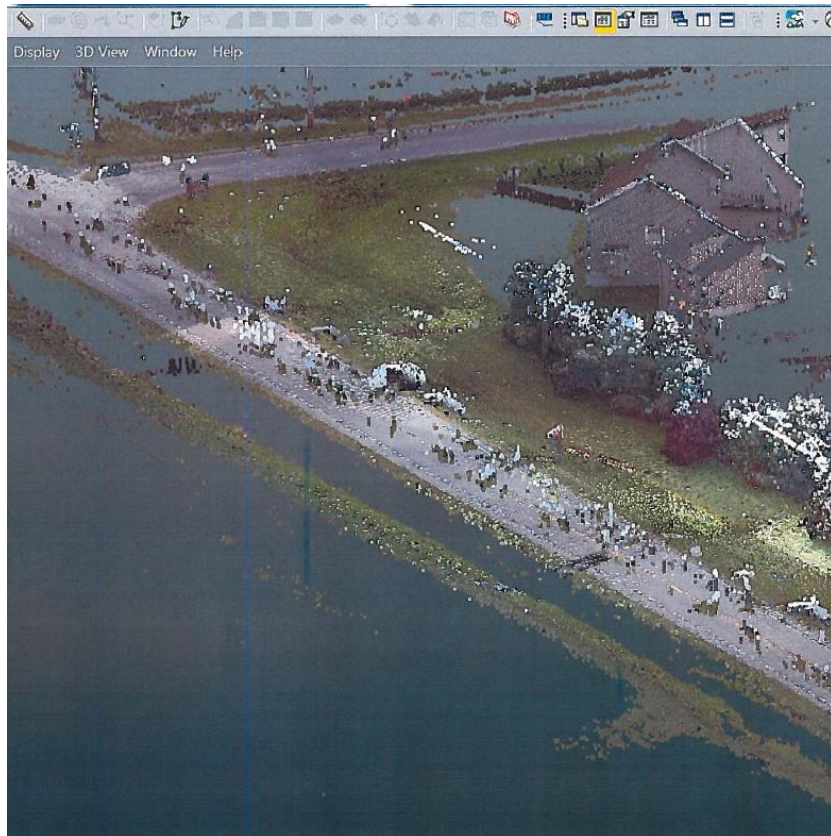


Figure 4: Contract No. 76J0099, west side of intersection along IL 158 at Plum Hill School Road, laser scanner-generated point cloud with image superimposed.

