How May Location Analytics Be Used to Enhance the Reliability of the Smart Grid?

V. Sultan and B. Hilton

1 Center For Information Systems & Technology, Claremont Graduate University, Claremont, CA 91711, USA

Abstract - Recent major power outages across the country have highlighted that the U.S. electric-power infrastructure urgent needs renovation. The media discussed U.S. aging infrastructure and the Public Utilities Commission called for a comprehensive review of recent power outages. Without optimization algorithms to consider the many operating parameters and outage scenarios, planning engineers may locate components nonoptimally. To answer the research question—"How may location analytics be used to enhance the reliability of the smart grid?"—we constructed worksheets in Insights for ArcGIS to reduce the risk of power outages. Three case studies demonstrate various risk scenarios. This research proposes an elegant, interesting, and novel solution to facilitate disaster planning and vegetation management, identifying optimal grid locations requiring inspection or repair and detecting regions where new components may provide net benefits considering many operating parameters and outage scenarios. This research demonstrates that GIS can play an integral role in problem resolution.

Keywords: Geographic Information Systems, Power Outage

1 Introduction

The placement of a new automated distribution switch has long-term impacts on the reliability of the circuit in which it is installed [1]. Common placement strategies rely on manual processes and the inherited knowledge of the planning engineer regarding the configuration, past reliability performance, future load growth, planned distributed energy resources, and other protection-related schemes of the circuit being analyzed in order to select a new switch location [2]. Without optimization algorithms to account for the many operating parameters and outage scenarios, the planning engineer may select a non-optimal location. According to Horstman, a utility-industry consultant, a non-optimal placement may lead to a less-than-optimal reliability performance and adversely affect customer satisfaction.

The objective of this study was to provide instantiation of a geographic information systems (GIS) model and an analysis framework developed in previous research by the author of this manuscript. To instantiate is to create a real instance or a particular realization of an abstraction or a process [3]. Therefore, the solution offered in this paper could lead us to a GIS-based application prototype that identifies optimal grid location(s) that need inspection or infrastructure work, as well as detect regions where new components such as distribution switches may provide net benefits to the grid, considering the many operating parameters and outage scenarios.

The Environmental Systems Research Institute [4] defined GIS as a class of tools for seizing, storing, analyzing, and demonstrating data in relation to their positions on the Earth’s surface. Analysts use GIS to view different objects’ locations and study their relationships. Satellite and tabular data can be entered into GIS for a single map display. GIS applications include recognizing site locations, mapping topographies, and developing analytical models to forecast events [4].

Though predictive modeling existed since the inception of statistics, the penetration of GIS fostered a new approach to forecasting and data analytics. Predictive modeling is a process to determine a mathematical relationship between two or more variables [5]. Future dependent variables can derive if their relationships to independent variables become known. Predictive modeling with GIS has been applied in various sectors such as public health [6] and public-works asset management [7]. GIS is not limited to any specific field; it is only restricted by the availability of geospatial data.

GIS is a catalyst for improving multiple facets of smart grids. For instance, Resch et al. [8] integrated GIS-based modeling into the energy system to address renewable energy infrastructure planning. Sultan and Bitar [9] used GIS to optimize the locations of a distributed energy resource such as solar panels. Similarly, Sultan et al. [10] investigated power-grid reliability incidents/power outages and their correlation with infrastructure age by using GIS-based modeling. Therefore, GIS enhances the research inquiries in the smart-grid domain. Based on previous research, referenced as Sultan and Bitar [9] and Sultan et al. [10], we posit GIS can highlight the optimal locations for different components of the electric power network including the new automated distribution switches. For this research study, we designed an artifact: a GIS-based solution that resolves current challenges faced by utilities to reduce the risk of power outages.

2 Study Design and Methodology

The artifact/solution uses a design science research (DSR) methodology. DSR was conceived by Walls, Widmeyer, and El Sawy [11] who laid the foundations and arguments for DSR in behavior-centric information-systems research. March and Smith [12] elucidated DSR further by
separating natural science from design science. A decade later, DSR became integrated into the fabric of information-systems research through several seminal publications [3, 13–16].

Every DSR needs a design principle as guidance. Hence, for this study, we used the principle outlined in Peffers et al. [16]. The principle, collectively called design science research method, was also used as a basis for a study by Gregor and Hevner [13]. Figure 1 depicts the design science research method.

Design principle
The design science research method contains six activities. These activities interact sequentially. In addition, iteration through one or more activities is likely. The design science research method includes four possible entry points that indicate how a DSR project would start.

2.1 Possible Entry Points
Even though Peffers et al. [16] did not elucidate on the four entry points—(1) problem-centered initiation, (2) objective-centered solution initiation, (3) design and development center initiation, and (4) client/context initiation—they did provide four case studies to demonstrate how each entry point works. Conceptually, researchers could start their research endeavors using any of the entry points, as long as the researchers defined all activities in the design science research method in their entirety.

This research entry point is classified as an objective-centered solution initiation. As noted above, our objective in this research was to advance smart-grid reliability through the use of location analytics. Due to the rapidly changing nature of energy generation, new developments in the electric power network, the incorporation of distributed energy resources into the grid, and circuit and equipment overloads, grid reliability research has been unable to keep pace. Power outages can be especially tragic in life-support systems in hospitals and nursing homes or systems in synchronization facilities such as airports, train stations, and traffic control. According to LaCommare and Eto [17], the economic cost of power interruptions to U.S. electricity consumers was $79 billion annually in damages and lost economic activity. These facts highlight the need to investigate grid reliability, which is the objective of this research and the entry point to an objective-centered solution initiation.

2.2 Process Guiding Design
In conjunction with the design principle elucidated in the previous section, the research used the process steps in Takeda, Veerkamp, and Yoshikawa’s [18] design cycle to create an artifact/solution. This cycle has five simple steps: awareness of the problem, suggestion, development, evaluation, and conclusion. The Takeda et al. design cycle demonstrates how DSR was embraced as a research paradigm for information-systems research projects [3]. We used the three design science research cycles of relevance, design, and rigor [14] to perform each of the Takeda et al. process steps leading to the final prototype in this paper.

This study aimed to address the following question: “How may location analytics be used to enhance the reliability of the Smart Grid?” To answer the research question, we propose a GIS-based application that would be an elegant, interesting, and novel solution to aid in storm/disaster planning and vegetation management, identifying optimal grid location(s) that need inspection or infrastructure work, and detecting regions where new components such as distribution switches may provide net benefits, considering the many outage scenarios. This study illustrates how utilities can address current challenges to improve grid reliability. The artifact demonstrates that GIS can play an integral role in the problem resolution.

We used a scenario-based methodology to evaluate the proposed solution. We extracted case episodes of actual site use by users (described as scenarios) to define the objectives of the target application. The key strength of the scenario-based methodology is its ability to support investigation of phenomena such as power failures that are hard to research by more conventional means. Segawa et al. [19] highlighted its

Figure 1: Design science research method [16]
potential, for example, to break down an extracted scenario into steps of actions and answer questions about the actions given as check items. To complete the evaluation, we elicited opinions from industry experts regarding the viability of the model. Getting expert feedback is helpful at this phase to see if the instantiation demonstrated the overall usefulness of the intervention.

3 Deployment

One of the newest technologies is Insights for ArcGIS, which is part of the new ArcGIS Enterprise family from ESRI. Insights for ArcGIS can open doors for utilities to expand the use of asset-management data, for example, to support business-related decisions. According to ESRI [20], Insights for ArcGIS has transformed how we traditionally performed spatial analysis. It is a web-based, data analytics application with the capability to work with interactive maps and charts at the same time.

In this research, we developed three case studies to demonstrate various risk scenarios/challenges that entail a utility company taking action and preparing for the unexpected.

3.1 Utilities Case Studies

3.1.1 Challenge 1/Storm scenario:

Strong winds, heavy rain, and storm surge have the potential to cause extreme damage and dangerous flooding. Electric companies in the path of a storm should be taking steps to prepare, activate their emergency-response plans, mobilize restoration workers, stage equipment, and coordinate response efforts with federal, state, and local government officials. Personnel, including linemen and damage assessors, should be ready to respond quickly to power outages should they occur. Having additional resources on standby and ready to go is essential to restoring power to customers.

In this scenario, the National Weather Service issued a Red Flag Warning for the region, cautioning extreme risk from a storm. The challenge the utility is trying to answer is, “Where should we preposition workers, and equipment in preparation for the storm?”

3.1.1.1 Challenge 2/Vegetation scenario:

Utility systems have come under attack from storms, trees, squirrels, fires and firearms. Last year was particularly bad for outages with wildfires in California. Regulators struck back against utility companies, imposing tens of millions of dollars in fines related to wildfires, including $37 million for the 2007 Malibu fire; $14.4 million for the Witch, Rice and Guejito fires the same year; and $8.3 million for the 2015 Butte Fire [21]. One issue is that the grid has many poles and wires that are vulnerable to falling trees and flying debris.

According to Pennsylvania Public Utility Commission [22], fallen trees or tree limbs caused approximately 50 percent of the total minutes of service interruptions in 2017 (p. 14). According to the National Interagency Fire Center [23], in 2018 more than 48,347 wildfires burned more than 7.3 million acres, as of late September. Figure 2 shows some overall data on the total number of outages caused by weather/falling trees [24].

![Figure 2: Eaton’s Blackout Tracker](image)

To reduce the risk of wildfire and keep customers safe, electric utilities need to accelerate their vegetation-management work. Utilities are already working to meet new state vegetation and fire-safety standards. In California, for instance, the new standards require a minimum clearance of 4 feet around power lines in high fire-threat areas with clearances of 12 feet or more at the time of trim to ensure compliance year round [25]. However, accelerated wildfire vegetation-management work is still needed to address overhanging branches or limbs. The idea is to reduce vegetation below and near power lines that could act as fuel in a wildfire, as an added layer of protection and to enhance defensible space. Thus, the challenge for an electric utility in this case is, “Where should a utility improve tree cutting and trimming-related initiatives to foster operational excellence and reduce the risk of vegetation coming into contact with power lines?”

3.1.2 Challenge 3/Aging infrastructure scenario:

The aging of the grid infrastructure is a noteworthy reason for power failures. In 2008, the American Society of Civil Engineers gave the U.S. power-grid infrastructure an unsatisfactory grade [26]. The report stated that the power-transmission system in the United States required immediate attention. Furthermore, the report mentioned that the U.S. electric power grid is similar to those of third-world countries. According to the Electric Power Research Institute, equipment such as transformers need to be replaced as they have exceeded their expected lifespan considering the materials’ original design [27].

Willis and Schrieber [28] identified equipment age as the active factor of aging systems and implied it was the catalyst for utilities problems. Their book described the characteristics of an aging infrastructure, including that (1) the majority of equipment in the area is more than 40 years old, and (2) the area is plagued by an above-average equipment-failure rate [28].
The industry is spending hundreds of billions of dollars to replace and upgrade infrastructure, rushing to meet consumer demand for higher quality power enabled by construction of a more reliable grid. Considering the utility goal to reduce labor and cost of inspection contractors, the research question in this case is, “Which infrastructure should be inspected to reduce the risk of power outage?”

3.2 Insights for ArcGIS Solution

We created an artifact in Insights for ArcGIS using DSR methodology. Insights for ArcGIS workbooks were developed to explore and discover trends and details in a utility company’s data. The workbooks are templates that can be imported from a utility company’s analytics models built in Insights for ArcGIS. Having the data in Insights for ArcGIS provides powerful analysis that can be shared.

In this research, we propose an elegant, interesting, and novel solution to aid in storm/disaster planning and vegetation management, identifying optimal grid location(s) that need inspection or infrastructure work, and detecting regions where new components such as distribution switches may provide net benefits, considering the many operating parameters and outage scenarios. Because Insights is so easy to use, everyone at the electric utility, from personnel in the field to the chairman of the board, can take advantage of its capabilities. The following section describes one Insights worksheet we developed to demonstrate how the proposed solution might address the first risk scenario/challenge examined in the previous section.

3.2.1 Solution For Challenge 1: ArcGIS Insights storm scenario investigation worksheet

We selected the ArcGIS Insights tool to identify the critical locations where a utility company needs to stage workers and equipment in the event of a storm. All relevant data were imported from the supervisory control and data acquisition/outage management system/distribution management system at a power utility into Insights for ArcGIS.

Page 1: Developed to investigate weather-related outages and the reported causes shown in Figure 3. This page allows utility personnel to answer the following questions.
1. What is the reported weather category contributing to the largest count of outage events?
2. What is the reported weather category contributing to the largest duration of outages?
3. What is the reported weather-related cause contributing to the largest count of customers’ calls?

Page 2: Developed to investigate weather-related outages associated with storms in specific locations shown in Figure 3. This page allows utility personnel to answer the following questions.

1. What is the reported type of storm contributing to the largest count of outage events?
2. What is the reported type of storm contributing to the largest duration of outages?
3. Where do you see weather-related outages emerging hot spots?
4. In which county do you see the consecutive emerging power-outage hot spots associated with weather?

Page 3: Developed to investigate the association of weather-related outages with the Infrastructure Age (using pole age as a proxy), shown in Figure 4. This page allows utility personnel to answer the following questions.

1. In which counties do you mainly see infrastructure-age hot spots?
2. What is the reported age interval of infrastructure contributing to the largest count of weather-related outage events?
3. If you were to stage crews to replace poles in preparation for storm, does this map tell you where you stage them?

Page 4: Developed to investigate the relationship between weather-related outages and precipitation values shown in Figure 4. This page allows utility personnel to answer the following questions.

1. What is the average precipitation value associated with weather-related outages?
2. What is the reported weather category associated with the largest average precipitation value?

Figure 4: ArcGIS Insights storm scenario investigation Worksheet Pages 3 and 4
3. At how many inches of precipitation, on average, do we start risking outage?
4. How many outage events align with 3.7 to 4 inches of precipitation?

4 Evaluation

The proposed solution in this paper brings forth an important contribution to help practitioners identify the optimal location(s) for the placement of smart-grid interventions while considering many operating parameters, outage scenarios, and potential benefits. The GIS model presented in this study can advance smart-grid reliability by, for example, elucidating the root cause of power failure, defining a solution for a blackout through data, or implementing the solution with continuous monitoring and management.

This study illustrated how Insights for ArcGIS, a GIS-based solution, can be used to perform quick analysis, produce illustrative maps and charts, and share that information with managerial staff on the utility side. Because Insights for ArcGIS is able to record workflows, utility personnel will be able to rerun analysis monthly, whenever inspection budgets become available or whenever a storm is expected to hit the service area.

According to utility industry consultant Horstman, the solution offered here provides useful insights. However, Horstman pointed out that it still needs work as the terminology used about hot spots, for example, are statistician’s terms not layperson’s terms. Horstman commented that utilities are becoming more “analytical” and beginning to understand the value of this research.

Dorr, a research program manager at Electric Power Research Institute, confirmed the potential of this application offered by the prototype. According to the program manager, “ArcGIS Insights worksheets are very easy to use and understand. Other layers like where the lines run and where the customers are located would be an additional useful integration consideration. Utilities would need to do some customization in order to make it truly actionable. Visual analytics and the ability to look at data over time is critically important. I really like the hot spots concepts.”

5 Conclusion

This study aimed to answer the question, “How may location analytics be used to enhance the reliability of the smart grid?” To answer the research question, Insights for ArcGIS was used to build worksheets, a GIS-based application aimed at resolving current challenges faced by utilities to reduce the risk of power outages. The proposed solution provided instantiation of the GIS model and the analysis framework I developed previously. We developed three case studies to demonstrate various risk scenarios that entail a utility company taking action and preparing for the unexpected. We used the artifact in Insights for ArcGIS with a DSR methodology. The resulting proposal is an elegant, interesting, and novel solution to aid in storm/disaster planning and vegetation management, identifying optimal grid location(s) that need inspection or infrastructure work, and detecting regions where new components such as distribution switches may provide net benefits, considering the many operating parameters and outage scenarios. The artifact demonstrated that GIS could play an integral role in the problem resolution.

6 REFERENCES

[1] A. Abiri-Jahromi, M. Fotuhi-Firuzabad, M. Parvania, and M. Mosleh. “Optimized Sectionalizing Switch Placement Strategy in Distribution Systems”; IEEE Transactions on Power Delivery, 27, 1, 362–370, (2012).

[2] Electric Power Research Institute, EPRI Data Analytics Case: Optimal Placement of Automated Distribution Switches”. (2017). Retrieved from http://smartgrid.epri.com/doc/DMD-Use-Cases/Optimal Placement of Automated Distribution Switches - Short Version.pdf

[3] A. R. Hevner, S. March, J. Park, and S. Ram. “Design Science in Information Systems Research”; MIS Quarterly, 28, 1, 75–105, (2004).

[4] Environmental Systems Research Institute. “Understanding GIS—The Arc/Info Method”. (1992). Retrieved from http://www.ciesin.columbia.edu/docs/005-331/005-331.html

[5] D. Dickey. “Introduction to Predictive Modeling with Examples” SAS Global Forum Proceedings, (2012). Retrieved from http://support.sas.com/resources/papers/proceedings12/337-2012.pdf

[6] A. Idowu, N. Okoronkwo, and R. Adagunodo. “Spatial Predictive Model for Malaria in Nigeria”; Journal of Health Informatics in Developing Countries, 3, 2, 30–36, (2009). Retrieved from http://www.jhildc.org/index.php/jhidc/article/view/34

[7] D. Totman. “Model Predictions: GIS Helps Public Works Manage Assets”. (2013). Retrieved from http://americancityandcounty.com/gis-amp-gps/model-predictions-gis-helps-public-works-manage-assets

[8] B. Resch, G. Sagl, T. Törnros, A. Bachmaier, J.-B. Eggers, S. Herkel, S. Narmsara, and H. Gündra. “GIS-Based Planning and Modeling for Renewable Energy: Challenges and Future Research Avenues”; ISPRS International Journal of Geo-Information, 3, 2, 662–692, (2014).

[9] Vivian Sultan, and H. Bitar. “Geographic Decision Support Systems to Optimize the Placement of Distributed Energy Resources”; Proceedings of the 22nd Americas Conference on Information Systems, San Diego, CA, (2016).
[10] Vivian Sultan, A. Alzahrani, H. Bitar, and N. Alharbi. “Is California’s Aging Infrastructure the Principal Contributor to the Recent Trend Of Power Outage?”; Proceedings of the 22nd Annual California GIS Conference, Anaheim, (2016).

[11] J. G. Walls, G. R. Widmeyer, and O. A. El Sawy. “Building an Information System Design Theory for Vigilant EIS”; Information Systems Research, 3, 1, 36–59, (1992).

[12] S. T. March, and G. F. Smith. “Design and Natural Science Research on Information Technology”; Decision Support Systems, 15, 4, 251–266, (1995).

[13] S. Gregor and A. R. Hevner. “Positioning and Presenting Design Science Research for Maximum Impact”; MIS Quarterly, 37, 2, 337–356, (2013).

[14] A. R. Hevner. “A Three-Cycle View of Design Science Research”; Scandinavian Journal of Information Systems, 19, 2, 87–92, (2007).

[15] A. R. Hevner and S. Chatterjee. “Design Science Research in Information Systems”. (2010). Retrieved from http://link.springer.com/chapter/10.1007/978-1-4419-5653-8_2

[16] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee. “A Design Science Research Methodology for Information Systems Research”; Journal of Management Information Systems, 24, 3, 45–77, (2007).

[17] K. LaCommare and J. Eto. “Understanding the Cost of Power Interruptions to U.S. Electricity Consumers”. Berkeley, CA: Lawrence Berkeley National Laboratory, (2004).

[18] H. Takeda, P. Veerkamp, and H. Yoshikawa. “Modeling Design Process”; AI Magazine, 11, 4, 37–48, (1990).

[19] Satoko Segawa, Masahiko Sugimura, and Kazushi Ishigaki. “New Web-Usability Evaluation Method: Scenario-Based Walkthrough”; FUJITSU Scientific & Technical Journal, 41, 1, 105–114, (2005).

[20] Environmental Systems Research Institute. “Insights for ArcGIS”, September 4, (2018). Retrieved from http://doc.arcgis.com/en/insights/

[21] California Public Utility Commission. “Electric and Fire Related Fines”. n.d. Retrieved from http://cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Safety/Electric_and_Fire_Related_Fines.pdf

[22] Pennsylvania Public Utility Commission. “Pennsylvania Electric Reliability Report 2017”. July (2018). Retrieved from http://www.puc.pa.gov/General/publications_reports/pdf/Electric_Service_Reliability2017.pdf

[23] National Interagency Fire Center. “Year-to-Date Statistics”. September (2018). Retrieved from https://www.nifc.gov/fireInfo/nfn.htm

[24] Eaton’s Blackout Tracker. “Power Outage Annual Report”. (2017). Retrieved from https://switchon.eaton.com/blackout-tracker

[25] State Board of Forestry and Fire Protection. “2018 Strategic Fire Plan for California”. August 22, (2018). Retrieved from http://cdfdata.fire.ca.gov/pub/fireplan/fpupload/fppdf1614.pdf

[26] American Society of Civil Engineers. “Infrastructure Fact Sheet”. (2009). Retrieved from http://www.infrastructurereportcard.org/2009/sites/default/files/RC2009_rail.pdf

[27] D. Stone. “September 9. It’s the Electric Grid, Stupid”. (2011). Retrieved from http://www.thedailybeast.com/articles/2011/09/09-major-power-outage-shows-weakness-of-aging-electric-infrastructure.html

[28] H. Willis, and R. Schrieber. “Aging Power Delivery Infrastructures” (2nd ed.). Boca Raton, FL: CRC Press/Taylor & Francis, (2013).