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# Inspection Technology for Vegetation Management

*Overview of GeoDigital International LiDAR Inspection Approach*

**3002003573**

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# ABSTRACT

Recent regulatory changes and budgetary pressures by the North American Electric Reliability Council (well recognized as the NERC) have prompted utilities to seek a more in-depth understanding of the terrain along their transmission-line corridor rights-of-way (ROWs) and the vegetation on that terrain. Vegetation inspections play an important role in acquiring this information and in avoiding costly vegetation-related outages. Although the methods by which the inspections are conducted vary from utility to utility, some form of periodic inspection of transmission ROWs is required to manage encroaching vegetation.

Traditional methods of transmission-line vegetation inspection have generally relied on human observation and data recording, whether performed from the ground or by airborne methods. New approaches to vegetation inspection take advantage of sophisticated laser-based technology, recording equipment, global positioning system technology, and specialized software for data analysis.

This report provides an overview of the approach taken by GeoDigital International, as follows:

- Brief overview about light detection and ranging (LiDAR) technology
- Emerging software tools and diagnostic technologies being used to optimize LiDAR data
- How LiDAR data are collected, converted into information, and presented to the utilities
- Application of processed LiDAR data information

The Electric Power Research Institute's intention is to explore other new vegetation inspection technologies or approaches in the future.

### Keywords
Helicopter surveys
Laser surveys and mapping
LiDAR (light detection and ranging)
Transmission line ROW
Vegetation inspections and management
Vegetation vendor/service provider

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# 1
# INTRODUCTION

Traditional methods of transmission-line vegetation inspection have generally relied upon human observation and data recording, whether performed from the ground or using airborne methods. The North American Electric Reliability Council (NERC) regulatory changes and budgetary pressures have prompted utilities to seek improved information of the terrain and vegetation along their transmission-line corridor rights-of-way (ROWs). New approaches to vegetation inspection take advantage of sophisticated recording equipment, global positioning system (GPS) technology, and software. There is interest from electric utilities about these new technologies, how well they work, and the information that they provide.

Recent technological developments with light detection and ranging (LiDAR), particularly data processing, can model and analyze data in new and more efficient ways. This can provide information as to the location of transmission lines and their 3-D relationship to surrounding objects such as vegetation, structures, and other objects.

This report provides information on the application of LiDAR—in particular, LiDAR post-processing techniques, software, and deliverables provided by one vendor/service provider of transmission-line vegetation inspection, that is, GeoDigital International. The information covered includes the following:

- Understanding the use of LiDAR survey and mapping and the information collected and analyzed
- Information on various technologies and sensors used by the vendor
- Description of  software tools and the analysis approach used by the vendor
- Details on the format of data/information provided to the utilities

Information in this report will help the Electric Power Research Institute (EPRI) members better understand how GeoDigital collects LiDAR data, how they are processed, and how they are provided to the utilities.

Note that EPRI does not specifically endorse vendors, and the information provided in this report is for informational purposes only.

# 2
# OVERVIEW OF LIDAR TECHNOLOGY FOR VEGETATION INSPECTION

The Chapter gives a brief overview on Light Detection And Ranging (LiDAR) technology and typical utility requirements.

## LiDAR Technology

LiDAR is an optical remote sensing technology that can be used to determine the distance of a target from the sensor by measuring some of the basic properties of a reflected laser light pulse, such as intensity and timing. LiDAR employs GPS satellites and an inertial navigation system to accurately and continuously record the position of a rotary or fixed wing aircraft while flying along a transmission line ROW with an on board scanning laser. LiDAR systems operate in the near infrared band, emitting high energy pulses that can be realized in short intervals on a narrow optical spectrum. Each pulse sends back a number of reflections, typically two, one from the first object (conductor, tree branch, tower member, etc.) and the other from the last object (typically ground). The position and first and last pulse strike are recorded by on-board equipment. This laser data is the raw data set.

The principle of airborne LiDAR is that laser pulses (up to 150,000+ pulses/sec) aimed toward the ground or ROW are emitted from an aircraft at known times. When light strikes a target on the ground, some of it is scattered while the remaining light energy is reflected back to an aircraft mounted receiver. Target coordinates x, y, and z are calculated using on-board and base-station GPS, derived aircraft location, the speed-of-light constant, and laser-pulse geometry (distance and angle of the pulse). Rapid laser pulsing increases the light's ability to penetrate vegetation and reach the Earth's surface. The collected set of target points for an area is known as "mass points." From selected mass points, derivative products such as topographic contours and digital elevation models (DEM) data can be produced. The accuracy of the DEM derived from LiDAR postings and derived software products is affected by several factors such as sensors, aircraft platform, navigation, LiDAR point processing, and geographic environment.

The reason for laser ranging is to measure distances from the sensor to the ground or the desired feature. By combining all the information gathered, it is possible to derive the 3D co-ordinates of each laser return that can be either from the terrain or objects above it. The collection of more data points may increase the accuracy of terrain or power line models developed from the raw data set.

LiDAR is especially useful in low elevation areas because of its ability to detect small changes in land elevation. It can also provide elevation data for modelling that can be combined with other data information systems such as Geographical Information Systems (GIS) for analysis. LiDAR data can also be integrated with high-resolution orthoimagery.

Raw data points need to be identified or classified to make the information useful. Software packages make this classification easier. However, for best results, the right amount of data is required, as too little data can reduce object classification accuracy or might miss some important information. Too much data can be cumbersome and slow to model. The quality of data is influenced by:

- **Flying Height** – Flying at relatively lower levels can produce high laser point density.
- **Flying Speed** – Higher speed results in a reduced point density.
- **Laser Repetition Rate** – Increasing the rate of laser signals allows for more points to be collected at a fixed flight height.
- **Laser Scan Pattern** – A regular pattern is more likely to pick up various objects.
- **Laser Point Density** – There are various opinions, but approximately 1 point per square foot is considered adequate for most transmission line applications.

### *Usages, Point Densities, and Classifications*

An important aspect of designing a successful LiDAR project is knowing the information you want. It is important to know how the data will be used so that this is clearly communicated to the LiDAR vendor/service provider. Early definition of the data's intended purpose will help avoid spending energy, time and money for data that does not meet an organization's technical and business needs.

Depending on the application, point densities can range from 1 point to 900 points/sq. ft. Users interested in bare-earth information (1 or 2-foot contours) typically require a lower point density. Accuracies as great as 1.2 inch vertical can presently be achieved.

Contour datasets are a common LiDAR deliverable. It's important to understand that contours are derived from the LiDAR bare earth surfaces. As a result, the contour vector lines developed from LiDAR data are only as accurate as the input data used to define the contours, so density and accuracy of the LiDAR bare earth points are what should be considered when defining the accuracy and interval of the contour delivery.

For years, LiDAR data were delivered as a bare earth DEM in ASCII format. However, LiDAR derived products contain much more information than just the bare earth points.

## Influencing Factors on Quality of LiDAR Data

Ground and environmental conditions such as fog, smoke, fog and rain during LiDAR acquisition can affect the quality of the final product. Additionally, snow on the ground or a large amount of standing water (flooding) can affect the data quality because LiDAR data reflects well off snow, therby biasing the ground elevation. Whilst standing water causes significant issues for LiDAR, as most standing water will not reflect the laser pulses well.

Outside of ground conditions dictated by weather, vegetation can also be a concern. LiDAR doesn't penetrate vegetation; however, LiDAR data can filter to the ground through the vegetation as long as there is light below the tree canopy.

## Data Processing and Information Derived LiDAR [1]

LiDAR surveys coupled with high resolution oblique and downward imagery can provide information on transmission lines and their facilities such as ROW data, and the location of towers, vegetation, buildings and roads. Additionally, LiDAR surveys can provide accurate 3-D information on power lines such as catenary sags, pylon center lines, cable fixations and attachment points. When coupled with appropriate software, this allows for cross and longitudinal sections created from the imagery and high-density point clouds that allow clearances to vegetation, ground and structures to be determined with an accuracy of a few inches.

Aerial LiDAR systems optimized for transmission line surveys typically generate LiDAR data point clouds, color and near infrared (NIR) image data while associated systems collect information on the line, weather and current loading. This data is then processed into true-orthographic images, and digital elevation models (DEM) or digital surface models (DSM) in common file formats usable by common computer-aided design (CAD) or geographic information systems (GIS). With this data, individual transmission lines can be modeled in 3-D and the sag of the line predicted when operating at maximum load under various weather conditions. This allows transmission line conductor clearances to vegetation and other objects to be predicted with accuracy.

Current commercial LiDAR processing software does not provide one filter for all terrains, vegetation, buildings or other man-made structures. For this reason, after automated filtering, human editing typically is required to ensure all the data anomalies have been removed or corrected. This manual processing and quality assurance ultimately dictates the speed at which accurate data can be provided to the client. It is the art of data processing and the ability to add value to the information that ensures customers obtain what they need. Thus, it is the data processing that is most critical in creating final client LiDAR product and deliverables

## Typical Utility's LiDAR Vegetation Inspection Survey Requirements

LiDAR technology has been available for commercial mapping applications for about 20 years, which has evolved to provide evaluation models using a rapid and accurate data acquisition. LiDAR's adoption across a number of geospatial organizations, improved data analysis, and data presentation has increased the need for utility education about this technology and how it can be specifically applied for vegetation inspections of transmission line corridors or ROW.

Examples of typical electrical utility's LiDAR survey vegetation inspection requirements can include:

- Identify specific vegetation clearances areas and vegetation volume
- Tree counts, volumes, biomass vegetation height classification, carbon stocks, etc.
- LiDAR plus imagery for fire fuel, tree health modelling, etc.
- Vegetation encroachment violations
- Vegetation change detection
- Identify dead or alive trees
- Slope elevation for site accessibility

- Improved information to prepare more accurate RFPs for contractor related work
- Identify, cut/trim, and track vegetation management
- Work scheduling of vegetation management
- Permits for vegetation trimming on neighboring non-utility or private property
- Audit of work performed or completed
- Identify other structures, objects, roads, watersheds, etc. in the utility's ROW and outside their ROW into private property
- Lower the utility's budget to only cut down or trim vegetation in the highest category
- Identify areas that are prone to wild fires
- Identify erosion areas near transmission structures
- Reporting for NERC FAC-003 compliance
- Customized detection reports in shp,.dxf, .kmz file formats
- Specific LiDAR point densities for vegetation surveys
- Indentify specific dates or time of year to optimize inspections

In addition to the vegetation inspections and follow-up vegetation management activities, utilities are also typically interested in engineering related aspects listed below. It should be noted that these engineering topics is **not** the focus of this report:

- Thermal line ratings
- Thermal analysis for conductor sag and sway calculations verification
- Height of towers and conductors
- Tower alignments
- Damage or destruction to transmission line components:
  - Towers or poles
  - Crossarms and cross-braces
  - Insulator strings
  - Conductors and accessories
  - Switches
  - Broken or missing guy wires and anchors
  - Missing aerial markers and FAA warnings
  - Missing structure numbers, or incorrectly numbered structures, etc.
- Mapping for future transmission lines construction
- Construction permits
- Asset mapping and management, etc.

# 3
# GEODIGITAL INTERNATIONAL LIDAR SURVEY METHODOLOGY AND DELIVERABLES

This Chapter summarizes an investigation into a laser survey mapping vendor/service provider (GeoDigital International) as to their methodology, field data collection, analysis and information made available to utilities for LiDAR based vegetation inspections and follow-up management. Engineering related analysis and deliverables in this chapter are provided for informational purposes only. This investigation includes the following pertaining only to GeoDigital International (GDI) and their LiDAR based vegetation inspection, and data processing and analysis capabilities:

- Data Acquisition and Processing
- Data Modeling and Analysis
- Vegetation Quantification
- Vegetation Management Software
- Data Hosting and Visualization
- Precision Corridor Management (PCM)

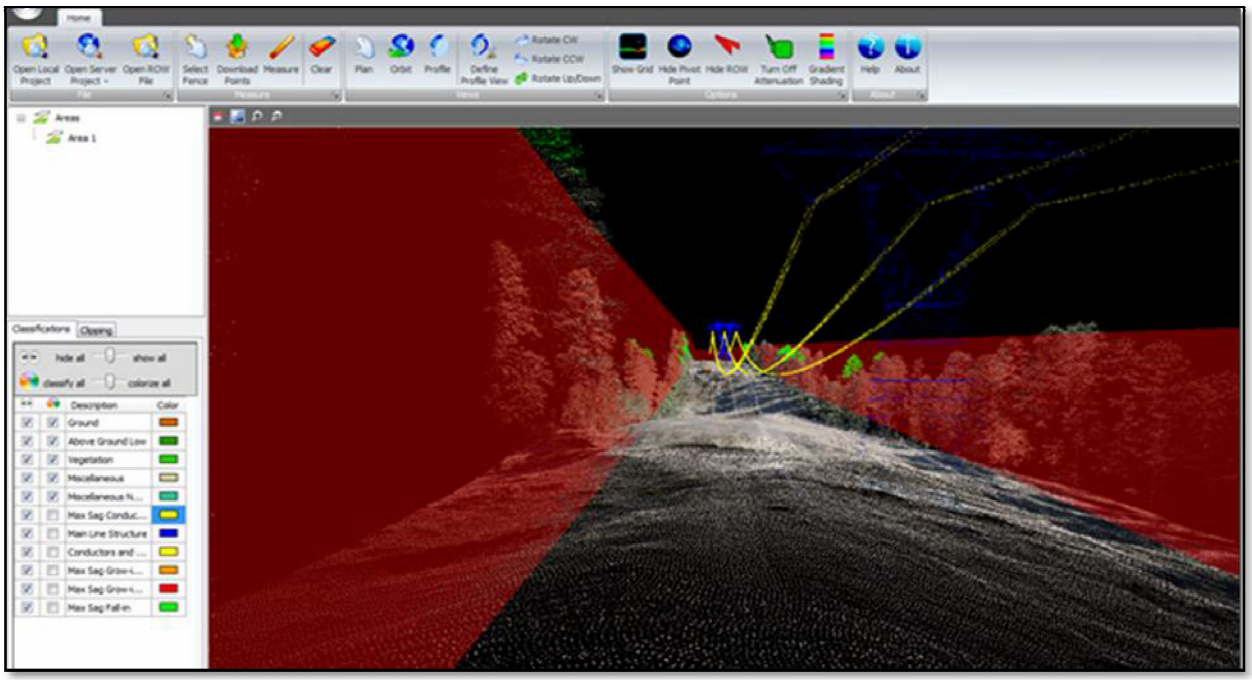


**Figure 3-1**
**Example of vegetation corridor or ROW encroachment for follow-up vegetation management [8]**

## Technical Approach – Data Acquisition and Processing [3, 4, 5]

Airborne LiDAR is typically mounted in a helicopter. Due to the maneuverability of a helicopter and its ability to fly slower and lower in elevation, linear features such as transmission lines can be followed with ease.

Helicopter-mounted LiDAR technology can collect data up to 200 miles in a single day and typically average 50-70 miles per day during a project including weather and mobilization to the site. By completing sections of LiDAR data collection in less time, changes in sag and variations in environmental conditions are minimized during the time of the survey. LiDAR, orthographic and oblique imagery, video (if requested) and weather data are typically captured during the data acquisition phase of a project.

### *Data Capture Platform*

This vendor has developed a data capture platform it calls Transmission Corridor Observation and Reporting or TCOR. The TCOR acquisition system deliverables include a 3D high-resolution visual inspection of a utility's assets accessible on a computer. The TCOR data acquisition system allows for the generation of high resolution LiDAR data, ortho imagery and high resolution oblique images of every inch of the transmission line corridor. The TCOR system utilizes a Gimbal platform which corrects for the movement of the helicopter and provides coverage of the ROW that leads to consistent, higher density LiDAR point coverage and images.



**Figure 3-2**
**TCOR data capture platform [8]**

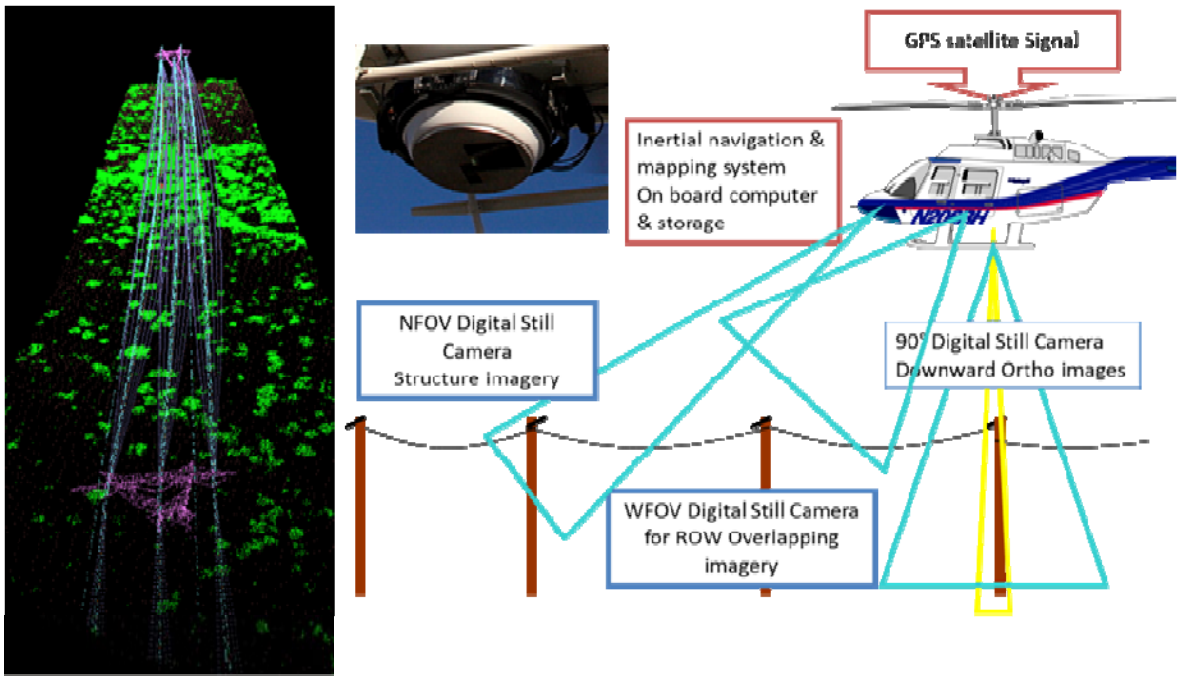



**Figure 3-3**
**Diagram of transmission corridor observation and reporting (TCOR) acquisition system [8]**

### *Calibration and Quality Control in the Field*

Upon mobilization and before commencing survey operations, the vendors Transmission Corridor Observation & Reporting (TCOR) survey systems are calibrated. Calibration is performed by the comparison of pre-surveyed coordinates of recognizable ground objects with the respective measurements acquired by the airborne sensors. Within the project area, one or more buildings are surveyed using GPS, establishing points on the edges and corners, and of the area of the surrounding land. A separate calibration site using cooperative targets is also established and located near the survey or staging area, so that before and after each survey program the aircraft flies over this calibration site. A surveyor formally surveys this calibration site and the LiDAR and photogrammetric coordinate results are used to demonstrate that the desired geodetic survey accuracy is being achieved. Data from this site is acquired and processed periodically during larger programs to confirm that the system continues to operate within specification to ensure consistency in the collected data.

As an additional accuracy control measure, they select a number of locations within the survey area where the survey team will conduct independent kinematic GPS survey measurements for comparison with the LiDAR data, commonly referred to as Ground Truth Points (GTPs). Features that can be easily identified in the LiDAR data are surveyed, such as roads, buildings, etc. using conventional ground survey techniques and are included in a survey report for the project.

Using onboard survey equipment and a GPS based guidance system; the airborne operator monitors the quality and consistency of the data being acquired by following prescribed quality control procedures. In the event that the operator detects a gap in GPS coverage or unacceptable quality of data, the crew re-flies the section of the route that is suspect to ensure complete coverage.

After each survey flight, the ground crew conducts preliminary processing of the collected data and performs both automatic and manual quality control tasks.

Quality parameters checked include:

- Survey area coverage
- Accuracy of measurements
- Density of points
- Sufficiency of laser reflections from conductors and other elements
- Density of measurements under vegetation cover
- Quality of aerial still imagery, its overlap, resolution

All quality control procedures are documented. Quality monitoring occurs on-site within 12-24 hours of the flight, and the re-acquisition of any missed or sub-standard data occurs before departing to other survey areas. This ensures the vendors full compliance with utility-defined data specifications. Quality control is an ongoing process throughout the survey operation.

### *LiDAR Point Density*

LiDAR systems such as the Riegl Q560 and Q380 waveform LiDAR's are used by this vendor. The systems operate with pulse rates of between 100 kHz and 500 kHz and are designed to discriminate multiple returns from each outgoing laser pulse often recording 4-5 or more returns for each emitted pulse (Figure 3-4). This allows the system to simultaneously detect reflections from conductors and other power line elements, such as, under-build, various levels of the vegetation canopy and terrain.

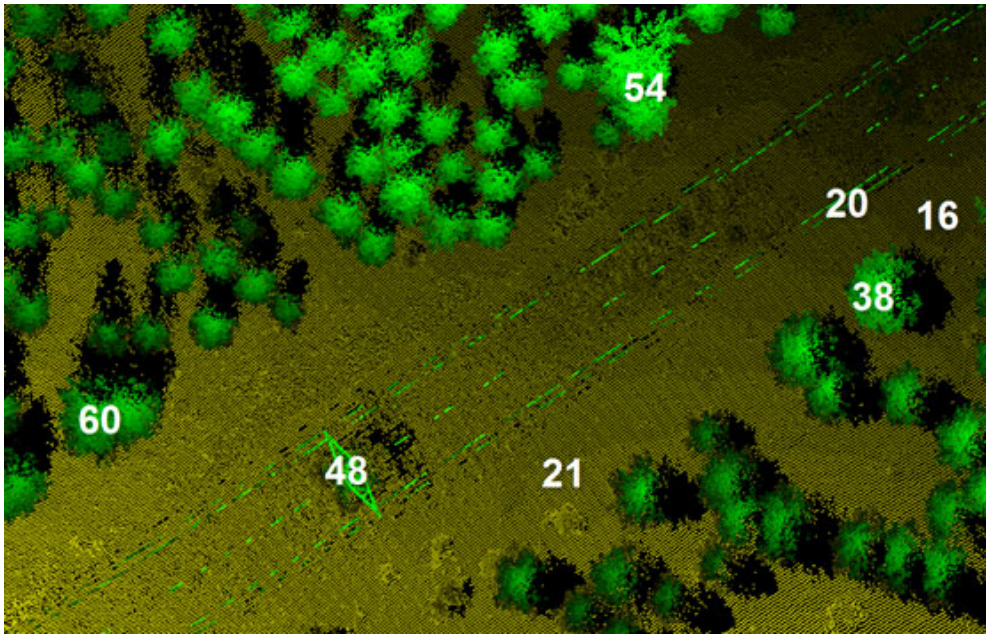



**Figure 3-4**
**Example of LiDAR point density variations with scene structure increasing from 20 to >60 points per sq m [8]**

By recording multiple reflections the point density achieved will vary from approximately 20 per square meter on open flat ground. This provides increased detail where needed and less where it is not, optimizing the total volume of data that must be recorded and processed. The detection and recording of multiple returns by a waveform recording laser is provides the ability to identify and measure the position of conductors and other elements of power transmission lines such as under-build, map low level vegetation the land surface under vegetation, and discriminate vertical structure within trees necessary to support vegetation encroachment analysis and attribution (Figure 3-5).

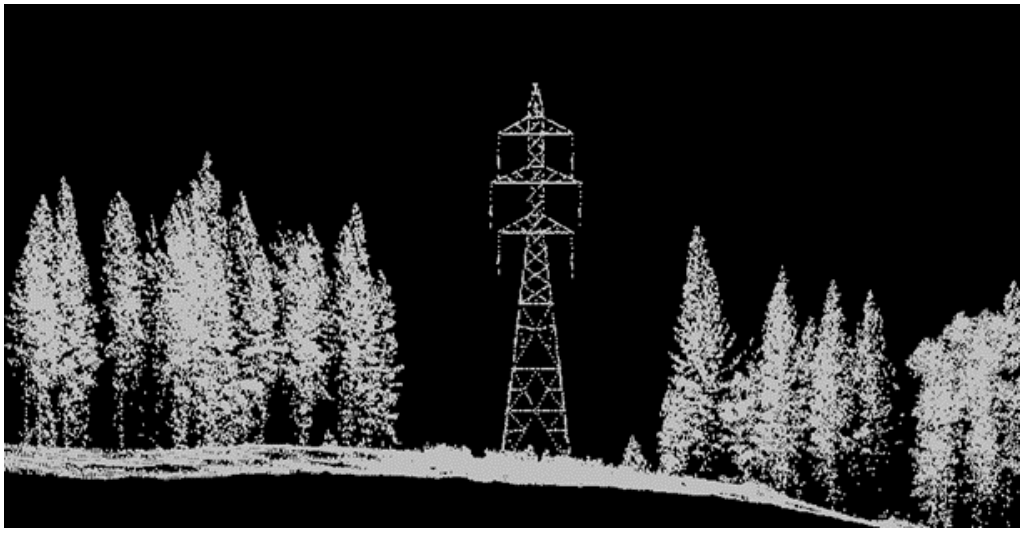


**Figure 3-5**
**Example showing increased detailed by recording multiple reflections [8]**

### *Survey Accuracy*

For vegetation surveys, control methods using Precise Point Positioning (PPP) or equivalent method allow LiDAR data to be delivered to utilities with between 0.5 ft. and 0.75 ft. horizontal and vertical positional accuracies and 2 in.–3 in. relative (point to point) accuracies while providing the overall value as compared to GPS base stations. To further refine the accuracy, this vendor has created operational procedures and Ground Truth Point (GTP) techniques to further enhance the accuracy and consistency of the survey result.

### *Airborne Data Probe*

This vendor participated in a 2011 EPRI study comparing the results from their Airborne data Probe (ADP) with actual measured conductor temperatures [2]. This proprietary approach to the use of the airborne data probe allows the vendor to deliver weather data to clients without the use of field stations beyond local airport and other scientific weather reporting stations.

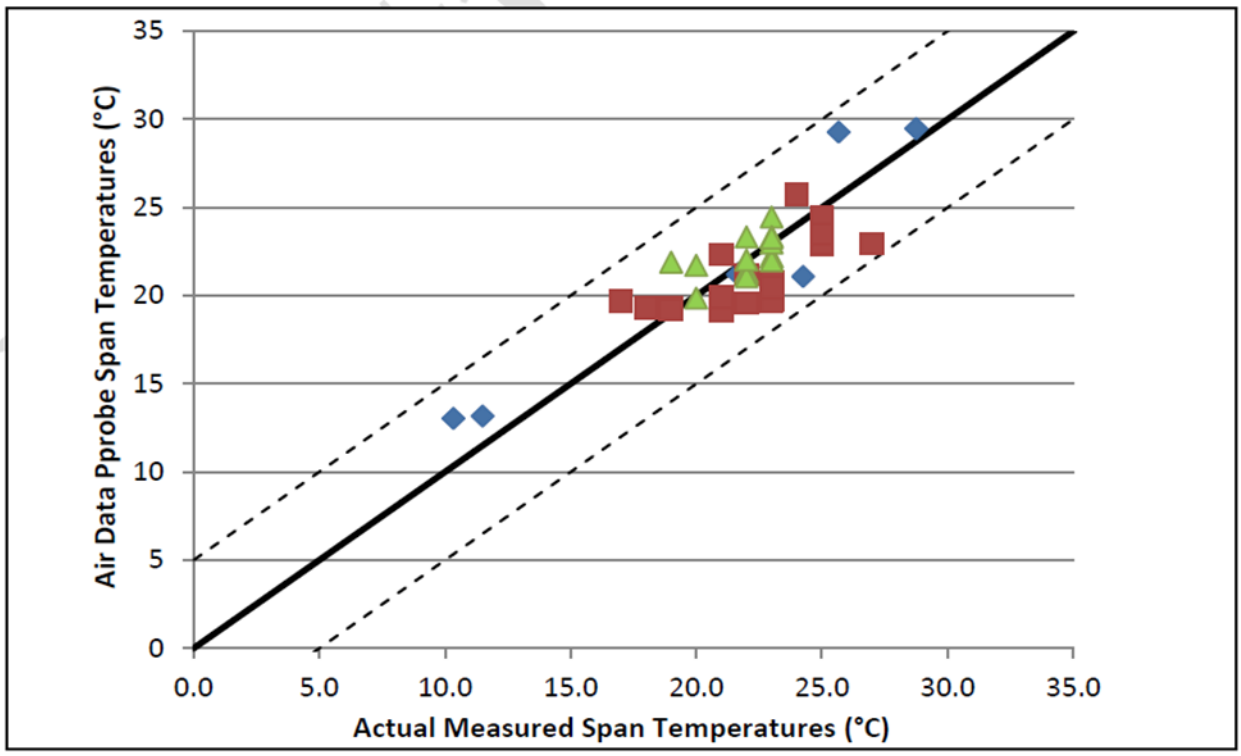



**Figure 3-6**
**EPRI study comparing ADP with measured conductor temperatures for different lines**

## Processing of Data

Data deliverables vary with utility requirements and whether requested by vegetation management, engineering, asset management, or all of the above. Typical deliverables include:

- Vegetation clearance analysis
- Feature coded LiDAR data
- Stick and wire models (ready for use in PLS-CADD)
- Digital terrain models
- Thematic mapping of geographic features
- Digital structure images
- Ortho-photography and ROW imagery

To provide these deliverables, the acquired LiDAR data typically undergoes two main stages of data reduction: pre-processing and thematic processing. Pre-processing involves downloading raw LiDAR data and preparing to extract the information provided by individual subcomponents. To achieve this, they combine GPS data from the reference stations with satellite correction information and the airborne GPS receiver to produce a smoothed trajectory file that includes a continuous record *of* roll, pitch, and heading of the aircraft. Next, they merge laser range and angle data with the smoothed trajectory and calculate the 3D position of each range measurement in a real-world coordinate system. Before delivery, they typically convert the results into a customer specified local coordinate system using industry standard transformation techniques. At this stage of processing, which typically takes place in the field, the LiDAR imagery is reviewed to ensure full coverage of the desired right of way, and various quality control checks are performed to ensure the accuracy and coverage is as required by the customer specifications.

Having undergone pre-processing, the acquired LiDAR data is then forwarded to the data processing group for further thematic processing. The methods of LiDAR data thematic processing are organized so that every stage is followed by both automatic and manual quality control operations.

The initial step is post survey filtering. This is an automatic data classification process, during which all laser reflection points are identified according to various filtering algorithms which tag them as being reflected from the ground surface or from other types of objects (conductors, towers, vegetation, buildings, etc.).

The next stage includes specification of power line parameters utilizing proprietary software that expedites the creation of the PLS-CADD model files:

- Calculation of the coordinates of tower base points and specifying tower base elevations
- Creation of structure centroid
- Approximation of conductors
- Calculation of X, Y, Z coordinates for conductor attachment points
- Obtaining coordinates of the insulator attachment points

When desired, the initial feature coding can be extended to allow the classification, using utility defined feature codes, of all visible features that might be desired for inclusion in engineering models, plan and profile sheets or other CAD data files. Selection and identification of reflections from the ground surface, objects, and vegetation, is performed using a manually supervised, custom application program that runs as a Bentley Microstation application.

The LiDAR analyst, referring to the digital imagery to identify specific objects, manually classifies points and trains the supervised computer classification of the 3D digital cloud xyz data generated from the laser reflection points (Figure 3-7).

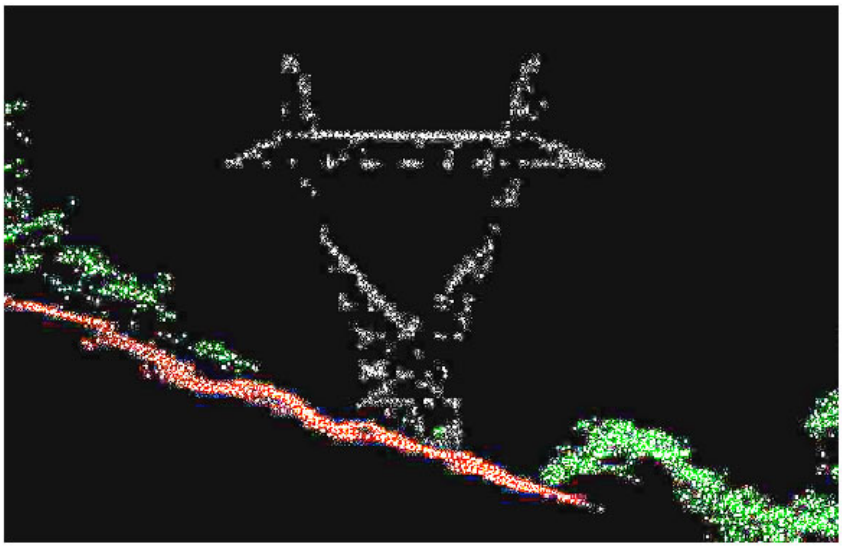


**Figure 3-7**
**Example of classified LiDAR data sowing vegetation, ground points and tower structure [8]**

The LiDAR analyst, refers to the digital imagery to identify specific objects, manually classifies points and trains the supervised computer classification of the 3D digital cloud xyz data generated from the laser reflection points.

On the basis of the classified LiDAR data, the vendor is then able to create, when requested, 3D vector models of objects, and PLS-CADD XYZ, DXF and or DGN files containing polylines and contours of all objects. The files are used to store planimetric line work and can be directly read by GIS and CAD software. Points that fall within the boundaries of particular contours are attributed (feature coded) to corresponding classes of objects.

Points reflected from each power line, ground surface and adjacent objects receive specific feature codes often unique to each customer. Feature code lists can also be customized with the client to address specific requirements or optimize costs related to this process which requires significant manual supervision if high accuracy is required.

The coordinates of points that were separated (feature-coded) into different classes of objects are stored either as ASCII files readable by GIS and CAD-based software or exported as LAS files consistent with any of the current or legacy LAS specifications. Ground point files are when requested “intelligently” thinned based upon industry standard algorithms that estimate, using the LiDAR data, local slope. The point density is then thinned in each region based upon the local slope such that fewer points are retained in flat areas while a greater point density is retained in areas with changes in terrain. This is contrasted against the typical methodology of simply picking every 10th point. This methodology optimizes the terrain detail retained while reducing the total number of points in the final data file. ASCII / LAS files, ortho-photos and DXF/DGN files are then compiled into sets for each power line, and typically delivered ready for use in PLS-CADD, as a PLS-CADD *.BAK file.

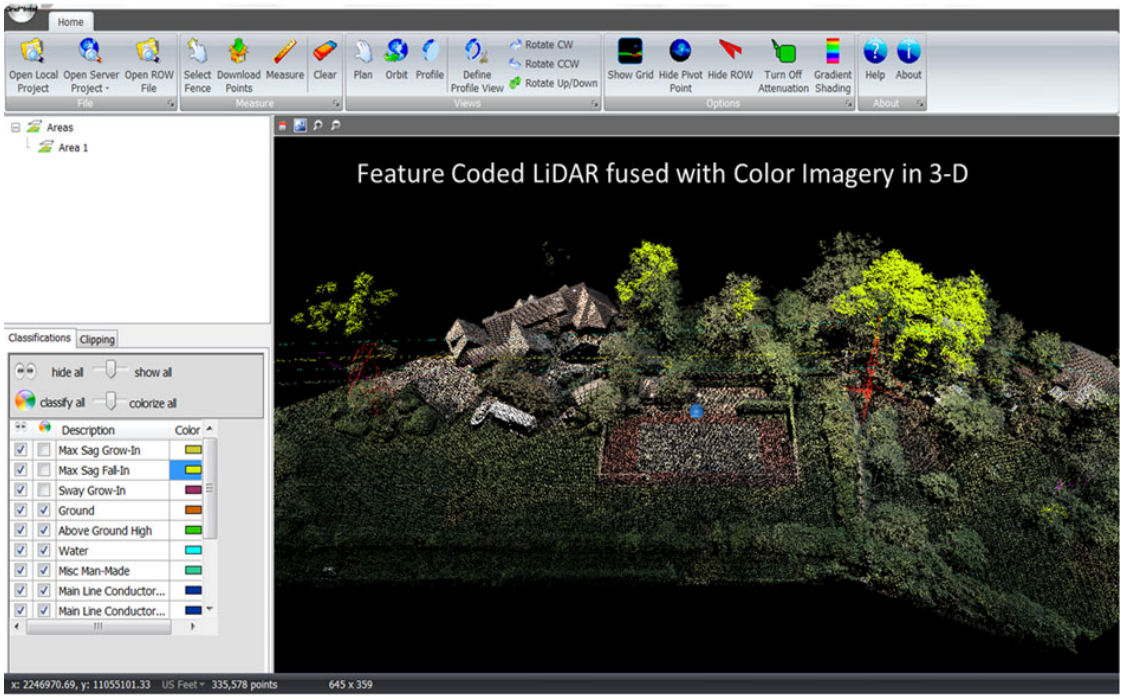



**Figure 3-8**
**Example of LiDAR combined with color imagery in 3D [8]**

### *Digital Color Ortho Photography*

Color and IR imagery are typically requested deliverables and they can be acquired for the same corridor width as the LiDAR, providing full coverage of all trees and vegetation that are likely to represent a hazard to the power lines (Figure 3-9).



**Figure 3-9**
**Example of ortho-photo strip mosaic [8]**

To achieve this the vendor provides the client with an ortho-photo generated by a high resolution downward looking digital camera integrated into the TCOR ALS system that is capable of providing color imagery. The acquired images are then processed with the LiDAR terrain data to produce a mosaic that eliminates the distortions caused by the camera lenses, variations in terrain elevation, and perspective geometry. This ortho-rectification process allows the vendor to achieve a high degree of accuracy. The accuracy of the final ortho-photo is affected by several factors: photo scale, ground control, camera characteristics, and the elevation model used to ortho-rectify the image.

Because the digital color image is acquired simultaneously with the LiDAR data, it is possible to fully rectify the imagery and to accurately superimpose the LiDAR data on each individual image pixel. This allows the vendor to determine the coordinates of each point to a higher degree of accuracy than possible with a conventional film or digital camera. The resulting images are high quality and accurate but otherwise indistinguishable from conventional ortho images.

The area covered by the ortho-photos will correspond to the desired width of the survey swath specified by the utility. Individual images are merged together to cover the whole power line right of way in a continuous strip and can be delivered in standard formats (e.g. GeoTIFF, JPEG, or ECW file formats). Individual image blocks when delivered as *.tiff and *.tfw files are sized to meet utility needs with any borders set to a “clean” white background level of 255 to ensure pure transparency – file sizes are typically required to be less than 350Mb for *.tiff files and less than 5 megabytes for ECW files for ease of handling in PLS-CADD. Index files are created for deliverable imagery in an *.dgn format for use in PLS-CADD or other software programs.

The procedures implemented by this vendor require them to validate the camera calibration before every survey. For the digital system this is achieved by acquiring images of the LiDAR calibration targets in flight while validating the calibration of the LiDAR system. Typical accuracy of geographic references within an ortho-photo mosaic for power line surveys is better than half a foot. The resolution of ortho-photos depends on the camera characteristics and the flying height of the aircraft. The lower the aircraft flies the higher is the resolution of the ortho-photos and the narrower the survey swath. Typical resolution of ortho-photo images produced by the TCOR system for power line surveys is 2–4 inches.

### *Oblique Structure Images/Video*

It is typical that utilities and power line engineering firms request high-resolution images of the right of way and structures as they greatly assist them in identifying vegetation species types and the various types of wire crossings, encroachments, and other contextual information Figure 3-10). Conventional commercial LiDAR sensors typically do not incorporate high resolution digital image sensors that are capable of producing high-quality oblique imagery.



**Figure 3-10**
**Example of high resolution imagery provided to the vendor [8]**

The vendors TCOR systems have the ability to facilitate the acquisition of continuous overlapping high-resolution (16–28 megapixels) digital imagery of the right of way and structures during the same flight pass as the LiDAR data and ortho photography. This is accomplished using two oblique cameras where one is in portrait mode with a zoom lens to acquire the best structure images and the second is in landscape mode with a wide angle lens to acquire the best right of way images. The right of way oblique images are acquired as sequential overlapping images at frame rates up to 5 frames per second, which can then be played in the firms viewers as a pseudo-video. In other words, the pseudo-video is played at less than 30fps, but with high quality frames. For example, traditional video typically resulted in frames that are approximately 640 × 480 pixels compared to an 11MP camera, which has approximately 4000 × 2500 pixels.

By using this technology, the TCOR systems are able to produce an enhanced (close up) image of each tower for inclusion in the PLS-CADD files or in a stand-alone GIS database together with a HD quality “pseudo-video” view of the entire ROW, that can be paused to display a still image that does not contain an image blur and interlace artefacts. The tower image is typically displayed with the tower occupying the majority of the frame to maximize detail. All imagery is directly accessible from PLS-CADD using the Powerline Systems approved viewer integrated into and accessible from the PLS-CADD main menu.

When flown at a typical operating height of 250–500 feet with a 30 degree depression angle from horizontal, the forward oblique camera will generate imagery with a resolution of approximately 25 mm (1 inch) and is adequate to allow the identification of a number of structure defects or faults.

The system captures imagery for every foot of the right of way in an oblique mode rather than just providing images of the structures. This can often eliminate field excursions to identify wires, objects, or other small features that are typically not identifiable in video images or that are located between towers (Figure 3-11).

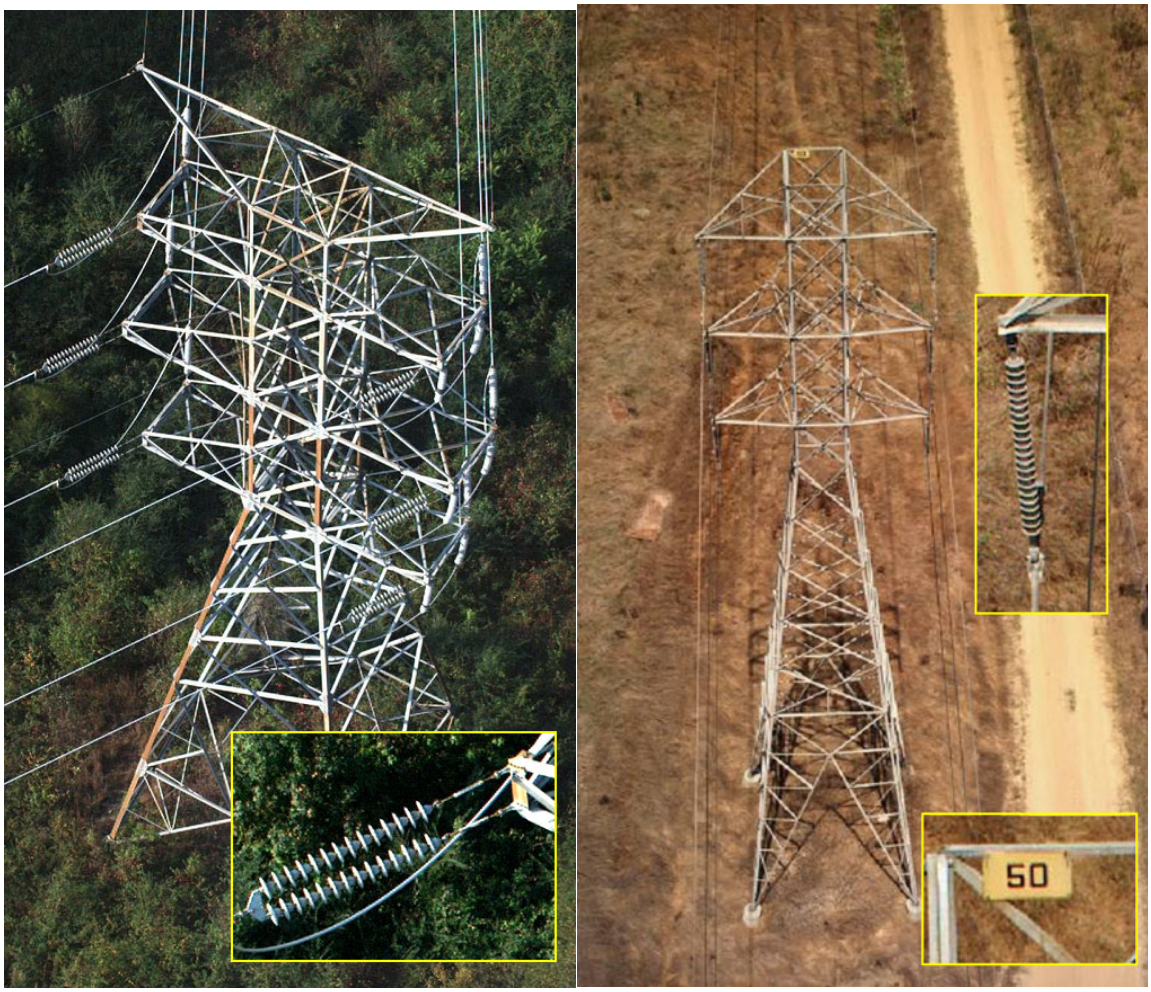



**Figure 3-11**
**Examples of tower image with conductor detail (left) and tower image with structure number (right) [8]**

## Technical Approach – Data Modeling and Analysis

### *PLS-CADD Modeling*

The process steps in modeling are standard to generating any PLS-CADD deliverables. First the utility specified feature code file (NESC clearances), criteria file and fully featured coded LiDAR data is imported into PLS-CADD and a 3D tin model is created based on the ground feature classes. A centerline alignment is then created by visually establishing PI (point of intersection) at the center of each structure location based on the specified alignment direction. PLS-CADD method 1 stick structures (Figure 3-12 and 3-13) with adjusted insulator lengths are created and spotted at each existing structure location. The vendor's standard set convention is used unless utility specified. The structure types (deadend/suspension) are matched to the existing structure LiDAR and cable attachment points defining all tension sections in the circuit based on utility specified accuracy. The existing PLS-CADD conductor cable types are strung and snapped to the as-surveyed catenary LiDAR thus defining the as-surveyed cable span tensions. An IEEE-738-2006 conductor temperature study is conducted based on the span for span as-surveyed meteo data (ADP), solar conditions and matched with client line load time

stamp. The cables are then sagged to Creep FE (finite element). Interpolated points along centerline and side profiles can be generated. Orthos, oblique's (attached in staking table), planimetric DXF's, and plan and profile template sheet will be attached for display of properly displayed scaled plan and profile sheets.

PLS-CADD bak file will be generated along with all client specified outputs.

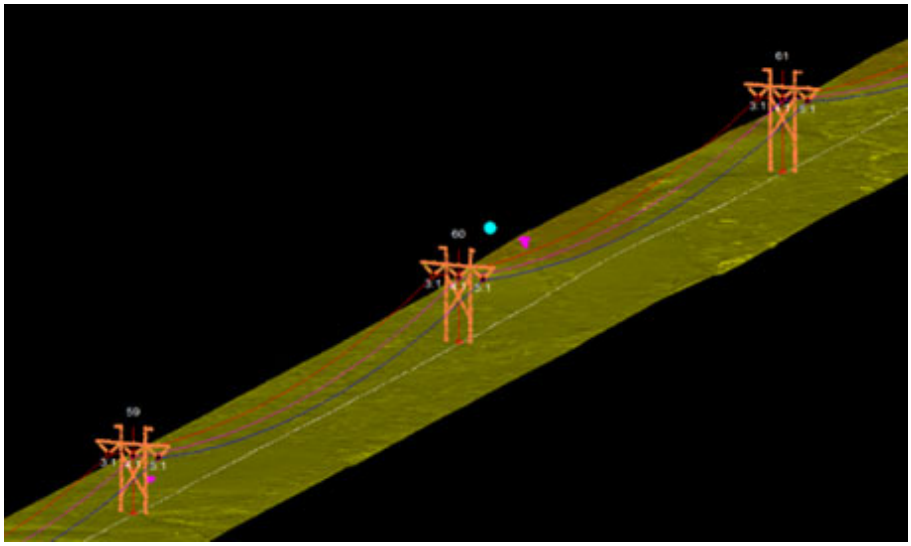


**Figure 3-12**
**Center alignment with Method 1 stick structure [8]**

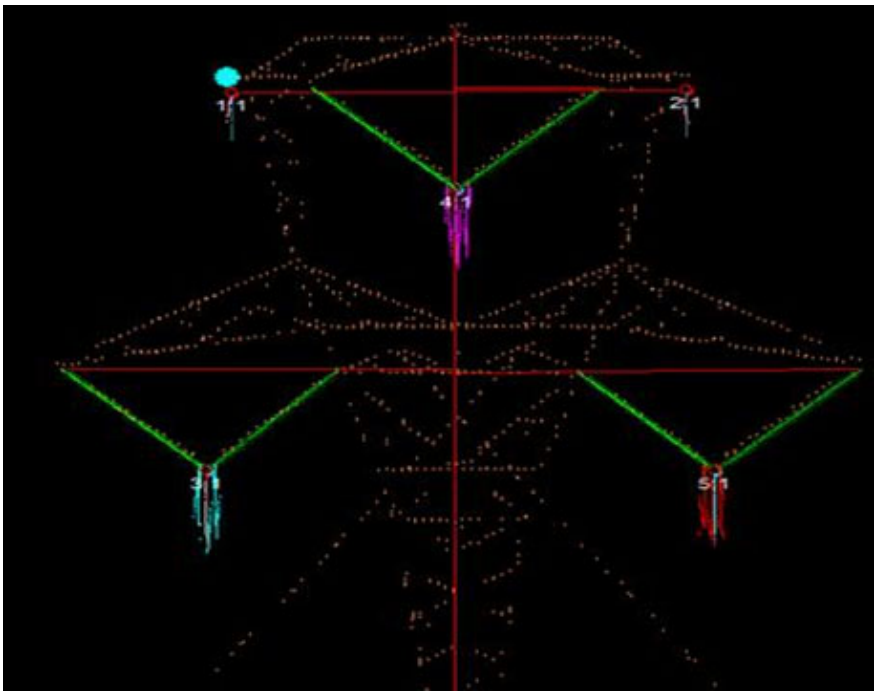


**Figure 3-13**
**Example of Method 1 stick structure V-string insulator [8]**

### *Reports*

Thermal Rating and Danger Tree reports will be run based on utility specified criteria. Danger Tree clearances (MVCD) will be based on FAC-003-3 plus a growth buffer added unless otherwise directed by utilities (Figure 3-14). Results from PLS-CADD will be exported to the PCM process explained below. The vendor uses NESC clearances on all aerial and ground class as-surveyed LiDAR using client specified weather cases for the thermal rating analysis.

FAC-003 — TABLE 2 — Minimum Vegetation Clearance Distances (MVCD)[16]
For **Alternating Current** Voltages (feet)

| (AC) Nominal System Voltage (kV) | (AC) Maximum System Voltage (kV)[17] | MVCD (feet) Over sea level up to 500 ft | MVCD (feet) Over 500 ft up to 1000 ft | MVCD feet Over 1000 ft up to 2000 ft | MVCD feet Over 2000 ft up to 3000 ft | MVCD feet Over 3000 ft up to 4000 ft | MVCD feet Over 4000 ft up to 5000 ft | MVCD feet Over 5000 ft up to 6000 ft | MVCD feet Over 6000 ft up to 7000 ft | MVCD feet Over 7000 ft up to 8000 ft | MVCD feet Over 8000 ft up to 9000 ft | MVCD feet Over 9000 ft up to 10000 ft | MVCD feet Over 10000 ft up to 11000 ft |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 765 | 800 | 8.2ft | 8.33ft | 8.61ft | 8.89ft | 9.17ft | 9.45ft | 9.73ft | 10.01ft | 10.29ft | 10.57ft | 10.85ft | 11.13ft |
| 500 | 550 | 5.15ft | 5.25ft | 5.45ft | 5.66ft | 5.86ft | 6.07ft | 6.28ft | 6.49ft | 6.7ft | 6.92ft | 7.13ft | 7.35ft |
| 345 | 362 | 3.19ft | 3.26ft | 3.39ft | 3.53ft | 3.67ft | 3.82ft | 3.97ft | 4.12ft | 4.27ft | 4.43ft | 4.58ft | 4.74ft |
| 287 | 302 | 3.88ft | 3.96ft | 4.12ft | 4.29ft | 4.45ft | 4.62ft | 4.79ft | 4.97ft | 5.14ft | 5.32ft | 5.50ft | 5.68ft |
| 230 | 242 | 3.03ft | 3.09ft | 3.22ft | 3.36ft | 3.49ft | 3.63ft | 3.78ft | 3.92ft | 4.07ft | 4.22ft | 4.37ft | 4.53ft |
| 161* | 169 | 2.05ft | 2.09ft | 2.19ft | 2.28ft | 2.38ft | 2.48ft | 2.58ft | 2.69ft | 2.8ft | 2.91ft | 3.03ft | 3.14ft |
| 138* | 145 | 1.74ft | 1.78ft | 1.86ft | 1.94ft | 2.03ft | 2.12ft | 2.21ft | 2.3ft | 2.4ft | 2.49ft | 2.59ft | 2.7ft |
| 115* | 121 | 1.44ft | 1.47ft | 1.54ft | 1.61ft | 1.68ft | 1.75ft | 1.83ft | 1.91ft | 1.99ft | 2.07ft | 2.16ft | 2.25ft |
| 88* | 100 | 1.18ft | 1.21ft | 1.26ft | 1.32ft | 1.38ft | 1.44ft | 1.5ft | 1.57ft | 1.64ft | 1.71ft | 1.78ft | 1.86ft |
| 69* | 72 | 0.84ft | 0.86ft | 0.90ft | 0.94ft | 0.99ft | 1.03ft | 1.08ft | 1.13ft | 1.18ft | 1.23ft | 1.28ft | 1.34ft |

* Such lines are applicable to this standard only if PC has determined such per FAC-014 (refer to the Applicability Section above)

**Figure 3-14**
**Table of FAC-003 minimum vegetation clearance distance**

**Thermal Rating Reports** – The Report is generated for all points of interest on ground, aerial LiDAR and TIN surface to determine the maximum thermal limit that the conductor can operate without violating the specified vertical/horizontal clearance distance in each span up to the maximum conductor temperature line rating. Survey clearance reports will generate all points of interest based on ground, aerial LiDAR and TIN surface to determine the minimum vertical/horizontal clearance distance to the conductor in each span for the specified feature codes based on the specified weather cases. Depending on the detail needed it will summarize results based on worst case violation per feature code per span (Figure 3-15 and Figure 3-16).

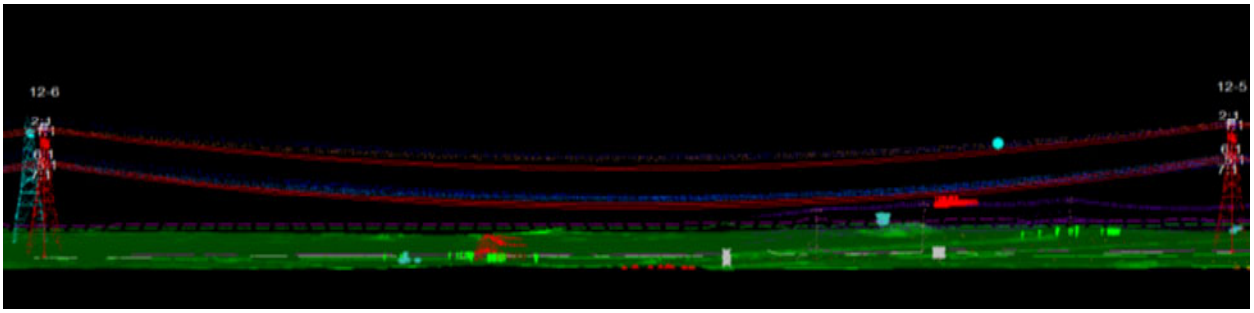



**Figure 3-15**
**Red violation markers show encroachments [8]**

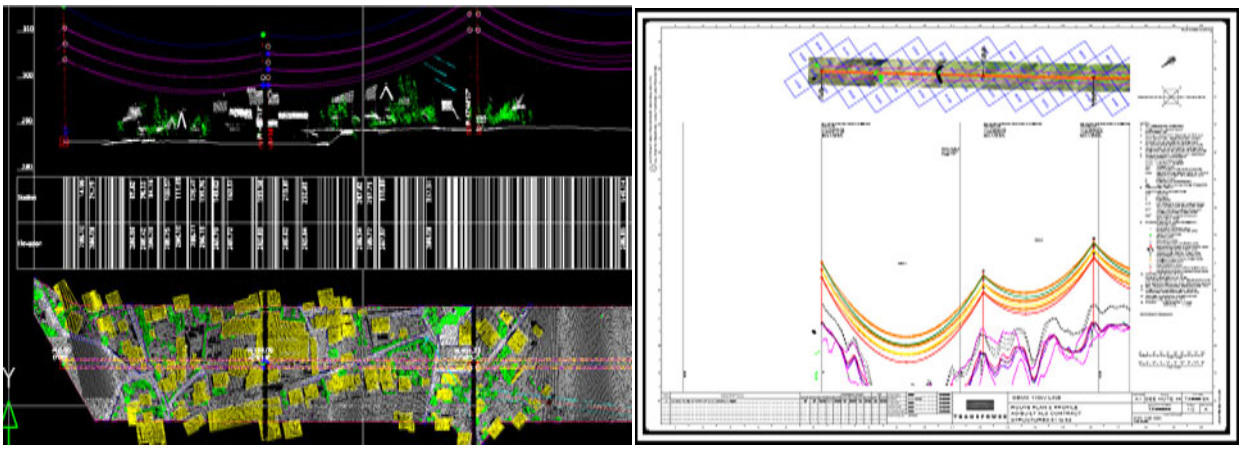


**Figure 3-16**
**PLS-CADD plan view (left) and profile view (right)**

**Danger Tree Growth-in Report** – The Report generated for all points of interest based on a minimum clearance distance (radial or rectangle) to conductor at the specific weather cases. A violation occurs when the conductor comes in contact with that clearance buffer at the specified weather case (Figure 3-17 and Figure 3-18).

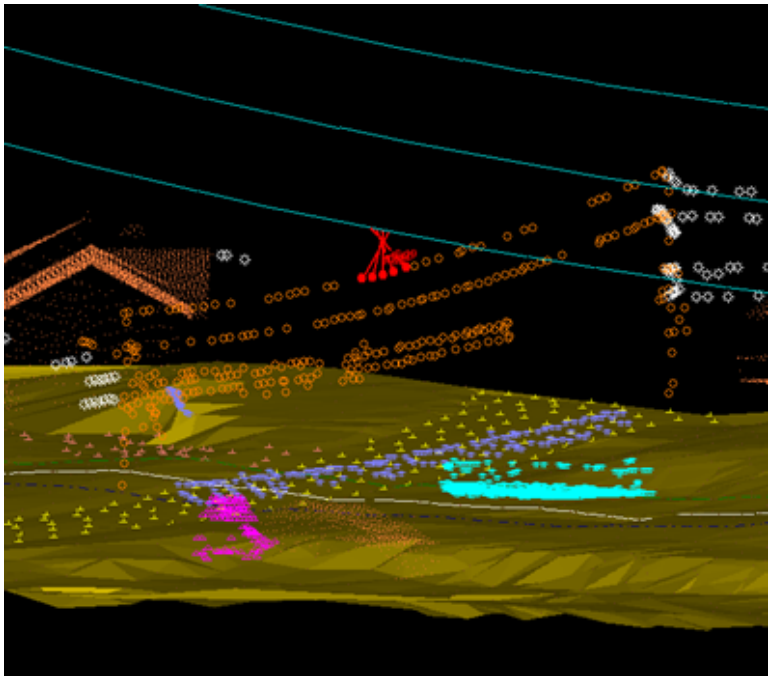


**Figure 3-17**
**Example of violation markers on distribution crossing**

**The Danger Tree Fall-in Report** – The report generates all tipping tree overshoot violations made by contact with conductor with no growth allowance and all undershoot violations which make contact to the conductor with a growth allowance at a specified weather case. All other PLS-CADD Engineering reports will be run at the utility's request and all reports will be formatted based on utility specifications. FAC-003-3 compliance requires annual compliance with the MVCD clearance distances as stated in the FAC-003 2 Minimum Vegetation Clearance Distance (MVCD) (Figure 3-14). The vendor will process the vegetation clearances in conjunction with the PLS-CADD modeling for thermal analysis and line rating studies. Because failed clearance points by themselves provide limited information about the number of trees that are potentially in need of removal, the vendor combines this information with their canopy segmentation algorithms which will then allow a more discrete determination of total number of trees at a project level that have failed clearance.

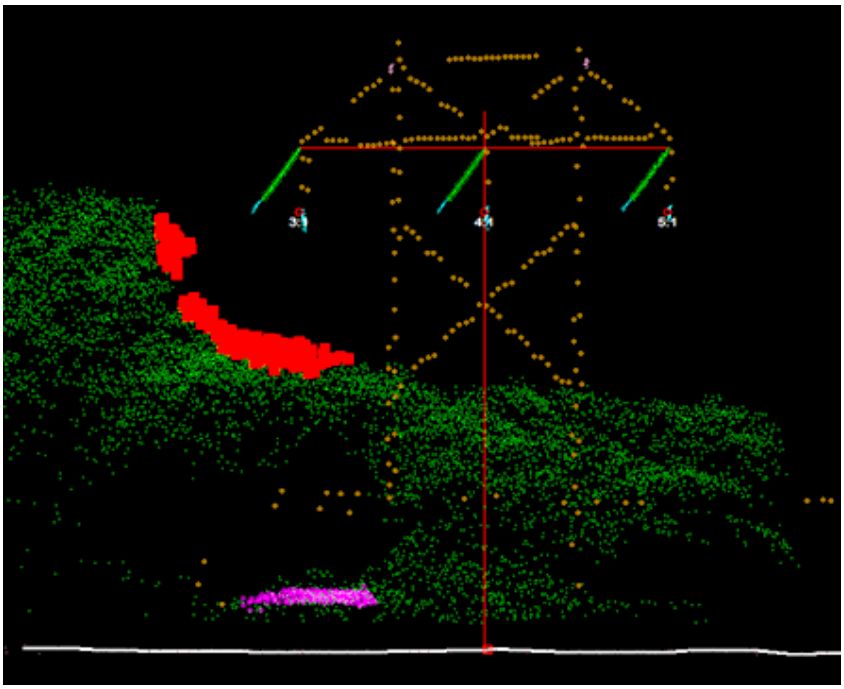


**Figure 3-18**
**Vegetation clearance failure [8]**

## Technical Approach – Vegetation Quantification

### *Vegetation*

Historically, vegetation quantification in the utility sector has largely been a manual process. The inefficiencies can be costly to the utilities as the lack of valid quantification and identification of vegetative threats also increases the potential risk exposure to the utilities service reliability and regulatory compliance. This vendor has worked with a number of utilities to solve problems such as tree health, fire fuels analysis and FAC-003 compliance.

### *A Patented Process*

Through its 2008 acquisition of ImageTree Corporation's assets and key personnel, the company has acquired patented technologies specifically designed for vegetation quantification. From this base of expertise, it has developed vegetation quantification offerings specifically for the utilities market.

At the core of the solution are the vegetation polygons which are created by feature extraction algorithms. From the basic construct of vegetative polygons the vendor can create a host of utility specific span and project level deliverables for both on and off Rights-Of-Way (ROW), including vegetative height classes, area calculations by treatment types, volumetric quantification, vegetative risk assessments and other types of analysis.

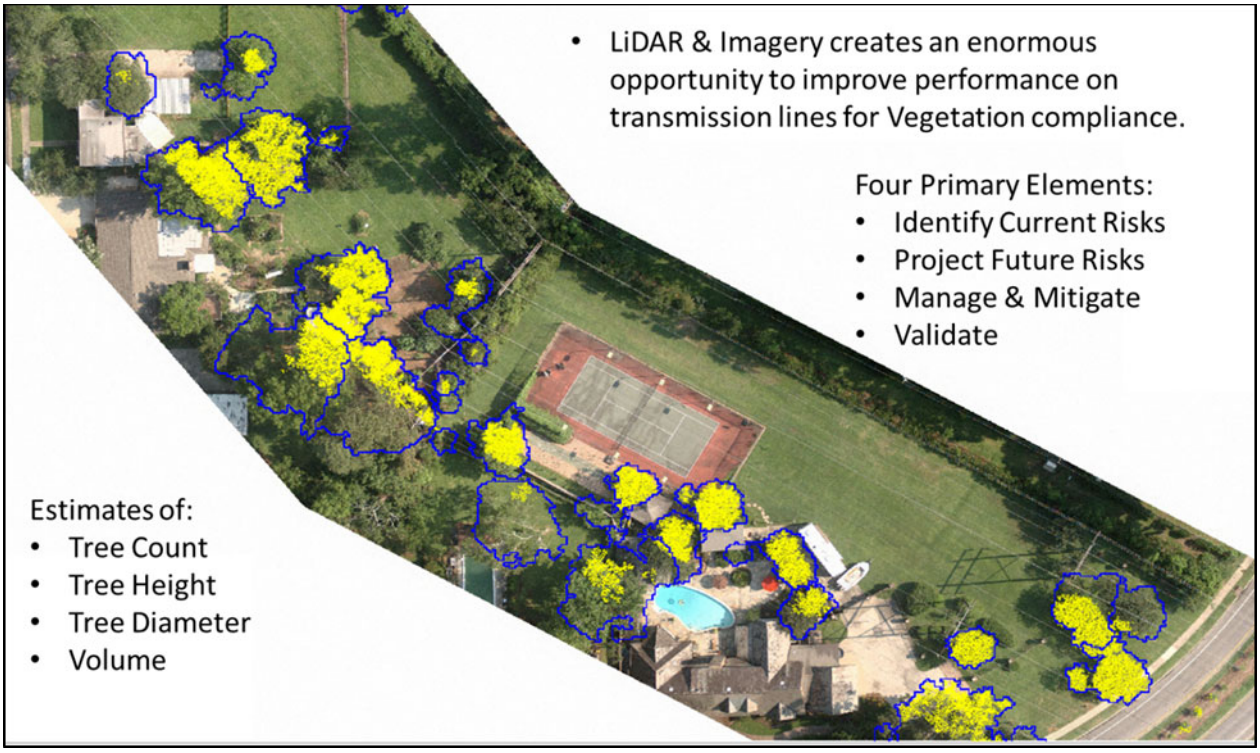



**Figure 3-19**
**Example of MVCD LiDAR points and canopy software identified segments [8]**

The product deliverables can be spatially enabled and allow for either standalone delivery via web portal, PDF format, or full integration within a utility's existing Information Technology (IT) or Geographic Information System (GIS) architecture. Thus, polygons in the form of shape-files or geo-referenced maps can be displayed online, in the office, printed as paper maps, or on GPS enabled field computers and handheld mobile devices (see Figure 3-19).

### *Tree Health Assessment*

The assignment of tree health is an important part of hazard tree identification. This assignment is made from true color and infra-red imagery as well as the segmented canopy height model. Orthographically registered true color and infra-red imagery is used to summarize the reflectance of the canopy. The imagery is intersected with canopy segments derived from a canopy height model and a sample of the segments is chosen. Health tags are manually assigned to the selected segments and a supervised model is created. The results are applied back to the population as a whole. Hazard trees are those that can intersect the buffered line location and have health issues.

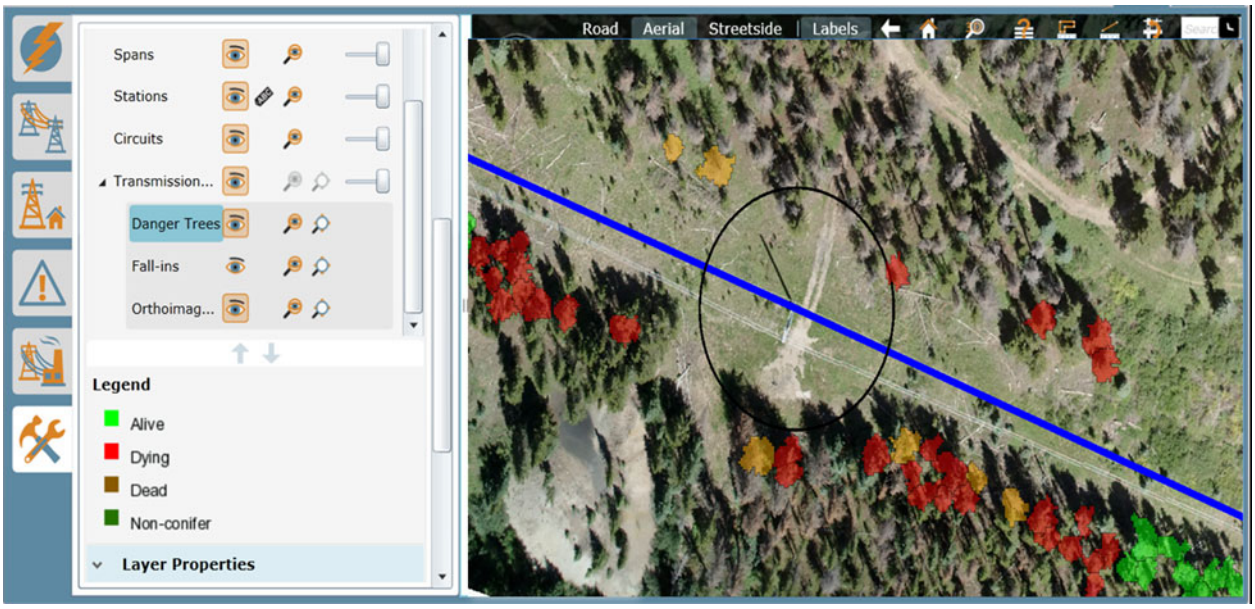



**Figure 3-20**
**Tree health assessment [8]**

The collected LiDAR data are processed and feature coded into reflectance classes. These feature codes capture the difference between vegetation and conductor support structures, as well as buildings and other important reflectance classes. The ground returns are used to estimate the elevation of the ground surface and the vegetation returns the elevation of the top surface of the vegetation. These values are differenced to produce the above ground vegetation height.

The raw image data is orthographically registered to the ground surface model. The canopy height model is divided into segments such that homogeneous regions of vegetation are grouped together. The orthographically registered imagery is intersected with these canopy segments and the enclosed pixels are summarized. The average and variance of the normalized difference vegetation index as well as the ratio of infrared intensity to red intensity are used to characterize the vegetation within each segment.

A sample is drawn from the canopy segments and each sampled segment is examined in the orthographic imagery, the oblique imagery and the classified LiDAR returns. Based on this examination a health class is assigned to the segment. Typical health classes are healthy, diseased, and dead. The assignment technique is ‘virtual’ in the sense that no operator visits the tree in place all visits take place in the data.

The results of the virtual sample are split into training and validation datasets. The training dataset is used to 'train' a supervised classifier with a support vector machine or a tree based process based on Approximate Bayes Computation. These techniques create rules for assigning the canopy segments not included in the sample to one of the health classes. Based on these rules the rest of the segments are assigned to one of the classes. The efficacy of the classification is tested using the validation dataset. The sample is augmented and the process repeated until a predetermined level of precision is achieved.

Health estimation requires clear views of the fully leafed canopy of the target vegetation. It is not possible at this time to distinguish a tree that has lost its leaves in a seasonal senescence from one that has died. It is also very imprecise to estimate species from the growth forms as seen by LiDAR returns at typical survey pulse densities. In addition snow can obscure enough of the vegetation and reflect enough light from below to make the IR to visual intensity ratios unusable. Late spring through early autumn is the best time for these surveys. In addition the best time of day is near noon and the best light conditions include a high overcast. While these days are not common the results are noticeably more precise.

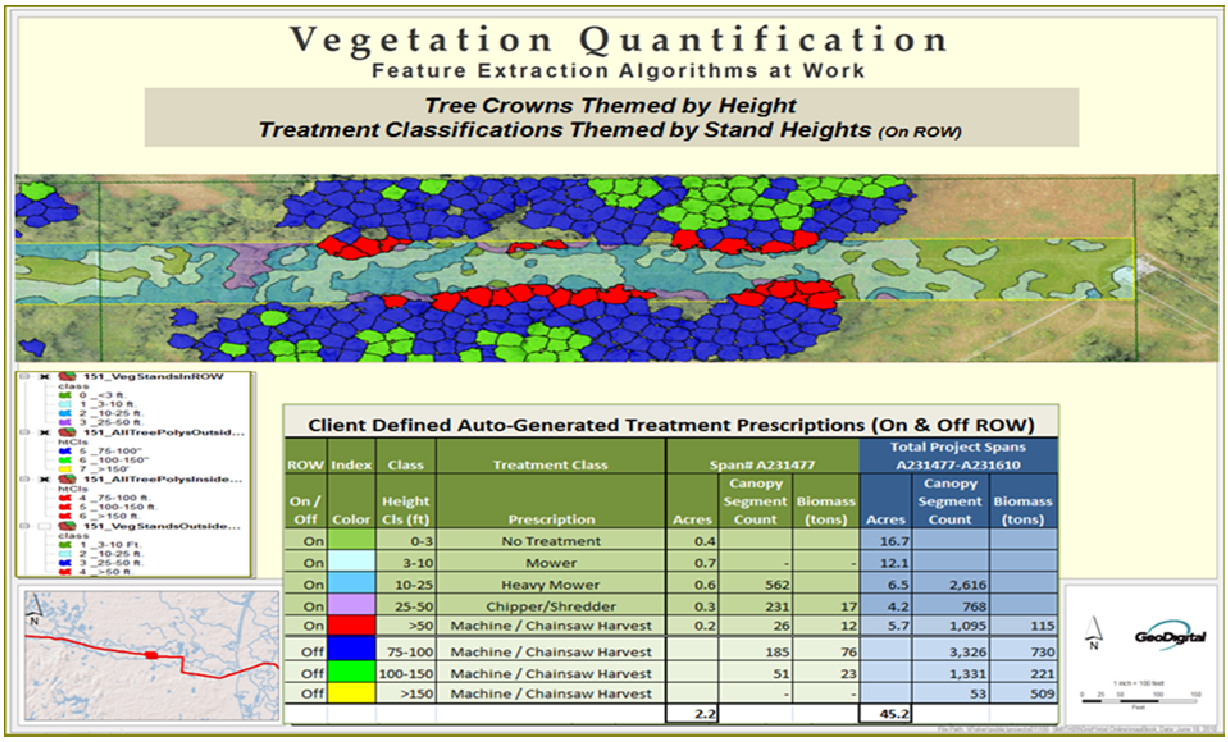
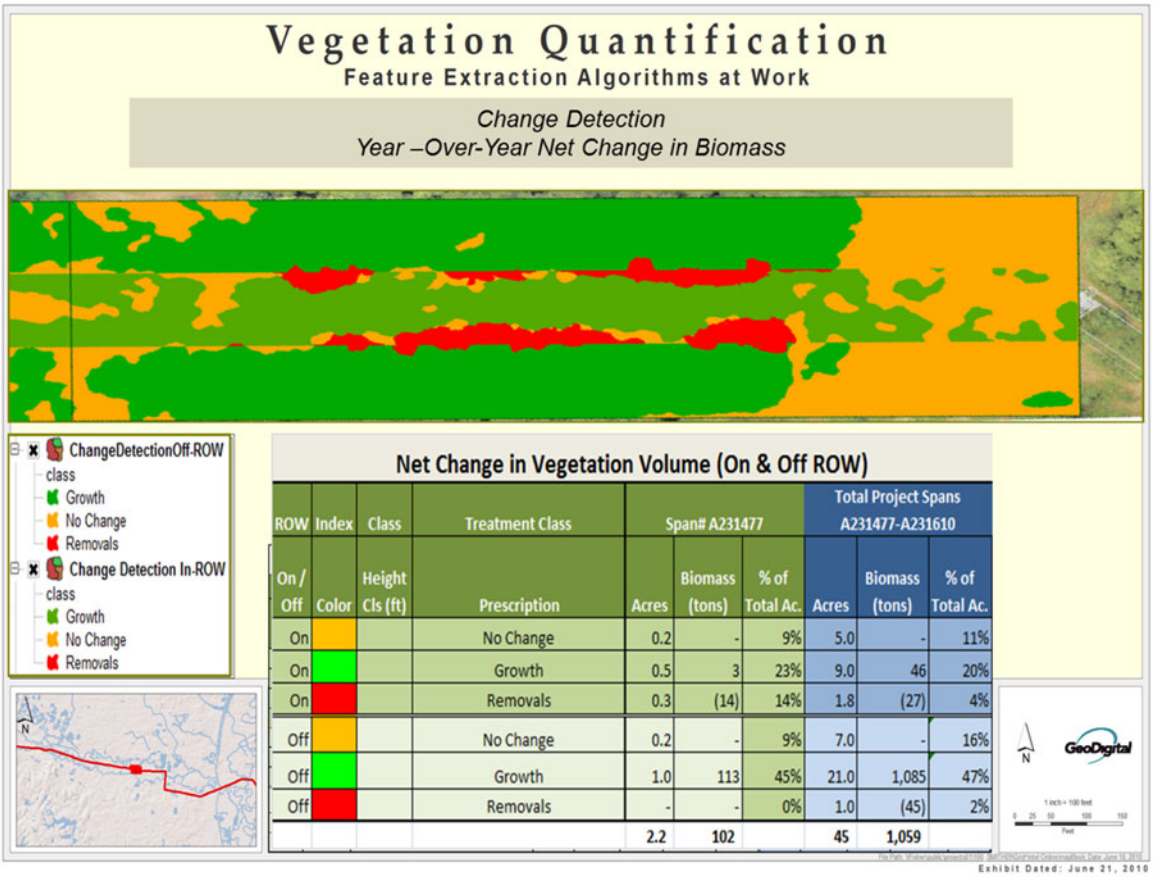



**Figure 3-21**
**Example of vegetation quantification [8]**

### *Change Detection as Part of an Annual or Periodic Reflight Program*

Change detection deliverables have been developed by the vendor using their proprietary processes combining LiDAR, software and biometrics. The use of change detection by utilities in growing as multi-year reflight programs are evolving. Change detection can be used for auditing completion of work previously determined to be a threat to the lines as a 100% line audit. Change detection can also be used for trending analysis as changes in net biomass may indicate a correlation between service reliability and/or potential for future compliance issues (Figure 3-22).




| ROW | Index | Class | Treatment Class | Span# A231477 | | | Total Project Spans A231477-A231610 | | |
|---|---|---|---|---|---|---|---|---|---|
| On / Off | Color | Height Cls (ft) | Prescription | Acres | Biomass (tons) | % of Total Ac. | Acres | Biomass (tons) | % of Total Ac. |
| On | | | No Change | 0.2 | - | 9% | 5.0 | - | 11% |
| On | | | Growth | 0.5 | 3 | 23% | 9.0 | 46 | 20% |
| On | | | Removals | 0.3 | (14) | 14% | 1.8 | (27) | 4% |
| Off | | | No Change | 0.2 | - | 9% | 7.0 | - | 16% |
| Off | | | Growth | 1.0 | 113 | 45% | 21.0 | 1,085 | 47% |
| Off | | | Removals | - | - | 0% | 1.0 | (45) | 2% |
| | | | | 2.2 | 102 | | 45 | 1,059 | |

**Figure 3-22**
**Example of graphic representation of vegetation quantification [8]**

## Vegetation Management Software

This Vendor has developed a software platform suite specifically for the utility industry called WorkStudioTM (WS). WorkStudio is designed to simplify transmission line asset inspection, vegetation management, engineering analysis and asset management for utilities. WorkStudio Online enables utilities to access the WorkStudio software functionality through a familiar web browser, making it immediately actionable for day-to-day utility operations.

By combining WorkStudio with the data acquisition and LiDAR-derived business intelligence, utilities can:

- Dispatch work to the field
- Monitor work in progress
- Document compliance
- Generate reports and analysis that support system reliability
- Plan multi-year vegetation maintenance programs
- Help reduce maintenance and vegetation management costs

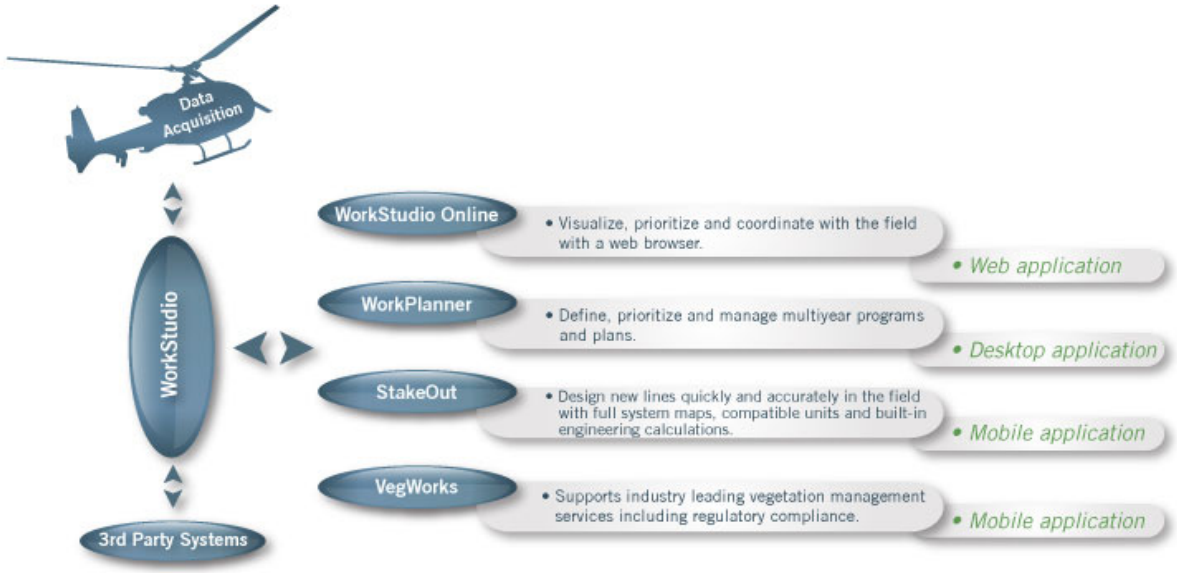



**Figure 3-23**
**PCM modules with WorkStudio integration with other applications for vegetation inspections [3, 8]**

WorkPlanner technology can help a utility manage their transmission multiyear maintenance programs in order to maintain assets within your right-of-way.

VegWorks is a module and mobile application within the WorkStudio suite for utility vegetation management. Utilities can use VegWorks to assess, perform, and audit vegetation work. VegWorks synchronizes assigned work orders to the field. Once work is completed, it is automatically synchronized back to the WorkStudio platform, so the results are visible and accessible for reporting and integration with other business systems.

## Data Hosting and Visualization

This vendor has developed a data hosting and visualization platform called WorkStudio Online (WSO). WSO is a hosted solution allowing controlled access to view projects in an easy to use navigation environment with pre-loaded centerlines, colorized LiDAR, ortho imagery, oblique imagery, canopy segments and client defined areas of interest identified (Figure 3-24, Figure 3-25, Figure 3-26).

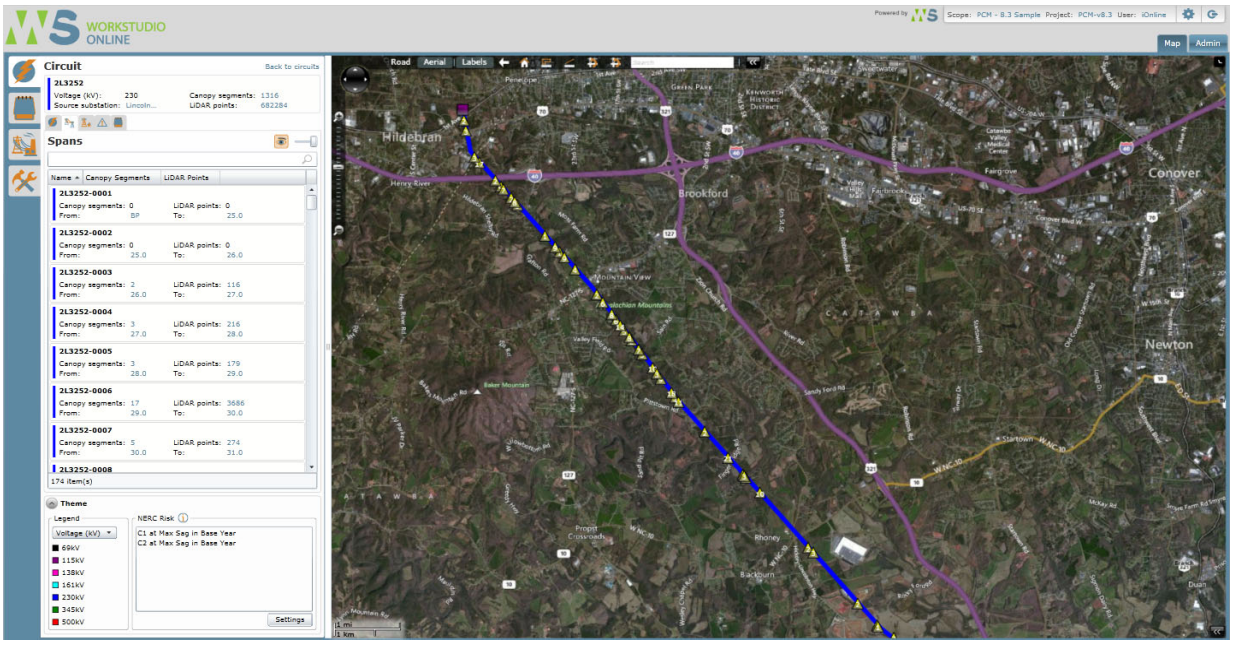



**Figure 3-24**
**WorkStudio Online user interface [8]**

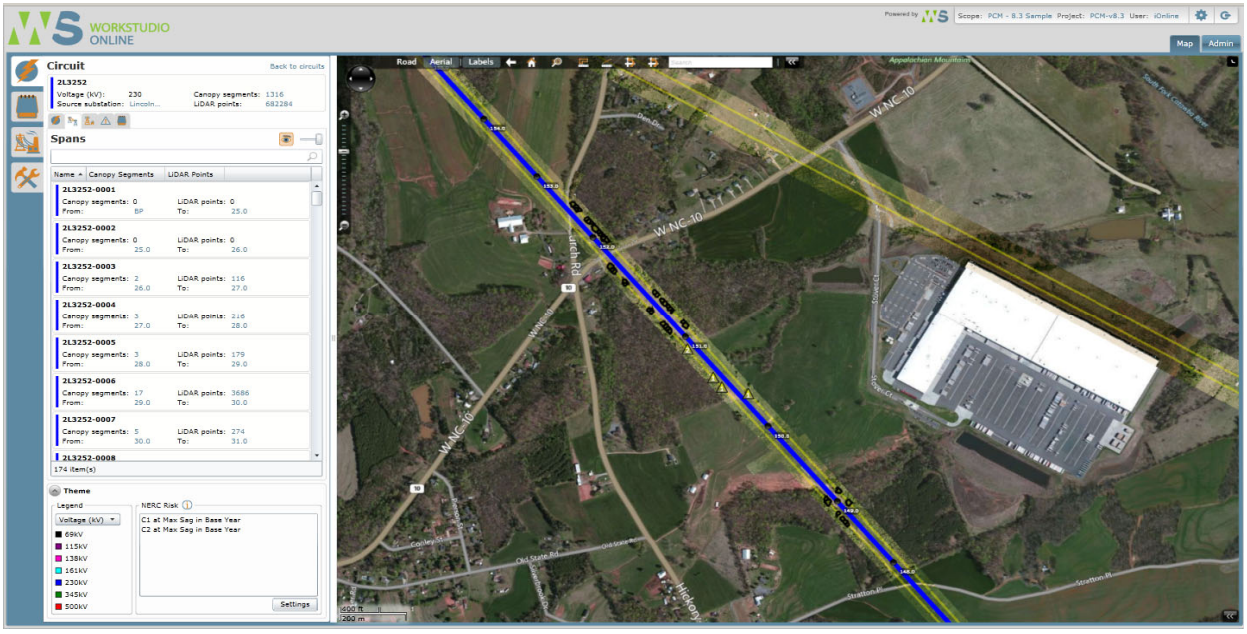



**Figure 3-25**
**WorkStudio Online user interface (medium zoom)**

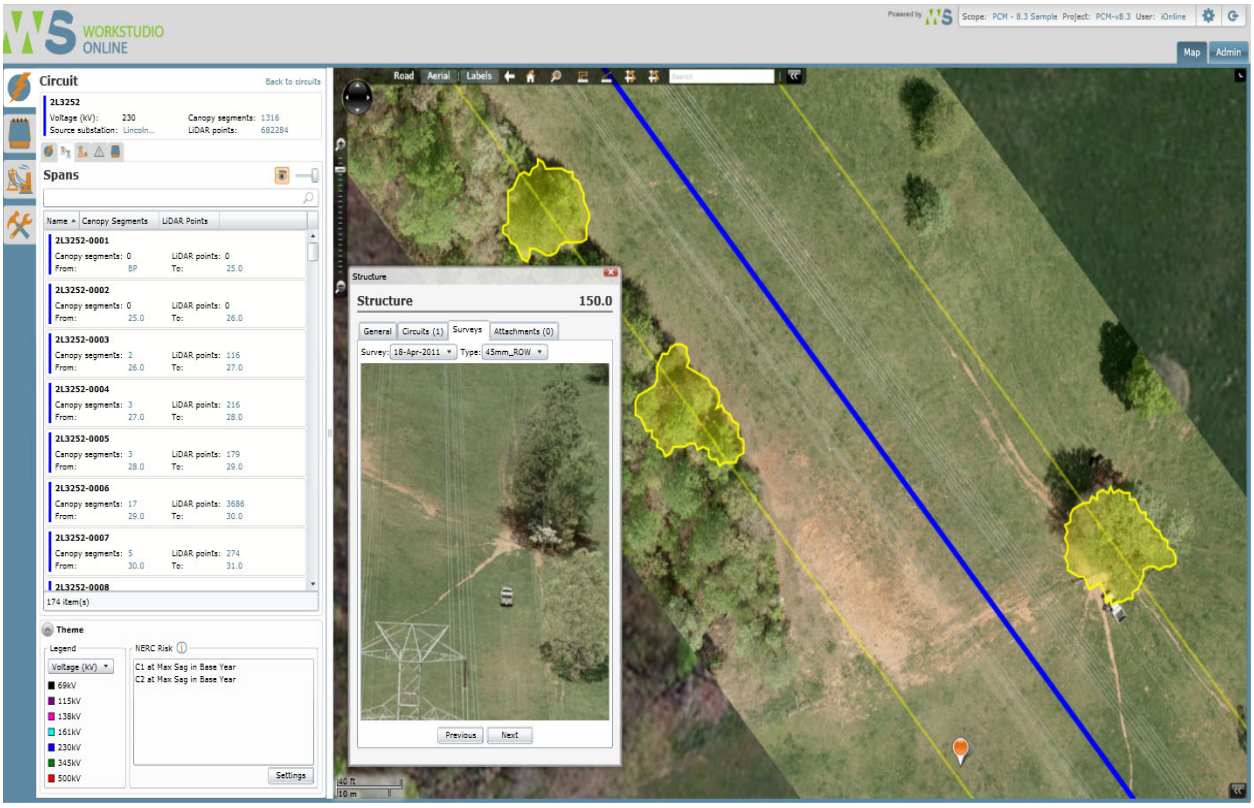



**Figure 3-26**
**WorkStudio Online (zoomed with canopy segments displaying vegetation alerts)**

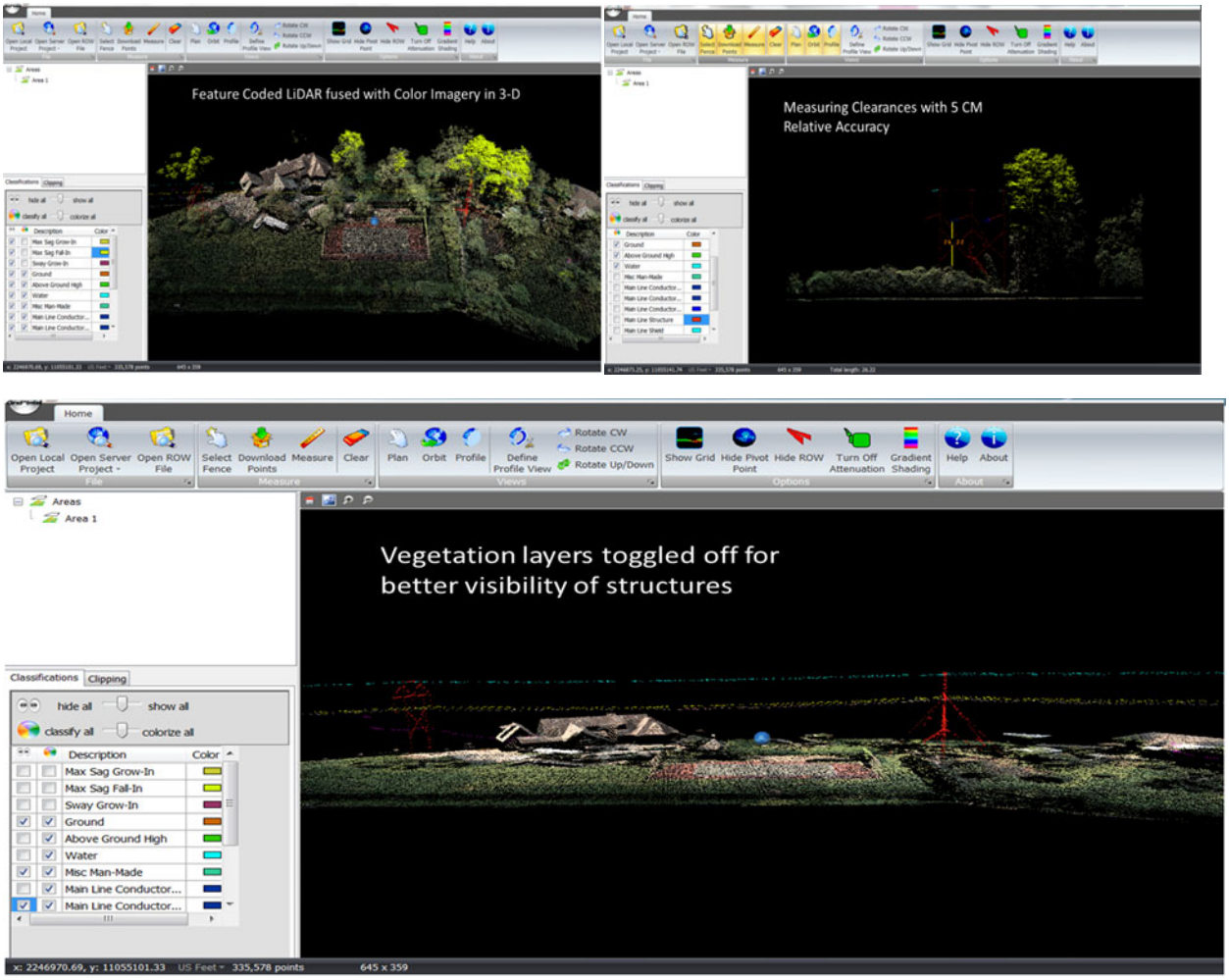



**Figure 3-27**
**WorkStudio Online includes integrated 3D viewing capabilities of colorized and classified LiDAR [8]**

## FAC-003-3 Compliance

FAC-003-3 introduces several key changes in how transmission vegetation management is regulated. First, it requires utilities to validate annually that no vegetation encroaches into the Minimum Vegetation Clearance Distance (MVCD) around transmission lines at maximum rated conditions. Because maximum rated conditions can rarely be observed in the field, utilities typically must create massive safety buffers.

FAC-003-3 also presents a unique paradigm with respect to annual compliance. Whereas earlier regulations simply required utilities to have a documented Transmission Vegetation Management Program (TVMP), the new standard requires utilities to complete 100% of their planned inspection and maintenance work each year (Table 3-1).

**Table 3-1**
**Relevance of PCM to FAC-003-3 compliance**

| FAC-003-3 Requirements | LiDAR and Imagery | WorkPlanner | VegWorks |
|---|---|---|---|
| **Defined Right-of-Way:** Establish Transmission Line Corridor | √ | | |
| **R1 & R2:** Assign Inspections and Audits; Inspection and Audit Reports | √ | √ | √ |
| **R3:** Work Methods, Maintenance Schedule, and Vegetation Inspection Schedule | | √ | |
| **R4:** Capability to Provide Notification of a Likely Fault | | | √ |
| **R5:** Initially Planned and Subsequent Work Orders; Data and Signatures for Constraints | | √ | √ |
| **R6:** Assigning Inspections; Completed Inspections and Work Orders | | √ | √ |
| **R7:** Annual Work Plan, Modified Work Plan, Documents Changes; Work Order Data, Inspection Records | | √ | √ |

## Precision Corridor Management (PCM) Program

This vendor has recently released a fully integrated solution designed specifically to meet the new FAC-003-3 standards. They call it the Precision Corridor Management program. PCM borrows from precision agriculture in its use of technology to make highly prescriptive recommendations for utility right of way management, while reducing total costs and improving performance.

The PCM program combines an annual LiDAR reflight patrol with the software and information as Service (SAIAS) model. Adoption of PCM allows that annual FAC-003-3 compliance checks to be conducted with PLS-CADD models to the MVCD at maximum rated conditions.

Planning and tracking work via the WorkStudio platform including VegWorks and WorkPlanner modules allows clients to track performance to plan as well as budget to plan by circuit, region and company (Figures 3-28, 3-29, 3-30, and 3-31).

PCM provides the capability to support utilities in attaining compliance with NERC FAC-003-3 via the planning component of the system, WorkPlanner which supports R1, R2, R3, R5, R6, and R7. Additionally, the data that is collected in the field through VegWorks supports the applicable components of R1, R2, R4, R5, R6, and R7 (see Table 3-2).

**Table 3-2**
**PCM prevalence of NERC FAC-003-3 table of requirements for annual compliance [3]**

| FAC-003-3 Requirements | LiDAR and Imagery | WorkPlanner | VegWorks |
|---|---|---|---|
| **Defined Right-of-Way:** Establish Transmission Line Corridor as Provided by the Utility | √ | | |
| **R1 & R2:** Assign Inspections and Audits; Inspection and Audit Reports | √ | √ | √ |
| **R3:** Work Methods, Maintenance Schedule, and Vegetation Inspection Schedule | | √ | |
| **R4:** Capability to Provide Notification of a Likely Fault | | | √ |
| **R5:** Initially Planned and Subsequent Work Orders; Data and Signatures for Constraints | | √ | √ |
| **R6:** Assigning Inspections; Completed Inspections and Work Orders | | √ | √ |
| **R7:** Annual Work Plan, Modified Work Plan, Documents Changes; Work Order Data, Inspection Records | | √ | √ |

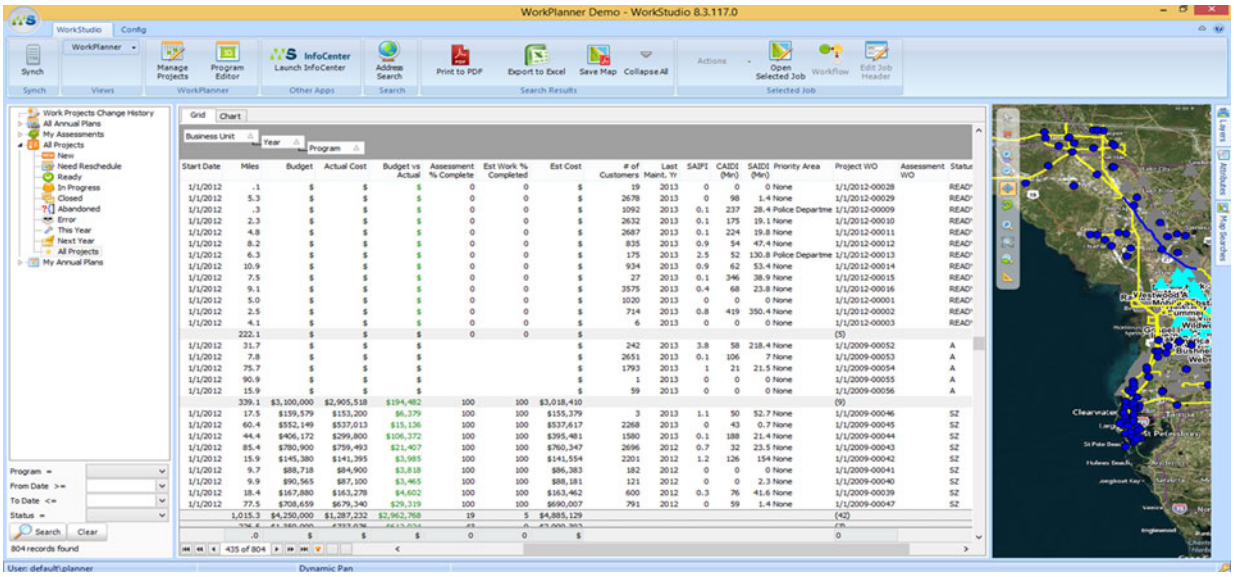



**Figure 3-28**
**WorkPlanner as part of PCM [8]**

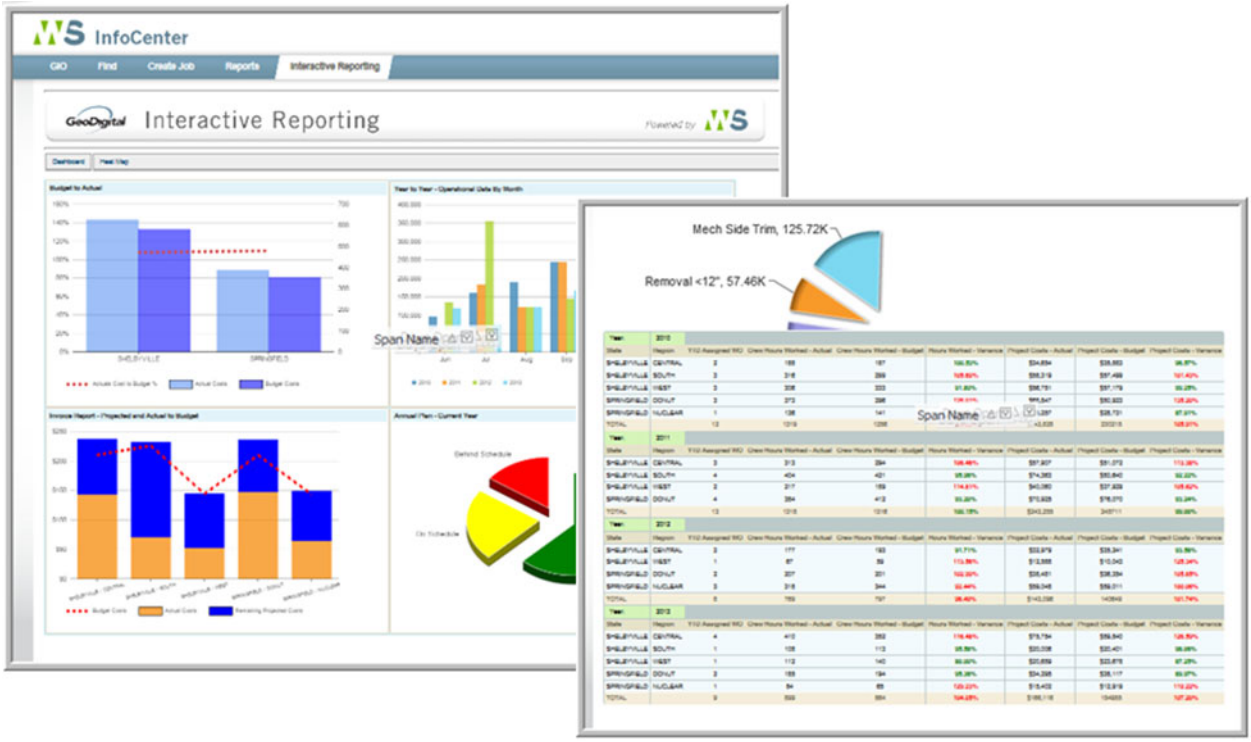



**Figure 3-29**
**Tracking performance against plan in WorkStudio [8]**

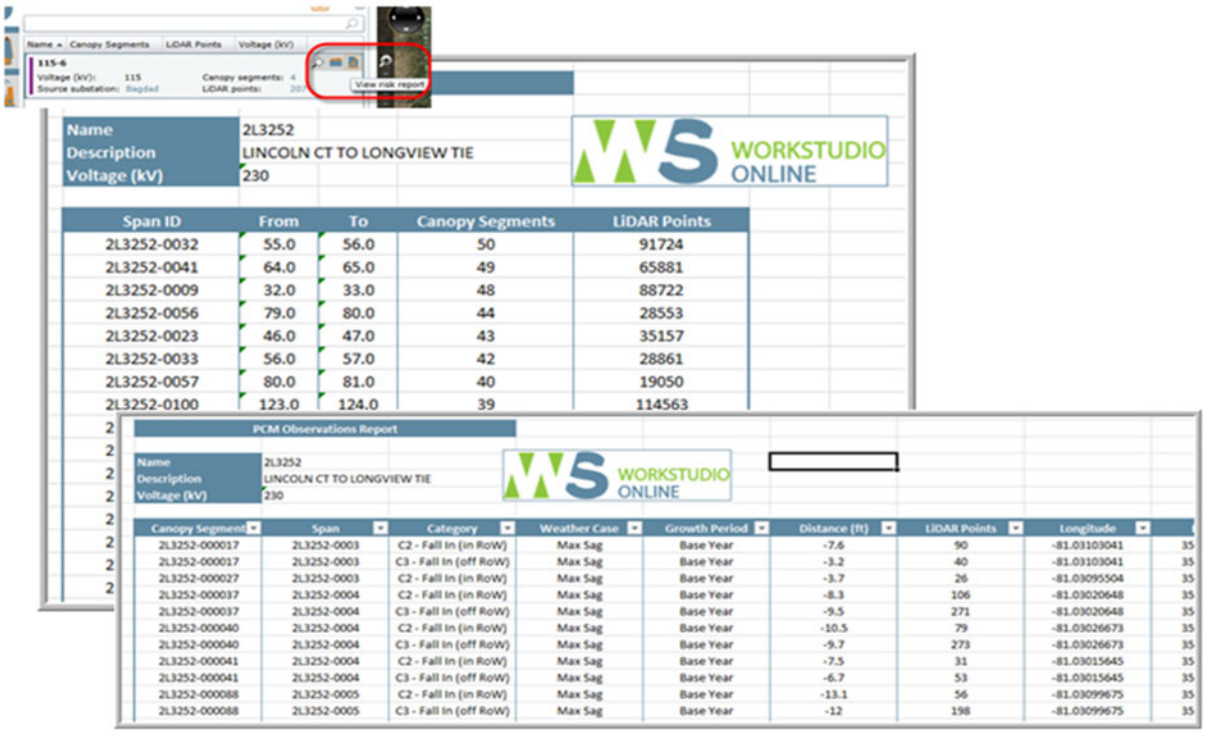
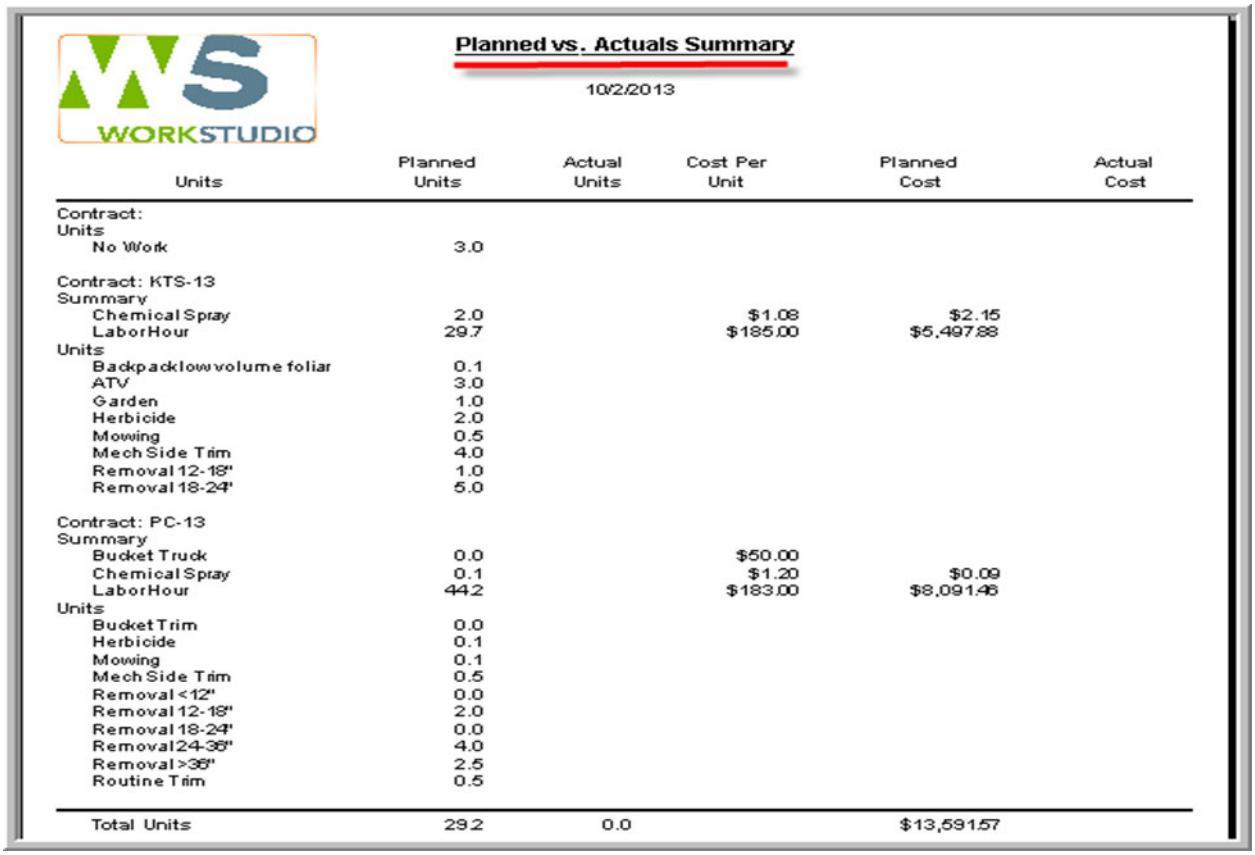



**Figure 3-30**
**Work prioritization (exports to Excel) [8]**



**Planned vs. Actuals Summary**

10/2/2013

| Units | Planned Units | Actual Units | Cost Per Unit | Planned Cost | Actual Cost |
|---|---|---|---|---|---|
| Contract: | | | | | |
| Units | | | | | |
| No Work | 3.0 | | | | |
| Contract: KTS-13 | | | | | |
| Summary | | | | | |
| Chemical Spray | 2.0 | | $1.08 | $2.15 | |
| LaborHour | 29.7 | | $185.00 | $5,497.88 | |
| Units | | | | | |
| Backpacklow volume foliar | 0.1 | | | | |
| ATV | 3.0 | | | | |
| Garden | 1.0 | | | | |
| Herbicide | 2.0 | | | | |
| Mowing | 0.5 | | | | |
| Mech Side Trim | 4.0 | | | | |
| Removal 12-18" | 1.0 | | | | |
| Removal 18-24" | 5.0 | | | | |
| Contract: PC-13 | | | | | |
| Summary | | | | | |
| Bucket Truck | 0.0 | | $50.00 | | |
| Chemical Spray | 0.1 | | $1.20 | $0.09 | |
| LaborHour | 44.2 | | $183.00 | $8,091.46 | |
| Units | | | | | |
| Bucket Trim | 0.0 | | | | |
| Herbicide | 0.1 | | | | |
| Mowing | 0.1 | | | | |
| Mech Side Trim | 0.5 | | | | |
| Removal <12" | 0.0 | | | | |
| Removal 12-18" | 2.0 | | | | |
| Removal 18-24" | 0.0 | | | | |
| Removal 24-36" | 4.0 | | | | |
| Removal >36" | 2.5 | | | | |
| Routine Trim | 0.5 | | | | |
| Total Units | 29.2 | 0.0 | | $13,591.57 | |

**Figure 3-31**
**Reporting of planned versus actual [8]**

The vendor has the capacity to host the PCM solution entirely or it can be hosted by the utility and (if desired) integrated with back-office systems such as Oracle, Maximo and GIS systems.

### *LiDAR Vegetation Survey Deliverables to Utilities*

Data deliverables vary with utility`s requirements and whether requested by vegetation management, engineering, asset management, or all of these. Typical deliverables include:

- Vegetation clearance analysis
- Feature coded LiDAR data
- Stick and wire models (ready for use in PLS-CADD)
- Digital terrain models
- Thematic mapping of geographic features
- Digital structure images, ortho-photography and ROW imagery

### *Engineering Projects Deliverables*

For engineering projects, the initial feature coding can be extended to allow the classification of all visible features that might be desired for inclusion in engineering models, plan and profile sheets or other CAD data files. Selection and identification of reflections from the ground surface, objects, and vegetation, is performed using a manually supervised, custom application program that runs as a Bentley Microstation application. The LiDAR analyst, referring to the digital imagery to identify specific objects, manually classifies points and trains the supervised computer classification of the 3D digital cloud xyz data generated from the laser reflection points. On the basis of the classified LiDAR data, it is possible to create 3D vector models of objects, and PLS-CADD, XYZ, DXF and or DGN files containing polylines and contours of all objects. The files are used to store planimetric line work and can be directly read by GIS and CAD software. Points that fall within the boundaries of particular contours are attributed (feature coded) to corresponding classes of objects. Points reflected from each transmission line, ground surface and adjacent objects receive specific feature codes often unique to each customer. Feature code lists can also be customized with the client to address specific requirements or optimise costs related to this process which requires significant manual supervision if high accuracy is required.

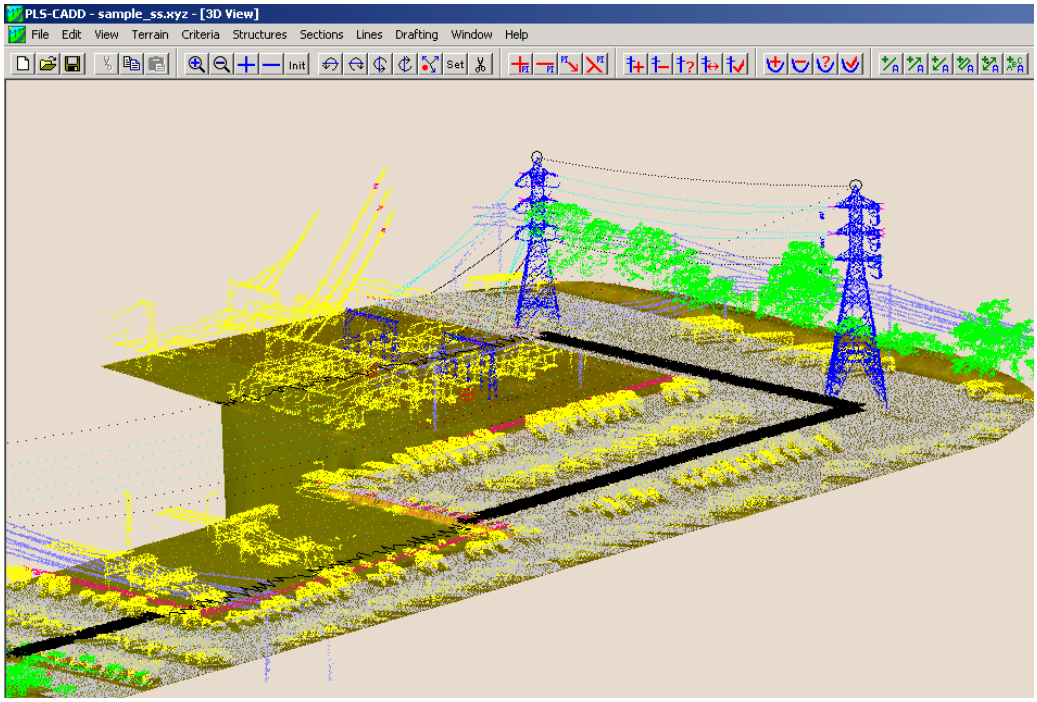



**Figure 3-32**
**Example of engineering LiDAR 3D modeling [8,3]**

# 4
# CONCLUSION

This report presented an overview of LiDAR technology and the approach taken by GeoDigital. LiDAR data together with high resolution oblique and downward imagery provides information on transmission lines, vegetation and ROWs. When coupled with analysis, reporting and work flow software, LiDAR data sets can provide clearances to vegetation, ground and structures to be determined with good accuracy. With this data, individual transmission lines can be modeled in 3-D and the sag of the line predicted when operating at maximum load under various weather conditions.

EPRI intends to continue reviewing/evaluating other new technologies and/or software for vegetation inspection and management.

# 5
# REFERENCES

A list of references that are applicable for this report is presented below:


1. Mangold, Roland. “For vegetation management, all LiDAR is not created equal.” Utility Automation & Engineering T&D, Feb. 2009 Issue.
2. *Evaluation of Emerging Line Inspection Technologies: Results of 2011 Field Tests*. EPRI, Palo Alto, CA: 2012. 1026639.
3. GeoDigital International web site www.geodigital.com.
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6. NERC FAC-003-3, “Transmission Vegetation Management,” Sept. 2013.
7. LAS Specification Version 1.2, Sept. 2008.
8. Photos courtesy of GeoDigital International, Nov. 2014.

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