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Grid Modernization, resilience and hardening – a framework for asset management to allow for practical application.

CORNELIUS HENDERSON
Valard Construction LP
Canada

SUMMARY

Distribution grid infrastructure can be severely damaged by large scale weather events and natural disasters. It is difficult for management to address because of the constrained chaos that underlines everything regarding grid modernization, which pops up when the decision is made to invest in modernization, resilience / hardening. Recent increases in large scale weather events show that subjugation of this daunting task of modernization isn't an option. Structural failures and associated customer level disruptions often require highly complex and costly restoration in a short amount of time as it is an essential service. The effects often stretch further than physical damage to the utility assets, as it can cause wildfires, and interrupt everyday services relying on power and disrupt joint-use telecommunications infrastructure. All while modernization could predict, increase resilience, and decrease the impact of large-scale weather events.
Customers expect distribution systems to be reliable, properly engineered and maintained. That said, many have seen newsfeeds with a plethora of large-scale events ranging from wildfires and hurricanes to polar vortexes and ice-storms, all of which (multiple types of events) continue to place grid resilience in the spotlight.
In 2018 six U.S. states broke wildfire records and California saw its deadliest and most destructive wildfire season ever recorded. In 2019, Atlantic hurricane season marked the fourth consecutive year of above-average storms, with a record 18 named storms [1]. Flooding across the nation impacted 14 million people. Disturbances increased from less than 10 in 1992 to almost 80 in 2009 [1].
Nearly 21,000 Manitoba homes and businesses were left without power in October 2019 in the wake of a snowstorm that the province's Crown energy utility said, had left an unprecedented amount of damage to infrastructure [3].
The paper aims to set a framework, backed by numbers produced from a technical study, for the process of mechanical grid modernization including hardening and improved resilience.

Email: Cornelius.henderson@valard.com

KEYWORDS

Distribution grid modernization, distribution grid resilience, weather hardening, telecommunication joint use, customer service disruption, targeted investment, asset management, rural broadband, telecommunication outside plant.

SPECIAL RECOGNITION

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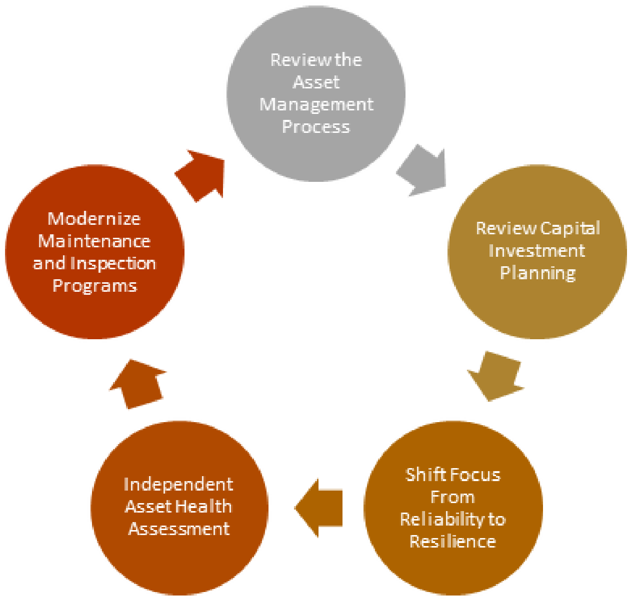
FUNDING THE NEED FOR GRID MODERNIZATION

When looking at the scale of destruction of large weather events it is difficult for any asset manager to know how much money to budget for and where to apply it. A survey by Black & Veatch showed asset managers allowing for more than $200 million to update distribution systems [4], including grid modernization. Improving resilience is the main driver for this.
In 2020 SaskPower plans to inspect 119000 poles for decay, carpenter ant infestation and general damage [5]. The utility also plans to replace 2500 poles. And while inspection of the adequacy of the distribution pole material still has its place in the allowance for spending to ensure a resilient grid, modernized modeling of the grid has shown to possibly be of great importance.
Florida Governor Ron DeSantis signed Senate Bill 769 in June 2019, to facilitate strengthening utility infrastructure to improve grid resilience (against weather events) [6].



The new rules would allow utilities to separate resiliency services from traditional ratemaking. Utilities would be allowed to implement a monthly storm hardening fee, a surcharge that will be passed on to ratepayers. But utilities shouldn't underestimate their ability to educate their customers about the tangible benefits of storm hardening – home and business owners, for example, will experience firsthand the benefit of underground power lines when the next hurricane hits and the lights stay on.
On the other hand, they would see how problematic and costly installation and repair of underground cables can be when compared to overhead utilities. And possibly see that underground cables still don't mean much when the overhead lines that feed them fail. Is the move to underground cables the best way forward? The question again turns to the reason for distribution pole failure in the first place. Are poles falling over because they were not adequately designed?

ALIGNING SPENDING WITH NEEDS

When it comes to grid modernization, exactly how much utilities want to invest, and where asset managers target their funds is still difficult. Utilities spend millions to hundreds of millions on pole inspections over widespread areas focusing on the poles that are the oldest. The mindset of utilities is changing, and asset managers are starting to see that this approach is not solving the problem. While the result helps reinforce if poles' materials are adequate, it simply doesn't explain why poles are still falling over (or widely seen in the field showing excessive rake, cracking, split tips).
Regulators want utilities to be innovative but has resorted, in Canada, to pushing them in the right direction with requirements of modelling and doing non-linear analysis when additional load is placed on a structure. The push has been met with resistance as it places more strain on overburdened workforce and constrained budgets. Utilities are forced to review internal processes, budget for grid modernization, and start to implement it with little guidance on

what such a process should look like. The first large scale modernized grid analysis and resiliency studies will offer asset managers and utilities the focussed approach they need to budget and control spending when investing in improving or hardening their assets.

RESILIENCE STUDIES AND MODERNIZATION

A recent study by SaskPower [7] and SaskTel [8] working together, may just give the insight to the cost of hardening a distribution grid to improve resiliency and to try and answer the question where and why poles might fall over in large scale weather events. It also shows regulators how innovative they can be. Valard Construction [9] was tasked to survey, model and do a full non-linear analysis of over 2500 distribution structures, complete with the exact primary-, secondary- and telecommunication cables obtained from the partner's GIS data. The study formed part of a large scale FTTP rollout project. Although the cheapest way to connect properties to a large fibre optic network remains through areal connections, the requirement by regulatory bodies for utilities to model the additional mechanical loading on the infrastructure can halt such FTTP expansion plans entirely. Similar predictions are already made for future 5G implementation. The telecommunication projects require fundamental change in the Distribution utility asset management to be successful. Valard Construction LP proposed modernizing as a solution that would benefit all parties and ultimately also have a positive impact on the communities in the form of high-speed communication connections.

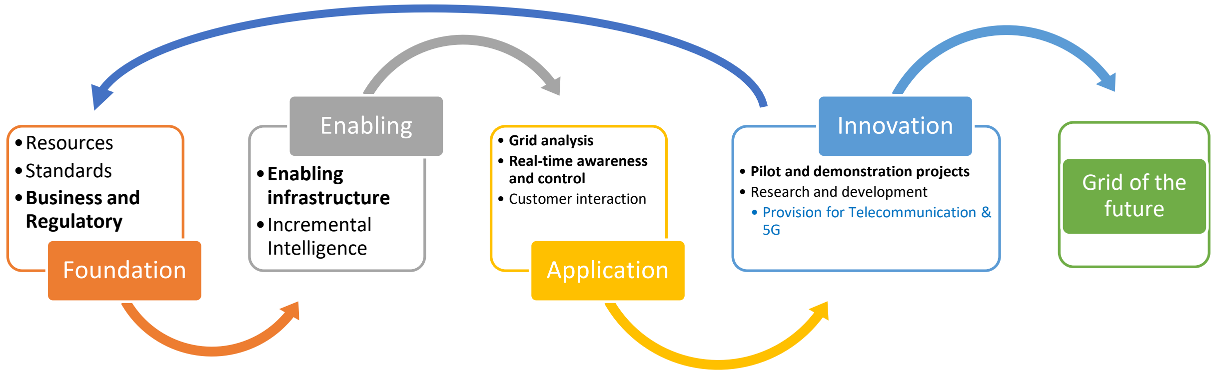


Figure 1: Grid modernization process flow

The assets modelled were spread over a dozen communities and included commercial-, residential- and industrial zones, each of which has its own different needs with regards to both power and telecommunication.
The telecommunication cables were modelled exactly as per data from the telecommunication service provider and using publicly available information of average telecommunication cable sizes and weights. All pole data was captured in the field during the survey and included the pole species, class and height. The embedded depth and attachment heights were measured using photogrammetric survey using the Katapult [10] cloud-based platform. Mid-span sag was also measured in the same way to accurately model overhead cable tensions. The location of all poles, guy anchors and mid-span sag points were measured with GPS to millimetre accuracy.
The cost of all of this was roughly $110 / pole. Different survey techniques such as the use of LiDAR could lower the cost of a larger study group. Was all this worth the money spent? The result was a razor-sharp indication of where infrastructure would likely fail in a large-scale weather event (Figure 1), and more importantly, why they would fail (Figure 4, Figure 5).

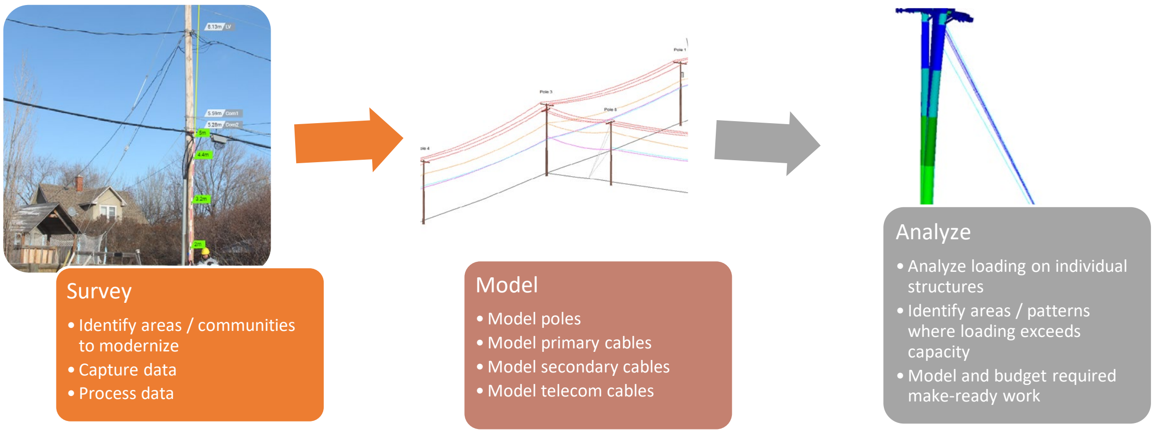


Figure 2: Basic process of modernization

It also gives the bonus of an audit of the accuracy of the utility GIS data, as well as a digital model containing all as-built data which can easily be used to design for expansion and design for replacement (if hit by a large-scale event).
The study shows reoccurring (or patterns) of failure mechanisms, and all of this was done on the base assumption that the pole material was adequate to handle the load that was applied to it. Deviating from the mindset "it has been standing there for 30 years, the only reason it would fail would be because of deterioration". Results showed as much as 10% of poles at risk of failure during a large-scale weather event, just because of the current mechanical loading applied to the structure is too much for it to handle.

SCALE OF INCREASED LOADING

When specified weather loading criteria [11] is applied, the study showed that there is a general increase in loading around certain areas, when compared to other areas. A general rule in overhead lines is that fewer / smaller cables will show reduced loading. The non-linear analysis study was therefore restricted to study 3-phase structures to make the study affordable. The loading on poles studied is therefore similar in this regard. The area of the studies was also in a very flat area so that differences in weight span had very little (to negligible) impact on the loading comparison across the whole of the communities studied. Communities had as little as 5m difference between the maximum height above MSL vs. the lowest measured height. All poles were modelled as new [12].

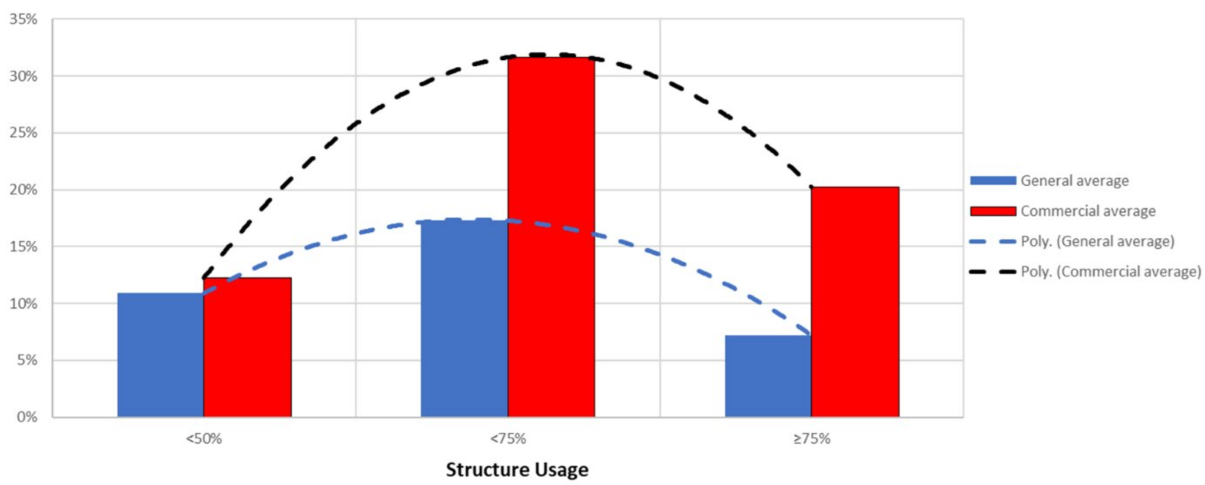


Figure 3: Comparison of residential and commercial zone structural usage

The loading for all pole's studied was compared with the quantity of poles, in the same area, from the utility's GIS data. The average loading of poles was divided into three categories; low usage (<50%), medium usage (>50%, <75%), and exceeding 75% to failure. Results of this can be seen in Figure 5 and shows, as can be expected, that most poles are being used at medium capacity and only 5% used at high capacity.
When the same comparison was drawn but limited to commercial zones (as obtained from municipal mapping), the average of wood poles used at medium capacity jumps from 17% to 31.6% while highly loaded (and failing) poles increased from 7% to 20.2%.
The quantity of poles showing failure during non-linear analysis when high weather loading criteria is applied exceeded 10% on average. While a non-linear analysis showing the possibility of a 1-in-10 pole failure rate during a large-scale weather event is certainly a concern for a utility, it is a studied model and far better than the actual event of failure combined with the large-scale fallout.

IDENTIFICATION OF HIGH LOAD CORRIDORS

In the community shown in (Figure 4, Figure 5) high mechanical load corridors are identified as the distribution lines running parallel to the main roads, in the commercial zone as identified in the community's zoning map. The lines in these corridors feed the lines branching off into the residential zones. The poles are shown as red and black dots (red for loads exceeding 75% and black for loads more than 50% of pole capacity).
The green dots indicate poles that are used at less than 50% of their mechanical loading capacity. The yellow circles show intersection points.
With the focused approach applied to the commercial zones the count showed a drastic jump in the structures in mid- and high usage divisions (31.6% and 2.2% respectively) and geographically it shows the jump attributed to specific alignments in back lanes paralleling main roads.

The high load corridors commonly carry larger diameter distribution primary cables which acts as the greatest contributor to the load on the structure. The high load corridor also shows a larger increase in the loading contributed by joint-use telecommunication partners. Telecommunication distribution stations are commonly located in the commercial zones, and from there feed outwards to the rest of the community.
While areas like these are known for poles showing excessive rake, and being heavily loaded, only a non-linear study of the as-built structures can truly show the scale of over-loading and how the risk of collapse during large scale events could impact grid resilience.

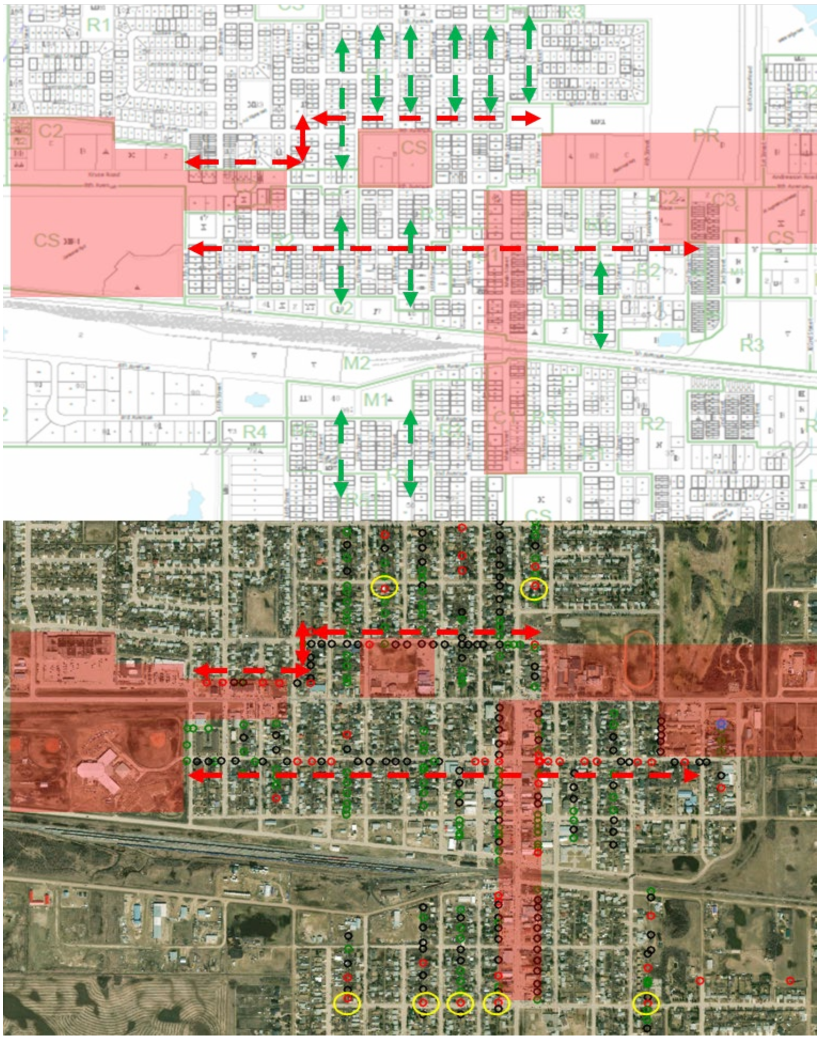


Figure 4: Comparison between structural loading and commercial zoning, example 1

These corridors also see the highest volume of traffic in the form of delivery trucks that damage anchors and poles. Waste removal bins and trucks that continuously move in the back alleys causing damage on poles' surfaces and force the cable attachments higher on the pole, in turn creating larger overturning moments. It also sees the most laterals added onto poles to connect with civil infrastructure (both electrical and telecommunication). Pole laterals are often seen as only as a subsurface disturbance or a nuisance for traditional pole maintenance such as climbing. In terms of non-linear analysis, it is a marker for changes in telecommunication bundle diameters creating longitudinal imbalances or increased loading because of equipment (transformers, breakers, etc.).

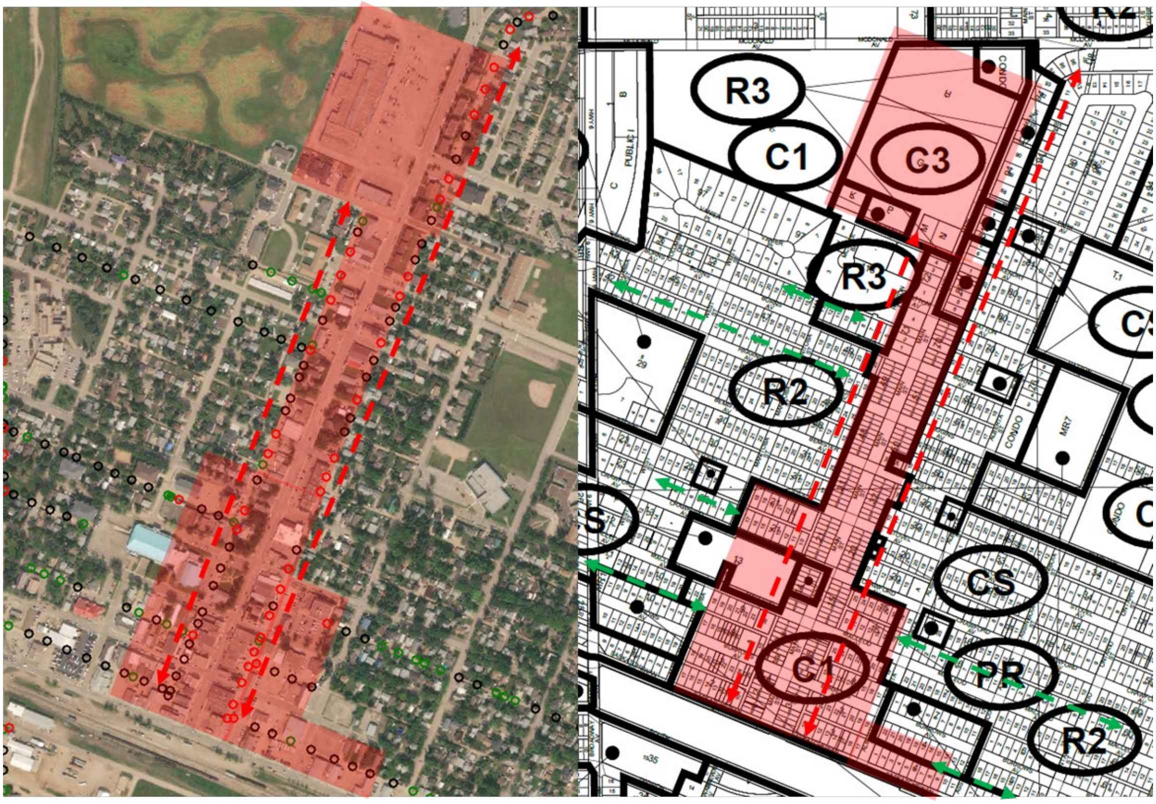


Figure 5: Comparison between structural loading and commercial zoning, example 2

ADDITIONAL PATTERNS OF FAILURE IDENTIFIED WITH NON-LINEAR ANALYSIS

There is another reason than the weight and diameter of cables contributing to the excessive loading on the structure. The reason is, for lack of a better word, over-maintenance. While linesmen do their work very well and with pride, they are forced to "keep the lights on" in a highly congested area. Continuous expansion, connections, maintenance, and small moves of attachments add up over time to create an unstable structure in a dynamic environment. The same age pole just a few spans away in the residential back alley will likely not have been subjected to such changes since it's installation. During everyday work, a non-linear analysis isn't showing the actual loading on the structures or used to model and track all the changes on these structures in high-load corridors while linesmen work and make small changes. Expansion of buildings, increasing sizes of parking lots etc. constrain the practical application of mechanical stabilizing parts such as guy anchors. Linesmen are forced to remove anchors that are constantly damaged while simultaneously adding equipment and large secondary cables to feed customers. Telecommunication connections face the same problems where new technology drives the need for more cables (FTTP connections).

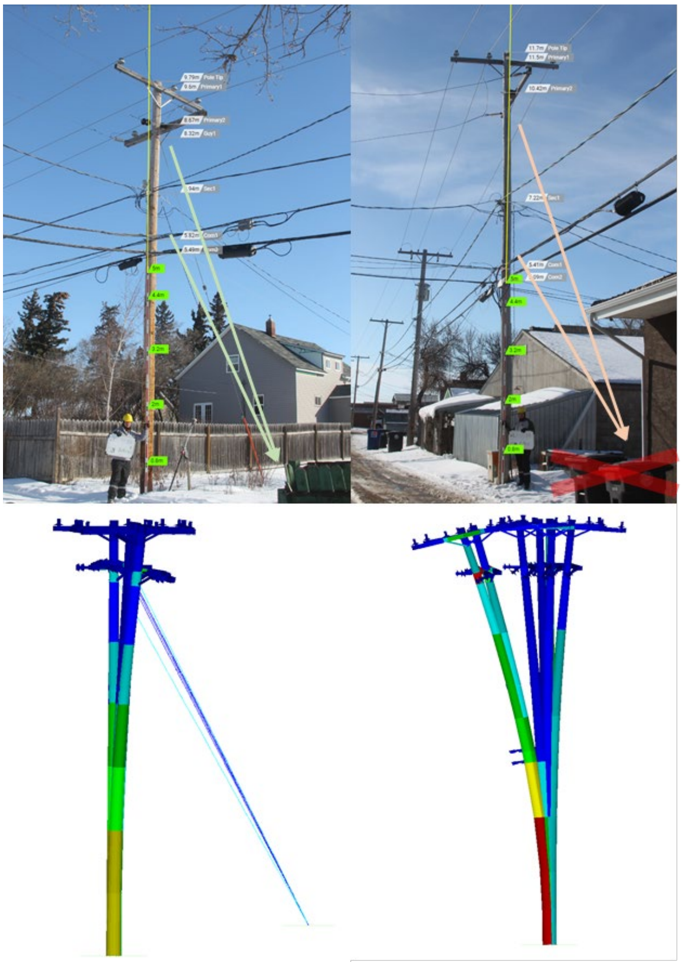


Figure 6: Impact of commercial congestion on structural footprint and loading

The study also found a pattern of failures in structures located at crossings or intersections. These structures not only carry more than one circuit, which doubles the wind- and weight span, but also act as a point where telecommunication cable routes change direction. Some messenger wire crossings are tied together, and lashed telecommunication bundles jump from one to another and change direction in mid-air above road intersections. The multitude of attachments combined with the possible change of cable weights on all sides of the poles by both the utility and joint use partners, and very little to no space for stabilizing anchors, makes the poles see increased failure rates.

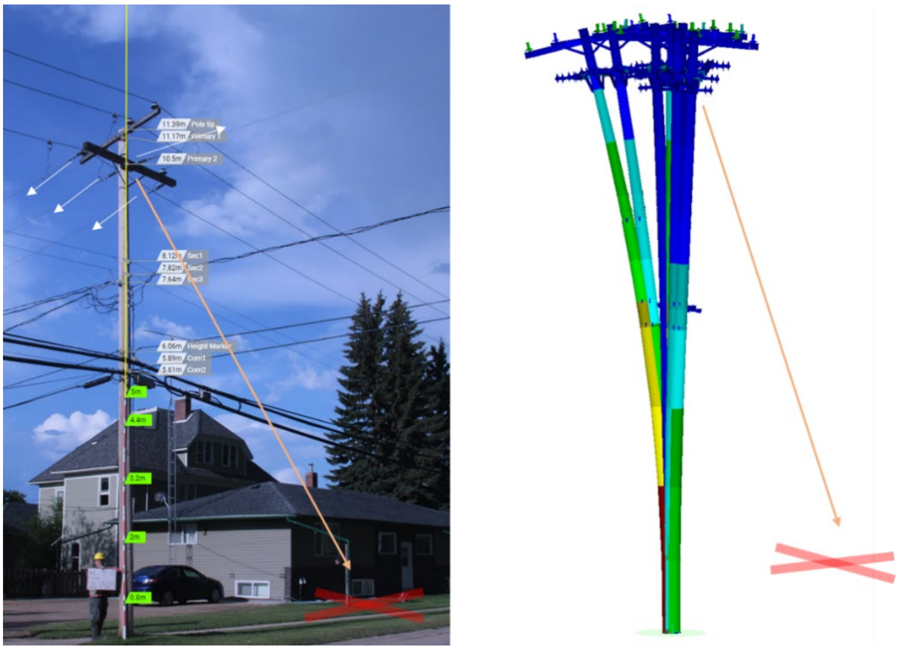


Figure 7: Impact of footprint congestion at intersections on structural loading

Applying logic, engineering judgement, and experience can possibly lead to the same conclusion of failure in certain regions and reoccurring patterns, the actual scale of the possible impact goes unnoted until either a large-scale weather event damages the assets, or a resilience study like this is done. The latter without the obvious footprint of damage and the associated impact on the community. Driving by poles with excessive rake and very large diameter lashed-bundled cables are indicators to a utility of increased loading but it still doesn't show a percentage of capacity. Asset managers see poles with excess rake and excessive loading (also referred to as being under-engineered by linesmen) but action is subjugated because of the difficulties of budgeting for pilot projects without numbers. The scale of the problem remains hidden as there is little scientific data and numbers in the utilities to back up what utilities already see through application of proper judgement.

STRATEGIC PLANNING FOR MODERNIZATION

Modernization of an entire grid seems like a daunting task, although not impossible, but a study, like the one done here, of as few as 2500 poles can identify high load corridors, their coincidence with set property zones or reoccurring patterns of failure using non-linear analysis.

After pilot projects like these, asset management can use the results to narrow their focus on identified areas for modernizing, and associated spending on the assets posing the greatest risk of damage / collapse and thereby improve resilience. Modernization of infrastructure and an engineering study of resilience could cost as little as ($110 / pole). A study of less that $300000 can give engineers and asset owners a great insight into the cause of failures, shortfalls in distribution standards and associated costs of increasing grid resilience.

The geographic layout can show the number of possible customer interruptions and duration while structures would have to be replaced.

Although the expected frequency of disruptions over the lifespan of the assets are far less than failures associated with vegetation management and other relatively small faults, the duration and restoration time can make the cost of the anticipated down time (sum of kVA during the interruption) of great importance and worthy of justifying resilience studies.

The results can feed back into the foundation of investment and regulations in the utility. It is a measure of resilience that can be used to harden the grid against large-scale weather events in areas where it affects the greatest number of customers.
The cost of pilot studies can even be split between the affected utility and its joint-use telecommunication partners and not necessarily be pushed onto customers. The joint-use partners might even take initiative themselves to do it entirely themselves in expectance of broadband rollouts.

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