Predicting Weather-Associated Impacts in Outage Management Utilizing the GIS Framework

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***Abstract*—Weather-related impacts are at the top of all outage causes. Yet, traditional outage management (OM) approaches do not integrate all available and relevant weather-associated data automatically. This paper presents a predictive method that correlates different weather-associated data layers to provide predictive OM process implemented using the geographic information systems (GIS) framework. Examples for both transmission and distribution OM are demonstrated using vegetation, wind, and power system data in ArcGIS.**

***Index Terms*— Data analytics, distribution systems, fault location, geospatial analysis, geographic information systems, meteorology, outage management, smart grids, transmission systems.**

I. INTRODUCTION

Weather-related electrical outages are one of the major challenges for utility industry [1]. Fig. 1 shows the reported power outages by cause in Texas in 2013; as shown weather causes presents the greatest percent [1]. The efficiency of outage management (OM) has direct impacts on system reliability as well as economic loses, and potential fatalities.

Reference [2] proposes a method to enhance outage forecasting by incorporating hurricane data into the OM process. In [3], the reliability of distribution systems utilizing restoration resources for different weather conditions is assessed. Reference [4] describes an intelligent crew management system within complicated scenarios which include multiple outages and voluminous data. The authors show how to optimize the restoration process through a Weather Research and Forecasting (WRF) model in [5]. In [6], geographical information systems (GIS), global positioning systems (GPS), and lighting data are utilized for improving the accuracy of traveling wave fault location method. Reference [7] discusses enhancements which may be used to improve current outage management system (OMS) for large scale storm conditions. Reference [8] identifies that the application of weather data may bring additional benefits to OM. Reference [9] demonstrates how to use GIS-based support systems for urban power network planning in the context of real-world examples. Authors of [10] discuss GIS usage during OM processes when outage data becomes available. Predicting outages is an important task that affects the cost and performance significantly and requires innovative data analytics to correlate the weather-associated impacts.

According to Federal Energy Regulatory Commission (FERC), as a means to minimize outage possibilities, North American Electric Reliability Corporation (NERC) reliability standards obligate utilities to administer vegetation growth around their transmission lines to restrain vegetation from contacting the lines [11]. In fact, the most common weather impact that contributes to faults is the combination of high wind activity and trees falling on the lines [12], [13]. Thus, the data of interest for this implementation is wind, vegetation, and power system data. The contribution of this paper is an illustration of how using GIS to correlate data from power systems and weather-related sources provides predictive OM capabilities. ArcGIS [14] is applied as the GIS platform for such purpose. The predictive data analytics for both transmission and distribution networks are described.

The paper is organized as follows. Section II provides background. Section III shows the data collection. Section IV demonstrates GIS integration. Section V describes through use cases how GIS analysis provides predictive OM improvements. Section VI contains conclusions.

II. BACKGROUND: WIND AND TREE CAUSES

For the purpose of this research, it is of interest to analyze trees that are candidates for coming in contact with lines if (1) branches were to break off and fly into lines; (2) complete trees

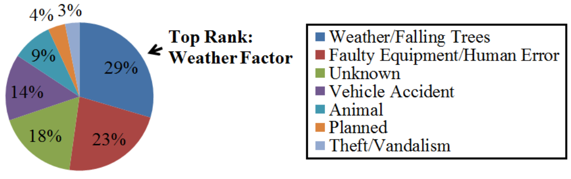


Figure 1. Reported power outages by cause in Texas in 2013 [1].

topple or move in the wind, or (3) tree branches were to grow into the lines. Table I lists the impact that different wind speed values have on tree movement, [15]. The classification of specific vegetation regions located along the transmissions lines allows for grater outage mitigation by identifying hazardous vegetation areas [16]. These areas can be overlaid with wind forecast data to predict which segments of the electrical network will have a high vulnerability for outages.

III. DATA COLLECTION: NETWORK, WIND, AND VEGETATION

The distribution network data used in Fig. 2 (a) was extracted from the Storm Vulnerability Assessment tutorial from Esri [17]. The components utilized were primary overhead feeders. The transmission network data was digitized from the imagery data. High-resolution multispectral imagery (NAIP 1 m spatial resolution, [18]) was acquired for the study location in southeast Texas.

The wind forecast data are taken from the National Digital Forecast Database (NDFD) [19]. The data is accessed through graphical user interface (GUI) (named “tkdegrib”) provided by NDFD and then converted to polygons in Shapefiles (a standard GIS data format) for further processing in ArcGIS [20]. The spatial resolution for the Contiguous United States (CONS) is nominal at 5 km with real spacing varying by latitude [21]. For distribution network, the data from southeast region of U.S.A. is used (Fig. 2 (b)). For transmission network, the wind data in Texas is used.

The canopy height data in Fig. 2 (c) used in the analysis comes from the three dimensions Global Vegetation Map [22], [23]. The data format is raster at 1 km resolution using data from the Geoscience Laser Altimeter System (GLAS) aboard Ice, Cloud, and land Elevation Satellite (ICESat) [23].

IV. GIS FOR OUTAGE MANAGEMENT

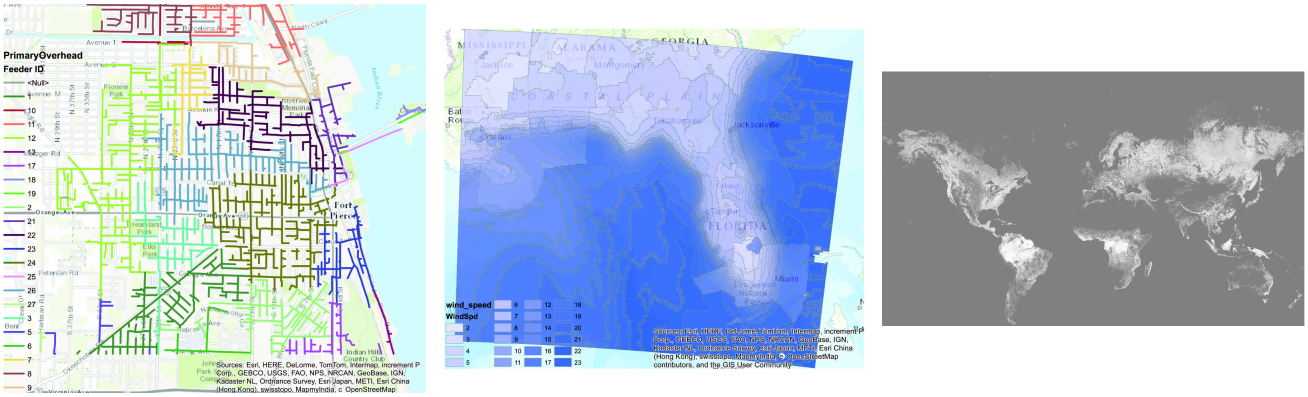
Within a traditional utility context, GIS is understood to be a tool for visualizing geographic objects on maps. Yet, the spatial information can be used not only for visualizations, but also for analysis, interpretation and as a tool for enabling better decision making. One clear example of the importance of GIS may be understood from context of restoring power in large-scale outages caused by severe weather conditions. In such cases, dispatch and field management operations may be decentralized and organized into smaller groups within a GIS raster. This approach would significantly minimize the assignments of outage work orders and communication flows. However, such an approach requires a GIS platform with mobile access in order to design the decentralized workflows and operations that keep all progress up-to-date. Simultaneously, a geospatial database which includes data on the location of outages, damages to equipment, and restoration resources would allow the optimization of the restoration process.

TABLE I. IMPACT OF WIND ON VEGETATION

Wind speed [m/s]	Effect on trees
5.5-7.9	Small branches movement
8.0-10.7	Movement of moderate sized branches
10.8-13.8	Movement of large sized branches
13.9-17.1	Whole trees in motion
17.2-20.7	Twigs broke from trees
20.8-24.4	Large branches broke from trees
24.5-28.4	Trees uprooted or broken
Greater than 28.5	Severe vegetation damage

In order to attempt a GIS-based OM approach, the OM process can be viewed as sequenced steps: (1) outage data collection, (2) data analysis and prediction, (3) decision making for crew dispatch, and (4) post-event documentation. Achieving such a workflow requires an enterprise-based GIS within a utility, which should include the following two features [24]:

- A GIS platform for servers, desktops, and mobile devices; applications/extensions built in GIS platform to interface with existing utility infrastructures (e.g. Outage Management System),
- Geospatial database specified for OM application purposes and a spatial database management system.



(a) (b) (c)

Figure 2. Data collection. (a) An example of overhead distribution network. (b)Wind data of southeast region of U.S.A. (c) Global vegetation data.

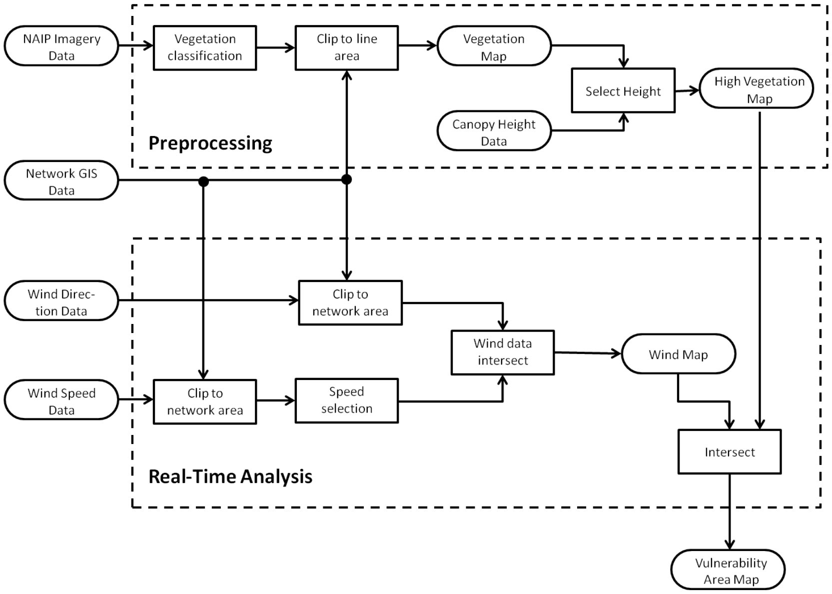


Figure 3. Data analysis description.

1) GIS Platforms and GIS Programming:

Modern GIS platforms, such as ArcGIS, provide tools for spatial analysis and the integration of different data sets [24]. These spatial tools typically enable user to do the following:

- Convert between vector and raster data: power network data is usually represented as vector data while other data sources such as vegetation and weather factors may be rasters.
- Create buffers: This operation is useful for representing the narrow area around distribution lines.
- Perform logical and relational operations: These operations permit the selection of areas within certain distances to utility components.
- Classification of grid data: This operation allows the separation of the network area into several sub-areas that are vulnerable to different outage causes.
- Network analysis: Operations such as network routing, calculation of distances, location-allocation and others are useful for network representation and prediction analysis.

In order to provide a predictive analysis platform for a distribution network outage management system, the following actions can be taken:

- Building GIS extensions that implement OM-specific analyses for transmission and distribution outage prediction
- Automating routine tasks by building models using ModelBuilder inside a GIS.
- Implementing predictive algorithms as scripts and tools inside a GIS, such as Python in ArcGIS.

2) Geospatial Database:

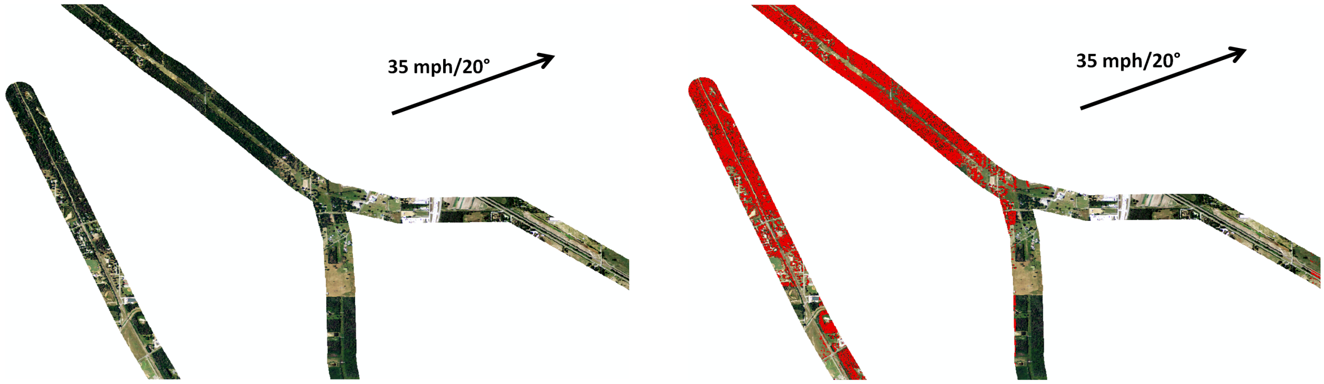
For a utility, the ultimate goal is to have one single geospatial database system containing the latest information, where the components are labeled with a unified geographic coordinate system such as GPS points (latitude/longitude) that locates them in space. The major challenges inherent in constructing such a database include:

- Designing a database for a large number of network components,
- Maintaining the most recent database using updates from daily field operations.

As mentioned before, a geospatial database is an indispensable component for a utility, particularly as related to OM processes. A common approach is to use structured query language (SQL) for accessing and manipulating geospatial databases. Running SQL on an enterprise databases server - such as Microsoft SQL Server or Oracle [25] - results in multiple advantages including reliability, availability, and scalability. These enterprise systems can trace data and transactions to optimize query processing for geospatial operations. ArcGIS, for instance, can be connected to an enterprise database platform to scale queries and performance in big data scenarios needed for utility operations and OM predictions.

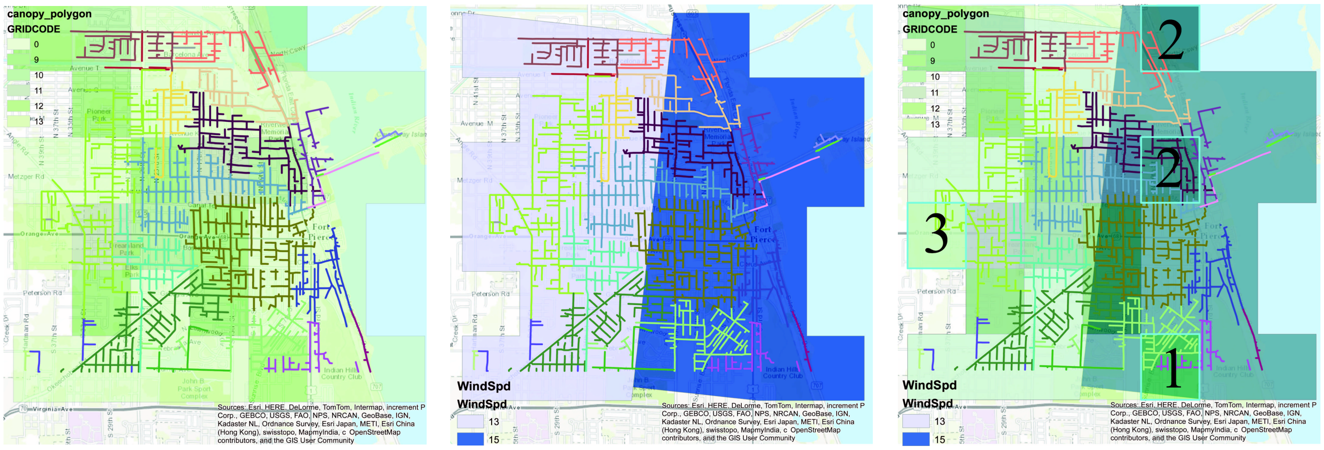
V. DEMONSTRATION EXAMPLES

In this section, performing analysis to predict vulnerability for power system outage management in ArcGIS is demonstrated. Application description is presented in Fig. 3. Vegetation data is processed only once in advance while wind data is processed in real-time. New wind prediction is available every 3 hours. The results are presented for both transmission and distribution network examples.



(a) (b)

Figure 4. Selecting areas with trees higher than 50 ft. The scale is 1 to 20,000. (a) Original map. (b) Map with trees in red dots.



(a) (b) (c)

Figure 5. Data layer correlations. The scale is 1 to 40,000. (a) Canopy height and power system data. (b) Power system and wind data. (c) All three layers of data.

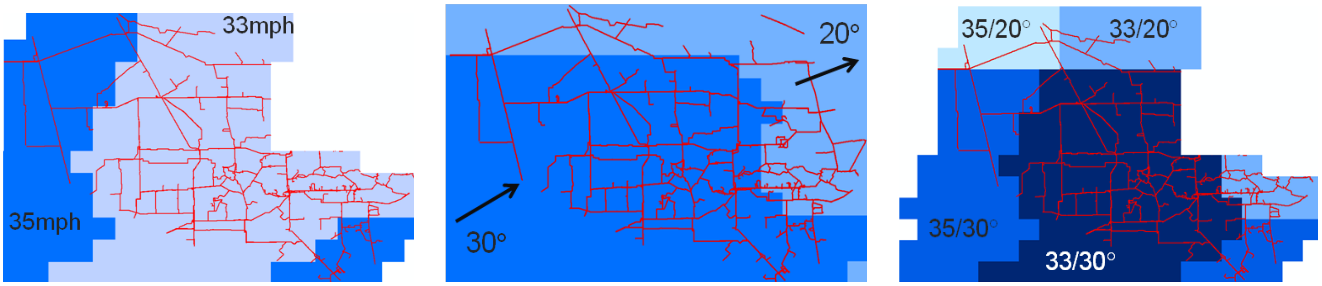
A. Network Data Integration

While correlating other data layers with power system data layer, the power system must be divided into different sections where components may be separated into multiple groups to account for this. The GIS data sources are used as inputs to generate outage vulnerability assessment for different geographic areas. These are then correlated with transmission lines and feeder data for outage vulnerability mapping. In case of distribution network the complete area around the network is considered, while in case of transmission network a buffer was created covering 100 m (328 ft) around the transmission lines.

B. Vegetation Data Integration

In case of the distribution example, the canopy height data from Global Vegetation Map is used. In case of the transmission example, an unsupervised classification algorithm (Isocluster) was applied on NAIP data. Three distinct classes were identified: forested, grassland, non-forested (urban and water) and then compiled to create a raster dataset that can be displayed and analyzed in a GIS environment. Resolution of 3D Global Vegetation Map is 1 km. NAIP imagery data has a greater resolution of 1 m but did not contain information about canopy heights. By intersecting data from two sources, the estimation of canopy heights was accomplished on a high resolution map. With this data, it was viable to predict the areas exhibiting a high risk of contact between power lines and trees within the electrical network.

For the transmission network, only the areas with trees higher than 15 m (50 ft) were selected based on extracted canopy heights data. In Fig. 4, the results of the vegetation analysis before and after the canopy height selection for one part of transmission line are presented. Fig. 4 (a) shows the buffer around the line containing NAIP imagery data. In Fig. 4 (b), the result of combining NAIP imagery data with canopy heights map is presented. The red dots represent the trees higher than 50 ft.



(a) (b) (c)

Figure 6. Data layer correlations of zones where wind speed was greater than 30 mph. The scale is 1 to 400,000. (a) Wind speed data. (b) Wind direction data. (c) Classifying area into four groups based on wind speed and direction data.

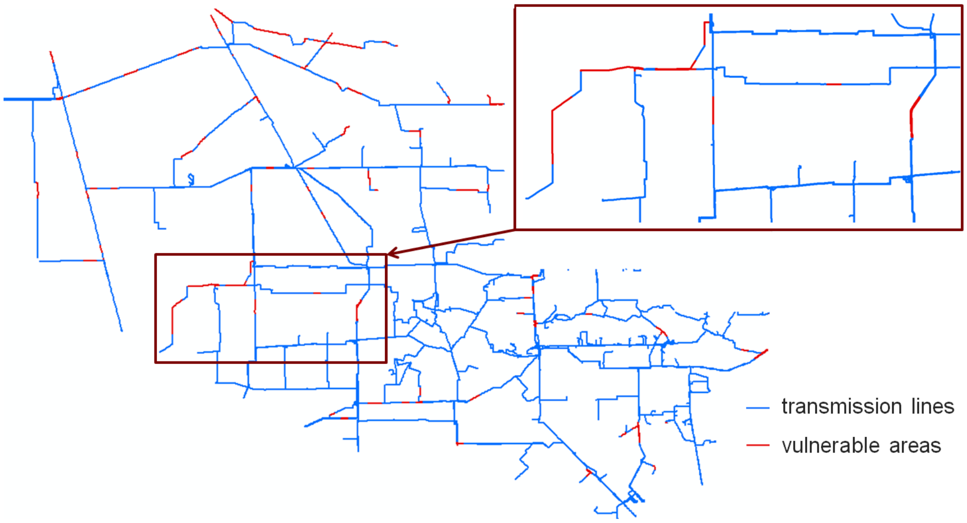


Figure 7. Identify zones with high risk for outages. The scale is 1 to 200,000.

For the distribution network, Fig. 5 (a) shows the power system and canopy height data [26]. The saturation levels of green color represent different height of canopy, where the darker green color represents the larger canopy height.

C. *Wind Data Integration*

Based on the data provided in Table I, the wind speed of 13.9 m/s and greater is considered hazardous. For Distribution network, each grid cell is labeled for prioritizing the outage search sequences. One component (e.g. a line) may stretch across multiple polygon or grid areas (i.e. not just inside a single area). This task requires an update in the spatial data, using the function "Intersect" to properly account for partial line segments which overlap multiple grid cells.

Transmission network data and classified vegetation areas were overlaid with the wind speed and direction. Wind speed data is presented in Fig. 6 (a) and wind direction in Fig. 6 (b). The parts of the transmission network and vegetation data that were not in the zones of high wind activity were removed. Based on wind speed and direction, different line segments were considered as potentially vulnerable zones. The lines representing tree vegetation were projected onto the transmission lines in the direction parallel to the wind direction. Using the wind data, four regions of risk were classified for each combination of wind speed/direction as it is presented in Fig. 6 (c). Each region was analyzed individually.

Distribution network data and classified vegetation areas were overlaid with the wind speed in Fig. 5 (b) [26]. It shows the power system and wind data layers where the larger wind speed with darker blue color is at the right hand side, which means the zones at the east side of city has greater chance of potential outages happening.

D. *Results*

To obtain the results, the vegetation data were masked to obtain the grid cells containing the area around the network. The conversion between data formats was done to make all data into polygons. The wind polygon data were clipped to match the processed vegetation polygon. The data from the wind polygon were spatially joined with the vegetation polygons.

In Fig. 5 (c), the final results of the distribution network predictive analysis are presented [26]. It shows the result of combining each of these layers together. Based on the wind and canopy data, the first three areas to be searched by the dispatched crews are labeled in Fig. 5 (c).

In Fig. 7, the final results of the transmission network analysis are presented. Layers containing the line segments that are predicted to be at most risk for outages caused by wind impact on vegetation are overlaid with transmission network layer. For the predicted weather conditions the red areas have the highest potential for outages and can be marked as the first areas to be searched by maintenance crews. Depending on the wind forecast data, different areas of the network can be candidates for outages. With the method described here, these areas can be identified up to seven days in advance.

The examples discussed here can be applied both during planning (crew allocation) and real-time execution of OM schedule. It should be denoted that the two major differences between the transmission and distribution OM examples here are the input data properties (e.g. availability, precision) and the process of data correlation for prediction analysis (e.g. the wind direction was considered in the transmission example). Due to the localized nature of weather conditions (e.g. various types of storms), the OM prediction process for corresponding types of outages could be very different from what were demonstrated in these examples. In general, data used for these types of analysis must be appropriately chosen and processed for specific application purposes, realizing that the GIS platform and the structure of geospatial data may be the same. The predictive analysis used to characterize the risk and develop the response priority should be based on both the real conditions (i.e. latest data) and the past experience (i.e. historical data).

VI. CONCLUSIONS

This paper makes several contributions:

- It shows how the current state-of-the-art GIS platform needs to be extended to interface with utility OMS.
- It illustrates how geospatial databases can be used to perform spatial operations through enterprise databases servers to ensure robust database management.
- It gives two examples that demonstrate how correlating different types of information involving vegetation, wind, and power system data helps predict outages and plan responses.
- It explains how to use wind forecast and vegetation data to predict areas with high risk for outages.

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