This study began with the hypothesis that large Light Detection and Ranging (LIDAR) data sets applied to forestry conditions on a transmission ROW can improve short and long term Utility Vegetation Management (UVM) planning and implementation by transforming the LIDAR measurements into information actionable in the field. After applying this hypothesis to a small 160 km (100 mile) transmission system, it was found that LIDAR data management and ground inspection processes are critical variables in the successful field application of LIDAR technology. The study found that only the most salient and discrete xyz coordinate points of vegetation are needed by a ground inspector to adequately schedule and plan work. The filtering criteria for feature-coded LIDAR data determine what ground inspectors target during inspections. The inspector identifies the location and augments the LIDAR data with findings obtained from the ground, creating work orders for crews and enabling implementation of the findings. LIDAR has historically been promoted as a visual mapping tool, but for applications such as performed in this study, LIDAR was found to be most effective as an information matrix. The information matrix is a predictive quantification of ROW biomass and can be used to devise appropriate corrective action for long term planning.

# A Study of UVM Planning and Implementation with a LIDAR Information Matrix

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**Keywords:** ANSI A300 Part 9, LIDAR Point Conditions (LPC), tree risk assessment, transmission ROW, utility vegetation management (UVM)

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## INTRODUCTION

Beginning in 2010, CN Utility Consulting (CNUC) performed a two year study of transmission vegetation management planning and implementation based on a LIDAR information matrix.

This study began with the hypothesis that:

> Large LIDAR data tables referenced in a GIS street map and applied to electronically captured ground inspections of forestry conditions on a transmission right-of-way (ROW) can improve short and long term utility vegetation management (UVM) planning and implementation by transforming the LIDAR measurements into information that is actionable in the field.

After applying this hypothesis to a 160 km (100 mile) transmission system, which consisted of both 115 kV and 345 kV lines, it was found that:

1) LIDAR data management and ground inspection processes are critical variables in the successful field application of LIDAR technology.
2) LIDAR challenges some of the historical assumptions regarding UVM, posing new opportunities for understanding and providing effective UVM.

From the perspective of a transmission forester, the purpose of LIDAR is to measure and locate vegetation in and along transmission ROW. This purpose requires the forester to find the right tree at the right time and perform the right treatment. Considering the high volume of trees that need to be addressed on a regular basis, methods should be available to provide only the necessary information needed to efficiently get an arborist to the right trees. The high-stakes consequences of vegetation-caused outages punctuate this need. This study is based on two cycles of transmission line ground inspections supported by LIDAR measurements and GIS data. The study attempts to decipher the most economical and effective LIDAR supported method for achieving the desired outcome of a transmission vegetation management program (TVMP).

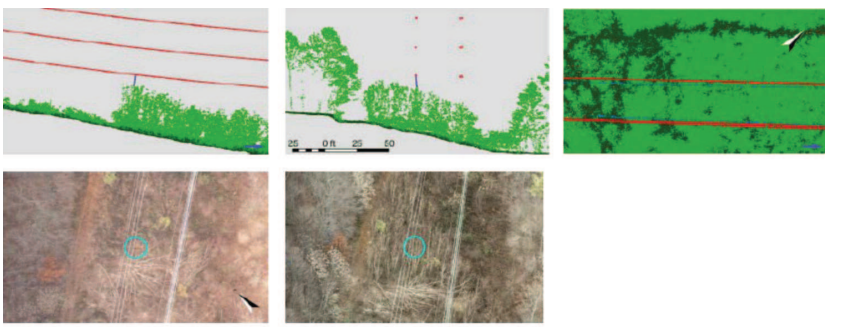

**Figure 1.** LIDAR and photographic images of a tree identified as a grow-in in the critical wire zone.

Making LIDAR technology a practical tool for UVM requires:

1) Understanding how to negotiate the massive amount of information included in LIDAR data sets (more than 409,113 LIDAR identified conditions were found on the transmission system).
2) Determining how to make the data actionable in the field.
3) Training ground inspectors in how to integrate LIDAR information into their inspections in order to create work plans that are easy for the line clearance crews to understand and implement.
4) Making LIDAR data sets useful for more than one year.

A common product supported by LIDAR data and used to locate trees is a photograph. A photograph is normally a powerful tool, but finding a tree that is encroaching on the critical wire zone may not be easily accomplished by looking at an image or a video (see Figure 1). The tree in question could be hidden behind other trees. LIDAR identified vegetation may not visually appear to be posing a threat. Tree canopy at the time of maintenance could be vastly different from the photographs due to the time of year the aerial scan was performed, making identification difficult. The photographs' resolution does not allow for species identification, and aerial shots require that the persons on the ground reorient their perspective. CNUC's experience was that the aerial images did not expedite locating target trees.

Pictures contain much more information than is required, and their large files must be powered through servers and field computers. When presented with the big LIDAR data set required for the comparatively small but complex transmission system that was the object of this study, it was decided the photographs and LIDAR images could possibly overwhelm the data collection system employed to gather inspection information. As the study progressed, it was found there was less and less need to reference aerial images of trees.

One option for LIDAR use in the field would be to supply each line clearance crew with training and technology to identify the trees associated with photographs and LIDAR images overlaid on maps and delineated with color coded polygons. Another option would be to have trained inspectors identify, tag and prioritize LIDAR-identified trees located through the use of pre-screened tabular data sets. Based on the assumption that pre-planning is more efficient than crew on-site planning, our approach was to examine and filter the LIDAR data sets and inspect the transmission ROW with software that incorporated the filtered data. Inspectors were trained to locate trees associated with LIDAR point conditions (LPC).

## METHODOLOGY

Making LIDAR technology a practical tool for transmission UVM required a multi-step process. See Chart 1 *Making LIDAR Technology a Practical Tool for UVM* for a summary of this process. The methodology of this study is separated into the following categories:

1) The Data Capture
2) Post Flight LIDAR Data Processing
3) LIDAR Data Processing for Field Inspection
4) The Field Inspection Process
5) Quantifying Transmission ROW Risk Beyond the High Risk Clearance Categories

Since this study was done in conjunction with implementing improvements to a TVMP for a northeastern utility, methods were monitored and altered to facilitate the development of effective utilization of LIDAR information in the field.

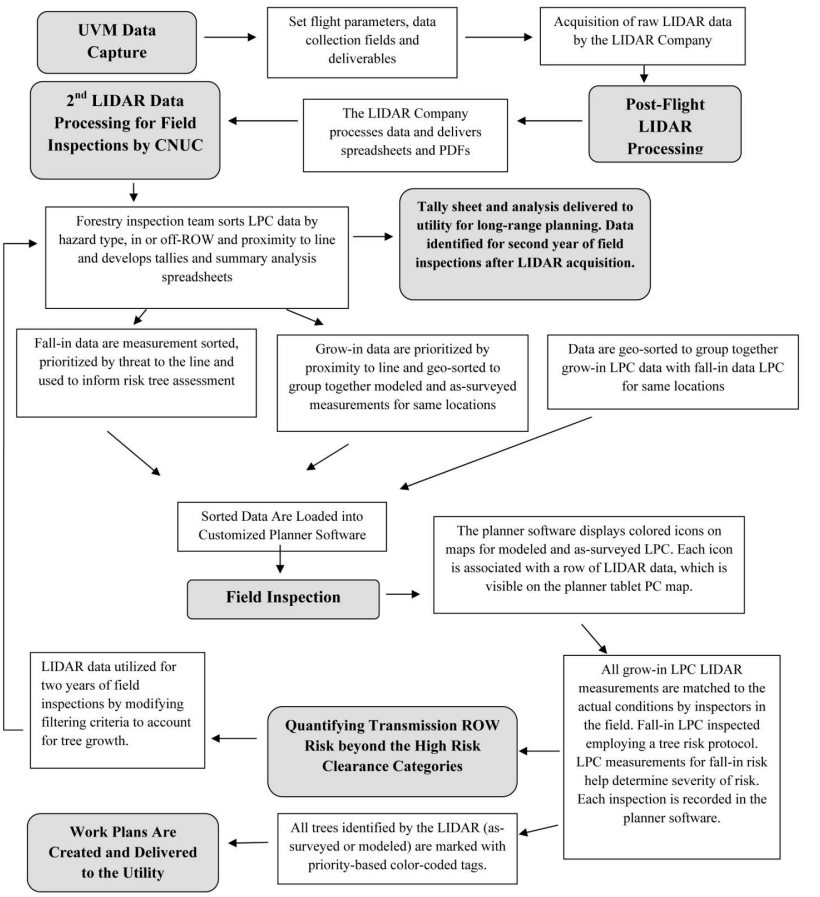


**Chart 1.** Making LIDAR Technology a Practical Tool for UVM.

### The Data Capture

The project began with specific data objectives and a rigorous pre-flight plan. The acquisition of LIDAR from a helicopter required data and flight path preparations that were communicated by email and webinar prior to the day of flight. For the purposes of this study, the project required a smooth helicopter patrol at constant height and constant velocity to capture oblique and orthophotographs and high density LIDAR data. This is possibly a safer and less stressful method than a visual aerial patrol, which requires flying next to, or as close as possible to, the line and frequently shifting the position of the helicopter to get a better look, or a second look, at suspected encroaching vegetation seen from potentially deceptive viewpoints. LIDAR is assuredly a more precise method that can yield a rich and useful database. The LIDAR scanner yields a large cache of raw survey data associated with a stream of photos that support the features of the LIDAR data imagery. The large volume of tabular GIS referenced survey data, which supports the imagery of the LIDAR and the photos, is the LIDAR product CNUC found most useful for vegetation management planning.

### Post Flight LIDAR Data Processing

The processing of LIDAR data was performed by the same LIDAR company that did the data capture, and it was more time intensive than the acquisition. It took six weeks to get the initial as-surveyed data and another eight weeks to get the modeled data. Faster processing may be available, but in this case, a high demand for LIDAR services was overloading the available resources. The high demand was the result of an alert posted on October 7, 2010, by the North American Electric Reliability Corporation (NERC) that requires knowledge of actual asset conditions for the purpose of line ratings methodology (NERC 2010). LIDAR has been a recognized tool for measuring the actual conditions of transmission lines. Although initially, for this project, LIDAR was to be employed exclusively for vegetation conditions, LIDAR was also used to satisfy the NERC Alert.

The delivered end products of the LIDAR processing were spreadsheets and PDFs. A LIDAR and photographic viewer were delivered after the project was completed. The viewer was not used for the ground inspection project. For each transmission circuit or segment of a circuit, the LIDAR company delivered a spreadsheet and a folder of PDFs for grow-in conditions. The spreadsheets

were used extensively, but the PDFs were rarely used and then only as a point of reference in an office setting.

## LIDAR Data Processing for Field Inspections

The spreadsheets delivered by the LIDAR company contained a row of LIDAR measurements for each LIDAR Point Condition (LPC). CNUC defined a single LPC as one vegetation condition associated with a single row in the table of LIDAR measurements and corresponding to a specific point in a tree. These spreadsheets were analyzed, and a summary table was produced to aid in the planning of ground inspections. Several tallies and sorts were performed to create the summary table, which also provided an overview of LIDAR findings. The summary analysis reduces hundreds of thousands of lines of data to a level of big picture understanding but not to a level from which a crew could take action. There were 409,113 rows of data, or LPC, for this project. The summary tally table was used to define the type of ground inspections, as well as to provide a plan for where the inspections would be concentrated and how many would be performed.

For long-term planning, the summary and analysis of deliverable LIDAR data can provide a quantification of ROW biomass concentrations, adjacent forest densities and the relative sizes of trees. A ratio of LIDAR points to number of trees can be devised by statistical sampling and by making reasonable assumptions based on the data sets. Based on the search criteria, it was estimated in this study that between 50 and 85 percent of the LIDAR points were unique to a single tree. This was estimated from inspection results. It is hypothesized that larger grow-in clearance distances correspond to more unique LIDAR points per tree (excluding LPC redundant to multiple modeled conditions).

Once the analysis of delivered LIDAR data was complete, the LIDAR spreadsheets were revised appropriately to facilitate field use in customized software. An interpretive sample of LIDAR data used in the field is listed in Table 1. For example, each LPC found within 3.05 meters (10 ft) of the transmission line was selected from the field computer as a location to be inspected. According to the LIDAR data, these LPC are called grow-ins because of the potential to grow into the conductor.

Grow-in LPC could also be represented in the data set as fall-in LPC, because the point is close enough to grow into the conductor and tall enough to fall into the conductor. In addition to fall-in and grow-in conditions, the LIDAR data included non-modeled (as-surveyed) LIDAR points and modeled LPC. As-surveyed or non-modeled LPC are GPS/altitude points in a tree measured between the line and the tree as found at the time of the survey. This compares to modeled LIDAR points, which are points measured when the line is at a theoretical position due to electrical and/or environmental conditions. The three modeled conditions processed for this project were maximum temperature, ice loading and blowout of

| LIDAR Term | Condition Measurement Grow-in or Fall-in | Clearance | Clearance Criteria | Search Criteria | Conductor Condition: As-Surveyed or Modeled | Station | Offset (Neg= Right Side of ROW) | GIS | | Above Ground Height | Point at Conductor Height | Span Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Description | Geometric calculated fall-in or linear measured grow-in | Distance from LPC to the conductor: Grow-in = as-surveyed distance; Fall-in = modeled distance if tree falls to line | Area of interest or measured limit from conductor | Interval area of each LPC | LIDAR data type | Horizontal distance from LPC to last structure as flown during LIDAR scan | Horizontal distance from LPC to center line of ROW and/or trans-mission structures | Latitude | Longitude | Height of LPC | Height of a point on conductor measured for clearance to LPC | Span length |
| Data Row | Fall-in | 5.70 m (18.71 ft) | 6.10 m (20 ft) | 3.05 m (10 ft) | Not Modeled | 49.31m (161.8 ft) | -11.58 m (-37.98 ft) | 42.1 864 | 75.1 709 | 12.88 m ( 42.2 ft) | 16.36 m (53.69 ft) | 80.50 m (264.1 ft) |
| Data Row | Grow-in | 2.76 m (9.05 ft) | 3.05 m (10 ft) | 3.05 m (10 ft) | Modeled for maximum loading and temp., ice or wind | 33.54 m (110.06 ft) | -3.96 m (-13.02 ft) | 42.1 134 | 75.2 335 | 18.59 m (60.99 ft) | 21.08 m (69.15 ft) | 90.89 m (298.21 ft) |

**Table 1 - An Interpretive Table of Target LIDAR Point Condition Measurements in Meters [Note: This data have been altered for security reasons but the presentation is similar to the way forestry inspectors view it in their tablet PC. A negative fall-in clearance distance = measurement of how far a tree could fall *beyond* the point of contact with the conductor. A negative offset represents a measurement from the structure centerline to LPC on the *right* side of the ROW].**

the line due to a specific wind speed. It is possible for one tree to be a grow-in and a fall-in for as-surveyed conditions, a grow-in in all three modeled conditions, and a fall-in at maximum temperature. Thus, this one tree could be represented as six different LPC. This does not take into account that any one tree could have several LPC associated with it in each of the six categories.

For many LPC, this redundancy of inspection locations was repeated throughout each modeled and non-modeled condition. It was not uncommon for a LPC to be listed in multiple rows of data and on separate spreadsheets for as-surveyed or as-modeled data. Without reconciling this redundancy, the summary of LIDAR data can be skewed, and inspections can be confusing. The first method required the inspector to recognize the problem. The second method required data filtering and elimination to reduce the confusion. Finally, a process of finding equal or nearby GPS data was used to integrate the redundant data. All three methods were employed for the project, and there is a need to improve the data scrubbing process in future projects. This is discussed at the end of the paper.

A fall-in measurement is any LPC corresponding to a location in a tree that could come within a specified number of feet short of or past the line, if the whole tree were to fail at the ground and fall perpendicular to the line. Fall-in measurements comprise the preponderance of LPC, depending on how far the clearance distance is set. The clearance distance is determined prior to LIDAR data processing. For many systems and transmission conductor configurations, the vast majority of these points do not currently qualify as actionable risk. One reason is a tree or tree part can fall in any direction, but the fall-in LIDAR measurements only apply to a tree that falls from the root in one direction – perpendicular to the line.

Fall-in measurements are useful for supporting the results of risk tree inspections. This study found fall-in measurements to be best used as a reference for visually locating risk trees, instead of points to be inspected. However, the original plan specified an inspection for all trees that could fall and strike the line or fall within ten feet of the line. The number of qualified fall-in LPC was too large to realistically inspect each one. Many combinations of fall-in LIDAR data could be used to plan and execute a risk tree assessment program. It is advised to run an extensive fall-in risk tree assessment project separate from a grow-in risk inspection project that has a multitude (hundreds to thousands per span) of grow-in LIDAR points.




**Figure 2.** Screenshot of PlannerVM from Terra Spectrum Technologies.

All as-surveyed LPC found within the ROW should be the highest priority targets in a LIDAR-based ground inspection. If there are many fall-in LPC in the ROW with a negative clearance distance, the risk for a Category 2 outage violation will be higher. If there are many grow-in, as-surveyed/non-modeled LPC with a clearance distance approaching the Clearance 2 requirement, a high-priority set of work orders should be expedited according to level of priority. For this study, several priority levels and associated trigger distances were established prior to the inspection process. The LIDAR provider supplied PDFs of as-surveyed, grow-in conditions. Most of the time the PDFs were not needed to find the as-surveyed locations.

## The Field Inspection Process

Once the data had been filtered and sorted, the revised spreadsheets were loaded into customized software (See Figure 2). Much could be written about the challenges of inspecting in a multitude of terrains and land types while reading an electronic map containing a maze of redundant LPC icons and associated tables of LIDAR data. There were eight different types of LPC icons, and each was color coded or filtered for identification. The icon on the map within the software identified the inspector and automatically repositioned using internal GPS as he/she traversed the ROW. This feature indicated when a target tree was close by. By clicking on the LPC icon, the inspector could view a filtered and highlighted line of associated LIDAR data below the map. By measuring the height of the tree, the distance back to a structure, or the distance to the center line with a laser rangefinder, the inspector validated he/she was standing by the exact xyz coordinates that were identified by the LIDAR scan and shown on the tablet under the map. Using the associated LIDAR measurements, the inspector performed an assessment of the tree and recorded vital data such as property address, diameter breast height

(DBH), species, tree condition, work prescription, and more.

When an inspection record was entered, it contained all of the associated LIDAR data and the data provided by the inspector. In the first year of the study, the information was recorded on the work order given to the tree crew. It was found that the LIDAR-associated data were challenging and time consuming to decipher when the crew tried to match the marked tree to the work order. In the second year, a tagging system was devised to ensure the line clearance crew would find the correct tree associated with an inspection without needing to peer at photographs, data tables and GPS locaters. A priority color-coded, semi-permanent tag was marked with a unique number and attached to the tree. Later the tree crew matched the number on the work order to the number on the tree. This tagging system also identified who inspected the tree.

In more densely vegetated spans or where there were clusters of LPC, a polygon was drawn on the electronic map that fenced in the targeted LPC. A single LPC was used to link them together. This use of polygons is being studied to improve the way that multiple LPC are accounted for, especially in larger polygons. There may be more than one priority of work contained in a polygon. One method is to count the trees in a polygon. Another is to tag all the trees in the polygon with the same work order number. In some cases the work included by a polygon is self evident. The most common problem found in the study was that inspectors liked to expedite the inspection process by including many trees in one polygon under one prescriptive work order. This type of inclusive prescription could lead to a potential omission of a higher priority tree. It also could lead to a lack of awareness of LIDAR measurements, particularly in modeled data, that indicate a clearance problem.

## Quantifying Transmission ROW Risk Beyond the High Risk Clearance Categories

Much of the LIDAR data available for use in transmission vegetation management are modeled data. The conductor is theoretically measured for clearances to vegetation through a predictive range of conductor motion calculated according to measurable variables such as electrical load, ambient temperature, wind speed and ice loading. Modeled data cannot be taken lightly, and it was found in the study that field inspectors tend to initially ignore modeled data because it does not conform to visual assessments. The inspector's visual perceptions and subsequent tree risk evaluations revealed a significant variability. Although the inspectors learned how to be very accurate in locating grow-in conditions, there are still many challenges to identifying fall-in risk trees. During the course of two complete annual inspection cycles and many audits of inspections, several different ISA Certified Arborists and degreed foresters were trained and rotated through the schedule of inspections. Each person brought a unique perspective to the process, resulting in improvements to the inspection process in the second year. These improvements, highlighted in this paper, were also incorporated into the software used to display the LIDAR data, collect tree and site condition data, and prescribe work. Project managers monitored and participated in the inspections, including field audits, during and after inspections. All of the inspectors who participated during the two inspection cycles said the LIDAR data were helpful, and most of the inspectors offered their views on how the process could be improved.

In the second year, a process was devised to prioritize some of the modeled data and emphasize the data's importance as a measurement. A simple sort of the LIDAR data tables according to heights of conductors reveals the ROW areas with the highest risk of a clearance violation or outage. The LIDAR measurement called Point at Conductor (see Table 1) corresponds to the height of the conductor at the point used to measure clearance to the LPC. CNUC sorted the LIDAR data table according to conductor height. CNUC extracted all of the rows of data that were equal to or less than a preset height, such as 9.14 meters (30 ft). This set of data was called critical wire zone (CWZ) LIDAR point conditions (Ballard et al. 2007). CNUC then identified circuits and spans that had more or less LPC in the CWZ. By knowing where modeled LPC exist and are concentrated under and adjacent to low hanging lines, CNUC could prioritize a large number of modeled LPC. These locations are susceptible to the largest variety of species. The heights of vegetation may be more specified in the TVMP for these areas. This practice is sometimes referred to as a modified wire and border zone in some TVMPs. Using LIDAR, the CWZ can be identified more precisely.

LIDAR data have the capacity to measure all vegetation heights and clearances, down to the ground and as far from the line as necessary. The LIDAR data have multiple long-term applications beyond capturing the grow-in clearance risk. For example, fire risk and hazard tree management may require an assessment of vegetation beyond the ROW. LIDAR data and the inspections generated from the data were used the second year to verify that the prescribed work had been performed on the correct trees. In the second year of inspections, the process for risk assessment was revised to bring it into compliance with ANSI A300 Part 9 Level 1 visual tree risk inspection protocol (Johnson et al. 2011, Smiley et al. 2011). The LIDAR data supported these inspections by providing the critical fall-in measurements that help define risk assessment and priority of prescription. This was a departure from the first year, when fall-in LIDAR data determined which trees were inspected for risk. Second year inspections were based almost exclusively on modeled data (audits of as-survey data were the exception). The priority definitions were revised again to ensure improved risk reduction response.

## PROJECT IMPLEMENTATION RESULTS AND RECOMMENDATIONS

### Results

The results of the study indicated that only the most salient and discrete xyz coordinate points of vegetation captured in a LIDAR scan are needed by a ground inspector to adequately schedule and plan work. The filtering criteria for feature coded LIDAR data determine what ground inspectors target during inspections. The inspector, an essential component to the LIDAR process, must revise his/her visual assessment assumptions and frequently defer to the accuracy of LIDAR data. The inspector must use the tabular LIDAR data to correctly locate the identified vegetation. The inspector augments the LIDAR data for each LPC with new findings obtained from the ground, creating work orders for crews and enabling implementation of the findings. The inspector is essential to the process in that he/she is able to assess the condition of the vegetation and can prioritize the work with the added knowledge obtained from the ground.

LIDAR has historically been promoted as a visual mapping tool, but for applications such as performed in this study, LIDAR was found to be most effective as an information matrix. The information matrix is a predictive quantification of ROW biomass. Adequate and environmentally appropriate corrective action may require data analytics, long range planning, and programmatic changes.

### LIDAR Company Recommended Deliverables

The following are proposed deliverables from a LIDAR scan that, based on this study, can improve the efficiency of getting a UVM service provider to the right tree at the right time:

1) Using appropriate search criteria and canopy segmentation, provides an identifying target LPC per tree or, where data are insufficient, per cluster of trees, within a search criteria of 3.05 m (10 ft). This point should either be the closest point to the conductor (grow-in) or the point showing the greatest fall-in value. Grow-in points always take precedence over fall-in when assigning a target LPC to a single tree or tree cluster.
2) For each tree or cluster of trees, group all of the associated LPC measurements with the identifying target LPC, including modeled, as-surveyed, fall-in and grow-in.
3) Measurements for LPC, identifying target, and associated non-target should include:
    - Latitude and longitude of LPC
    - Height of LPC
    - Clearance distance
    - Topographical elevation for conductor and trunk and/or fall-in LPC
    - Vertical distance of LPC to conductor
    - Horizontal distance of LPC to conductor
    - Height of conductor at the point where a perpendicular line from the LPC intersects the conductor
    - Span length
    - Distance to last structure
    - Horizontal distance of trunk and/or LPC position to centerline of conductor structures.

Provide a mapping and photographic LIDAR viewing tool for stakeholder communication, office analysis and field use.

## CONCLUSIONS

The technical knowledge gained from performing this LIDAR project was most apparent in the way in which tables of LIDAR measurements are vital to a field forester's understanding of distances from trees to conductors and the geometric possibilities of trees that may place energized conductors within the target areas of tree failure. The relationship between the LPC and individual trees will continue to challenge our utility forestry perspective of trees being measured principally by the standard of forestry production: the DBH. Other measurements, such as crown size, canopy size, and risk tree identifiers, and the measurements gained from technologies such as LIDAR, will soon become as important as DBH. The abilities of the inspector are limited by some paradigms of visual assessment. The future of ROW inspection will most likely transform the process to a more measurements-based activity. The precision and accuracy of LIDAR and similar technologies will be a driver of this change. LIDAR data management and electronic communication of complex data in the field will continue to provide many opportunities to improve transmission vegetation management.

The LIDAR spatial mapping industry has expanded in a relatively short period of time to encompass many uses and a range of capabilities. My conclusions, although influenced by the current state and evolution of spatial mapping sciences, are focused on solving the problems experienced during this study. The basic conclusion is LIDAR can be used to solve specific UVM problems without introducing a myriad of other problems that come with using virtual visual modeling and 3D mapping systems.

This deliverable package outlined above will facilitate efficient identification of tree locations, while providing a database that can be used in long term planning. It will allow vegetation managers to make summary characterizations of the ROW vegetation conditions. It will encourage new innovations in data analysis.

The ground inspection process proved to be a critical component of LIDAR supported vegetation

management, because professional foresters could successfully apply LIDAR measurements to locate and code-tag target trees to aid LIDAR information transfer to line clearance crews. Additionally, inspection foresters could provide a thorough understanding of site characteristics and tree inventory in terms of species, structure, health, maturity, environmental impact, tree failure risk, and prioritized prescription.

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