Which Grid Infrastructure Needs Utilities' Immediate Attention to Reduce the Risk of Power Outages?

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Abstract

Aging grid infrastructure is one reason for power failures. Equipment age is the active factor, catalyzing utilities' problems. The industry spends hundreds of billions of dollars to upgrade infrastructure to meet consumer demand for a more reliable grid. This research addressed, "Which grid infrastructure needs utilities' immediate attention to reduce the risk of power outages?"

Insights for ArcGIS was used to build worksheets using a geographic-information-systems application to reduce the risk of power outages. This case study demonstrates the risk scenario with a utility company preparing for the unexpected. The artifact uses a design-science-research methodology to propose an elegant, novel solution to identify critical locations where aging infrastructure and equipment need to be replaced or inspected more often.

Keywords: power failure, GIS model, design-science-research, equipment failure, grid infrastructure.

I. INTRODUCTION AND PROBLEM DEFINITION

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 [1], stating that the U.S. power-transmission system required immediate attention and averring 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 [2].

Willis and Schrieber [3] identified equipment age as the active factor of aging system and implied it was the catalyst for utilities problems. The authors described the characteristics of an aging infrastructure, including that the majority of equipment is more than 40 years old, and the area is plagued by an above-average equipment failure rate [3].

This study's objective was to instantiate a geographic information system (GIS) model and an analysis framework developed in previous research by this author. To instantiate is to create a real instance or a particular realization of an abstraction or a process [4]. The solution offered in this paper could lead 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 [5] 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 displayed on a single map. GIS applications include recognizing site locations, mapping topographies, and developing analytical models to forecast events [5].

Though predictive modeling has 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 [6]. 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 [7] and public-works asset management [8]. 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. [9] integrated GIS-based modeling into the energy system to address renewable energy infrastructure planning. Sultan and Bitar [10] used GIS to optimize the locations of a distributed energy resource such as solar panels. Similarly, Sultan et al. [11] investigated power-grid reliability incidents/power outages and their correlation with infrastructure age by using GIS-based modeling. Thus, GIS enhances research inquiries in the smart-grid domain. Based on my previous research [10, 11], I posit GIS can identify optimal grid location(s) that need inspection or infrastructure work and detect regions where new components such as distribution switches may provide net benefits, considering the many operating parameters and outage scenarios. For this research study, I designed an artifact: a GIS-based solution that resolves current challenges utilities face to aid in identifying critical locations where infrastructure and equipment, such as aging poles, need to be replaced or inspected more often.

II. STUDY DESIGN AND METHODOLOGY

The artifact/solution uses a design science research (DSR) methodology. Walls, Widmeyer, and El Sawy [12] conceived DSR and laid the foundations and arguments for DSR in behavior-centric information-systems research. March and Smith [13] elucidated DSR further by separating natural science from design science. A decade later, DSR was integrated into the fabric of information-systems research through several seminal publications [14–17].

Every DSR needs a design principle as guidance. Hence, for this study, I used the principle [17]. The principle, collectively called design science research method, was also used as a basis for a study by Gregor and Hevner [14]. Figure 1 depicts the design science research method.

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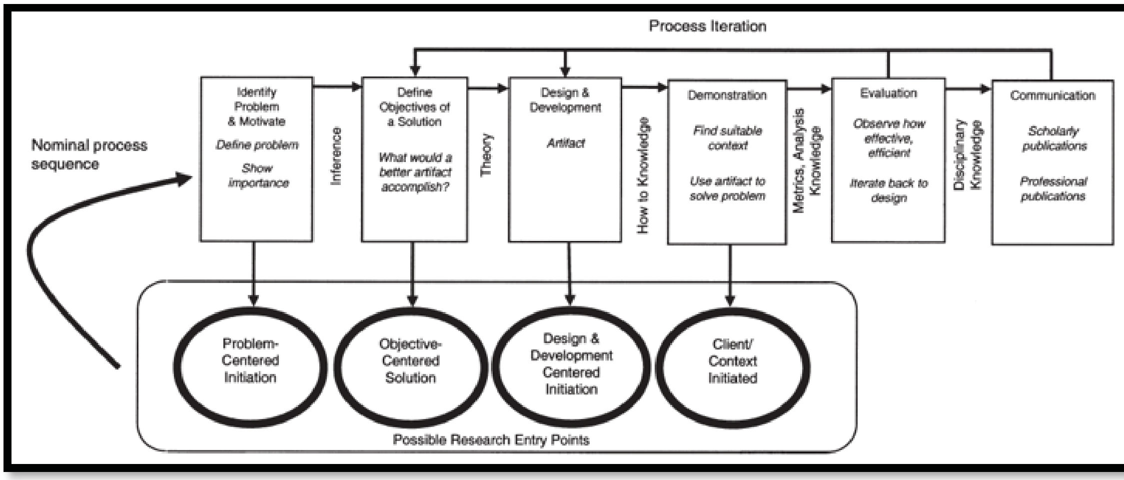

Figure 1: Design science research method (Peffers et al., 2007)

A. Design Principle

The design science research method contains six activities that 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.

B. Possible Entry Points

Even though Peffers et al. [17] did not elucidate the four entry points—problem-centered initiation, objective-centered solution initiation, design and development-center initiation, and client/context initiation—they did provide four case studies to demonstrate how each entry point works. Conceptually, researchers may start their research endeavors using any entry point, as long as they define 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, my objective in this research was to reduce the risk of power outages by identifying optimal grid location(s) that need inspection or infrastructure work. 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. The economic cost of power interruptions to U.S. electricity consumers was $79 billion annually in damages and lost economic activity [18]. These facts highlight the need to investigate grid reliability, which is the entry point to an objective-centered solution initiation.

III. 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 [19] 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 [4]. I used the three DSR cycles of relevance, design, and rigor [15] to perform each Takeda et al. process step leading to the final prototype in this paper.

This study aimed to address the following question: "Which grid infrastructure needs utilities' immediate attention to reduce the risk of power outages?" To answer the research question, I propose a GIS-based application that would be an elegant, interesting, and novel solution to aid in identifying optimal grid location(s) that need inspection or infrastructure work. This study illustrates how utilities can address current challenges to improve grid reliability. The artifact demonstrates that GIS can play an integral role in problem resolution.

I used a scenario-based methodology to evaluate the proposed solution. I 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. Sugimura and Ishigaki [20] highlighted its 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, I elicited opinions from industry experts regarding the viability of the model. Getting expert feedback was helpful at this phase to see if the instantiation demonstrated the overall usefulness of the intervention.

IV. 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. Insights for ArcGIS has transformed how we traditionally performed spatial analysis [21]. 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, I developed a case study to demonstrate the risk scenario/challenge that entail a utility company taking action and preparing for the unexpected.

A. Utilities Case Study/ Equipment Failure scenario:

The industry spends 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. Solutions must consider the utility goal to reduce labor and cost of inspection contractors.

B. Insights for ArcGIS Solution

I created an artifact in Insights for ArcGIS using DSR methodology, developing Insights for ArcGIS workbooks 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, I propose an elegant, interesting, and novel solution to aid in identifying optimal grid location(s) that need inspection or infrastructure work, and detect 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 I developed to demonstrate how the proposed solution might address the risk scenario/challenge examined in the previous section.

V. SOLUTION: ARCGIS INSIGHTS EQUIPMENT FAILURE SCENARIO INVESTIGATION WORKSHEET

I selected the ArcGIS Insights tool to identify the critical locations where infrastructure and equipment such as aging poles need to be inspected more often. 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 equipment-failure-outages and the reported causes (Figure 2). This page allows utility personnel to answer the following questions.

1. What is the reported equipment-failure-related outage category contributing to the largest count of outage events?

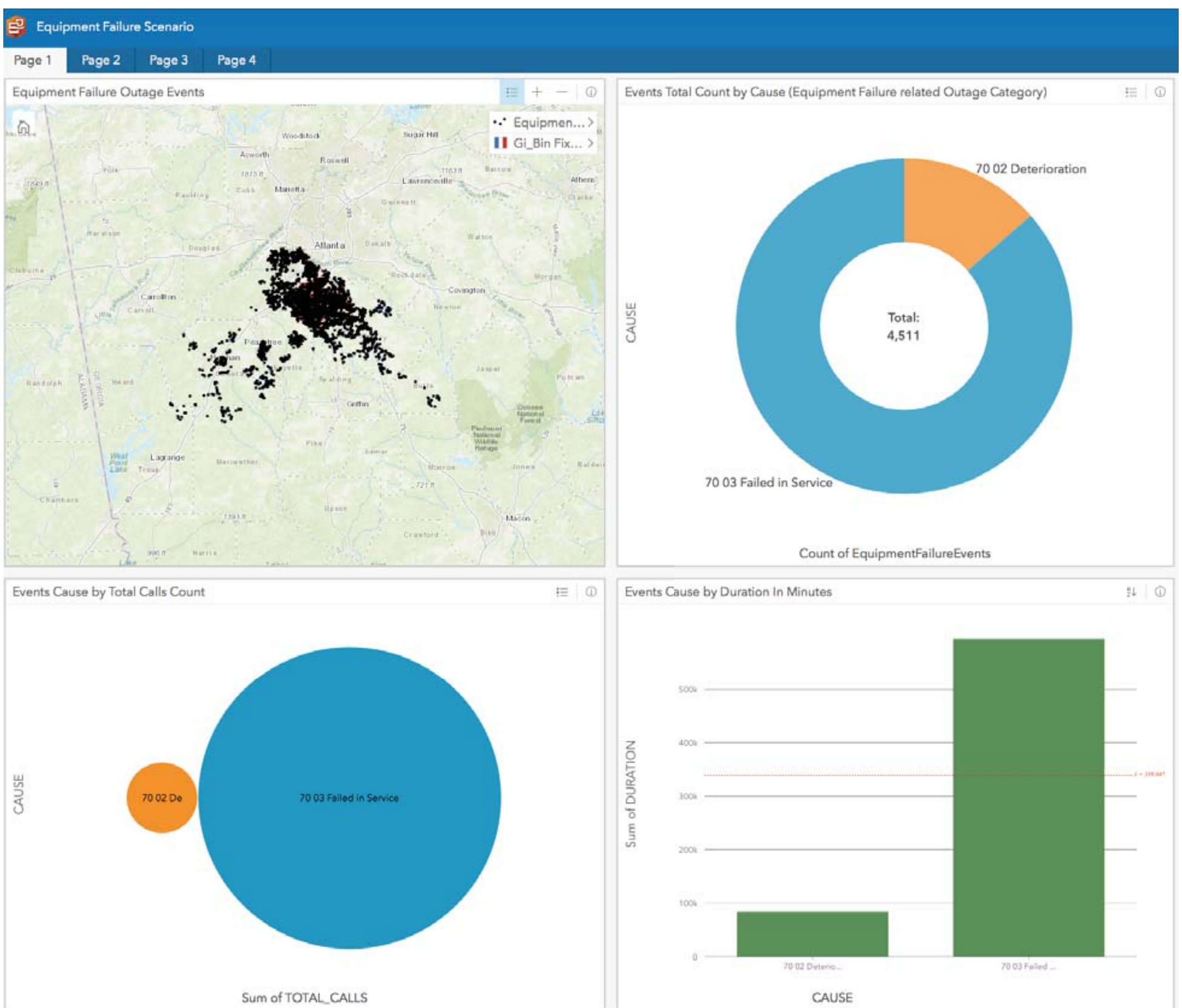

Figure 2: ArcGIS Insights Equipment Failure scenario investigation Worksheet Page 1

2. What is the reported equipment-failure-related outage category contributing to the longest duration of outages?
3. What is the reported equipment-failure-related outage category contributing to the largest count of customers' calls?

Page 2: Developed to investigate equipment-failure-related outages optimized and emerging hot spots shown in Figure 3. This page allows utility personnel to answer the following questions.

1. In which county do you mainly see equipment-failure-related outages optimized hot spots?
2. In which county do you mainly see equipment-failure-related outages emerging hot spots?
3. What pattern types of emerging hot spots do you mainly see?
4. How many consecutive emerging power-outage hot spots are associated with equipment failure?

Page 3: Developed to investigate the association of equipment-failure-related outages with infrastructure age (using poles age as a proxy) shown in Figure 4. This page allows utility personnel to answer the following questions.

1. In which county do you see the largest infrastructure-age hot spot?
2. What is the reported age interval of infrastructure contributing to the largest count of equipment-failure-related outage events?
3. If you were to send crews to inspect aging poles, does this map tells you where you need to send inspection contractors first?

Page 4: Developed to investigate the relationship between all power-outage events and infrastructure age (using poles age as a proxy) shown in Figure 5. This page allows utility personnel to answer the following questions.

1. In which county do you see the oldest poles on average?
2. What is the average age of poles associated with the oscillating emerging power-outage hot spots?
3. Which emerging hot-spots pattern is associated with the oldest poles, on average?
4. If you were to send crews (limited resource) to inspect equipment, does this map tells you where you need to send inspection contractors first?

VI. EVALUATION

The solution proposed in this paper is an important contribution to help practitioners identify optimal location(s) for the placement of smart-grid interventions while considering many operating parameters, outage scenarios, and potential benefits. The GIS model presented

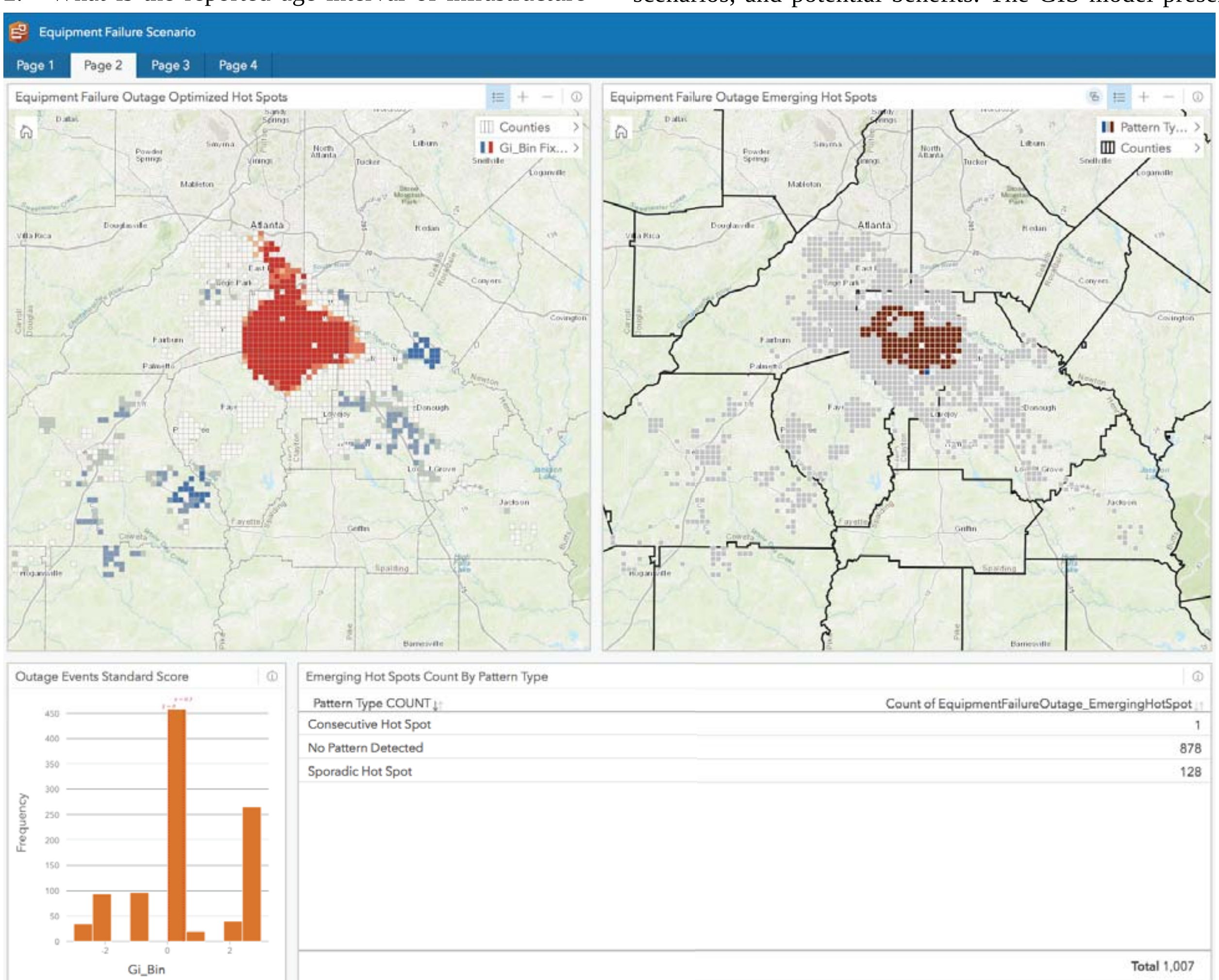

Figure 3: ArcGIS Insights Equipment Failure scenario investigation Worksheet Page 2

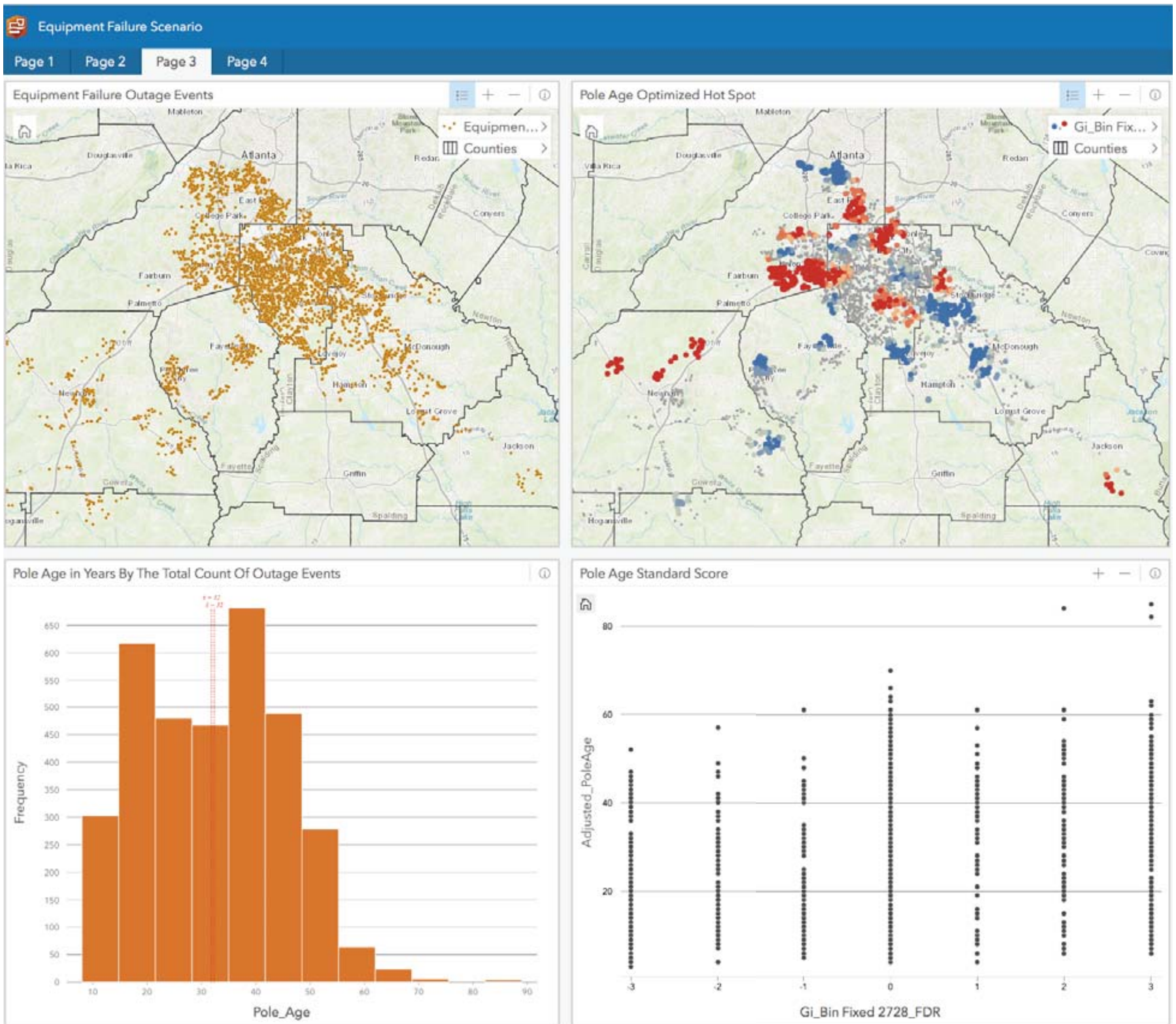

Figure 4: ArcGIS Insights Equipment Failure scenario investigation Worksheet Page 3

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 in a utility. 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 terms 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.

Doug 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."

VII. CONCLUSION

This study aimed to answer the question, "Which grid infrastructure needs utilities' immediate attention to reduce the risk of power outages?" To answer the research question, Insights for ArcGIS was used to build worksheets using a GIS-based application aimed at resolving current challenges faced by utilities to reduce the risk of power outages. A case study was developed to demonstrate the risk scenario that entails a utility company taking action and preparing for the unexpected. An artifact in Insights for ArcGIS was created using a DSR methodology. This research proposes an elegant, interesting, and novel solution to aid in identifying

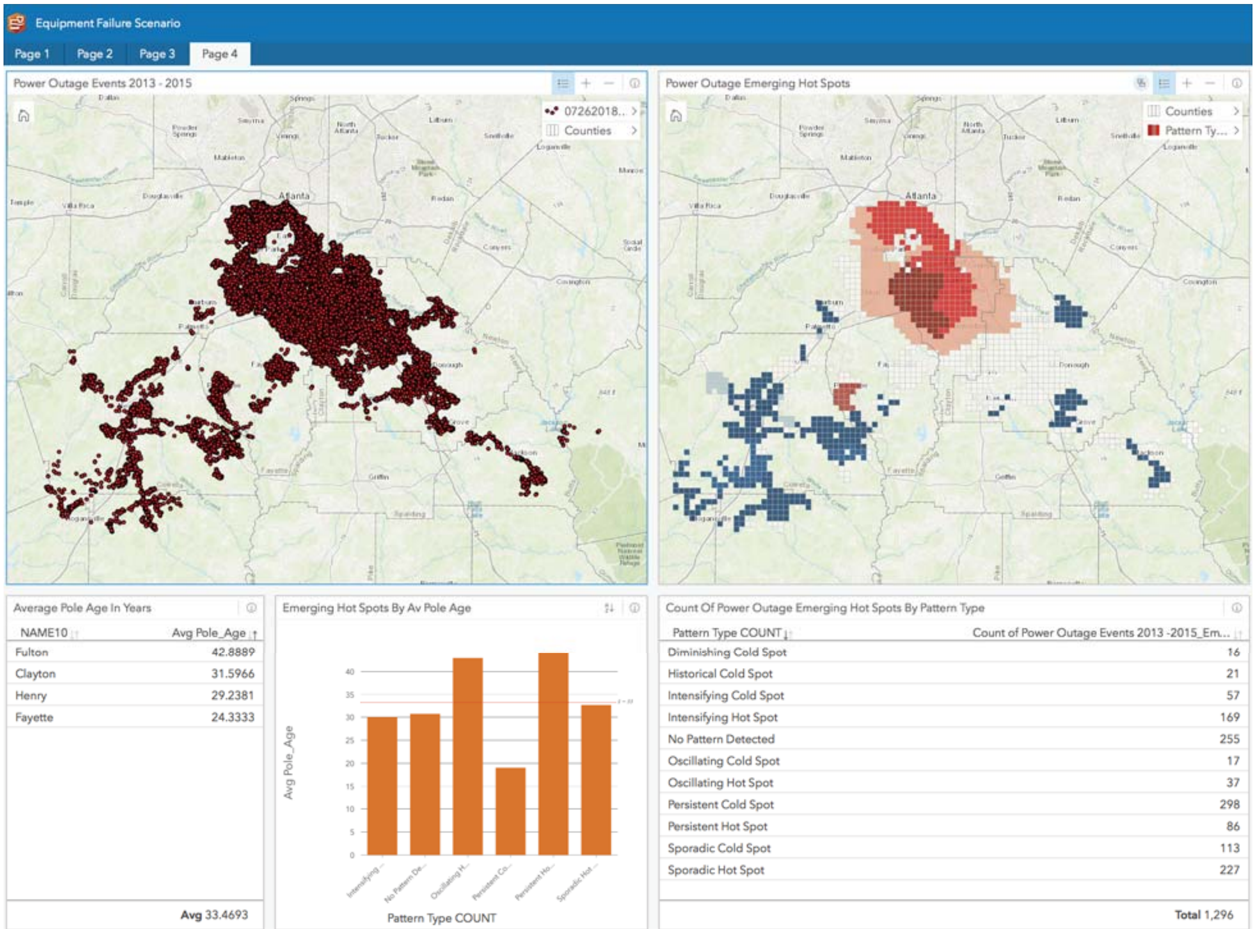

Figure 5: ArcGIS Insights Equipment Failure scenario investigation Worksheet Page 4

critical locations where infrastructure and equipment, such as the aging poles, need to be replaced or inspected more often. The artifact demonstrates that GIS can play an integral role in the problem resolution.

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