Leveraging Lidar Technology in Telecommunications Construction

A Technical Paper prepared for SCTE by

Camille Westlake
Program Manager of Commercial Innovation
NV5 Geospatial Inc.
421 SW 6th Ave, Suite 800, Portland, OR. 97204
503.505.5100
Camille.Westlake@nv5.com

Steve Lucente
Director, Business Development - Telecom
NV5 Geospatial Inc.
421 SW 6th Ave, Suite 800, Portland, OR. 97204
305.926.9179
Steve.Lucente@nv5.com

Dan Wagner, NV5 Geospatial Inc.

Arley Oddo, NV5 Geospatial Inc.

Conrad Hilley, NV5 Geospatial Inc.

Chris Andersen, NV5 Geospatial Inc.

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1. Introduction

The telecommunications industry is experiencing rapid growth and technological advancements with higher demand for data. The 5G rollout is driving that growth and the demand is putting pressure to build the infrastructure. 5G can use existing 4G/3G cell sites but has a lower cell radius of 100m, which means it will require the deployment of many more cell sites. The best locations for these existing cell sites are on existing infrastructure such as utility poles or buildings. Utility poles are ideal locations because the 5G cell sites use more energy (around 11.5 kW vs. 6.8 kW of 4G) and need a backhaul network (i.e., fiber connection).[1]

The struggle is working within the utility industry regulations to get additional fiber and antennas placed in a timeline needed for the 5G rollout. Telecommunication companies are finding their applications to deploy cell sites taking much longer than the shot clock governance of 90 days for reviewing the application. Some have reported that seventy percent (70%) of their applications have exceeded the 90-day shot clock and forty-seven percent (47%) have exceeded 150 days.[2]

Utilities want reassurance that the pole passes the make-ready assessment and can support the added infrastructure 5G needs. The traditional boots-on-the-ground method of measuring attachment points is time-consuming and cannot keep up with the needs of the 5G rollout. An alternative solution is a Mobile Mapper Unit which consists of a mobile lidar (light detection and ranging) system and a spherical camera. The lidar unit scans the pole and wires generating 3D point cloud data that can be analyzed by computer algorithms to extract the attachment locations on the pole, while image recognition can be applied to the spherical imagery to identify smaller equipment and pole tags.

Many telecommunication companies have large fiber densification projects in the largest cities. As a result of these projects, they will need to attach fiber cables to millions of electric utility poles. This will more than double the number of new attachments that would normally go on a pole. Time is of the essence for these projects and utilizing the normal utility attachment/inspection process will not meet the required timelines. However, utilities need to ensure that their facilities are being managed correctly and that all rules and regulations are being followed when it comes to pole attachments. Telecommunication companies and utilities are looking for ways to meet their timelines, while still achieving regulatory and safety compliance.

A large utility company, referred to as Utility, approached NV5 Geospatial (NV5G) to collaborate on investigating whether remote sensing can be utilized to:

- Shorten the asset attachment inspection timeline;
- Ensure that the Utility is capturing the information necessary to determine if telecommunication companies can attach to its poles while still adhering to government regulations (e.g. National Electric Safety Code (NESC) clearances), and;
- Create as-built records of change after construction.

Through this project, an accurate, efficient, and cost-effective remote sensing-based methodology was developed that produced an average ninety-four percent (94%) match with in-situ measurements and allowed for 40 miles of pole lines to be collected in a day. This white paper presents an overview of the remote sensing methodologies developed and a comparative quantitative analysis of conventional survey methods vs. a remote sensing based option.

2. Methods

2.1. Overview

A remote sensing mobile mapping system was used to collect lidar and spherical imagery data, which were then processed via automated routines, pole modeling tools, and image recognition to identify and extract utility poles, wires, and various pole attachments, as well as calculate wire measurements and identify clearance detections. This process also generated output data that could be run through a 3rd party application to generate pole-loading models.

The following workflow overviews the different phases from data collection to data processing and attachment, clearance, and loading analyses; highlighting areas of manual and automated data processing along with optional phases that can be applied to improve accuracy and provide more detailed results. Each phase is further detailed below, and the results comparing in-situ to remote-sensing-derived measurements are presented.

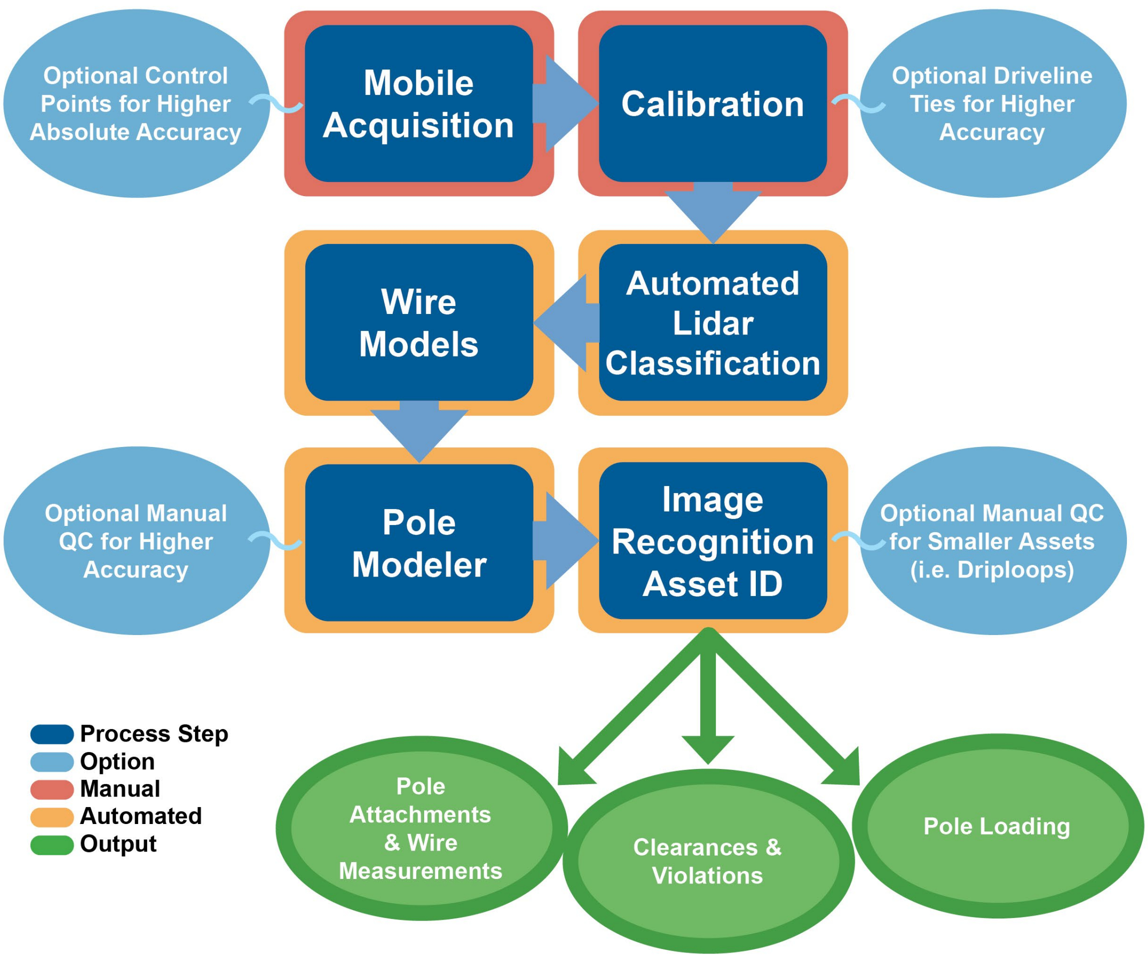

Figure 1 – Pole Modelling Workflow

2.2. Data Acquisition

2.2.1. Mission Planning

To maximize asset detection by the lidar and imagery systems, an acquisition route must be planned. Upon receipt of pole locations or a survey area of interest (AOI) from the utility client, the mission planning team creates a drive-route utilizing an in-house or 3rd party routing application. Lane prioritization (maximize feature visibility) and additional factors such as weather (precipitation), solar windows (sun angle for imagery), traffic volume (time of day dependent), and, roadway accessibility (construction, blockages, one-way/bi-directional/divided) and conditions (paved, gravel, etc.) are taken into account. This process ensures complete route coverage in the most time and cost-efficient manner possible.

2.2.2. Survey Control

NV5G survey teams utilize industry standard equipment (Trimble GNSS dual-frequency L1-L2 receivers) and survey methodologies (static, real-time kinematic (RTK) or precise point positioning (PPP)) for survey and ground control. Absolute vertical and horizontal accuracies in the range of a few centimeters are possible. Additional ground control points are collected for both calibration support and positional (vertical and horizontal) accuracy assessments, with typically a handful of targets being collected every mile.

For some applications, such as the current one of asset attachment inspections and clearance analyses, this level of absolute accuracy is not required as the primary focus is not on having high accuracy latitude and longitude coordinates for features, but rather that features are correctly situated relative to one another so that measurements taken between them are accurate. For mobile systems relative accuracies in the millimeter range are possible, allowing for highly accurate clearance measurements.

2.2.3. In-Situ Measurements

Field crews were deployed to carry out in-situ measurements in two phases. One phase involved measurements taken by field crews as directed by a utility engineer. The second phase involved measurements collected by field crews following conventional survey methods. These later measurements were collected twice to analyze and control for inconsistent field measurements. The engineer measurements were utilized as truth control values for comparison against both conventional survey and remote-sensing-derived measurements.

Field measurements were made using a measured telescoping fiberglass pole with a cable hook on the end. Once hooked over the wire or placed adjacent to an asset, the measurement was read off the telescoping pole and recorded.

A total of 11 different measurements (Table 1 – Field Measurement List) were taken at each of the 100 study poles.

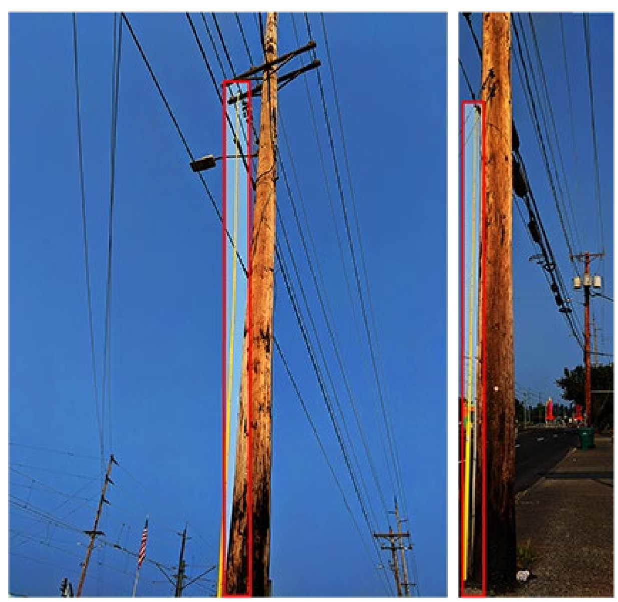

Figure 2 – In-Situ Measurements

Table 1 – Field Measurement List

Highest Comm	Streetlight	Comm/Electric
Neutral	SL Drip	Comm/Street Light
Secondary	Electrical 4" Riser	Comm/SL D Loop
Secondary Drip	Electrical 6" Riser	

2.3. Lidar & Imagery Survey

High-density lidar and georeferenced panorama spherical imagery were collected using Riegl's VMX-2HA lidar sensor and a LADYBUG-5 spherical imagery sensor (Table 2 – Mobile Mapping Sensor Specifications) mounted onto a truck. The VMX-2HA system is comprised of two (2) rear-facing VUX-1HA lidar sensors which collect point data of roadside features up to 475 meters away. The spherical imagery was included to collect images at fixed-distance intervals. All sensor inputs, monitored in real-time by operators, are recorded and time-stamped.

Additionally, Riegl's RiACQUIRE software is utilized to verify successful data collection by monitoring real-time sensor status, route coverage, and data condition.

Figure 3 – Mobile Mapping System

Table 2 – Mobile Mapping Sensor Specifications

Sensor	Specifications	
Lidar RIEGL VMX-2HA	Pulse Repetition Rate (PRR) (peak)	3.6 MHz
	Range	Min = 1m, Max = 475m
	Accuracy/Precision	5 mm / 3 mm
	Rotation	360°
Spherical Imagery LADYBUG-5	Number of Lenses	6
	Maximum Resolution	2048x1224 pixels (30 MB)
	Spectral Bands	3 (RGB)
IMU/GNSS	Type	Integrated
	Absolute Accuracy (typical)	xy = 2cm, z = 3cm

*inertial measurement unit (IMU)
ˆpulse repetition frequency (PRF)
˜red, green, and blue (RGB)
εglobal positioning system (GPS)
¨global navigation satellite system (GLONASS)

While mobile scanners can collect data at a point density of thousands per square meter and ideal densities are project and application-dependent, for reliable capture of pole and attachment features densities in the range of 750 PPSM (points per meter squared) are sufficient and more cost effective. (Figure 4 –Mobile Lidar Point Cloud Data).

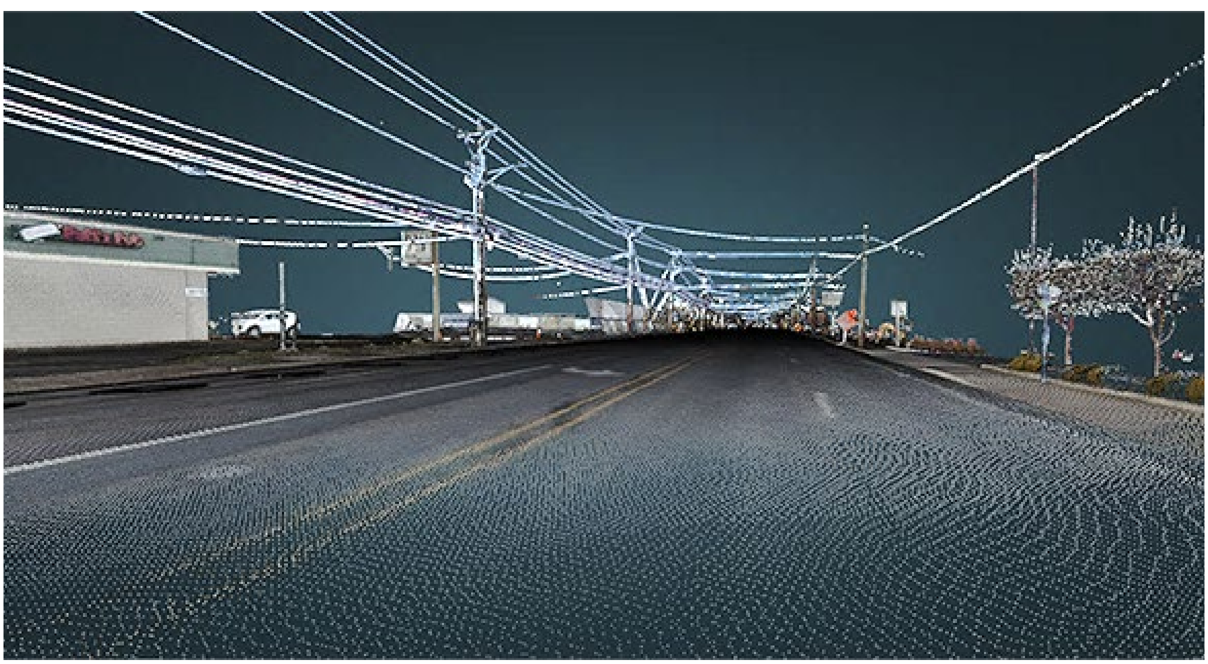

Figure 4 – Mobile Lidar Point Cloud Data

To aid in the identification of assets not readily identifiable with lidar data alone, spherical imagery is also collected. (Figure 5 – Spherical Imagery Data).

Figure 5 – Spherical Imagery Data

2.4. Data Processing

2.4.1. Lidar Processing

Post-acquisition processing of acquired lidar data begins with georeferencing and spatial refinement of the vehicle drive path known as the trajectory. Data from the onboard GNSS positioning system is differentially corrected using nearby reference base stations or PPP methods. This corrected GNSS position data is then combined with data from the onboard IMU to produce a smoothed best estimate of trajectory (SBET), data that captures the sensor position throughout the acquisition drive. With the vehicle and sensor position provided within the SBET, georeferenced lidar point clouds can be created.

To improve the absolute spatial accuracy of the derived point cloud, ground survey points placed on identifiable features can be used to make corrections to the point cloud position or further refine the SBET.

In areas where drive paths overlap, automated methods can be used to improve the alignment of the overlapping data, increasing the relative accuracy of the resulting point clouds.

2.4.1.1. Automated Point Cloud Classification

Following calibration, each point in the lidar point cloud is classified as real-world features (e.g. ground, poles, wires, etc.) using a series of advanced automated and manual routines. First, a ground surface model is developed using automated ground detection routines. The results are then refined using a statistical surface algorithm with constraints based on geometric relationships between points and lidar return characteristics. The resulting ground classification can then be used to generate a bare-earth digital elevation model (DEM). The DEM is quality-controlled to identify any ground classification issues that can quickly be resolved manually.

After ground points have been classified, above-ground features (e.g., buildings, wires type, poles, vegetation, fences, etc.) are automatically classified using a machine learning model specifically trained to classify utility infrastructure. Classification models used by NV5G leverage features of the lidar point cloud (e.g., height above ground, return type, return intensity, geometric properties, etc.). Further refinements of the wire types (e.g. Primary and Secondary electrical wires) can be completed via manual methods. As necessary, quality control is completed, and any misclassifications are corrected to ensure required classification accuracies are met. Using automated routines alone, classification accuracy is 95% or better. Typically, the automated classification results are sufficient to extract 3D vector models of utility infrastructure automatically.

2.4.2. Imagery Processing

The Ladybug 5 camera generates video stream files (.prg) that are turned into panoramic 3-band (RGB) JPEG (Joint Photographic Experts Group) files using the Ladybug CapPro software. Image position and orientation are calculated by linking the time of image capture, the corresponding vehicle position and attitude, and the SBET data (the same utilized in 2.4.1 Lidar Processing) in POSPac Mobile Mapping Suite (MMS) and outputting an initial Exterior Orientations (EO) file. The EO file is combined with the JPEG images in a proprietary georeferencing tool, tagging them with geographic locations. Image georeferencing is quality controlled (QC) to ensure processing is performed as per protocols.

2.4.3. Primary Asset Extraction via Pole & Span Modelling

Once the lidar data has been classified and wires are extracted, Pole Modeler is used to extract attachments on the pole (Figure 6 – Pole Asset Extraction from Mobile Lidar Data), calculate mid-span and pole clearances, and generate models for pole loading analyses. These tools are run in an automated fashion with no initial manual QC. With added manual QC, accuracies can be improved further by removing errors produced during automation, such as missing or misplaced attachments (± 6 inches).

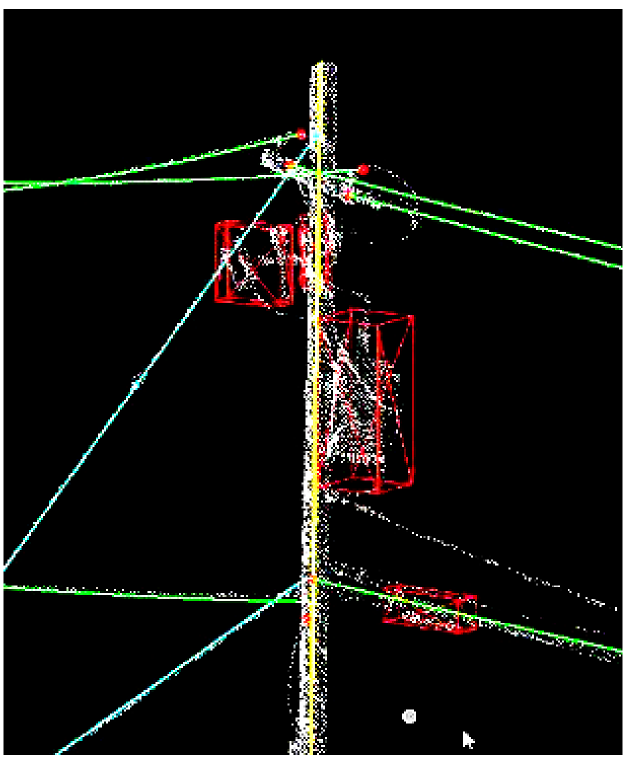

Figure 7 – Pole Asset Extraction from Mobile Lidar Data

Figure 6 – Drip Loop (Red Dot)

Pole Modeler first isolates the pole and calculates height, lean, lean angle, and diameter. Other features on the pole, such as cross-arms, larger equipment (e.g. streetlights, transformers), guy wires, service drops, and other attachments discernible within the lidar point cloud are also extracted. Next, if required, manual QC can be completed to adjust misplaced attachment points and capture smaller features that may have be missed (e.g. drip loops) (Figure 7 – Drip Loop) due to a lack of lidar point returns from the narrow cables. An analyst can quickly snap offset attachment points that are misaligned and add attachment points that were not identified by the automated routines.

2.4.3.1. Attachment Measurements

Once the necessary attachment assets have been identified, several measurements (Table 3 – Pole Measurements Common Attachment Points) between them can be completed (Figure 8 – Pole Measurements) automatically and used for clearance violation pole loading analyses.

Table 3 – Pole Measurements Common Attachment Points

Electric		Communication
Primary	Streetlight	Mainline
Secondary	Streetlight Drip Loop	Service Drop
Neutral	Riser	Crossarm
Transmission	Weather Head	Riser
Service Drop	Pole to Pole Guy	
Drip Loop	Down Guy	
Pole Top		

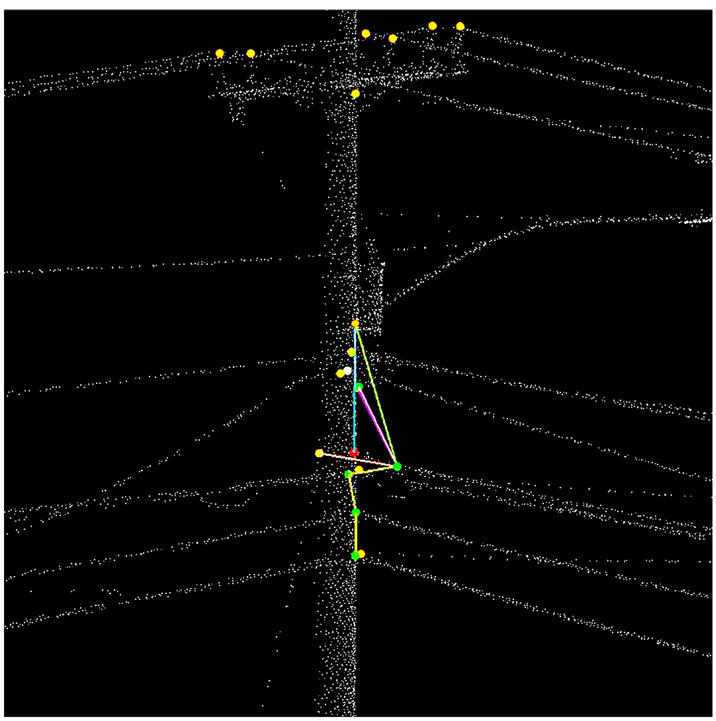

Figure 8 – Pole Measurements

Several different inputs (Table 4 – Pole Measurement Inputs and Outputs) are required within Pole Modeler to calculate pole attachment measurements. Different parameters (e.g. units, attachment radius) can be adjusted based on project-specific requirements (Figure 9 – Pole Measurement Inputs and Outputs).

Table 4 – Pole Measurement Inputs and Outputs

Inputs	Outputs
Lidar Ground Model	Measurements between Attachment Points
Modeled Attachment Points	Heights Above Ground
Pole Locations and Names	Minimum Clearances
	Clearance Violations

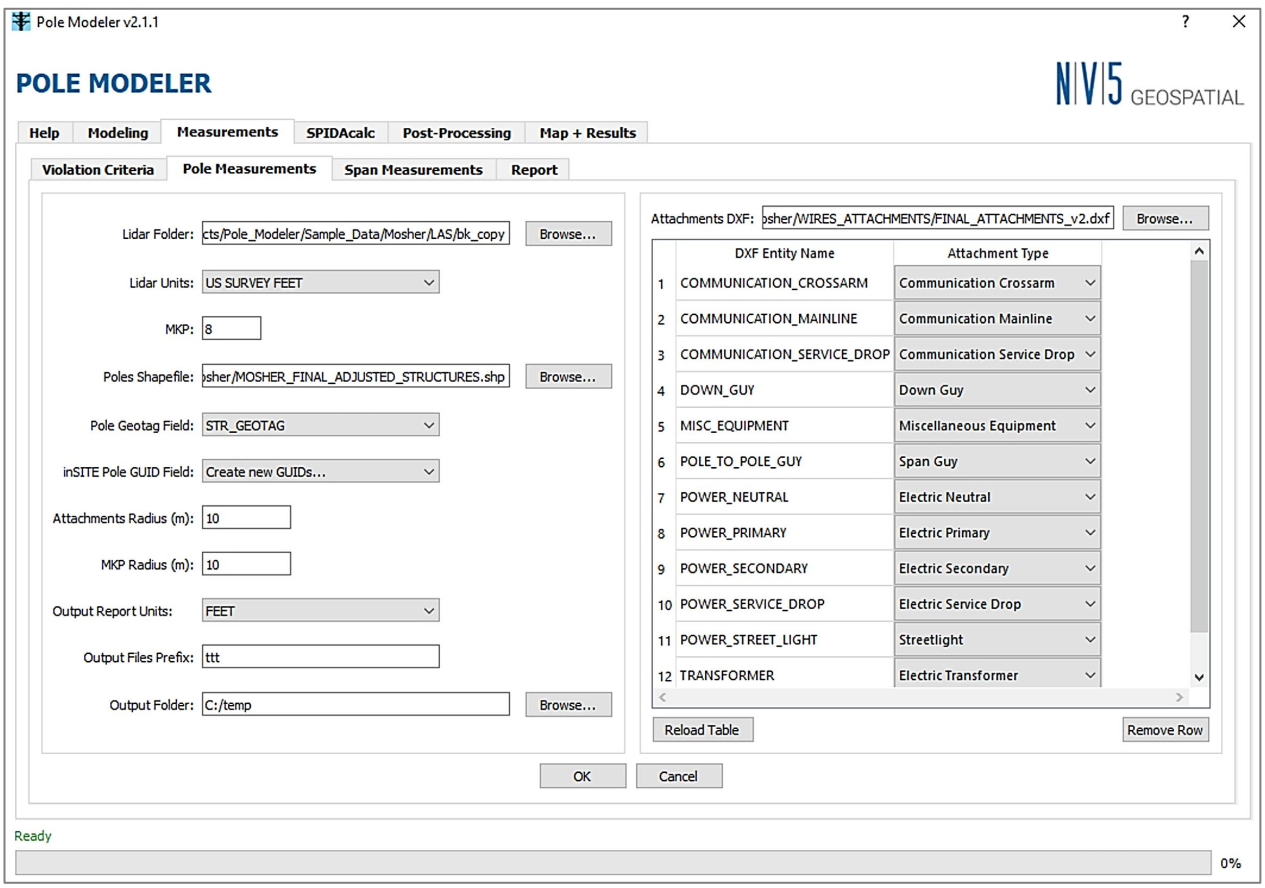

Figure 9 – Pole Measurements Inputs and Outputs

2.4.4. Wire (Span) Measurements

Wire (span) measurements (Table 5 – Wire Measurements) are calculated automatically within Pole Modeler from wire-to-wire or wire-to-ground between them can be completed (Figure 10 – Wire Measurements) and then utilized for clearance violation and pole loading analyses.

Table 5 – Wire Measurements

Wire Measurements
Communication Mainline
Communication Service Drop
Transmission
Primary
Secondary
Neutral
Service Drop
Pole to Pole Guy

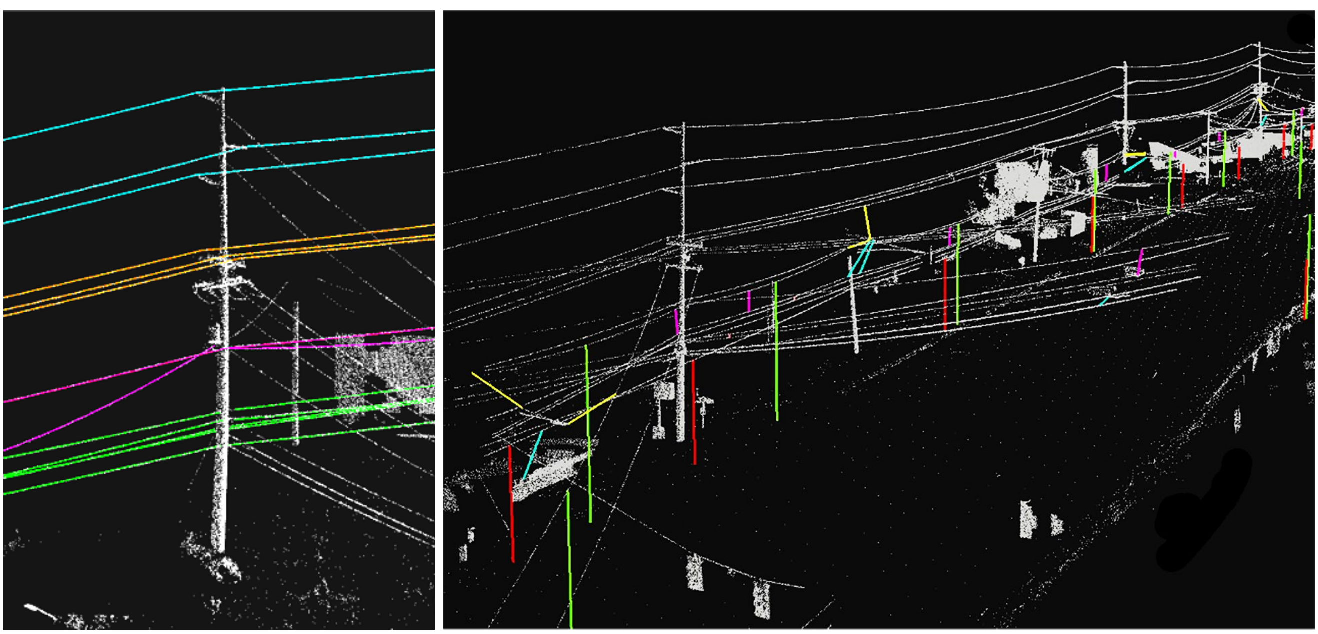

Figure 10 – Wire Measurements

As with pole measurements, several different inputs (Table 6 – Wire Measurement Inputs and Outputs) are required within Pole Modeler to calculate required wire distances. Different parameters (e.g. input and output units, surface type) can be adjusted based on project-specific requirements (Figure 11 – Wire Measurement Inputs and Outputs).

Table 6 – Wire Measurement Inputs and Outputs

Inputs	Outputs
Lidar Ground Model	Measurements between Span Wires
Hard Surface Points (optional)	Heights Above Ground
Span Wires	Minimum Clearances
Pole Locations and Names	Clearance Violations
Span Locations and Names	

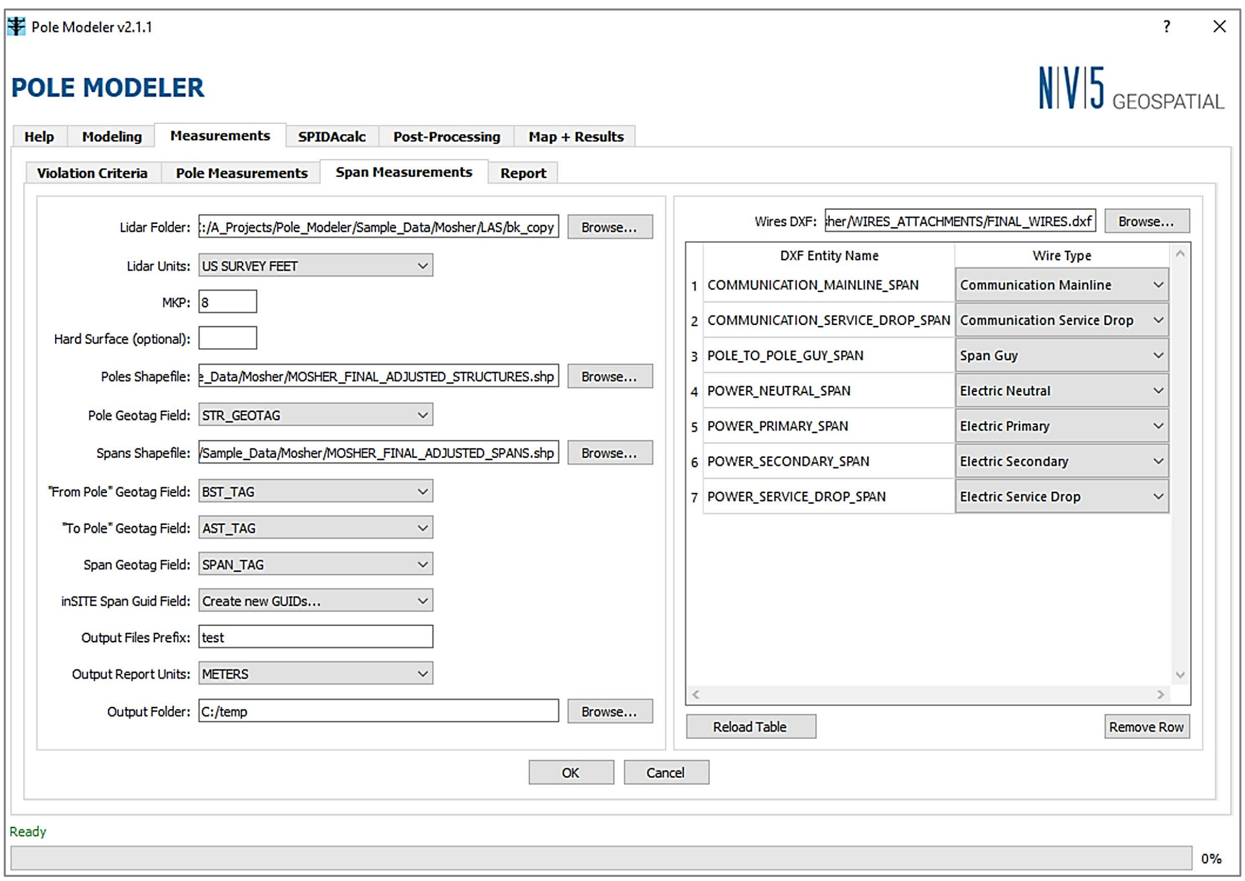

Figure 11 – Wire Measurement Inputs and Outputs

2.4.1. Clearance Violations

Once all the measurements and clearances have been calculated, analysis can be completed to determine if any violations are present. The clearance tool defaults to NESC regulations, but also allows customized clearance configurations (Figure 12 – User Defined Violation Criteria).

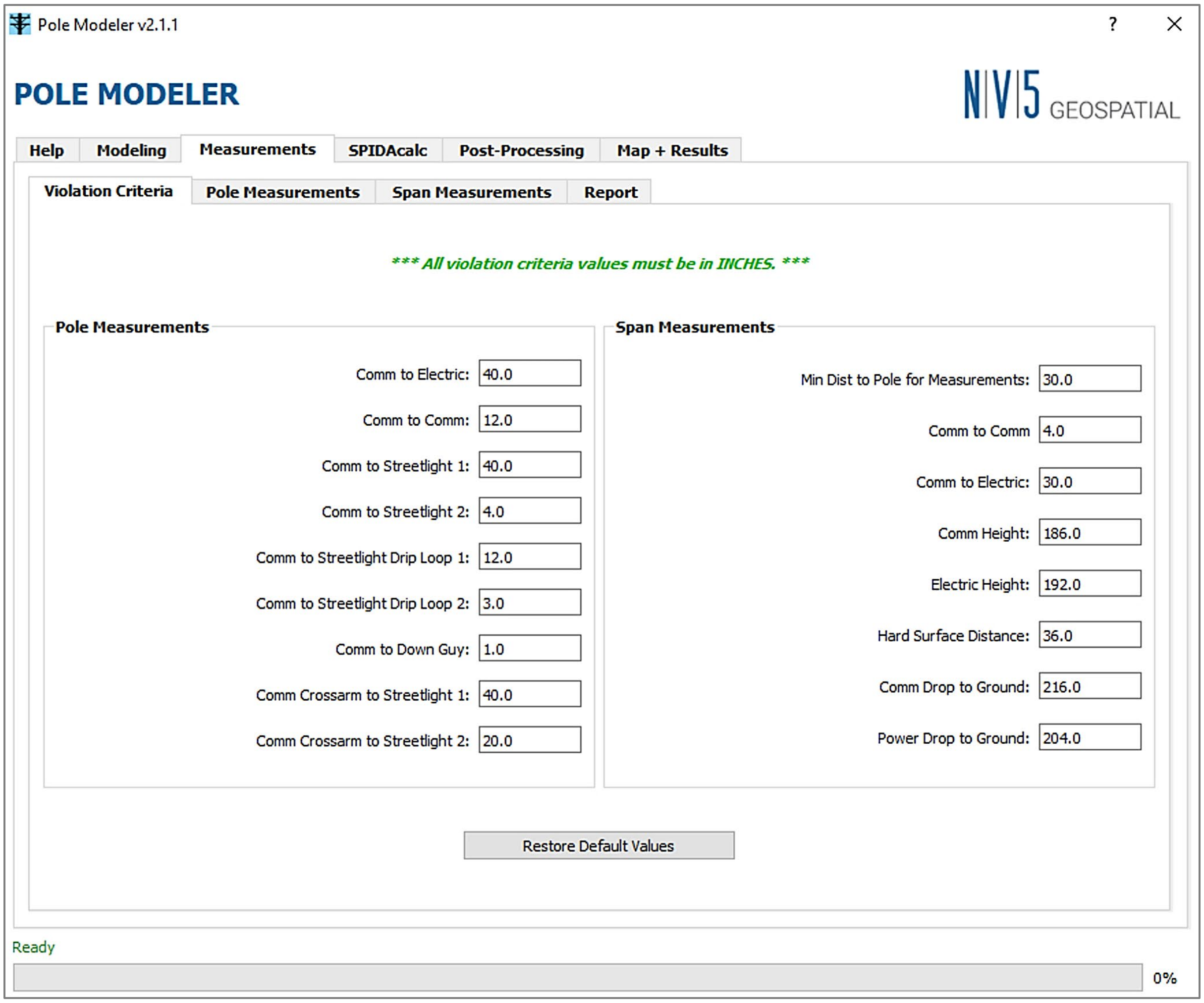

Figure 12 – User-Defined Violation Criteria

2.4.2. SPIDA®calc Integration

Two options are available that can be used to help generate SPIDA®calc files from the modeled asset polylines and their attachment points. The first tool ingests the modeled assets' DXF (drawing interchange format) files, takes dozens of measurements for each asset, assigns their positions on the pole, and connects the wires from span to span. It generates an Excel database with all the information required to build a SPIDA®calc model. The Excel file can easily be edited as part of a quality assurance (QA) or refinement process. For example, the insulator or wire type can be changed, insulator positions can be refined, wires can be connected to one another, etc. Once the Excel database has been deemed acceptable, it is processed by a second tool, which translates that data into a SPIDA®calc JSON (JavaScript object notation) file. During this step, a custom client file can optionally be incorporated into the SPIDA®calc file. It can then be opened and viewed directly within SPIDA®calc (Figure 13 – Pole Models in Pole Loading Software (SPIDA®calc).

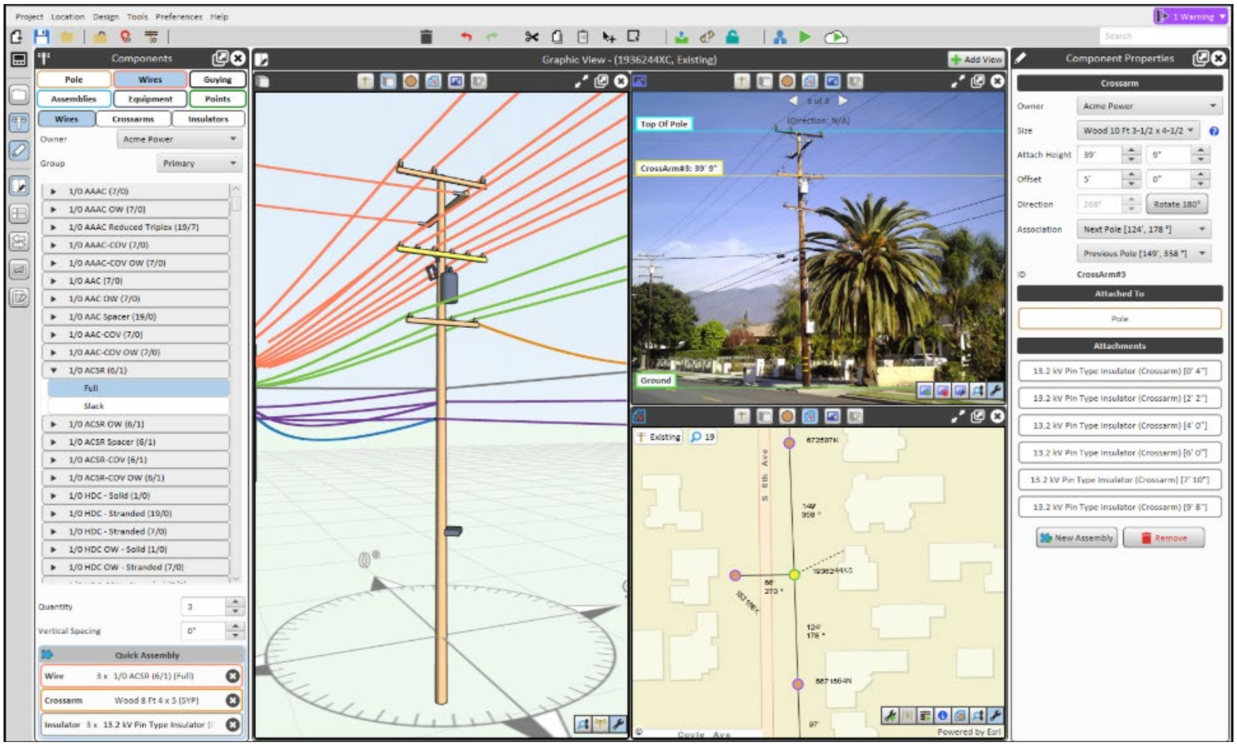

Figure 13 – Pole Models in Pole Loading Software (SPIDA®calc)

2.4.2.1. Additional Asset Extraction via Image Recognition

If, in addition to pole loading and clearance analyses, unique assets need to be identified (telecom panels, splice boxes, power boxes, fuses, switches, etc.), a deep learning object detection model workflow (Figure 14 – Image Recognition Workflow) can be applied to co-acquired spherical images which automatically identifies assets of interest. The image recognition results (Figure 15 – Image Recognition Results View) are quality-controlled and then used to update the geographic information system (GIS). Assets are associated with lidar-rectified poles and spans using lidar depth mapping (when available) or stereo triangulation.

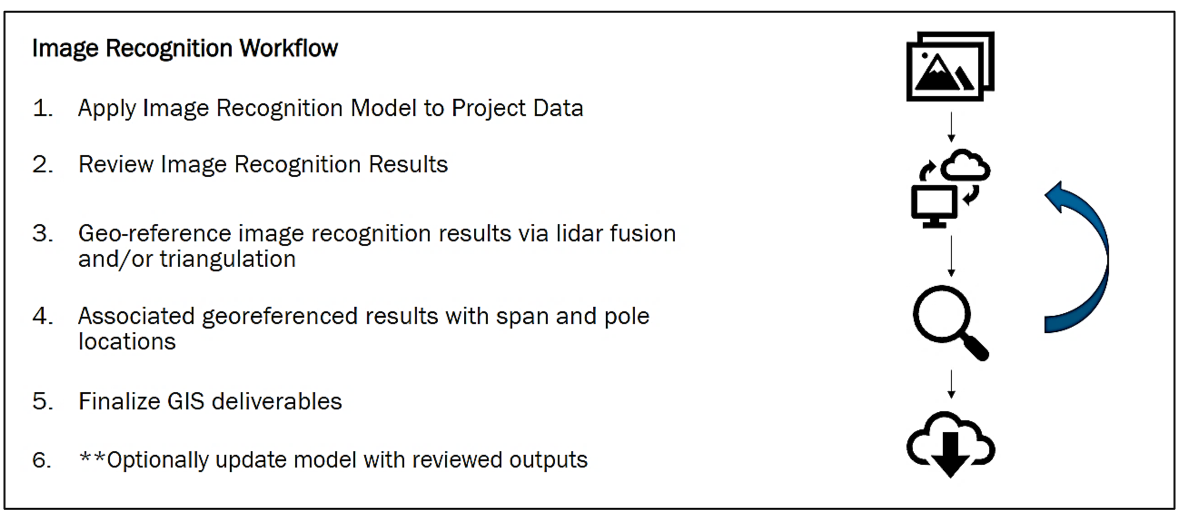

Figure 14 – Image Recognition Workflow

Figure 15 – Image Recognition Results View

The quality-controlled results (Figure 16 – Image Recognition QC Results View) are also leveraged to further fine-tune the object detection model as the project progresses. Continuous improvement of the model on project data allows for locally unique characteristics to be better captured. This continuous improvement results in higher model precision and accelerates throughput over the project.

Figure 16 – Image Recognition QC View

3. Results

An analysis was completed comparing conventional in-situ and remote sensing derived measurements of pole attachment, wire measurements, and clearance distances against in-situ field measurements. The analysis was controlled for inconsistent field measurements (variance >3" between field visits #1 & #2), and other known inaccuracies in the field capture (e.g. inability to access pole due to obstructions such as fences or vegetation). A threshold of 3" was considered an acceptable amount of variance by the Utility for measurements to agree.

To assess the consistency of field measurements, an analysis was done comparing first-visit (field crews) and second-visit (utility engineer present) measures. Twenty-two percent (22%) of field from-ground measurements and twenty-five percent (25%) of field clearance measurements agreed to within 3 inches between visits. This indicates that field measurements are consistent, on average, approximately seventy-seven percent (~77%) of the time.

Using the second-visit field measurements, which were deemed to be truth as they were directed by a utility engineer), an analysis comparing field to lidar-derived measurements was also completed. Here, ninety-seven percent (97%) and ninety percent (90%) of lidar derived from ground and clearance measurements matched field measurements respectively.

Table 7 – Variance of lidar-derived measurements vs. in-situ ground truth measurements

	Variance							
Measurements (from ground)	**Count**	**0”**	**<1”**	**<2”**	**<3”**	**<4”**	**<5”**	**>5”**
Highest Comm Wire	**21**	5	12	4	0	0	0	0
Neutral Wire	**4**	1	1	2	0	0	0	0
Secondary Wire	**12**	4	3	4	1	0	0	0
Secondary Drip Loop	**13**	4	4	3	1	0	0	0
Streetlight	**10**	1	4	5	1	0	0	1
Streetlight Drip Loop	**8**	2	2	3	0	0	0	0
Electrical 4” Riser	**0**	0	0	0	0	0	0	0
Electrical 6” Riser	**0**	0	0	0	0	0	0	0
Total Variance Count	**68**	**17**	**26**	**21**	**2**	**0**	**0**	**1**
Percent Total	**97%**	**25%**	**38%**	**31%**	**3%**	**0%**	**0%**	**1%**
Clearances (between)	**Count**	**0”**	**<1”**	**<2”**	**<3”**	**<4”**	**<5”**	**>5”**
Comm/Electric	**20**	4	7	5	3	0	0	1
Comm/Streetlight	**14**	1	10	1	1	0	0	1
Comm/Streetlight Drip Loop	**11**	5	3	0	1	0	0	0
Total Variance Count	**45**	**10**	**20**	**6**	**5**	**0**	**0**	**2**
Percent Total	**90%**	**22%**	**44%**	**13%**	**11%**	**0%**	**0%**	**4%**

4. Conclusions

To meet the ever-increasing data demands from their clients, RDOF and 5G deployments, cable and telecommunications companies need to expand their networks quickly. The most efficient way, both time and cost-wise, of building this new infrastructure is to utilize existing utility poles. The process of attaching additional fiber and antennas requires adherence to industry regulations aimed at ensuring utility poles are not overloaded and that both utility and telecom networks are reliable and safe. Some of these regulations include an assessment of the distance between different assets that are currently attached to the pole and those wanting to be added. These measurements are conventionally taken in situ by field crews. This project aimed to assess if remote-sensing technologies could achieve comparable measurements, which could potentially expedite the timeline required to obtain approval for additional cable and asset attachments.

Results indicate that comparable measurements can be achieved using lidar data and supporting spherical imagery, with lidar-derived measurements averaging a ninety-three-point five percent (93.5%) agreement with in-situ field measurements. Additionally, inconsistencies inherent in field-derived measurements were also brought to light, with an average of twenty-three-point five percent (23.5%) disagreement between same feature measurements and served to highlight another benefit of utilizing high-accuracy lidar data, that of consistency. As a result, utilities and telecommunications companies will have a high degree of confidence when using remote sensing data that pole loading requirements are being met and a safe and reliable network is being constructed.

While these preliminary results are very encouraging, some of the challenges associated with the use of mobile lidar data, such as back-yard poles that cannot easily be captured from street-based collected, laser penetration impediment by thick vegetation and weather conditions such as precipitation suggest that a combination remote-sensing and focused field-based approach may be the ideal solution that ensures complete network coverage while reducing costs and the time required to obtain the necessary measurements.

To further assess the applicability and efficacy of using mobile lidar and spherical imagery for this application, future analyses can be conducted with telecommunications partners to determine if this workflow results in a reduction in the asset attachment inspection timeline. With data collection currently achieving 40 miles per day and the extent of automation currently utilized in data processing and analysis workflows, the outcome looks quite promising.

Abbreviations

AOI	area of interest
DEM	digital elevation model
DXF	drawing interchange format
EO	exterior orientations
GIS	geographic information system
GNSS/GLONASS	global navigation satellite system/ Globalnaya Navigazionnaya Sputnikovaya Sistema
GPS	global positioning system
IMU	inertial measurement unit
JPEG	Joint Photographic Experts Group (digital image file format)
JSON	JavaScript object notation
lidar	light detection and ranging
MMS	mobile mapping suite
NESC	National Electric Safety Code
NV5G	NV5 Geospatial
PPP	precise point positioning
PPSM	points per square meter
PRF	pulse repetition frequency
PRR	pulse repetition rate
QA	quality assurance
QC	quality control
RGB	red, green, and blue
RTK	real-time kinematic
RDOF	Rural Digital Opportunity Fund
SBET	smoothed best estimate of trajectory
SPIDA®calc	Pole loading program by software company SPIDA

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