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Automated Corridor Clearance Analysis

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EXECUTIVE SUMMARY

The reliability requirements for power distribution have continuously increased over last years, and there is public and regulatory pressure to increase the reliability of the network. The proper maintenance of distribution and transmission line-corridors has a direct impact on the reliability of the network. The traditional way to plan the tree clearings and maintenance programs has been time-based, suffering from inefficiencies and inaccuracy.

The more modern way for corridor clearance maintenance planning is need-based, providing in theory many benefits. However, the current methods are labor intensive making them subjective, error-prone, and inefficient.

This document describes the key business and operative requirements for an improved solution. We present a novel approach to fully automate the corridor clearance analysis, and discuss the required data, processes and information systems to support it.

The proposed approach is quite advanced compared to currently operational solutions in production today, which provide only partial solutions to the problem.

This report provides rationality how and why the current state of technology can be substantially improved with a proposed new approach.

The section Proposed Approach contains a pragmatic steps how the new approach can be created and validated in a real life environment.

This report handles the details of advanced analysis and planning and also potential further development targets.

By deploying the proposed solution for Automatic Corridor Clearance Analysis, distribution companies can:

- Increase the reliability of power distribution
- Reduce the occurrence and impacts of power outages
- Manage and reduce the costs of contracting of clearance work
- Reduce the cost of manual work in corridor maintenance planning

BACKGROUND AND NEED

Increasing reliability needs

The reliability requirements for power distribution have continuously increased over last years. Incidents such as severe storms causing power outages for hundreds of thousands of households have attracted the interest of both regulators and general public to demand higher reliability of electricity distribution networks. Political decision-makers, consumers and other stakeholders demand even higher reliability of delivery and are putting pressure to distribution companies to take actions to improve both operative processes and the network itself. In line of the recent developments, it is likely the distribution companies will face an environment with increasingly stringent requirements for reliability and higher monetary liabilities for power outages.

Traditional approach to corridor maintenance

Traditionally the corridor maintenance (clearing, trimming and pruning) has been planned based on maintenance interval for each separate part of the network area. The distribution companies have validated the results and quality of trimming at sample locations manually, or based on aerial photography or LIDAR measurements. The limitations of the traditional approach include:

- the clearing is not guaranteed to target the areas needing most urgent attention causing increased risk of power outage
- the clearing can be performed inefficiently at a time when the clearing has no immediate or direct impact on the delivery reliability
- the clearing resources (and budgets) are not targeted optimally

New need-based approach

Some of the distribution companies have adopted need-based maintenance- and tree-clearing programs. In this approach the maintenance plans are created based on aerial photography or on LIDAR measurements. The interval between the clearings is usually smaller, and consequently the frequency higher in need-based approach. However, the actual work in clearing the line-corridors can be reduced, as a whole substation areas need not to be cleared on each iteration. The need-based approach provides the following benefits:

- the clearing is only performed when needed, reducing overall costs
- the clearing can be targeted to high-risk areas without delay, improving the reliability of the network

Requirements for need-based clearing

The need based clearing requires accurate and up-to-date information of the power network and corridors. Many Finnish distribution companies have successfully used aerial photography and LIDAR scanning for the purpose of planning the clearing of line-corridors. In this method a low-flying helicopter or fixed-wing aircraft collects observations (laser measurements, still photographs, video) of the power corridors and the collected information is used to analyze the clearing needs.

Forest industry has successfully used the LIDAR (laser) scanning in estimation of forest reserves, and therefore the LIDAR analysis practices have been an area of active research and increasingly commercial applications. The power distribution companies have not fully utilized the opportunities of LIDAR analysis, and the few current approaches in-use are labor-intensive and therefore not very cost-efficient. Further the major part of manual labor needed in the process increases the subjectivity of the results and dependency of key personnel's availability.

In order to maximize the benefits of LIDAR measurement, the process must be more automated to achieve repeatability, objectivity and cost-efficiency.

BUSINESS REQUIREMENTS

The key business requirements for automated corridor maintenance analysis include the following:

1. **The LIDAR measuring process must be separated from the analysis and planning**
   - the distribution company can efficiently tender the LIDAR measurement collection work in the market, and use multiple LIDAR measurement service providers to gather the data
   - the results of LIDAR measurements need to be made available in unified format, which can be analyzed in connection with any other measurements collected (by different provider and/or at a different time)
2. **The relevant of LIDAR data must be transformed into a smart model of real world, with separation of network elements (linked to NIS information) and natural objects**
3. **The analysis of LIDAR data must be made in the context of information in the Network Information System (NIS)**
   - LIDAR measurements must be linked to information in the NIS, and vice versa
   - LIDAR measurements not relevant to power corridors must be identified and ignored (for efficiency sake as it does not provide any value to corridor maintenance analysis)
   - When the power line maintenance is planned and documented in NIS, the additional information from LIDAR measurements can be linked to and made available through NIS
4. **The business rules for the clearing priorization and planning must be changeable, and without dependency of the LIDAR measurement process**
   - The vendor, source, and formats of LIDAR measurements are technical details and have no impact on the business rules for determining the clearing needs and plans.

- The business rules regarding clearing plans need to be able to be tuned without any changes in other parts of the process. This is very important as once the process is fully automated, the parameters may be optimized according to business criteria through iterative improvements. For example, the threshold for critical maintenance (to be started without delay) may be fine-tuned to balance between the clearing costs and the actual impact on the probability of power outage.

When all these requirements are met, the power distribution company can:

- efficiently put the measurement work out to tender, and get the measurement done at the best available market price without single-vendor dependency
- the business rules can be developed, changed and fine-tuned to achieve the desired business targets without the need (cost, latency) to change other parts of the process such as measurements and transforming the LIDAR data into a real-world model

OPERATIONAL REQUIREMENTS

To meet the needs of the business requirements, the following operational requirements must be met:

1. **The power distribution company must establish a minimum baseline for the technical requirements in the tenders and contracts for LIDAR measurements**
    - point density, corridor width
    - number of returns (first, or all)
    - type of return information (count, strength, material type) when available
    - minimum accuracy (x, y) and (z), e.g. 95% confidence within 5cm
    - format: e.g. XYZ (in WGS-84), or ASPRS LAS format
2. **The system for automated corridor analysis must contain a feature extraction engine, which can automatically form a real-life model by combining the LIDAR measurements and NIS information**
    - The location, orientation, shape and other attributes of the NIS objects are recognized from the LIDAR data.
    - The location, orientation and shape of natural objects relevant to the power line corridor are extracted from the LIDAR data, and corresponding object-oriented real-life model is created.
        - The natural and man-made objects relevant to power line corridor must be recognized, including trees, low vegetation, and buildings. Any arbitrary

objects outside the recognizable object types in the measurements must be flagged for manual attention.

- The prediction models for the changes of the natural objects (such as tree growth) must be implementable to the system without changes to the process or architecture. This will allow for later inclusion of different growth models to project the prior measured state to the future. This has the potential to make the maintenance priorization even more business efficient compared to just geometrical comparison of clearance requirements and actual clearance.

- In the recognition process, both the information of LIDAR (what was measured) and NIS (what was expected) is combined for increased recognition accuracy.
- The recognition of NIS object information must be made available to update back to NIS ("as built") in case that is desired. This could be used e.g. to update locations of poles, to update the height information of poles, or type and/or orientation of crossarms and guy-wires.
- The feature detection process must work automatically without manual digitizing of visual information, except in case of unrecognizable objects flagged for manual supervision.
- Any data, which fails to be automatically recognized (within agreed accuracy threshold), must be flagged for manual supervision.
- The feature detection process must be extensible, allowing new methods and algorithms to be included later (requiring system and software development, but not the change of architecture or process)
- The object-oriented feature database must be extensible, allowing new object types to be included later (requiring system and software development, but not the change of architecture or process)
- The resulting smart real-life model must be analyzable as such without the need to revert back to the original measurement data.

3. The feature database must be linked to NIS

- The network objects recognized from the feature database are linked with NIS object ID, allowing transfer of information between NIS and feature database

4. The maintenance and clearing planning must be configurable with parameters

- The business rules (for example rules for high-priority clearing) must be fully separated from the measurement process and actual measurements.
- The business rules are based on the information in the feature database (being linked to NIS).

- The business rules for clearing planning must be configurable through parameters, which are accessible to end-users.
- The business rules must be based on the geometrical relations between the network elements (such as poles and lines) and the recognized natural (trees) and man-made (buildings) objects
    - In case of natural objects, the rules must be applicable also to the predicted future state of the objects (e.g. if a growth model for trees is employed, the rules must be applicable to the predicted state of the trees).
- The business rules must extensible, allowing new business rules to be introduced (requiring system and software development, but not the change of architecture or process)

5. **The results of automated clearing analysis and planning must be exportable**
    - The results of automated clearing analysis must be linked with NIS objects, and exportable to NIS allowing the documentation, review, acceptance and work management to be performed in NIS.

EXISTING TOOLS, METHODS AND SOLUTIONS

The scope of the business and operative requirements in this document is very broad, and the currently available state-of-the art technologies fail to meet many criteria. This is due to the fact that the tools and technologies have been developed in the past to **assist experts in their manual work, instead as an attempt to automate the process**.

Also, many companies providing tools and services in the area are focused on LIDAR measurements and their analysis, making the approach measurement centric. There are attempts to automate the feature recognition of LIDAR measurement into an object oriented feature model, but these attempts are challenged by the enormous theoretical and technical difficulty in creating models which would be applicable to a wide range of real-world applications. A software or tool, which would automatically create a universal feature object model out of the LIDAR measurements, is still a futuristic vision.

The NIS vendors have not made substantial steps towards truly integrating LIDAR information into their systems, basically focusing on the traditional model where all information is maintained manually (or through mass input of simple measurement data such as coordinates of poles).

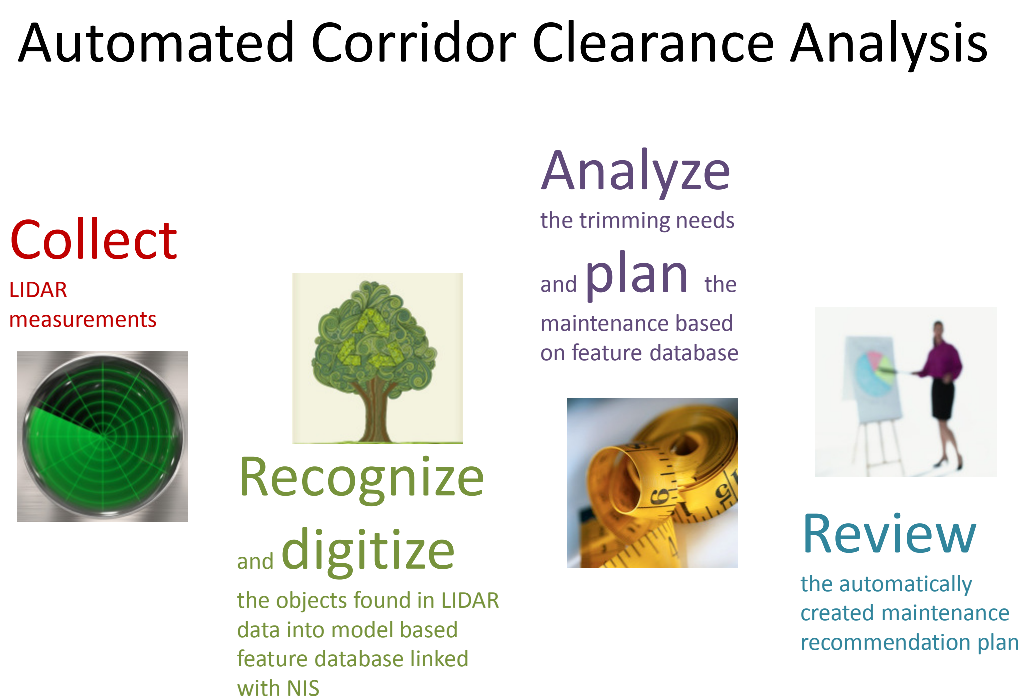
Besides these apparent challenges, **there is a realistic opportunity to create the world leading cost-efficient and business-driven system and process for automated power line corridor**

maintenance analysis based on the following key differentiators from the currently available solutions:

- **clear domain focus**: power line corridors
  - No need to handle other objects than relevant to the clearing needs for power lines.
- **clear business focus**: prioritize the clearing and maintenance work of power lines
  - Any attributes of the objects not relevant to the task can be ignored (e.g. color of objects, objects outside the potential impact to the power line, shape of buildings other than what the clearance requirements needs, shape of objects not impacting the clearance requirements such as internal structure of the trees)
- **combining NIS and measurement data**: increased accuracy in detection due to data fusion (NIS data provides information what to expect, LIDAR provides measurements, when combined the LIDAR data can be interpreted more accurately and efficiently)

PROPOSED SOLUTION

The following describes a proposed solution how the business and operative targets could be met in a cost efficient manner.

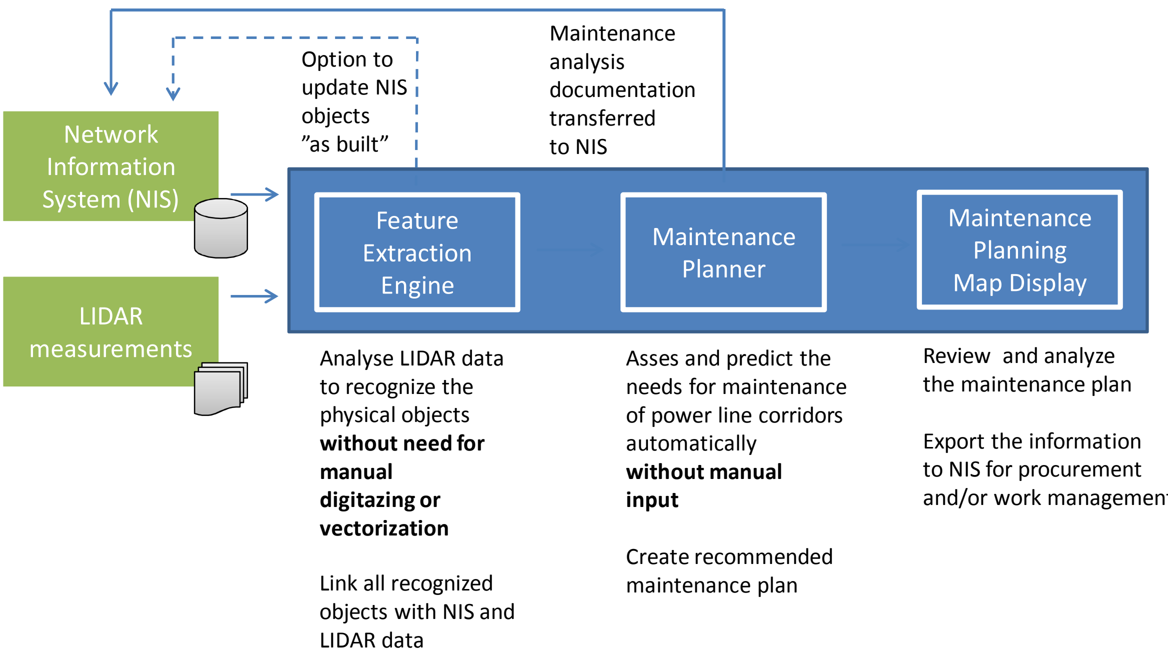


ACCA – Automated Corridor Clearance Analyzer

The solution consists of four parts:

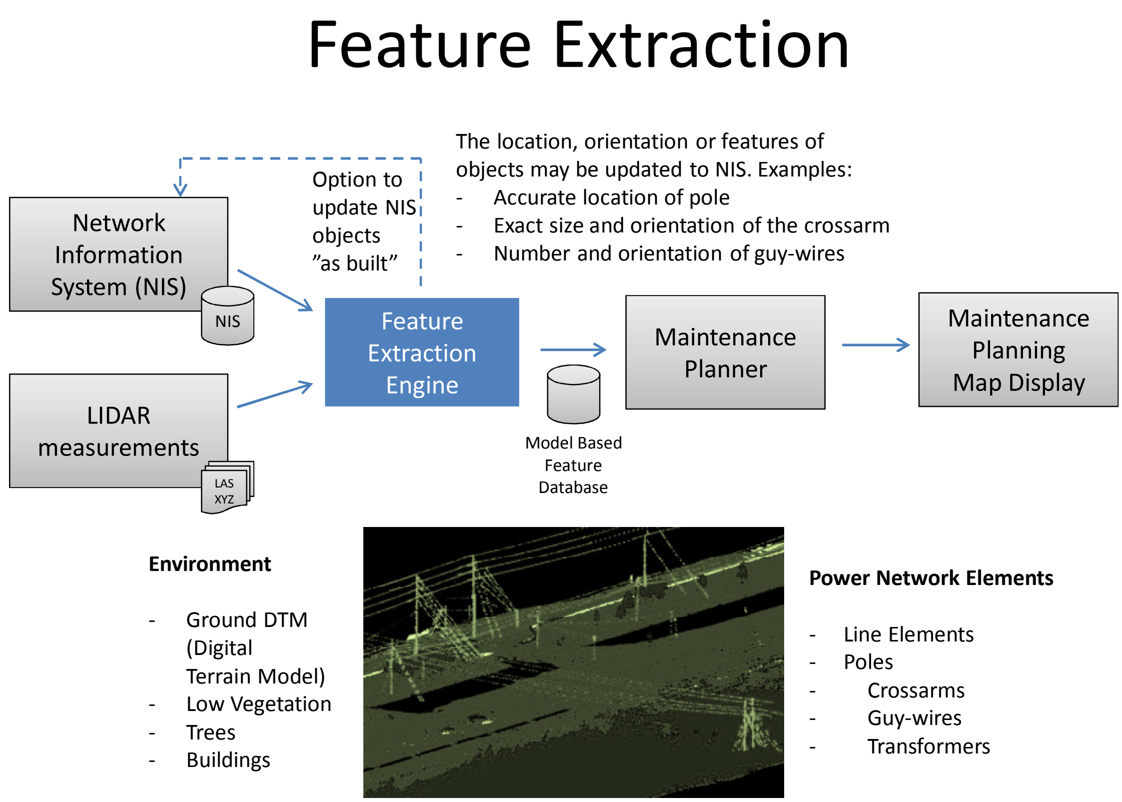
- Collect: as a service from the commercial LIDAR providers
- Recognize and digitize: a new software tool to automatically recognize objects in LIDAR measurements
- Analyze and Plan: a new software tool making priorization and plans for corridor maintenance based on the real-life model
- Review: existing NIS to approve, modify, document, and manage the clearing plans, and manage and document the work

Automated Powerline Corridor Clearance Analysis



The new software required consists of Feature Extraction Engine capable of automating the work for LIDAR data digitizing, and the Maintenance Planner, which has configurable business rules to create the maintenance plan based on the object-oriented feature model.

Optionally a Maintenance Planning Map Display may be needed; in the case if the existing NIS would not have the required features and capabilities to display and manage the maintenance plan data. The overall target is however, to centralize all user interaction into NIS to avoid management of the same data in multiple systems.

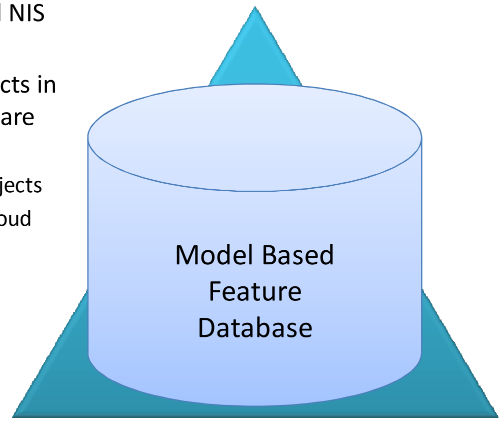


The Feature Extraction Engine shall recognize the following object types:

- Ground DTM (Digital Terrain Model)
- Low Vegetation
- Trees
- Buildings
    - Line Elements
    - Poles
    - Crossarms
    - Guy-wires
    - Transformers

Feature Database links NIS and LIDAR measurements with the physical world objects

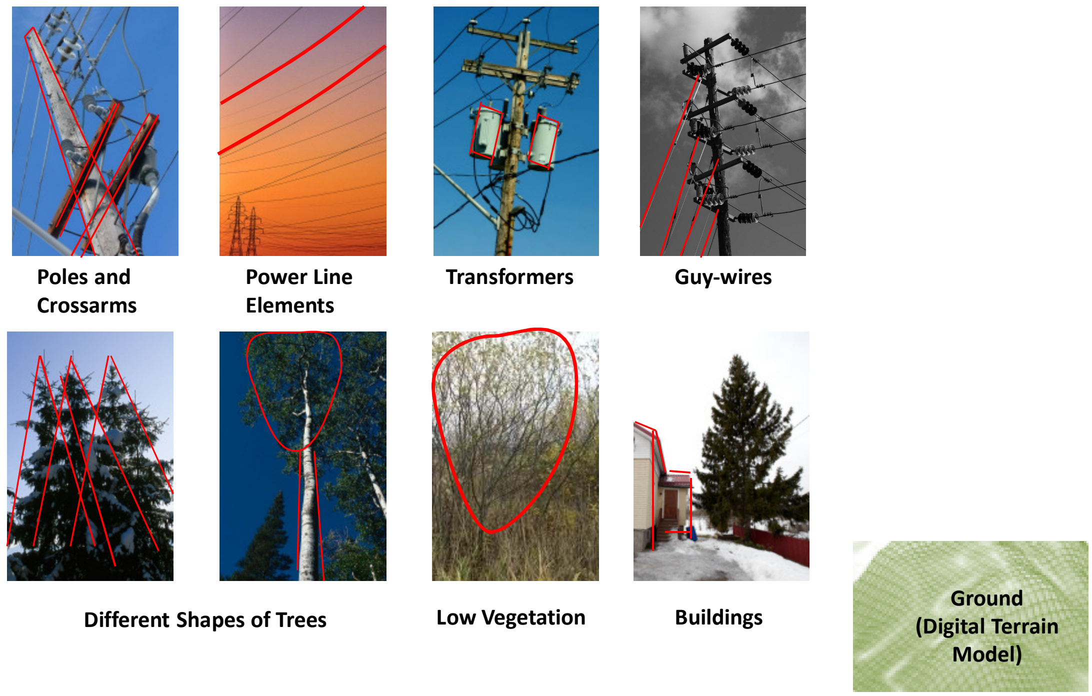
- Model based object database with the information as a combination of LIDAR measurements and NIS
- Recognized objects represent real objects in physical world and are linkable with
  - NIS database objects
  - Original point cloud measurements



- NIS information is used to assist the LIDAR analysis process for
  - Faster processing (only relevant LIDAR data needs to be analyzed)
- NIS and LIDAR data are fully combined
  - Better accuracy when all available information is utilized

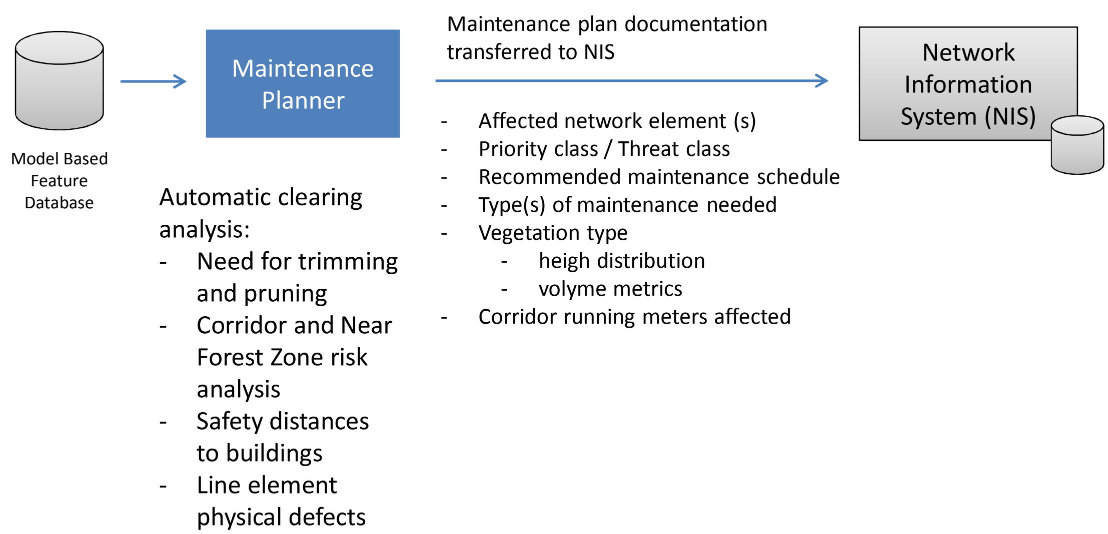
The Model Based Feature Database contains the recognized objects of the real world in a form that can be used for analysis. The Feature Database is linked with NIS objects (through NIS identifiers) and the set of LIDAR measurements related to the object.

Model Based Feature Database



The feature database can contain the Digital Terrain Model (DTM) calculated based on the LIDAR measurements, and available object types such as poles, crossarms, power lines, transformer stations, guy-wires, trees of a few specific types (based on their overall shape), low vegetation (bushes etc.), and outlines of buildings.

Automatic Maintenance Planner



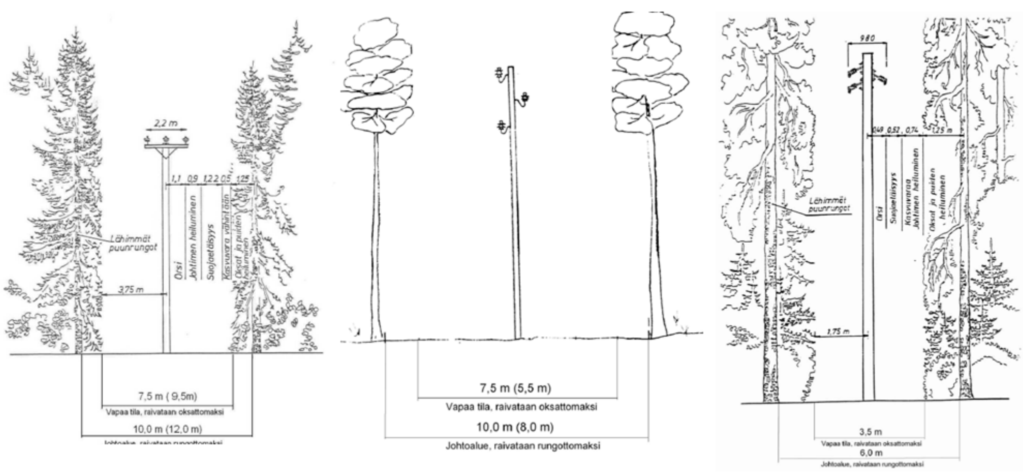
The Automatic Maintenance Planner uses the Feature Database to run the parameterized business rules to create the clearing plan. The results are transformed to NIS for further action: approvals, tendering, ordering, and documentation of maintenance work.

The output includes:

- References to affected network elements (poles, lines)
- Priority class / Threat class
- Recommended clearing schedule
- Type(s) of maintenance needed
- Vegetation type
    - Height distribution
    - Volume metrics
- Corridor running meters affected

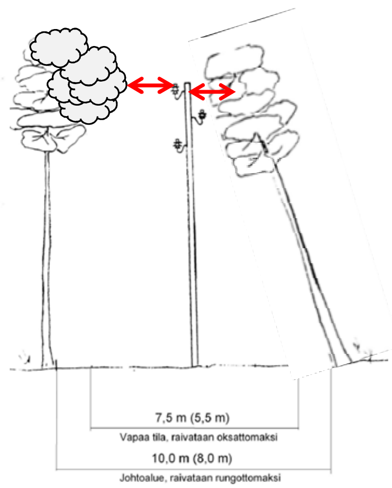
The output information may be used for efficient tendering of the maintenance work, as the contractors will have accurate and objective information on the needed work. This is expected to lower the costs for contracting of clearing work, as the contractors will have more accurate and well-documented information for estimating their work, and reducing the need for unnecessary "safety margins".

Automatic Clearance Analysis



Automatic Clearance Analysis consists of parameterized clearance requirements based on the geometrical distance from the power line elements to natural and other man-made objects in the Feature Database.

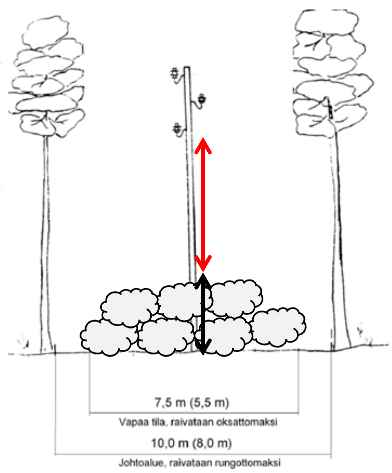
Automatic Clearance Analysis – Immediate Threats



Immediately threatening trees or branches

The immediate threats are classified as needing immediate actions, likely to cause a failure or power outage at the nearest future, or at any occurrence of severe weather conditions.

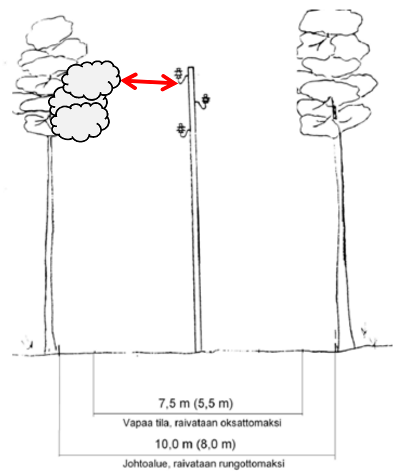
Automatic Clearance Analysis – Ground vegetation



Height of ground vegetation, and its distance to power lines

The height of ground vegetation is recognized, and its distance from the power line. This information is used to estimate the time, when the ground vegetation growth will risk the power lines. The ground vegetation height is considered across the actual catenary of the power line. When a threshold is exceeded, the line segment is marked for clearing the ground vegetation.

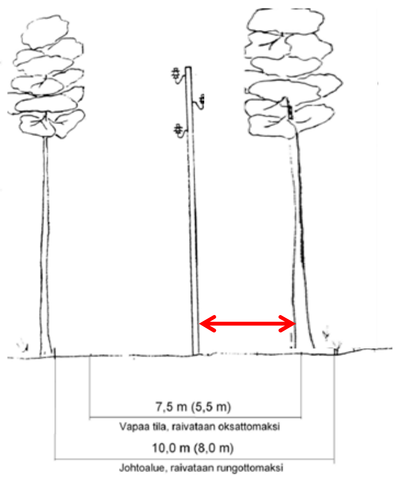
Automatic Clearance Analysis – Branches in the corridor area



Distance of branches from the power line

The distance of single or multiple branches from the power line is analyzed. When a threshold is exceeded, the line segment is marked for pruning the branches.

Automatic Analysis –
Trunks in the corridor area



Distance of trunks from the power line

The distance of trunks is calculated, and when the number of trunks within the clearance area for a line segment exceeds a threshold, the line segment is marked for clearance.

The inputs and outputs

In summary, the inputs and outputs of the proposed solution are described below.

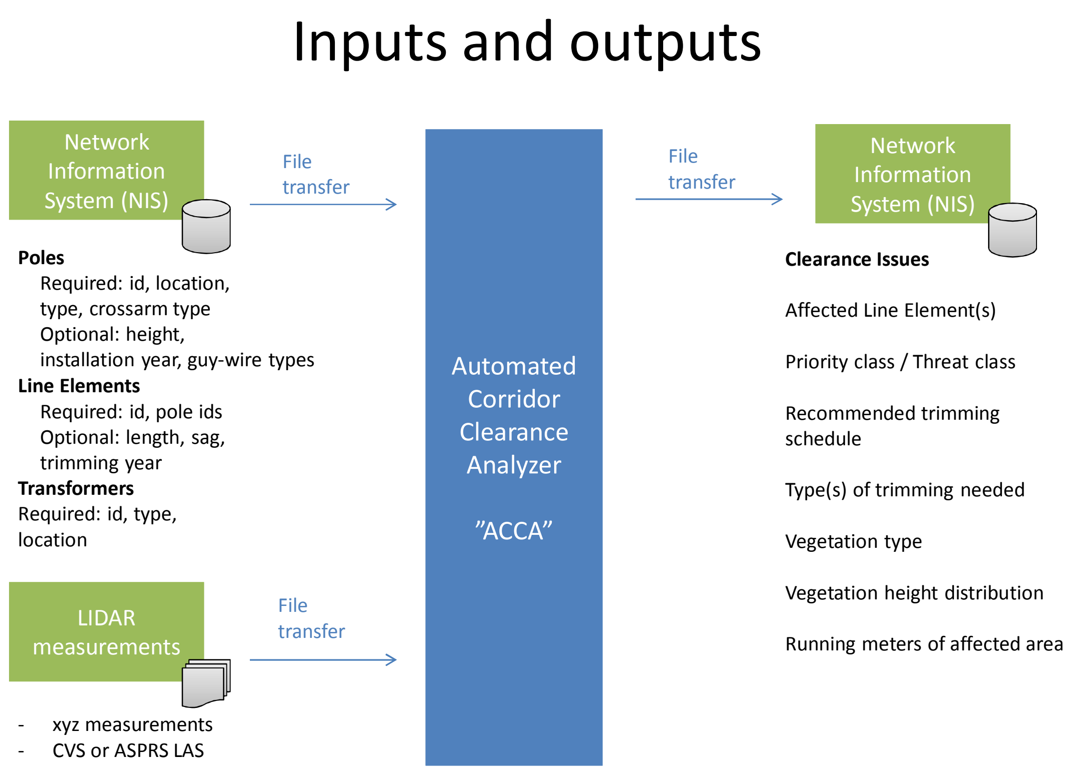
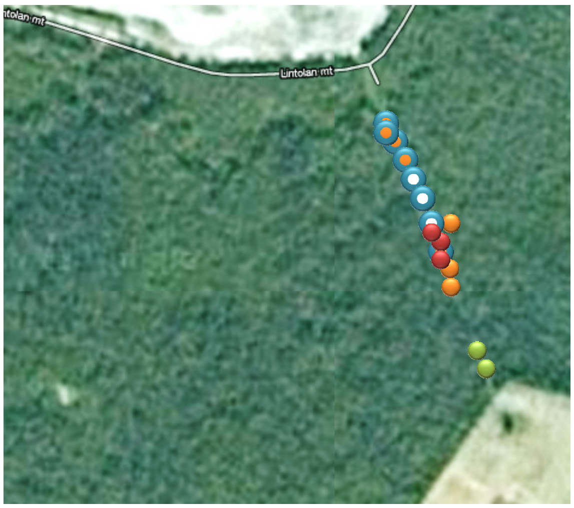


Illustration of output visualization

An example of the potential visualization of the clearance plans is presented below. Please note the picture is for illustration only, and not intended as user interface design template.

Map Visualization in NIS



Visualization **as example only**

- Välittömästi uhkaava ongelma
- Runkojen raivaustarve
- Oksimistarve
- Alustaraivaustarve
- Oksimis- ja alustaraivaustarve

Valittuna: johtolähtö ABC

Oksimistarve yhteensä:		1 238 m
Keskikorkeus	5.6 m	
Tiheys	3 / m2	
Runkojen raivaustarve yhteensä:		127 m
Keskikorkeus	8.6 m	
Runkoluku	60-70	
Alustaraivaustarve yhteensä:		876 m
Keskikorkeus	1.6 m	
Tiheys	3 / m2	

Proposed approach

The proposed solution is very novel and innovative, and requires substantial research and development.

The best practices from other areas and technology applications should be employed and adjusted to meet the purposes of the Automated Corridor Clearance Analysis.

The work is necessarily empirical and cannot be successfully completed in a lab environment (or to put it otherwise, the lab results would not necessarily guarantee similar results in real-life circumstances), it is recommended to start a pilot project where the proposed methodology is developed in tight co-operation with real-life operative departments across a number of power distribution companies. The overall approach for such a project would be a two-phase project:

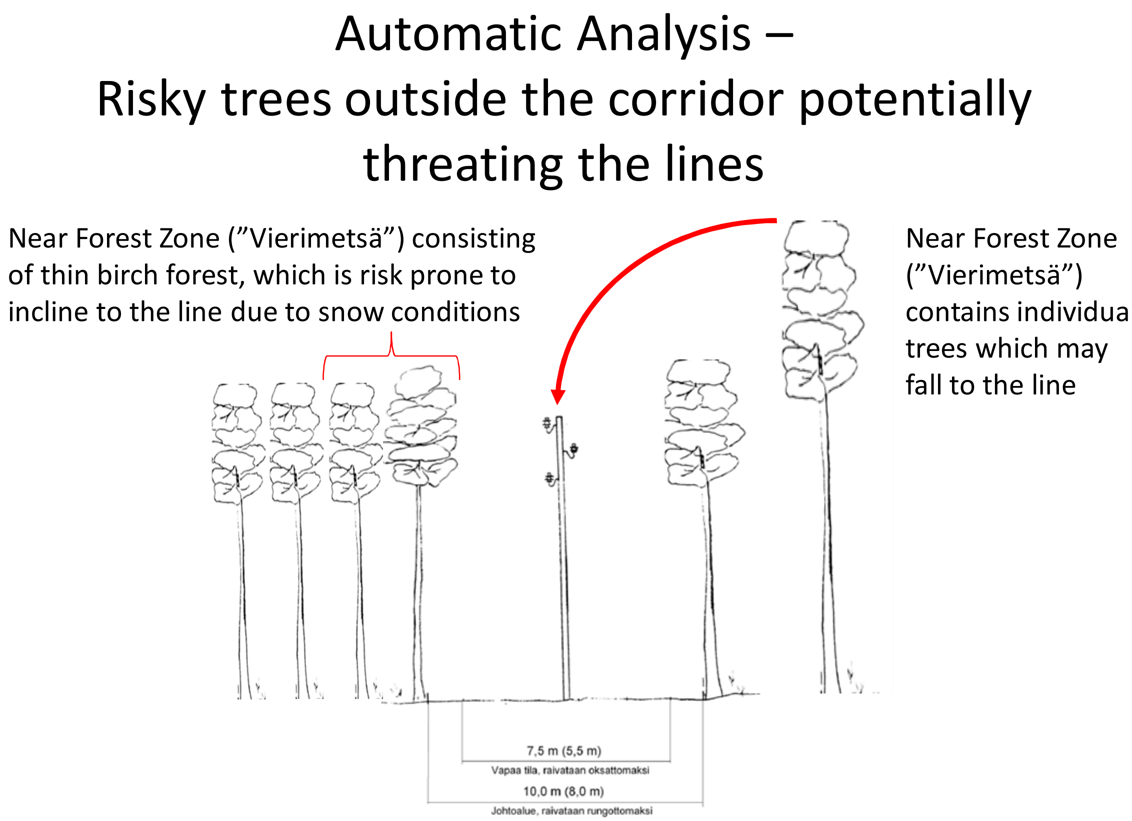
1. Technical implementation of the system
    a. Specification – detail the following:
        i. Available inputs, format and transfer procedures
        ii. The desired outputs of the system
            1. Clarify business needs
            2. Specify the format and presentation of the outputs to fit in the existing systems and processes, e.g. transfer to Network Information System (NIS)
    b. Implementation of Automatic Corridor Clearance Analyzer prototype
        i. The system is developed based on the detailed specifications and it is tested continuously throughout the development based on the specified test data

2. Piloting and validation of results
    a. The prototype is used to automatically create clearance analysis and maintenance plans based on a large test data
    b. The created plans are used to planning of maintenance, contracting and managing the clearing work
    c. Feedback to the system is collected from both from the personnel of distribution companies and the contractors (both selected in the tender, and those not selected)
    d. To the extent possible the results are used to validate the accuracy of Automatic Corridor Clearance Analysis:
        i. the scope and extent of clearing work
        ii. the clearing types
        iii. the priority for the clearing work

FUTURE OPPORTUNITIES

After the successful implementation and deployment of the basis process for automatic corridor maintenance analysis, there are several options to further enhance the business benefits.

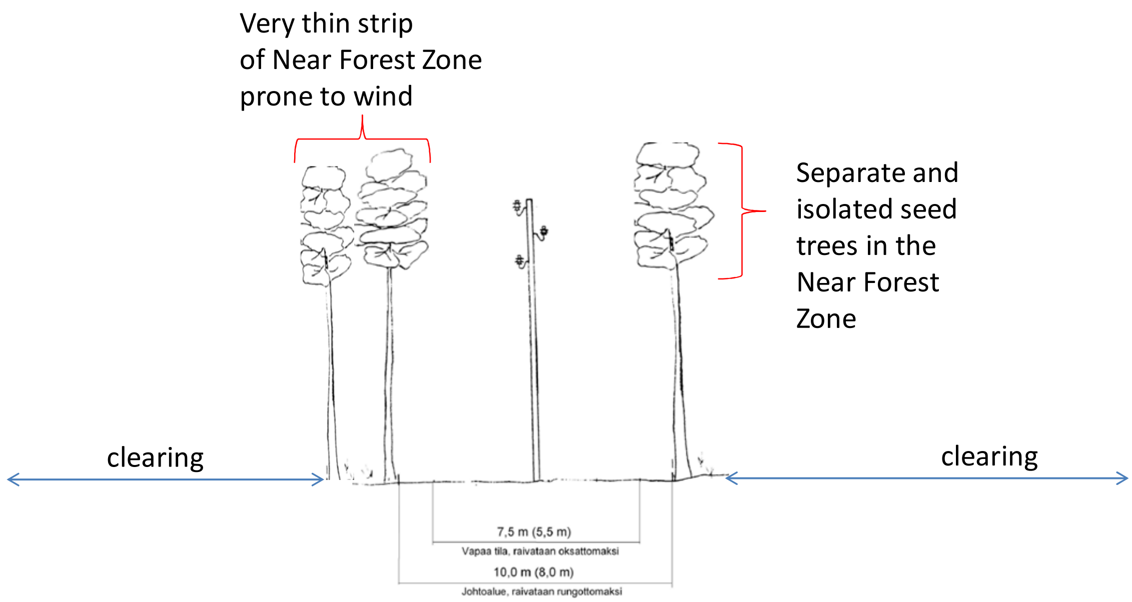
Risky trees outside the corridor potentially threating the lines



When the LIDAR measurements contain sufficient area outside the corridor, further analysis can be made such as identification of especially risk prone vegetation types (such as thin birches) which are likely to incline to the line under heavy snow load. Also individual trees outsize the corridor area, which can tilt/fall to the line, can be identified also outside the corridor in the Near Forest Zone.

Isolated trees or thin stripes just outside the corridor

Automatic Analysis – Isolated trees or thin stripes just outside the corridor



Further risk analysis can be made for the Near Forest Zone, including identifying the thin strips left just outside the corridor, which are prone to the effects of wind. Similarly separate and isolated seed trees can be identified in the Near Forest Zone.