

VEGETATION MANAGEMENT IN POWER LINE ROUTES

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Abstract: A large part of Slovenia's electricity transmission network runs through forest areas. Regular maintenance of vegetation along the routes of transmission lines is important to ensure safe and reliable operation of the system. The high volume of work represents a significant maintenance cost. In addition, the planning and management of the work is also a problem, as it has to take into account all the constraints and the time needed to prepare the work. In a study addressing this issue, we identified the need to set up an information system for vegetation management. Based on the requirements identified in the previous study and on the practical application of the process, the Vegeline application was developed to enable users to manage this area. The application is based on data. The data used are laser scanning (LiDAR) data of the routes, tree stand data in the individual areas, weather data (temperature, rainfall, insolation), soil composition data and technical data of the transmission lines. Based on the data, the application produces a map of permissible heights. Using machine learning algorithms, it produces a forecast of vegetation growth by year for the next 10 years since the last LiDAR survey. By comparing the predicted and allowed vegetation heights, it produces hazard maps showing where and when vegetation will grow beyond the allowed limit. The threat maps are also available as raster files to other applications. Vegeline suggests the most cost-effective course of action and time to the user, based on a cost estimate. The application is integrated with the asset management information system, where work orders are prepared, and the execution of tasks is monitored. The application's utility is also enhanced by the gradual introduction of laser imaging by drones, which will provide more data in the future and, consequently, more accurate predictions of vegetation growth.

Keywords: Power lines, vegetation, prediction, LiDAR

INTRODUCTION

ELES is the Slovenian operator of the electricity transmission network. As Slovenia is one of the most forested countries in Europe, with two thirds of its land area covered by forest, a large part of the electricity network, the transmission line network, runs through forest areas. According to actual land use data, one third of the electricity grid runs through forest areas. In order to ensure the safe and reliable operation of the network, it is necessary to ensure that tall vegetation is kept sufficiently clear of live parts at all times and to prevent the possibility of trees falling on the conductors. This in turn requires adequate maintenance of vegetation along the routes of the transmission lines. With such a large amount of forest under the lines, this represents a very high maintenance cost for the company. In addition, the planning and monitoring of vegetation works is also challenging. There is a strong spatial component to the preparation and implementation of these activities, which nowadays requires appropriate software support that uses as much available data as possible in the planning process and allows the user to have a proper overview of vegetation management.

The establishment of a vegetation management system was approached first theoretically, by carrying out a comprehensive study [1], and then more practically, by setting up an appropriate information system. The result of the study was, in addition to a good overview of the topics we need to pay attention to, a proposal for the design of an appropriate information system to cover the basic needs of vegetation management.

The study provided an overview of the state of the art of vegetation management in our company and an overview of the state of the art of some other European TSOs that were already working in this field at the time of the study. In the area of data, a detailed review was made of what data would be needed and what of the above is available. In most cases, other vegetation management applications are based on LiDAR surveys or photogrammetry to recognize the current state of vegetation and plan activities accordingly. With the rapid development of surveying technologies and consequently cheaper execution of more frequent surveys, these applications will enable increasingly better activity execution. The advantage over such systems lies primarily in the preparation of predictions, which take into account many parameters

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that affect growth. The most important data in this regard will become laser survey data as the survey periods shorten.

An overview of the processes in place in the company in this area and the possibilities for their renewal, supported by an IT system, was made.

1. USED DATA

Data is the basis for the entire system. The system uses data from different areas that have an impact on the growth and development of vegetation. The most important data in the system are those that show the actual state of the vegetation at a given moment in time. The basis is Eles' transmission network data. The data used are from the spatial database that Eles maintains internally. It includes the spatial layout of the transmission lines, the division of the areas by the deployed maintenance units and the coordinates of the standpoints, the transmission line poles. All three of these layers are updated on an ongoing basis on the basis of the laser scanning carried out at the completion of investment projects for the construction of new transmission lines or the reconstruction of existing ones, or on the basis of project documentation. The transmission line network is divided into transmission lines, which represent an object in space, and an independently maintained unit in the network. The transmission lines are further subdivided into spans with individual standpoints. Spans are spatial units that are treated by the Vegeline application in the process of route maintenance or vegetation management. In addition to the above, a 3-dimensional guide layer is also used to take into account the sags of the guides in the splays.

The next layer, which is mandatory for the application to work, is the laser scanning data (LiDAR data) in LAS format. The first is the aforementioned laser scan data after the construction or reconstruction of the transmission lines. These are carried out with LiDAR cameras on helicopters. The first recording of the entire network was carried out between 2002 and 2006. Since then, we have been updating and gradually supplementing the recordings by smaller sections. The obtained point clouds are classified according to the most commonly used ASPRS classification. During the course of these surveys, the main focus was on the terrain and the route of the transmission lines. The vegetation was a kind of additional information, which at that time only served to give an insight into the current situation and to warn if any critical points regarding the height of vegetation were detected during the recording. As a second source, we use the national LiDAR imagery taken in 2015-2017, covering the whole of Slovenia. At the end of 2024, the third source became laser point clouds taken by UAVs, which we carry out ourselves. By the time of writing this article, some experimental recordings have been made and testing of the use of these point clouds in

the Vegeline application has started. The plan is to set up a systematic exercise of periodic recordings throughout the network. From the point clouds, the application uses terrain points and vegetation points.

Other relevant data layers used are:

- the tree species composition layer, provided by the Forest Service, which covers the whole country,
- a soil map for the whole country, which provides basic information on soil composition,
- weather data obtained from the Environment Agency.

For the weather data, temperature, rainfall and solar radiation are important. This takes into account the average data over the periods.

The last group of data used is represented by the four constraint maps currently in use. All these data are available through the web services of various public agencies. The following maps are used:

- Nature 2000
- Protected Forests
- Water protection areas,
- Natural values.

All these layers are vector-based and uploaded to a common spatial database, where they are updated as necessary. These maps are mainly used in the preparation of the plan of activities on vegetation along the routes of the transmission lines, as they represent the conditions and constraints for the implementation of activities. In order to carry out vegetation management in such areas, the relevant permits must be obtained in advance from the agencies responsible for each type of area.

The possibility of using satellite imagery has not been overlooked in the context of the above-mentioned study. At the time of the application, it was assessed that the use of such satellite imagery, which could contribute to better prediction of vegetation growth, was not yet economically viable. However, given the rapid development of new technologies and the increasing availability of good quality data, it is expected that satellite data will soon also allow for the improvement of predictive models, since with a much shorter data update period it is possible to monitor vegetation status much more up-to-date.

2. DATA PROCESSING

The execution of data preparation, calculation, and final use involves several procedures. Below is a quick overview of the procedures. The entire calculation process is described in detail in published paper [2].

The first part involves preparing the foundations for subsequent calculations. After importing LAS data into the application, a digital terrain model (DTM) layer is created

based on terrain points. To prepare this layer, interpolation methods are simultaneously used to fill in small areas where terrain points are missing. After creating the DTM, a terrain slope layer is generated. Both layers are created with a resolution of 0.5 m.

A raster layer of vegetation height – canopy height model (CHM) – is created based on the difference between the terrain height and the absolute height of the vegetation top.

Based on terrain data and the layout of conductors in 3D space, and considering the required distances from conductors, a layer of permissible vegetation heights is calculated with the same resolution as the prepared DTM. The required distances for calculating permissible vegetation heights were provided as shown in the image below. Within the width of the power line route, the permissible distance from conductors is considered, while outside the corridors, a 45° restriction is applied, taking into account the possibility of trees falling perpendicular to the power line, which must not fall into the permissible distance from conductors with their tops.

Vegetation under consideration is divided into three categories based on its height: low, medium, and high. For calculations and use, medium and high vegetation are particularly important. The results of the vegetation growth prediction calculation are also divided into these categories. Based on the listed data and the results obtained in the described processes – maps, a growth prediction calculation is performed. The prediction is made for 10 years ahead from the data of the last laser survey in the specific area. For each year, maps of the predicted height of high, medium, and low vegetation are created. Subsequently, a comparison of vegetation height data with the permissible height map is performed. The final result is risk maps, which, using a selected color scale, show the areas where vegetation will exceed the permissible height in a given year, thus threatening the safe and reliable operation of the transmission network. The process is schematically shown in the Figure 1.

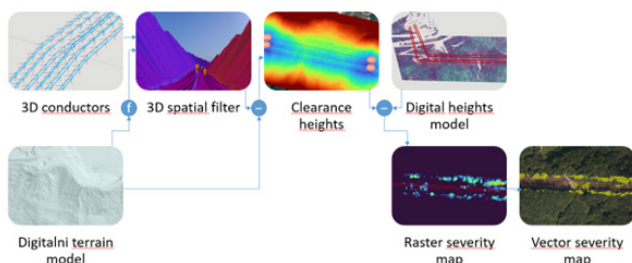


Figure 1: Schema of severity map preparation process

3. FUNCTIONALITIES OF THE VEGELINE APPLICATION

The Vegeline application was developed to manage the data, calculate growth forecasts, and plan and monitor

the implementation of activities. The complete system consists of an application running on a central dedicated server, a database on the server and an application installed locally at the user's premises which provides the user interface for working with the system.

The application allows data to be imported and displayed on a map. Most of the work is done with 2D map displays, but a 3D view of the data is also possible, showing the point cloud of LiDAR imagery, the allowable heights and the predicted vegetation heights. The application functions are divided into a data workflow and a planning and monitoring vegetation intervention workflow.

A module has been developed to collect, analyze and store vegetation data from different sources, including remote sensing, satellite images and field measurements. A method for automated vegetation species identification and growth determination has been established, allowing better planning of interventions. The module also includes a tool for manual correction and validation of data, ensuring greater accuracy.

A user interface is also part of the system, allowing access to the Vegeline system via a web browser. The system allows the management of vegetation data, the overview of the history of interventions and analyses of trends. In addition, a system has been implemented to monitor the operation of the application and manage user rights.

4. PLANNING AND MONITORING VEGETATION MANAGEMENT ACTIVITIES

The Vegeline application is connected via web services to the IBM Maximo asset management system. Through this, all vegetation management activities in the field are monitored using a mobile application for tracking work execution, which is standardly used in the company. Integration between applications is shown in the Figure 2.

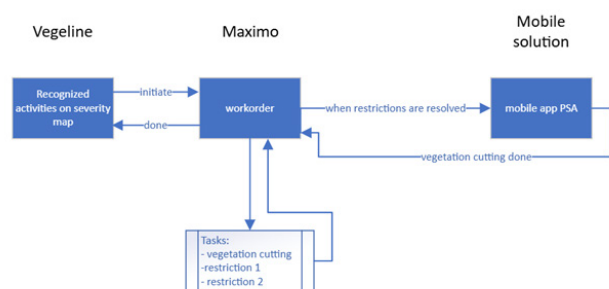


Figure 2: Integration with asset management system

The system is designed so that work preparation based on information about necessary vegetation work is carried out directly in the Vegeline application. Here, the user can see where interventions are needed in the network. A graphical display on the map is available to the user,

and icons in the list of spans on the selected power line indicate the vegetation status in each span (Figure 3). For each span, the predicted area and volume of necessary vegetation cutting are calculated. By graphically comparing areas requiring cutting and restriction areas, the restrictions that need to be considered for each span are known. A list of all parcels where work is expected to be carried out is also available. In another information system, this allows for an overview of ownership and already concluded agreements and restrictions related to landowners. The user reviews and selects the spans planned for interventions. Before sending the spans to the Maximo asset management system, they can view the details of the interventions. An important added value is that the system itself suggests the method of intervention (mechanical cleaning, felling, trimming the forest edge) and calculates the estimated costs of interventions based on the price list, enabling better planning of vegetation management costs.

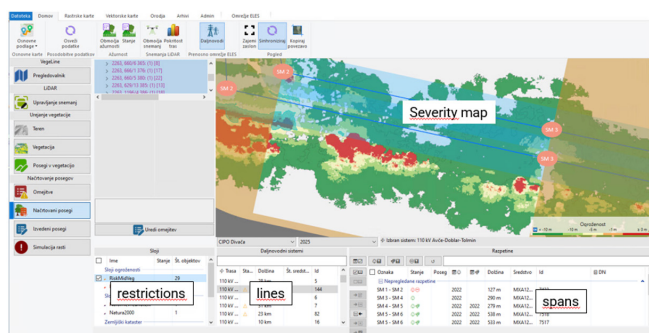


Figure 3: User interface for activities planning

The transfer function in Maximo creates a work order for each span, listing the necessary tasks. Each constraint that needs to be taken into account and resolved before the intervention is carried out is listed as its own task on the work order. In this way, the works preparation service is provided with all the necessary information on the permits to be obtained for the intervention and the conditions to be taken into account in the scheduling of the intervention. The added value of this approach is that work orders based on growth forecasts can be prepared well in advance so that all permits can be collected and all arrangements with landowners can be made before vegetation grows to the point where it could compromise safe and reliable operation. Once the work order is ready, the users must first sort out any restrictions and only then can they proceed with the work on the vegetation. The work order is transferred from Maximo to the mobile app, where operators in the field then confirm that the work has actually been carried out.

The information on the completed task is fed back into Maximo and, with confirmation that the work order has been completed, on to the Vegeline app. This informs the Vegeline application that the intervention has been carried out. The user of the application can then confirm the area

of the intervention as solved in the application according to the information on the work carried out.

Two options are available for managing the data on the actual state of the vegetation after the intervention. The user can either manually confirm the reduction of vegetation in the intervention area to the height received from the intervention contractor, or a new snapshot of the situation can be taken and imported into the system to obtain the exact post-impact situation. Prior to the use of drones, manual correction of data was more often envisaged. However, the use of drones has considerably speeded up and simplified the capture of the new situation, and it is foreseen to take a new snapshot of the regulated area in the future, thus avoiding manual editing errors and providing a more accurate forecast for future years, as the calculation takes into account the actual situation immediately after the intervention. This snapshot also provides the actual area and volume of the intervention.

In Slovenia, investment and maintenance planning is prepared or updated every two years as part of the development of the Slovenian transmission network. For budget planning for vegetation management work, primarily data on actual work performed in previous years is considered. A more detailed cost plan for work execution is also prepared every two years, which still mainly includes cumulative costs of work execution. A more detailed specification of interventions, which includes actual areas of planned interventions, is planned annually. In this planning, the Vegeline application is now assisting us.

5. ADVANTAGES OF ESTABLISHING THE VEGELINE SYSTEM

The full integration of the system into the processes of transmission line maintenance and vegetation management will bring several types of benefits. Maintenance costs are expected to be reduced, as the number of inspections of transmission line routes, which are currently carried out on a regular basis, will be reduced. Improvements in the predictive models, which learn from each new piece of data fed into the system, will increase the accuracy of the predictions and thus confidence in the correctness of the system. In this way, we reduce errors due to subjective assessments by route reviewers. As a consequence, this will have an impact on operational reliability by reducing the number of outages caused by trees falling on transmission line conductors. The optimization module will always be better able to suggest where and when to intervene to minimize costs, based on learning from historical data.

In addition, there are important benefits that the system brings that cannot always be precisely quantified in financial terms. Such benefits include the timely and easier negotiation of agreements with land and forest

owners, as agreements will be backed up by concrete data and it will be easier to take into account the requirements and wishes of the owners, which will lead to better cooperation with them in the future. For users of the application and those responsible for maintaining the routes, the application provides a better overview of the situation, facilitates decision-making on interventions and reduces the likelihood of late or unnecessary interventions on vegetation. Finally, the data collected will allow additional analytics to be carried out to facilitate decision-making when amending internal maintenance policies and adapting maintenance processes.

Given the guidelines on how vegetation under power lines should be managed in the future, where corridors should not be completely cleared but vegetation should be allowed to grow according to the distance even under the conductors (Figure 4), assessing the actual situation for route inspections will be even more difficult and the subjective assessments of the inspectors would have an even greater impact on the economic and technical viability of the interventions to be carried out. If such a method of route maintenance is introduced, a proper vegetation management information system will be indispensable.

Figure 4 on left side shows current area where vegetation must be maintained (between blue lines) where distance L is half width of the corridor (400 kV = 25 m, 220 kV = 20 m, 110 kV = 15 m). Figure 5 shows that in the future we will allow the vegetation to grow into the corridors, especially on corridor edges. That means less impact on the environment, but also demands more strict supervision of current state of vegetation heights. Until now we marked vegetation if their top could fall into clearance zone. In the next version we will change that and marked vegetation if their top could fall on the conductor or just touches it.

Reduced logging will also have an impact on the environment in hilly terrain. Vegetation plays a crucial role in reducing soil creep. Plant roots anchor the soil, preventing it from moving, while vegetation reduces surface erosion by holding the soil in place and slowing down rain impact. Additionally, plants improve soil structure and reduce soil saturation through evapotranspiration, further stabilizing the terrain. There is also positive impact on animal life. By preserving habitats and considering breeding cycles, we can minimize disturbances to wildlife. Additionally, promoting biodiversity through integrated vegetation management and preventing invasive species helps maintain natural plant communities essential for local animals.

Benefits of the system are primarily in two areas. Firstly, there is a reduced need for visual inspections of power lines by field teams. In the first phase, we could reduce the number of inspections by at least half, as approximately 80% of findings during inspections are related to vegetation. Annually, approximately 2700 findings related

to vegetation are recorded during inspections along 2500 km of routes. Based on data from 2024, this would save approximately 5000 hours annually spent on conducting power line route inspections. With sufficiently verified reliability of the predictive algorithms, this saving could be further increased. The second area of benefits is not so much in cost reduction but in easier and higher-quality work preparation. With data on predicted vegetation growth and thus anticipated work needs, we can start preparing work in a timely manner, especially by obtaining all necessary consents for interventions. This will enable better planning and execution of interventions during periods when tree felling is permitted and also makes sense from the perspective of further use of the felled wood. Improved timing of interventions can also mean savings in securing financial resources for carrying out the interventions.

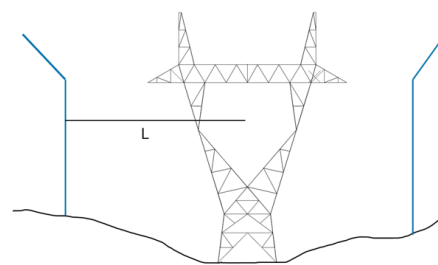


Figure 4: Current borders of vegetation in corridors

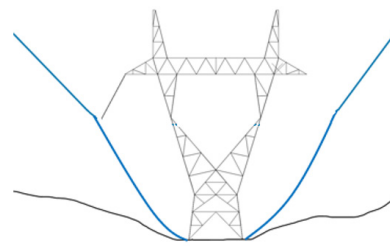


Figure 5: Future borders of vegetation in corridors

6. CONCLUSION

The system is partially in use in production. Initial experience has shown that the system will be very useful for vegetation management. The introduction of drone imagery will also contribute significantly to its usefulness, as the biggest drawback has been the obsolescence of data in some areas. At present, it is not yet possible to give a definitive assessment of what the introduction of the application will mean in terms of reducing the costs of maintenance of transmission lines, as the change in processes made possible by the introduction of IT support depends mainly on other factors. Users have already shown interest in the application during its initial use, as indicated by the first suggestions for further improvements to further enhance

the user experience. In particular, integration with some of the other IT systems that have recently been introduced into the company's IT environment.

The costs of implementing the Vegeline system were only the costs of developing the application itself. The application was custom-made for Eles based on the prepared specification. The costs thus include the hours of developers for application development and the hours of the client's project team for collaboration in development and testing of the application. During the testing phase and later operation of the system, we could partially consider the costs of making comparisons, although such analytics are performed internally as needed and would largely be carried out independently of the Vegeline system. The costs associated with drone recording of power lines would be difficult to attribute to the Vegeline system costs, as recordings would be carried out regardless of whether the Vegeline application is used. An additional cost for recordings may be the need for point cloud classification, which is not otherwise foreseen if the data were not used in the Vegeline system.

Users have recognized in the Vegeline application the possibility to systematically monitor the condition of vegetation and to prepare and carry out interventions on vegetation, which has not been systematically supported

so far. In the current use of the application, there have been no instances where the application failed to timely detect critical vegetation. It has been found that the application, based on the given parameters, even marked too much vegetation as critical, as the conditions for corridor boundaries were too restrictive. New criteria are currently being prepared, based on which we will reassess the predictions made and compare them with the actual state.

The rapid development of different technologies and the possibilities of obtaining new data means that the system in place will need to be continuously upgraded and adapted to the use of new data.

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