

A CASE STUDY: WORKFLOW ANALYSIS OF POWERLINE SYSTEMS FOR RISK MANAGEMENT

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ABSTRACT:

Typically, it has been a challenge for utility companies to implement more automated approaches to powerline maintenance. Our study considers using two emerging technologies – LIDAR and direct multiple viewing digital cameras – to address an aspect of this challenge. Airborne-LIDAR and the direct geo-referenced digital cameras are presented as tools for managing vegetation in a utility's Right-Of-Way: to maintain required clearances between powerlines and surrounding vegetation, and to detect change in the vegetation over a given timeframe. Digitizing LIDAR waveforms for powerline management will have an impact on the way powerline companies operate. We highlight here advantages and drawbacks utility firms may face in leveraging this new technology. This new surveying technique will also be assessed with respect to the risk management cycle and the national regulations to ensure it permits utility companies to fulfil the requirements of policies regarding powerline safety. Drawing from the review of a case, this study aims to introduce a workflow that utility firms can follow for their vegetation management programs. The workflow will provide utility companies a cost-effective method to manage their Utility Vegetation Management programs more effectively.

1. INTRODUCTION

On August 14, 2003, most of Ontario, Canada, and eight north-eastern states of the U.S. experienced the largest power outage in North American history (Task Force, 2004). The blackout was so extensive it lasted for up to a week in some parts. The investigative report into the incident revealed that a major cause of the blackout was trees interfering with overhead powerlines, causing the affected lines to trip and eventually contribute to the cascading power outage. The report also highlighted that three of the four lines whose tree contact led to the blackout were inspected only two or three months prior to the event – in the Spring of 2003 (Novembri, Cieslewicz, 2004). This series of events, coupled with the seeming ineffective process of inspection and maintenance of vegetation in utilities' right-of-way, prompted us to explore a better way for utility firms to assess and manage their infrastructure.

A Right-of-Way (ROW) is a corridor of land over which electric transmission lines are located. Transmission owners may own the land in fee, own an easement, or have certain license or franchise rights to construct and maintain transmission lines. It is the vegetation within the right-of-way that most concerns utility companies as these pose the most risk to the powerline structures.

The aim of our project is to look at the procedures that are being used to monitor and maintain powerline systems, and analyse if the current practices are suitable in light of available technology, or if the procedures can be improved upon. The case under study will serve as a basis for the workflow we propose a utility firm can follow for its vegetation management program.

Typical vegetation management for powerline deals with the scheduled maintenance cycle to identify hazardous trees that could fall and contact the transmission or distribution lines. Such trees are trimmed to obtain clearances that will last for the duration of the cycle, or they are removed altogether to provide the required clearance, improve access to the powerlines, and reduce future costs. The instituted Right-of-Way of the utility company determines which trees the company has access to for this maintenance.

Using airborne-LIDAR and direct geo-referenced digital camera as tools in Utility Vegetation Management first of all entails digitizing the LIDAR waveforms generated from surveying a region. The vegetation and powerline scene can then be extracted from the entire dataset and analysed. This will provide an estimate of the tree's structure, as well as show its proximity to the powerlines. Secondly, the geo-referenced camera provides the exact location the LIDAR data represents. This image and digitized waveform data can be overlaid with data collected from a previous survey. The overlay analysis will allow easy detection of the change that has occurred in the vegetation over the timeframe, and help project the vegetation's growth rate.

Prior to the blackout of 2003, the North American utility companies were not bound by North America-wide regulations when it came to supplying electricity to customers. Instead, the standards issued by the North American Electric Reliability Council (NERC) were, for the most part, followed voluntarily by the utilities. There was no power of enforcement granted to this regulatory body and so NERC could not force utility firms to comply with its standards. Following the recommendations of the investigations into the blackout, NERC became North America's Electric Reliability Organization and now its standards have become mandatory for North American

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transmission companies. A NERC official asserted that the 2003 blackout also drove the development of new regulations, such as the Vegetation Management Regulation FAC-003-1. Such regulations will help prevent the disasters associated with powerlines from becoming a reality. The change detection method we are developing which is based on LIDAR waveform analysis will help utilities to abide by these regulations.

2. THE POWERLINE NETWORK

2.1 Background

The powerline system is an interconnected network of generating plants, transmission lines, and distribution facilities (CFE, 2008). Utility companies seek to locate transmission lines in sites that are technically, economically, and environmentally acceptable to accommodate required facilities. Designating the Right-of-Way (ROW) is a significant factor when developing a transmission system. The ROW width is a function of several design considerations, e.g. transmission tower height, distance between towers, conductor size, clearances, line security, and the condition of the terrain through which the line will pass. Other factors to be considered in planning a transmission system include: amount of power the line must carry, length of the line, potential impacts to the environment and communities, costs to build and operate the line, and how the line fits into the overall electricity network or grid. It is important to know the structure of the powerline system so that the objects in the powerline scene can be properly classified and modelled in the detection model we are creating.

2.2 Components of Transmission Powerline Network

Electricity can be generated at a large scale from a number of sources such as coal, hydropower, wind, solar and nuclear power. The most common form of electricity generation in Canada is hydroelectric, followed by thermal coal (CFE, 2008). This section will highlight the main components that are used in transmitting power from generating stations to the distribution facilities.

The main components of the powerline network are:

2.2.1 Transformer: The current-flow while transmitting electrical power produces heat which is actually electricity lost in the transmission medium. To minimize the amount of heat generated in transmission lines, and thus electricity losses, electric power is transmitted at high voltage and low current. So after the electricity is generated, step-up transformers increase the voltage in order to carry electricity efficiently (with minimum losses) over long distances along the transmission lines. The line voltages can be as high as 735 kV. Transmission lines in Canada mostly carry electricity at 115 kV, 230 kV, or 500 kV however. At the other end where the electricity is used, step-down transformers are needed in the distribution system to lower the voltage to suitable levels for domestic, commercial and industrial uses.

2.2.2 Lightning Arresters: Lightning arresters are installed at strategic locations on the transmission lines, usually three or four spans apart. They protect the transformers and other electrical apparatus from voltage surges. Their ground wires are connected to the overhead ground wire and to the steel structure on tower lines, or to counterpoises where they exist.

2.2.3 Shieldwires: Transmission lines may have smaller conductors called shield wires strung above them. These are connected directly to the transmission line towers and protect the main conductors from a direct lightning strike. The shield wires provide an easy or low resistance path to the ground through the transmission towers. If lightning strikes, it will hit the shield wires rather than the conductors (CFE, 2008).

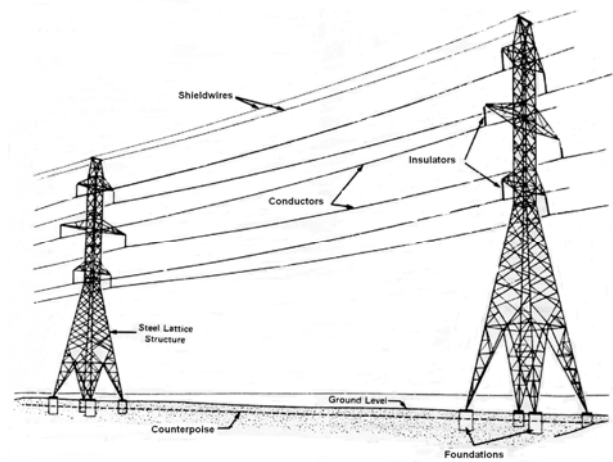


Figure 1. Components of a typical transmission line

2.2.4 Insulators: Insulators electrically isolate transmission lines from each other as well as from their supporting structure. Glass and porcelain were traditionally the insulators of choice but porcelain was usually more practical because it can withstand greater temperature differentials and does not break as easily as glass. More recently, polymer (in the form of fibreglass) has been favoured over porcelain as an insulator for powerlines and powerline system equipment because it has better water and sleet shedding properties, and has a better strength to weight ratio. A polymer insulator also permits increased conductor and static wire line tensions, resulting in lower construction designs by permitting longer spans, fewer towers or lower tower heights.

2.2.5 Powerlines: Powerline conductors provide electrical circuits between the points of electricity supply and use. They vary in size according to the rated voltage, and the number of conductors strung on a pole depends on the type of circuits that are used. Most commonly, aluminium and copper had been used as conductors because of their low resistance. Now, aluminium has replaced copper as the most common conductor metal for overhead transmission (Pansini, 2008). Power can be transmitted along overhead powerlines or underground cables. Most of Canada's transmission system has overhead lines; more expensive underground lines are used in urban areas or for crossing bodies of water.

2.2.6 Underground structures: Foundations are necessary to support structures. They may be made of steel grillage, reinforced concrete, or steel or wood piles with suitable cap. The counterpoise is a buried conductor running parallel to the transmission line that reduces the resistance of the tower footing (Pansini, 2008). It reduces the susceptibility of the line to outages caused by lightning. The counterpoise is normally made of galvanized steel or copper.

2.2.7 Transmission Towers: The transmission towers support conductors at a safe elevation above the ground. Towers are generally fabricated of galvanized steel members. Their height may vary from 50 feet to 150 feet depending on the voltage of the transmission line, the standards of distances for the lowest conductor at the lowest point of sag to the ground, and clearances between conductors. There are several types of towers. **Angle or corner towers** are designed to hold the spans of conductors on either side that are at an angle with each other. These towers have great strength and may also be guyed to balance the uneven force from the conductors attached to the crossarm on the tower.

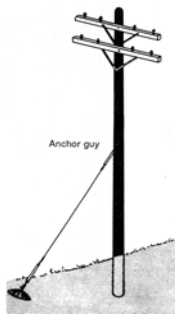


Figure 2. Guy: brace or cable fastened to the pole to keep the pole in position under strain



Figure 3. Corner Tower

Suspension or tangent towers are those where the insulators to which the conductors are attached are free to swing.



Figure 4. Suspension Tower

When a conductor terminates on a pole, it is said to dead-end on the pole. **Dead-end towers** carry the weight of the span of the conductor. This tower is stronger than the suspension tower; it is designed purposely to withstand failure. For instance, if all the conductors on one side break from being ice-laden or wind-driven, the other side should be able to balance the conductors there.

2.2.8 Switches: Switches are used to interrupt the continuity of a circuit. There are two broad classifications: air switches and oil or gas switches. Reclosers consist of an oil switch or breaker actuated by relays which cause it to open when predetermined current-values flow through it. They are usually connected to protect portions of primary circuits and may take the place of line fuses. The switch or breaker is arranged to reclose after a short interval of time and reopen again should the fault or overload which caused the excess current-flow persist.



Figure 5. Pole-mounted air-break switch in open position

2.3 Conventional Right-of-Way Maintenance

The study area on this project is the province of Ontario in Canada. Most of the transmission lines in Ontario are owned by Hydro One Inc. so we used their maintenance procedure as a point of reference for what normally occurs in our study region. Hydro One maintains vegetation according to their *Right-of-Way Vegetation Management Program*. It requires them to perform vegetation assessment on a six-year cycle for most of the province (the northern part of the province is scheduled on an eight-year cycle).

The focus of their program is ensuring there is adequate clearance between the live conductors and the surrounding vegetation. What they are most concerned with is determining the vegetation's rate of growth. Mid-way in the cycle, they do a patrol in the ROW to assess the condition of the vegetation's growth. At this stage, they are: (i) looking for any problems they have, (ii) analysing if it is alright to remain on the cycle, for instance the eight-year cycle. If the vegetation is not growing quickly in that area, they might put it on a longer cycle. All of these are ground-based activities at Hydro One. The measurements the crew takes may be done using laser measuring devices, optical measuring devices, or telescoping poles. For the most part, Hydro One uses optical tools for calculating the heights and distances. On the rare occasions that they survey the ROW by helicopter, they inspect the area with hovering binoculars and take photographs of the area being surveyed, recording the entire scene – not just identified problem areas. When doing aerial inspections, a GPS or notepad is used for record-keeping.

Hydro One has GPS coordinates of all their structure in the province. They also have imagery. But they do not incorporate GIS methods into their data collection. For now, the GPS data they have is used extensively by provincial mines and the forestry departments.

Following an inspection, the crew generates a Condition Assessment Report. A lot of Hydro One's programs are based on Condition Assessment Activities so it behoves the crew to ensure their data collection and data reporting are accurate.

Finally, based on the Report, Hydro One removes "Danger Trees" that have been identified. The reason 'Danger Trees' are a danger is because the utility does not own the land where the tree stands (it is outside the ROW), yet it poses a risk to the powerline structure. The tree may be unhealthy (might be hollow, leaning, or infested by insects), or its footing may be in poor soil or on eroded ground; such a tree is likely to get blown over in high wind conditions. There is provincial legislation to allow Hydro One to remove any tree that is deemed a danger tree. Trees or brush on the ROW that may grow too high before the cycle is over are either trimmed or sprayed with herbicide to slow the vegetation's growth.

Based on conversations we had with Hydro One staff, the diagram below can illustrate the workflow options Hydro One chooses from to maintain their ROW.

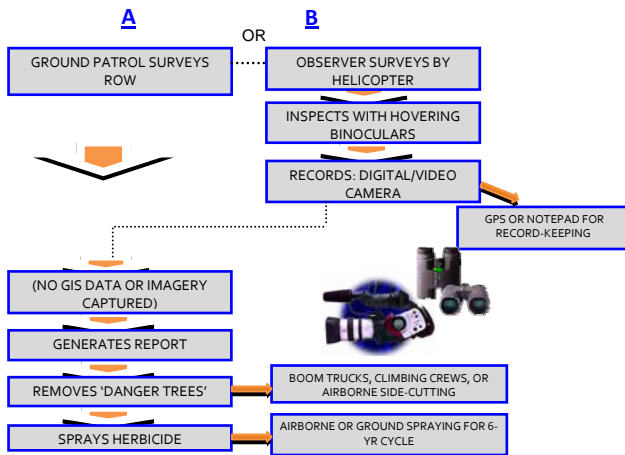


Figure 6. Typical Workflow of Hydro One’s Typical ROW Maintenance

3. REGULATORY FRAMEWORK

3.1 Right-of-Way Regulation Changes after Blackout

It is generally accepted that the single largest cause of electric power outages arises from trees, or portions of the trees, that grow or fall into overhead powerlines (Novembri, Cieslewicz, 2004). (Such vegetation is referred to as grow-ins or fall-ins respectively.) Prior to the August 2003 blackout that affected most of Ontario and part of the north-eastern U.S., NERC – the body that develops and monitors reliability standards for electric utilities in North America – did not have a standard related to vegetation along a transmission company’s ROW. In fact, the U.S.-Canada governmental investigative report into the incident stated NERC was lacking “strong, clear, and unambiguous” policies overall (Task Force, 2004). The report noted that some of NERC’s standards and processes were inadequate because they did not give sufficiently clear direction to the industry members regarding some preventive measures needed to maintain reliability. However, NERC did not even have the authority to enforce compliance with the standards. The August 14 blackout was a clear signal that voluntary compliance with reliability rules was no longer adequate (Task Force, 2004). As a NERC official told us, many NERC standards were followed based on ‘peer pressure’ in the industry since compliance was not mandatory: utility companies copied the procedures other utilities had had success with. After a while, these Best Practices may allow NERC to raise the standards higher.

NERC can now enforce standards with fines, and in 2005 NERC adopted a new vegetation management standard. The standard is intended to make utility companies develop a vegetation management program that would allow them to meet the performance requirements stipulated by the standard. NERC’s other intention for the standard was to improve the transmission systems’ reliability by: a) eliminating outages caused by vegetation in or adjacent to the ROW, and b) by maintaining safe clearances between the transmission lines and vegetation on the ROW. The standard also established a system for reporting vegetation-related outages.

The vegetation management standard (FAC-003-1) has a total of four requirements, one of which entails reporting outages to the Regional Reliability Organization according to categories.

The groupings are: Category 1 = Outages due to Grow-ins; Category 2 = Outages from Fall-ins in Right-Of-Way; Category 3 = Outages due to Fall-ins from outside Right-Of-Way. A summary of tree-related outages in North America over the last four years reveals that the majority of these incidents are caused by trees or portions of trees outside the ROW falling into powerlines (Table 1). This again demonstrates how crucial it is for utilities to perform proper danger-tree analysis to maintain reliable service to customers.

Year	Category 1 GROW-INS (inside/outside ROW)	Category 2 FALL-INS (inside ROW)	Category 3 FALL-INS (outside ROW)
2004	5	2	27
2005	8	8	25
2006	6	0	20
2007	16	3	22

Table 1. Recent Vegetation-related outages in North America

NERC’s Board of Trustees approved other vegetation-related standards namely the Transmission Vegetation Management Annual Work Plan (FAC-006-1) and Reporting for Vegetation-Related Outages (FAC-007-1), but they did not pass regulatory approval and so were not adopted. FAC-003-1 covers part of the scope these standards had proposed.

3.2 Developing Workflow around Regulations

Of the four lines where tree-related outages occurred which led to the cascading 2003 blackout, three had been aerially inspected in April and June ’03. The reports from the inspections indicated no vegetation-related problems were observed (Novembri, Cieslewicz, 2004). This led the consultants that were hired to support the federal investigation to conclude that helicopter patrols have problems identifying vegetation that might be violating the clearance requirements because it is not possible to “consistently and accurately determine the distance between vegetation and conductors” from the helicopter patrol (Task Force, 2004). The joint-government report also concluded that since the notes from flyovers of Spring 2003 found few problems, their aerial survey needs to be supplemented with ground patrols. However, we would suggest that if the helisurveys are done with better tools – rather than relying on the human eye and binoculars but combining the LIDAR and direct geo-referenced camera – more accurate data will be gathered and hence more reliable service delivered to customers. Another benefit of this process is that the ‘notes’ the crew brings back can be supplemented by visuals that other staff can also perform data processing and analysis on, making decisions less subjective to individual interpretation.

The case study, Hydro One, operates by their vegetation growth specifications. For them, vegetation is not allowed to come more than within 10 feet of the transmission line. They do brush clearing and tree clearing on a 6-year cycle so on a 115 kV line for instance, a clearance of 10ft + 6 years growth is obtained. A growth chart is available to estimate the growth rate of each species. They can then decide if there is sufficient clearance (according to stipulated guidelines) between the vegetation and the powerlines or if the shrubs, trees, or bushes need to be cut in order not to interfere with the safe transmission of power. In many parts of Ontario, there are different species of trees which have varying growth rates. For such areas, the initial estimate for growth rate is done using the dominant species.

If desired, another application of LIDAR can be incorporated in analysing the powerline scene: determining the health of the surrounding vegetation. A tree’s health can be estimated by

analysing the amount of chlorophyll in the tree's leaves. Again, this will require processing the raw LIDAR data gathered from the helisurvey, but it can be much easier than present manual methods – which may also be subjective. It is also possible to extract the terrain from the imagery captured in the survey. The slope of the terrain will be useful to utility companies to determine if a tree poses a risk to the powerline, being on an incline, especially if the soil conditions are poor.

NERC's FAC-003-1 Standard requires that each transmission owner has a Transmission Vegetation Management Plan. For the vegetation management plan to be effective, proper tools must be used to gather data, and subsequently good analysis must be done on the data collected. It is on the basis of these regulatory requirements, and the information utility firms express they need from an inspection, that we are developing this workflow that hinges on newer technology. This new method being proposed uses the airborne-LIDAR and direct geo-referenced digital camera as tools in Utility Vegetation Management.

3.3 Social Aspects in Creating our Maintenance Workflow

- Governmental authorities expect the recommendations raised in the joint-government investigative report to have been implemented with appropriate regulations in place
- Utility customers expect regulations to guarantee reliable electric service
- Switching to a more automated process may raise fears of job cuts for ground crews. However, they can be retrained for other positions the firm will require as they use this new method
- Property owners may hinder Utilities' Vegetation Management work, e.g. when a property owner refuses vegetation to be cut or trimmed for aesthetic reasons. Also, archaeological sites, wetlands, or the presence of endangered species may prevent tree-cutting along ROW
- The use of herbicides for controlling the growth of vegetation along the ROW may pose risks to the health of residents and to the environment
- Common risks associated with powerlines include fires, electrocution, damage to surrounding infrastructure, and major power outages
- Maintaining a proper corridor (the ROW) is crucial in serving as a firebreak, or as staging and access points to assist in wildland fire-fighting efforts
- The Wire-Zone–Border Zone model is most recommended for vegetation management. It involves creating a predictable and low-growing environment of vegetation under (wire-zone) and adjacent to (border-zone) the ROW. The model has been shown to reduce long-term maintenance costs, improved habitat for wildlife, biodiversity, and wildland fire mitigation. The Figure below illustrates this concept:

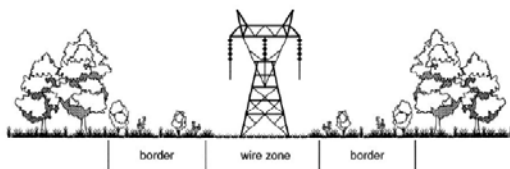


Figure 7: Wire zone-Border zone vegetation management

4. TECHNOLOGICAL ADVANCEMENTS

When decision makers only use static monitoring techniques, they cannot perform digital comparisons of a scene. But by making multiple passes over the scene with the airborne-LIDAR sensor and digital cameras, processing the data, and

observing the spatial-temporal results through a process like overlaying, they can see the difference in structures like buildings or the height of trees near or along the ROW. This is the process we intend to introduce to utilities' workflows to further automate and improve their risk management procedures. The LIDAR and digital cameras have been used separately to map corridor scenes. Merging their data will provide an even wider range of corridor scene information. Our ability to analyse the full LIDAR waveform will be vital for this process. Usually, only the first or second return of the LIDAR laser pulse is analysed, these being the strongest returns. However, analysing the full waveform will indicate a powerline structure, a building, a tree, brush, and so on. This is one reason why the heuristic knowledge of the powerline network was important for us to study. By knowing patterns in the setup – for example where a dead-end tower is normally located, or how many insulators are used on each span of powerline – we are better able to depict the scene we survey, from the LIDAR and imaging data.

A variation in waveform return amplitude indicates what structure is encountered. For instance, Figure 8 shows how different parts of the waveform indicate different scene objects.

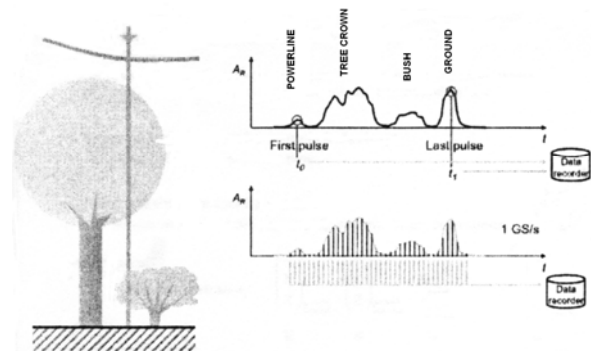


Figure 8. Full waveform analysis for scene modelling

A spectral analysis of the waveform can also be done to determine the chlorophyll content of leaves, giving an indication of health.

Advantages of surveying using this technique include:

- Data can be manipulated by data analysts for different purposes
- Displaying a scene in 3D makes it more realistic for decision makers to view and draw conclusions on the specific actions required.
- Using this technology will improve efficiency of maintenance procedures by allowing data to be processed and acted on quicker.
- The waveform data provides an almost unlimited number of laser returns so a more detailed description of object structure can be generated
- The accuracy and quality of the scene information is increased. It is also more reliable since it is not solely dependent on what helicopter observer notices
- When ROW and structural maintenance cycles coincide, the utility can survey for both purposes in the same run
- The costs for updating powerline information during subsequent data acquisition is much less compared to costs based on daily crew rates

LIDAR has been emerging recently as a tool for powerline corridor mapping. However, merging airborne LIDAR with

direct geo-referenced megapixel digital cameras is a new approach. It is especially attractive because these tools can provide a high resolution imagery of the powerline scene. Thus it will depict the corridor, vegetation, as well as small objects such as insulators, with high image quality and three-dimensional information.

Combining the data from these two sensors – the LIDAR and digital camera – presents unique challenges, particularly with correctly fusing data from two independent sources. Tests need to be done to find the maximum flight speed that will be within both instruments' tolerance level for accuracy. Perhaps the only reservations utility companies might have in adopting this technique for their ROW inspection is the initial cost. It is much higher than the traditional method using ground crews, but over subsequent years, the cost saving of labour per mile of data will show the method to be very much worth using.

5. DISCUSSIONS AND FUTURE DIRECTIONS

Scheduling vegetation management should be based on an analysis of the workload and current conditions. We believe a workflow designed to incorporate LIDAR and digital camera imagery will make vegetation monitoring easier. It also provides utility companies a more effective method to manage their vegetation management programs, and at a reasonable cost.

Apart from providing a safe and reliable electric service to customers, having a proper vegetation management program enables the utility company to operate at the lowest reasonable cost. It also allows the workers to safely access the facilities for inspection, maintenance, and repair. Power interruptions by tree contacts have contributed to over 20% of service interruptions (Eckert, 2004). This may reflect in momentary interruptions or current diversions, but the varying power quality can add up to huge monetary losses. For instance, industries that rely on power-intensive processes for their operations would be some of the hardest hit by power interruptions/fluctuations; some of these industries include the manufacturing, electronic/system designs, and telecommunications firms. Others may lose out in productivity as well; for example, in research labs where samples are meant to be under controlled temperature conditions, an entire experiment might need to be redone.

It has been estimated that the annual US economic loss due to power outages ranges from US\$50 billion to US\$100 billion (Guggenmoos, 2004). An incentive for utility companies to have good maintenance practices is that they make money only when customers have power: If the meters are not running, their source of revenue stops. Despite having a vegetation management program plan in place, there will always be unpredictable events such as extreme weather events, variable tree and vegetation growth rates, or even hindrances from legal battles with customers. However, monitoring the change in the vegetation growth between cycles is much easier using this advanced technological procedure.

Our study is still ongoing, with the finalized workflow to be completed within the next three months, but overall the study aims to solve a part of the problem of vegetation that poses a risk to powerlines going undetected. What we suggest is that instead of manual visual comparison for maintaining the ROW, LIDAR technology and digital camera imagery should be used. The maintenance will be more efficient, take less time, be much more accurate, and should prove less costly over the long term. To illustrate this method's speed, an aerial survey may take an

average of 50 km a day to gather LIDAR data, combining ROW and transmission structure inspection. This would typically take a ground crew about 4 days just to inspect. Thus, the automated process is much faster in generating usable information for decision making and analysis. The powerline system components can also be inspected from the survey data.

For now, the end-user of our workflow design is the electric utility companies. However, we anticipate the methods and technology will interest the road management, rail lines, and pipeline sector as part of their risk management activities. Asset mapping and inspection companies such as GeoDigital will also benefit from using this technique. We hope this project will provide a bedrock for future related research in modelling and classifying scenes, especially for detecting change in scenes. We look to build Ontario's research in corridor mapping techniques, reduce utility companies' maintenance costs, and most of all encourage electric utility firms to look at maintenance procedures a bit differently. We hope that in some way, our proposition of a new workflow for utilities will spur more sectors to innovate, and continuously find ways to improve.

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